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ABSTRACT

Prepared with the assistance of a panel of experts, this report sets forth available information for school architects and administrators facing the energy crisis. The booklet tells specifically how economies can be effected in the operation and maintenance of school buildings; in the modernization of existing schools; and in the planning of future facilities. School administrators are advised to (1) review operation and maintenance personnel to be sure that they are qualified to cope with the increasingly sophisticated mechanical/electrical equipment in schools; (2) identify sources of energy waste through an analysis of energy consumption in existing schools; (3) include energy conservation as a major part of an architectural program for both modernization and new construction projects; and (4) use life-cycle costing to replace initial cost as the sole basis for contract awards for energy-consuming systems. Appendixes provide an explanation of the basic techniques for computing life-cycle (longterm) costs, and a summary of the background to the energy crisis. (Author/MLF)

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THE ECONOMY OF ENERGY CONSERVATION IN EDUCATIONAL FACILITIES

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FOREWORD

You can't measure altruism but you can savor cost savings on a balance sheet. And that's what energy conservation is all about — helping to stave off a fuel shortage for the whole nation and reducing the amount of metered energy in your own buildings.

EFL has entered this philosophical and financial approach with more trepidation than usual before committing its views to print. We have attempted to explain that the energy crisis is real, but its impact on schools may be reduced. Nevertheless, this advice will work well in some circumstances, less well in others and perhaps not at all for another set of conditions. Obviously, there aren't easy or general answers, but if people are to receive any help with this major problem it is necessary to offer the best available information on hand.

To gather, distill and present the information in *The Economy of Energy Conservation*, EFL retained C. W. Griffin, a civil engineer who wrote EFL's *Systems: An Approach to School Construction*. Griffin's conjunction of writing and technical knowledge produced two books for the American Institute of Architects: *Development Building: The Team Approach*, and *A Manual for Built-Up Roof Systems*. An informal panel of specialists advised EFL during the development of the research for this book and reviewed the final form of its contents. We thank Fred Dubin, mechanical engineer; Bill Lam, lighting consultant; Harry Rodman, architect; Richard Stein, architect; and Ed Stephan, school administrator.

EDUCATIONAL FACILITIES LABORATORIES

INTRODUCTION

In the winter of 1972-73, Denver's school administrators had to temporarily put high schools on a three-day week because there wasn't enough natural gas to heat the buildings. Cities throughout the United States took notice since this gas shortage was one more aspect of an intensifying energy crisis that will make conservation an economic necessity in the years immediately ahead.

Yet the idea of conservation collides head-on with traditional American attitudes. For example, overheating of buildings is historically one of our wasteful habits. On his first visit here, in 1842, Charles Dickens denounced "... the eternal, accursed, suffocating, red-hot demon of a stove ..." Long habituated to apparently limitless sources of energy – from the vast forests, from mines, and from the subterranean oil wells – we Americans have perennially ranked among the world's biggest energy users. Today, on a per capita basis, each of us consumes nearly nine times as much energy as the average non-American.

But suddenly, after three centuries of plundering the resources of the continent, we confront an alarming fact looming in the path of heedless "progress". The earth's formerly "limitless" resources are becoming ever more palpably finite (and, therefore, costly).

There is no painless solution on the technological horizon. We simply must learn to conserve energy.

Associated with these grim facts is one significant and happy discovery: we are finally realizing that energy conservation usually *saves* money. Economy almost

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necessarily results in the long run, and often in the short run as well.

Thus, school boards continuing energy-wasting practices can expect soaring operating costs. According to a panel consulted by EFL, we can expect a roughly threefold multiplication of energy costs over the next decade.

Optimists hope that technology will solve the energy crises by presenting us with new, cheap, easily available, and non-polluting sources of energy. And a number of these are at various stages of R&D. (For a quick rundown on some things we may see in the future, see Appendix II.) But none of these – not even the current forms of nuclear generators – will provide the ultimate answer during this century. Today's consumers must solve today's problems by using the familiar fossil fuels – coal, oil, and natural gas.

The building industry has lagged in all conservation techniques, including energy conservation. Part of this can be blamed on the industry; part on building owners' preoccupation with capital cost as opposed to operating and maintenance (O&M) cost. School boards are often presented with a great handicap by ill-informed guardians of the public treasury who force them to minimize highly visible capital costs, while burdening the public with needlessly heavy O&M costs throughout a school's 40-year life.

Yet, there is nothing to prevent school boards and administrators from *trying* to obtain the most for the [illegible]lic's money. As New York architect Richard G.

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Stein points out, "In any given year, a mere 5% reduction in the energy costs for existing buildings would add up to a greater total saving than a 50% saving in new school buildings."*

A few energy-conserving techniques are appearing in the traditionally wasteful building industry. Some architects are turning away from the glass walls that convert buildings into radiant ovens. Some mechanical engineers are focusing on efficiency and long-term economy as the ultimate criterion for airconditioning and heating design. Some architects and lighting engineers are resisting the needless escalation of lighting levels.

Architects and engineers generally ignore these and many other available techniques for minimizing energy consumption because their clients don't *instruct* them to conserve energy. It is always easier to follow tradition. But a few pioneers are beginning to suggest them, and a few farseeing clients are beginning to demand their investigation.

For example, in modernizing an existing building, a capital investment in an improved combustion system can often cut long-term O&M expense by a disproportionate amount. And within the O&M budget itself, a slight increase in maintenance expense often yields a much larger reduction in operating cost.

*If 8% of all school buildings are "new" (i.e., built within the past year),)% energy saving would equal 4% of total school energy consumption, than a 5% saving in the remaining 92% (+4.6%).

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Mechanical engineer Fred S. Dubin, of New York City, advocates establishment of a national goal of a one-third reduction in U.S. buildings' energy consumption. Such a goal, says Dubin, can be achieved at a sacrifice of no essential services and few, if any, amenities. Most energy-conserving measures would yield long-term economies, according to Dubin.

"In new construction we should design for 40% less energy consumption than in conventionally designed and operated buildings. About half of this reduction would not reduce capital costs, but reduce long-term owning costs; a minor proportion of this energy conservation design – say 10% – would raise even long-term costs. In existing buildings, we should aim for 30% less energy consumption," says Dubin. "About two-thirds of the realized savings would bring long-term economy."

As collective administrators of a $5-billion annual construction volume, the nation's school officials have three basic reasons for stressing energy conservation. First, of course, is the long-term economy in school plant operation. Like other energy consumers, our schools are using increasing quantities of fuel energy – for airconditioning to make schools habitable for year-round use, for constantly rising lighting levels, for the operation of sophisticated audio-visual teaching equipment, and for laboratory and vocational training equipment in an increasingly technologically dominated world. With fuel-energy costs projected to rise dramatically during the next few years, reduced fuel consumption becomes an obvious economy target.

Second, the schools, which introduced systems building and other improvements in building technology, owe the public an even greater pioneering effort in fuel conservation. By instructing their architects and engineers to stress this long neglected aspect of design, school administrators can help turn this nation's largest industry onto a pathway more consistent with human welfare.

As a final justification for energy conservation, the schools can exemplify the conservationists' attitude. Today's students will need this attitude even more than their parents.

ENERGY CONSERVATION STRATEGIES FOR SCHOOLS

To maximize the resulting cost savings, a school district instituting an energy conservation program must concern itself with the problem's two basic constituents:

- The operation and maintenance of existing schools.
- The design of modernized or new buildings.

The first logical step is a review of annual O&M procedures, to identify cost-saving opportunities. For a school district with qualified personnel, this task may be accomplished without the hiring of outside consultants. But the majority — perhaps the vast majority — of school districts probably need to retain an architect-engineer or consulting engineer firm to perform this service. For all projects designed by architect-engineer firms, school boards should include energy conservation as a key point in the architectural program, along with spatial requirements, educational goals, and other common criteria. In evaluating architect and engineer applicants for design projects, school boards should interrogate them about their interest in energy conservation and investigate their competence in this area.

Life-cycle costing: the long-range view of building costs

The key to realizing the cost savings of energy conservation is an understanding of long-range (life-cycle) costing. The current system of awarding contracts on the [illegible] of first cost only is destined to become an ever

10 bigger folly as the energy crisis intensifies and fuel costs rise. In these days of rapidly escalating building costs (up 70% nationally between 1966 and 1972), the impulse to cut initial cost becomes almost reflexive. Yet over a building's lifetime, ill-considered economies in construction cost almost always prove expensive in the long run. A school should be conceived not merely as a physical structure, but as a "building-people" complex lasting 40 years. Viewed in this context, construction cost, which usually dominates the economic picture, fades into the background. First cost constitutes roughly 8% of the total 40-year cost; O&M costs represent 12%; and teaching-administrative costs represent an overwhelming 80%. Thus a 10% increase in capital cost is only a 1% increase in total owning cost. And it can often result in far greater reductions elsewhere in a building owner's budget — in reduced O&M costs, or even in improved productivity. Sometimes, notably in tradeoffs between added costs of efficient thermal insulation vs. reduced heating and airconditioning capacity, an energy-conserving design can cut first cost as well as O&M cost.

For example, in a bold break with conventional policy, the Fairfax County (Va.) Board of Education rejected the low first-cost bid for a $1-million HVAC system for Chantilly High School, awarding the contract for an alternative HVAC system carrying a higher first cost but much lower life-cycle cost. Computed on a "present-worth" basis for an assumed 20-year useful life, the winning HVAC System B would cut an estimated $282,000 from the cost of System A ($597,000 if energy

costs are assumed to continue rising at 7% annually.)
(See Appendix I on "Life-cycle Costing" for a formal economic analysis displaying long-term owning cost calculations for the above project.)

In existing buildings, improved O&M programs can dramatically reduce energy consumption *and* cut operating costs. O&M economies sometimes depend on small capital expenditures for upgrading equipment – improved furnace combustion efficiency, new airconditioning filters, and the like. Of the two components of O&M cost, operating costs range between three and four times as much as maintenance costs. A ratio exceeding this range – i.e., one unduly high in operations cost – indicates trouble in the O&M program, according to Edward Stephan, Fairfax County's assistant superintendent for educational facilities planning and construction. A slight increase in maintenance cost – perhaps for more frequent equipment inspections – often yields great reductions in operating cost.

Attack on three fronts

An overall energy conservation campaign for schools can be logically divided into three phases:

1. Operational improvement in existing schools, involving no physical changes (i.e., no capital investment), or, at most, relatively slight expenditures for upgrading mechanical equipment or other subsystems.

2. Modernization of existing buildings, involving sub-

 stantial capital investment for new equipment or architectural features.

3. New construction.

These three divisions appear in *descending* order of applicability and in *ascending* order of cost, though not necessarily in potential economy. Operational improvements are universally applicable to all school districts. Significant energy savings can be achieved through such simple operational procedures as turning out needless lights and educating O&M personnel about proper techniques in operating airconditioning systems. Renovation entails capital investment ranging from complete modernization (i.e., spaces redesigned with new partitions, and mechanical and lighting subsystems) down to small expenditures for new thermal insulation. In these days of defeated bond issues for new construction, modernization has grown rapidly over the past few years, accounting for nearly half the $5 billion total school construction market in 1970. But regardless of how much the American public resents paying for new school construction, that will remain, ultimately, the most important method of upgrading our educational facilities.

OPERATING AND MAINTENANCE CHANGES

Energy waste springs from two basic sources — lethargy and ignorance. Much stems simply from the historic American proclivity for waste. In our schools even more is attributable to the inability of O&M personnel to cope with ever more sophisticated mechanical and electrical equipment.

Lethargy was the explanation of gross energy waste discovered in an illustrative case study. The evidence emerged as an accidental by-product of an energy consumption study of the HVAC system in a Las Vegas high school. From metered data on electric power consumption, the investigators discovered a fantastic amount of electric energy being used during the evening cleanup period. Between 4 p.m. and midnight, when the school's normal daily population of 1,100 shrank to three custodians, the school consumed 30% of its total energy. Merely by switching off the lights and HVAC in local areas as they finished their work, the custodians could have cut the school's workday electric power consumption by 15% to 20%.

Stein recounts a similar example. For Public School 55 in Staten Island (New York City), Stein tried to exploit the economy of natural light. Each classroom has three rows of luminaires, all paralleling the peripheral wall, with the exterior row controlled by local switching. For roughly three-quarters of the school's operating hours, natural daylight suffices to illuminate the 8- or 9-ft-wide exterior strip bounded by the wall.

However, on several visits to Public School 55, Stein

 discovered that this easily achieved economy was never realized; the exterior row of lights apparently burned along with the two interior rows throughout the school's working day. Merely by flipping these classroom switches at the proper time, the school's teachers could have cut daytime classroom lighting by 25% and total daytime lighting cost by about 8%.

Confronted with human failure, Stein is considering for future schools photoelectric switches to turn off unneeded fixtures when natural light intensity is adequate. The added expense of automatic controls shouldn't be necessary. But it may be the only practical way to combat the wasteful habits programmed into the American psyche.

How to waste energy without really trying

Faulty O&M procedures waste even greater quantities of energy than the lethargy displayed in the two previous case studies, according to Stephan. His favorite example concerns the widespread mishandling of the unit ventilator. What makes this example so significant is the unit ventilator's tremendous popularity. Though its use in new schools is declining, the unit ventilator remains, by far, the most prevalent heating system in the nation's existing classrooms.

The unit ventilator mixes recirculated interior air with varying proportions of outside air, filters it, and forces it across a water or steam heated coil and into the room through a sill-level grille. Some unit ventilators are true airconditioning units, with chilled water circulating

either through a dual-purpose, heating-and-cooling coil or through a second larger coil, added for cooling alone.

To operate a unit ventilator efficiently and economically, a custodian must understand the following controls and their functions:

1. Damper control (which sets the proportions of fresh and recirculated air at the most economical ratio).

2. Low-limit setting (which prevents the temperature of incoming air from dropping below a minimum temperature – usually 55F to 60F).

3. Thermostatic control valve for heating coil.

4. Blower motor switch.

Faulty operation of a unit ventilator can double the energy consumption of the same properly operated unit, according to Stephan. This waste results from a tragicomedy, in which the first mistake leads the benighted custodian ever deeper into a bog of compounded errors. Here's how the vicious spiral usually develops:

A teacher opens the drama by complaining about cold air coming from the unit ventilator grille. The cold air comprises a mixture of fresh and recirculated air, introduced at a minimum temperature of 60F or so, to reduce the rising temperature caused by the heavy heat and lighting load of a populated classroom. To reduce room temperature from, say, 76F, to the desired thermostatic setting of 72F, the unit ventilator blower supplies 60F air until the desired 4F temperature drop is achieved.

 Not understanding this temperature-correcting process, the custodian checks the unit ventilator's "low-limit" temperature setting. "Aha!" he concludes, on seeing 60F. "No wonder the air is cold." He "corrects" the situation with the original sin of unit ventilator mishandling: he sets the low-limit up from 60F to 72F, the desired room temperature.

Act II follows inexorably. The unit ventilator begins to pour 72F air into the classroom, in response to the thermostatically signaled message that the room is overheated, and the blower persists until the teacher complains of hot air and again summons the hapless custodian. Noting the heating system's obvious malfunctioning (which he himself caused through tampering with the system's controls), the custodian concludes that the entire system is haywire, a problem he "solves" simply by switching off the blower.

Now with the unit ventilator no longer circulating forced air and the outside air damper closed, the heating system works with less efficiency than a fireplace. Hot water (or steam) flows continually through the coils, but without the blower operating to circulate the air, this energy is largely wasted. At this point the drama degenerates into pure farce. The stuffy classroom overheats, and the windows are thrown open; then it overcools, and the thermostatic setting is advanced. The only winner in this game is the fuel supplier.

The above scenario, staged in schools all over the U. S., does not exhaust the ways of wasting energy in the oper-

ation and maintenance of unit ventilators. Custodians ignorant of the principle of the seven-day time clock in the boiler room may remove the tabs ("dogs") that change the temperature control from 72F to 65F during unoccupied periods. Again, the price of ignorance is an inflated fuel bill. And maintenance lapses, notably in failing to clean or replace airconditioning filters, combine with operating errors to maximize energy costs.

Stephan's accounts of O&M waste in operating HVAC systems are corroborated by other experts. Dubin cites an instance of waste in a study of two identical Connecticut schools with all-electric HVAC systems. One of these twin schools recorded nearly double the energy consumption of the other.

The major cause of the energy waste in School A was the continuous inactivation of the outside damper control. Tremendous volumes of needless cold air had to be heated to comfortable interior temperatures. Dirty filters, a major failing in the maintenance program, also obstructed the delivery of heated air at great waste of energy.

Among other possible contributors to School A's energy waste were:

- The useless, continuous lighting of a cafetorium and other usually unoccupied spaces.
- Unnecessarily high thermostatic control settings for interior comfort.

[Pa]rtial blame for our schools' energy waste rests with

 the teachers. As we have seen, their sometimes insatiable demands for instant comfort can press anxious custodians into desperate, sometimes mischievous efforts to please. Teachers must be educated about the inevitability of a little temporary local discomfort, at least for some individuals, with any HVAC system, no matter how well designed, fabricated, installed, and operated. No HVAC system, short of providing each individual with his own insulated, individually powered and controlled thermal capsule, can satisfy everyone all the time.

"An ounce of prevention . . ."

The guiding principle of a good maintenance program is scheduling. A maintenance department should not operate like a fire department, passively awaiting breakdowns or malfunctions in mechanical, electrical, or plumbing subsystems. Labor productivity can be doubled by instituting a preventive maintenance program, with periodic inspection and scheduled parts replacement and repair. Reorganization of a desultory O&M program can sometimes cut its cost nearly in half. Judged by current indications, school administrators lag behind commercial and industrial building owners in instituting efficient O&M programs.

Apart from regularly scheduled inspections, several other strategies constitute good overall O&M policy. Most obvious is the scheduling of large electrical power-consuming operations at nighttime, off-peak hours. Candidates for this economizing practice include elec-

trically driven water pumps refilling water storage tanks, dehumidifiers for controlled humidity storage, and refrigeration plant compressors (provided doors to the refrigerated chambers are kept closed).

As a general policy change in current O&M practices, school administrators could institute conservation oriented programs for O&M personnel. They should demand improved O&M maintenance procedure manuals from the architect-engineer firms that design their schools. Supplementing inspection schedules, monitoring devices could be installed on energy-consuming devices to sound alarms or, if tolerable, to shut down equipment when its efficiency dropped below a prescribed level of performance.

For some types of sophisticated equipment, notably air-conditioning, the service contract with a manufacturer may offer advantages over maintenance by the school's own personnel. In recognition of the often neglected O&M cost component in owning costs, California's School Construction Systems Development (SCSD) program administrators included the offer of a maintenance contract as a mandatory part of the contract. The maintenance service contract may become popular as mechanical-electrical subsystems become even more complicated.

One of the important maintenance jobs is to recheck the calibration of controls, a task for which schools' O&M personnel are seldom qualified. A good control systems technician will often discover energy-wasting equipment malfunctions in the normal course of his work.

 A good O&M program obviously leaves no weak links in the chain. Some of the most obvious energy wasters are sometimes overlooked. To minimize air infiltration, which silently increases energy consumption every second of the operating year, inspect and recaulk doors and windows on a regular schedule. Poorly maintained minimum settings and poor calibration of dampers can admit even greater quantities of outside air. Regular inspection can prevent energy waste from poor thermal insulation on steam or hot water lines in airconditioned spaces and on chilled water pipes or cold air ducts. Keep condensers for airconditioning, refrigeration, and drinking water fountains free of paper and other foreign material that might interfere with air flow or otherwise impede heat transfer. Keep heat transfer coils free of dust, which can reduce efficiency by 25% or more. Also check for leaking faucets and radiators, and defective refrigerator and freezer door gaskets.

Lighting efficiency can be enhanced simply by more frequent light bulb replacement. Current maintenance policy often prescribes initial over-illumination, to allow for one or more bulb failures before the next general bulb replacement. More frequently scheduled cleaning of lamps, fixtures, reflectors, and shades will also increase lighting efficiency.

Dollars for dimes

Some O&M savings require small capital investments that are quickly recouped, thus justifying themselves as long-term (often even as short-term) economies

under the life-cycle costing concept. Improved furnace combustion is an obvious target for big, long-term returns from small investments. (Inefficiently operated heating plants in commercial, apartment, and institutional buildings pump some 600,000 tons of soot into the U.S. atmosphere every year, wasting millions of dollars' worth of fuel in addition to fouling the environment.) As an example of readily attainable savings, a $6,000 investment in improved combustion for a 50-unit apartment in Yonkers, N. Y. cut annual fuel costs by one-third. It will pay for itself in five years.

Inefficient combustion increases fuel bills in two ways. Extra fuel to produce the required heat adds 5% to 15% to the fuel bill. Compounding this primary waste is the buildup of soot (unburned carbon particles that ideally are exhausted as carbon dioxide gas) on heat transfer surfaces. (The unwanted thermal-insulating effect of a 1/8-inch-thick layer of soot can add 8% to a furnace's fuel consumption.)

Caused basically by improper atomization of fuel oil before it is burned, inefficient combustion resulting in soot exhaust can be controlled by the following steps:

- Maintain fuel/air ratio specified by burner manufacturer.
- Check burner alignment and condition.
- Maintain recommended fuel oil temperature at burner tip (so that fuel enters burner at proper viscosity to insure complete combustion).

conditioning equipment, a major source of energy

 consumption, offers correspondingly large opportunities for O&M economy. The best time to service airconditioning equipment is spring. Among the key maintenance jobs are:

- Checking and repairing cooling towers.
- Replenishing refrigerant.
- Checking fans, pumps, compressors, and other rotating equipment for poor seals, belt slippage, and other defects.
- Calibrating controls.
- Changing filters.

According to architect P. Richard Rittelmann, maintenance personnel often reduce fan speeds after the building is occupied (apparently in response to objections about noise or drafts). The resulting reduced air flow over the coils may cause their frosting, with drastic reductions in HVAC system performance. Rittelmann advises every school district to check all rotating machinery annually for proper rpm.

The experience of a large New England industrial plant illustrates the evolution of a good airconditioning filter replacement program. Filters perform a vital function, trapping dust particles that would impair duct efficiency and reduce interior air quality. Inefficient filters also squander fan power, which consumes a surprisingly high fraction (25% to 30%) of an airconditioning system's total energy consumption. Before the institution of a preventive maintenance program, the filters were inspected on a rule-of-thumb schedule. In the second stage, the inspection schedule was corrected to incor-

porate the lessons learned in the first stage. A big third-stage refinement resulted from the second-stage discovery that atmospheric dirt and general filter inefficiency were correlated with a considerable drop in pressure across the filter. Ultimately, a bi-weekly schedule cut filter inspection to a minor fraction of the formerly required time. Moreover, by substituting a rapid instrument check for the workmen's judgement, the new program vastly improved the maintenance crew's efficiency. Similar improvement – in cleaning and overhauling air-handling units, compressors, power circuit breakers, transformers, and other equipment – enabled this plant to nearly double its maintenance efficiency.

According to figures cited by Lennox Industries' Ted Gilles, the expenditure of $1 for airconditioning equipment maintenance can yield nearly $6 savings in operating cost. Dirty filters waste energy by impeding delivery of warm or cool air to airconditioned spaces, lengthening the operation of heating-cooling equipment. In conjunction with dirty filters, dirty burners can drop burner efficiency by about 20%. Maladjusted fresh air dampers, which admit excess outside air, waste energy on both heating and cooling cycles. An annual maintenance expenditure of $15 per ton of refrigeration capacity can cut a net $70 per ton from operating costs, says Gilles.

An effort to systematize the identification of energy-wasting sources has been launched in the Memphis city schools. Felix E. Oswalt, assistant superintendent of

 the department of plant management, has proposed a Computer Profile of School Facilities Energy Consumption. Planned for introduction in the 1973-74 school year, this program classifies buildings by coded designations. Input includes such items as height, floor plan configuration, percentage of glass coverage in walls, HVAC system, and school program. Output, in such terms as total energy cost per square foot of building or per pupil, allows comparisons among different schools of the same type (to identify, for example, poor O&M practices or malfunctioning equipment) or among schools of different types (to evaluate the efficiency of different mechanical systems).

The need for better personnel

As the preceding section indicates, the most immediately pressing task in a school district's energy conservation program is to assure high qualifications in its O&M personnel. Since World War II, the mechanical-electrical share of the school construction budget has more than doubled — from roughly 20% to 45% in today's schools. Meanwhile, the personnel policies for upgrading our schools' O&M forces have lagged far behind. The importance of an efficient O&M program is further underscored by its long-term cost — a bigger cost than the initial cost of new construction.

"Our post-World-War-II schools need more than the traditional custodial staff," says Stephan. "They need skilled personnel, trained to operate and maintain equipment that is largely unique to schools. Too often

school boards appoint loyal, but semi-skilled, or even unskilled, employees to oversee these operations."

As part of this personnel upgrading program, school districts must recognize the intrinsic difference between maintenance and operation, according to Stephan. To keep the modern school's increasingly sophisticated mechanical and electrical equipment in good working order, maintenance personnel require considerably higher skills than operating personnel.

Some school systems have already recognized this need for improved technical qualifications for O&M personnel. School district superintendents in New York State must acquire three graduate-level course credits in planning and administering school plants. This principle should be extended to O&M personnel, according to EFL's president, Harold B. Gores.

"Heightened qualifications, achieved through night courses in a community college or manufacturer-sponsored courses in boiler, HVAC, and lighting equipment maintenance, could professionalize a school's custodial staff, enhancing its self esteem as well as its competence. Promotions would depend on credits for these courses. School administrators would recognize the O&M personnels' new status by setting aside special places for equipment manuals and the like. Higher salaries must, of course, accompany higher status and competence. But they would constitute a cheap price, returned many times over, for the vastly greater O&M economies achieved through upgraded personnel policy."

26 Stephan believes that O&M salary increases must be pretty steep to attract the required caliber of personnel. "For the average school district, salary increases of 50% or so are in order. These increases should reward the higher qualifications required throughout the entire O&M hierarchy."

Top O&M management requires first attention. For the average school district with eight to 10 schools and some $25-million worth of school plant, the director of operation and maintenance (ranked as deputy, associate, or assistant superintendent) should have a degree in engineering with a minor in management. His salary and qualifications should approximate those of private plant maintenance engineers bearing comparable responsibility. Public and private employers compete for the same supply of personnel talent. Ill-conceived efforts to economize on this salary will almost certainly cost the school district many times the savings. A school district paying an unqualified O&M director $12,000 a year will save $10,000 or so on his salary and lose many times that amount in unnecessary energy expenditures.

In the typical small school district, the O&M director requires two middle management assistants: a supervisor of maintenance and a supervisor of operations. As indicated earlier, the maintenance supervisor requires the higher qualifications. He should be an engineering graduate, with experience and working knowledge of building trades, electrical power, and even electronics for fire-alarms, communications systems, etc. The operations supervisor should have strong vocational training.

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Formal education and experience is less important for the "line" jobs in the O&M department, but upgraded salaries and better motivation are needed. In-service training, featuring one- or two-week courses at manufacturers' service and technical schools can keep these supervisors abreast of the latest technology.

For the custodians working under the building supervisor, salary increases lifting them above the normal (poverty-line) $4,000-$5,000 range would help to raise morale. Successful energy conservation requires good morale throughout the entire O&M personnel hierarchy, from top to bottom.

MODERNIZATION OF EXISTING SCHOOLS

Though the same basic energy-conserving techniques apply to modernization and new construction, there are obvious differences in the approaches to each. Many techniques that are economically feasible for new construction – for example, wall shading with vertical screening – would be prohibitively expensive for buildings not designed for them. For modernization work, an architect is more or less limited to replacing clear, heat-admitting glass with tinted, heat-absorbing glass, adding such glass as an additional exterior layer, installing Venetian blinds between panes or shading devices outside the windows. Modernization generally puts high first-cost components at a competitive disadvantage compared with the same items included in new construction.

An obvious reason for this tilted competitive balance is the added cost of demolition and repair of existing buildings often associated with the addition of new HVAC, plumbing, and even electrical systems. Still another factor weighs against the installation in existing buildings of sophisticated new equipment that might be easily justified for a new building. For example, a structure whose remaining useful life is 10 years or less, the annual cost of installing a durable, sophisticated central HVAC system would be intolerably high. But the annual cost for the same HVAC system in a new building with projected useful life of 40 years would be eminently reasonable.

Airconditioning economies

Simply eliminating airconditioning may appear to be

a viable method of reducing a school's energy consumption, but this report does not consider it as a generally useful technique. In northern climates, architects may occasionally exploit natural ventilating patterns and wall shading to produce a tolerable thermal environment without artificial cooling. But usually airconditioning appears to be a necessity in the schools of the future for several reasons:

- The trend toward increasing summer use, which makes airconditioning mandatory almost everywhere in the U.S. This is an inherently efficient practice with capital cost economies that almost inevitably outweigh the costs of airconditioning.

- Available evidence suggests that airconditioning enhances teachers' and students' performance.

- Elimination of airconditioning and the consequent need for natural ventilation often forces the design into uneconomical building shapes.

In both modernization and new construction, the HVAC system offers a tremendous potential for reduced energy consumption. Energy consumed to maintain comfort within the nation's buildings constitutes about 20% of total national energy consumption.

Energy consumed by most HVAC systems could be cut by 30%, according to experts at a National Bureau of Standards/General Services Administration meeting in May, 1972. The mechanical engineer's choice of HVAC system depends on a host of local factors — building

 shape, availability and cost of fuel, competence of maintenance crew, etc. Yet there are some general principles that can serve as guidelines in the quest for energy conservation economy.

The first such principle concerns the performance criteria demanded of an airconditioning system. From the standpoint of precise, reliable performance in controlling the thermal environment, the "single duct, all air cooling and reheat" system offers the best combination of temperature and humidity control. But for energy conservation, this reheat airconditioning system is probably the worst choice. It first cools all incoming air to the lowest temperature required in any interior space. Then it compounds the energy waste of this excessive cooling by reheating large amounts of air circulated in spaces with a lower cooling demand, or even a heating demand. The additional heat generated by this excessive cooling is usually wasted.

Far more efficient than the single-duct, reheat system is the "variable volume" system. As the name implies, variable volume airconditioning matches the cooling load with a variable volume of air cooled to required temperature. There is a slight sacrifice in environmental quality, especially in summer humidity control (which can be achieved quite precisely with the reheat system). But this sacrifice seems tolerable in view of the great and growing economies promised by the variable volume system. The greatest obstacle to this system's use is the outdated ventilation requirements in many build-
g codes.

Both the foregoing airconditioning systems are variants of central airconditioning. Within the past 10 years, however, packaged, multizone airconditioning systems have begun competing with central systems. This new trend originated with California's SCSD program, initiated in the early 1960s. The new packaged units are especially well adapted to modular systems building:

Packaged HVAC systems differ from central systems in the location of the basic equipment (furnace, refrigeration units, and circulating fans or pumps). Instead of centralizing this equipment, the packaged HVAC system spreads it around the building in compact ("package") units. The packages contain a furnace, refrigeration compressor, condenser, and fan coil unit designed to aircondition (i.e., heat, cool, humidify, or dehumidify) a specified zone as large as four standard classrooms. Whereas central systems may exceed 20,000 tons of refrigeration capacity, packaged units seldom exceed 50 tons.

Renovation work further complicates the already complex tradeoffs between central and packaged HVAC systems. A project handled by School Renovation Systems (SRS), of San Francisco, illustrates several of these complicating factors. For Paul Revere elementary school annex, a two-story, concrete-framed, brick-faced building, two gas-fueled, central HVAC systems (one for each of two 15,000-sq-ft floors) proved most economical. What favored central HVAC at Paul Revere was the extensive reconstruction. Partitions and suspended plaster ceilings were demolished; a toy bulldozer cleared each floor. With the building cut back

 almost to its bare structure, the labor costs for cutting expensive openings for ductwork were minimized, thus removing a factor that often favors packaged HVAC units for modernization.

SRS sets some crude criteria for the choice of a HVAC system in a modernization project. For one-story buildings, packaged units on the rooftop are the most economical because the duct runs are minimized. Ducts can merely run down through the roof into the ceiling space, serving modular areas of 4,000 sq ft or so. When the building is two or three stories high, there is a contest between central and packaged units. For buildings four stories and higher, central HVAC units are favored, because the longer vertical duct runs reduce, or nullify, the advantage of packaged HVAC units.

More general criteria concerning the relative advantages of central vs. packaged, multizone airconditioning systems apply both to modernization and new construction. Packaged, rooftop units often permit large savings in fan power needed to move conditioned air to distant spaces. Thus they are best suited to low, sprawling buildings. Central airconditioning systems are most efficient in compact, multistory buildings where fan power requirements to circulate the treated air are relatively low. Moreover, the higher the heating and cooling loads (in Btu/hr/sq ft), the more efficient the central plant. Electrical distribution also favors central systems; it is easier and more economical to bring electric power to a central point than to many packaged units. Gas pipes for heating pose an even greater problem for packaged HVAC systems.

According to Dubin, a central HVAC plant is normally 10% to 15% more efficient than packaged HVAC units, for two reasons. First, its equipment is more efficient. Second, it has an intrinsically more efficient condensing apparatus. In every refrigeration cycle, the refrigerant (the basic cooling agent) must be condensed from gaseous to liquid state after it cools the water or air that is used as the cooling medium. In central HVAC units, the condenser uses water to condense the refrigerant. But for the rooftop packaged units, the necessarily light condenser normally uses air, a much less efficient cooling medium than water for rejecting the heat of condensation. An air-cooled condenser uses considerably more energy than a central system's water-cooled condenser. Thus the normally air-cooled packaged HVAC unit starts out with a basic energy-consuming handicap in its competition with a central HVAC system.

There are several other advantages possessed by central HVAC:

- It can burn cheaper fuel.
- It can be designed for lower total capacity than packaged or window units and usually for greater overall operating efficiency.
- It is more adaptable to automatic, computer control and maintenance economies.

As a general conclusion, a central HVAC system, skillfully designed to exploit all potential opportunities, seems most likely to conserve energy, and probably also to minimize long-term owning costs. Yet each project must be rigorously analyzed for its own unique combi-

nation of factors. Among the variables that can affect the choice between central and packaged units are *load factor* (airconditioning energy used/total capacity) and *diversity factor* (maximum overall demand/sum of individual peak loads).

Energy sources — natural gas, electricity, oil — constitute another major factor. And today, with energy prices changing and some sources (notably, natural gas) in short supply, the designer of an economical HVAC system must be something of a soothsayer.

Even when the system choice has been made, important decisions remain. Sizing of central units for long-term economy requires judicious weighing of assets and liabilities. Increasing the size of a central chiller unit reduces its capital cost; on a per-ton capacity basis, a 5,000-ton unit costs only half as much per ton to install as a 250-ton unit.

The mechanical engineer must carefully study the load factor in choosing units because a large unit operating at partial capacity loses efficiency. Energy consumption for central airconditioning systems is reduced by specifying at least two refrigeration machines, each complete with its own cooling tower, pumps and other auxiliary equipment. When cooling loads drop to 50% or less, it is more efficient to operate only one machine.

The same principle holds for boilers. Significant fuel savings are attainable through use of smaller units coupled together for independent firing to operate at peak capacity and efficiency as demand increases.

Because of the inefficiency of operating central HVAC equipment at very low capacities and on an intermittent basis, space with irregular occupancy hours might be more efficiently cooled with window or packaged airconditioners equipped with thermostatic controls. However, the efficiency of different manufacturers window and package airconditioning units varies widely and some require twice as much energy per ton of refrigeration than others. Assuming efficient equipment with thermostatic controls, there is less probability of energy waste through excess heating or cooling than with central airconditioning.

When central airconditioning is the choice, air distribution should be at low or moderate pressure, not high-velocity, high pressure. Fans and pumps use about 40% of the energy consumed by an airconditioning system. High velocity, high pressure air distribution raises duct friction losses and raises energy consumption needed to run the required larger fan motors. The smaller ducts allowed by high-velocity distribution may slightly reduce construction costs, because of a thinner floor-ceiling sandwich in multistory buildings. But, normally, this slight saving is soon dissipated by higher energy consumption.

Since heavy airconditioning loads are the chief source of electric power interruptions, research is under way on "cooling storage" techniques, which would flatten the jagged peaks of the energy demand curve and reduce the hazards of blackouts or brownouts when demand exceeds capacity. In addition, the altered power/ and profile would also conserve energy; electrically

 driven airconditioners would operate on 60% less power. Steady power demand representing the same total energy consumption as a jagged power demand curve with prominent peaks and valleys represents greater power-generating efficiency. Lower peak hour demand enables the utility company to operate its best equipment most of the time, without the necessity of using old, inefficient turbogenerators.

"Cooling storage" airconditioning depends on a basically simple scientific principle – thermal energy storage (TES). When the airconditioning unit is operating, refrigerant at 40F or so flows from the evaporator through a thin, lightweight panel of ribbed aluminum and plastic containing salt-hydrate crystals that freeze solid at 55F. Offpeak nighttime operation of the airconditioning system builds up "ice" in the TES panel. At maximum cooling load, the melting crystals replace the evaporator as the cooling source, relieving the energy load on the compressor. By evening, when the "ice" has melted, the compressor starts up again, renewing the airconditioning cycle. TES changes the airconditioning system from an energy-peaking drain on the electric utility into a power stabilizer. It adds further economies by reducing the required refrigeration capacity by about 40%.

The energy-storing principle is already in practical use. An electrically energized heat storage system, serving 250,000 sq ft of office space, cuts operating costs for the New Hampshire Insurance Company headquarters in Manchester, N. H. Operating between the hours of [illegible] p.m. and 7 a.m., this heat-storing system cuts working

day power consumption to 20% of total consumption.

The heat storage system features three 16,000-gallon tanks with electric resistance heating elements, each rated at 735 kw. Tank water, heated to 280F, merely stores heat; it does not circulate. Two heat exchangers per tank supply water for space heating and domestic hot water.

Electric heating, however, generally works against energy conservation. So long as oil, coal and natural gas constitute the prime fuel sources for electric power generation, electric heating will remain an inherently wasteful use of energy. What makes this practice inefficient is the two basic energy conversions – from heat to electricity and then back to heat – with transmission losses sandwiched in between. The 32% thermal efficiency of this process can be doubled when the fuel is burned at the site for direct conversion to heat.

The growing popularity of electric heat, especially in single-family homes, stems from lower first cost (which makes it popular with speculative builders), and the subsidized rates through which many public utilities have encouraged a rapid growth in this wasteful practice. In view of the energy crisis, it seems doubtful that these energy-wasting policies can be allowed to continue. Already, utilities in some cities (notably New York) have superseded sales campaigns for electric heat by "save-a-watt" campaigns.

Electric heat can, however, be efficient as a supplementary heat source – for example, in the periphery of a building with highly variable heat gains or losses

 through the walls. Electric heat is inherently inefficient only when it is used as the primary heat energy source. (The electrically driven heat pump is not, strictly defined, a form of electric heat.)[8]

Like TES, solar radiation may eventually become a nonpolluting, energy-conserving power source sometime in the foreseeable future. Even now, the solar radiation impinging on a school building's roof could supply several times the total winter heating loads. Solar energy might be particularly advantageous when used in conjunction with a heat pump.

Improved thermal insulation

Another largely ignored technique for reducing energy consumption is the use of better thermal insulating materials. But in conjunction with wall shading, it constitutes the most important determinant of heating and cooling loads. In fact, as a means of reducing long-range owning costs, thermal insulation is probably the most economical investment that can be made in a building. The additional cost of improved insulation can usually be recouped within two to five years, after which it becomes a perennial economy.

Closely related to thermal insulating quality is the heat-retaining capacity of building materials. Over the past several decades, the substitution of light wall and roof construction has greatly reduced the heat capacity of building materials. Traditional heavy stone, masonry, and concrete construction retards heat gains and losses;

thus flattening a building's energy demand curve for heating and cooling. Mainly because it reduces peak demand, a flattened energy demand curve promotes energy conservation in three ways:

- It reduces capital cost for heating and cooling equipment, which can be designed for lower capacity.
- It assures more efficient energy use, because equipment is most efficient when operated close to capacity.
- It relieves peak demand on electrical power utilities, which can meet peak demand only at the price of reduced efficiency.

Improved lighting design

At no real sacrifice in quality, energy consumption for lighting could be reduced by at least 25% in new buildings and by 15% in existing buildings, according to a panel of experts assembled by the National Bureau of Standards and the General Services Administration. Lighting is an extremely important factor in overall energy consumption. As indicated earlier in this report, excess lighting wastes energy in two ways: in direct consumption of electric power (to produce the light itself) and then in additional energy required to dissipate the quantities of waste heat generated by the lights. Even with modern fluorescent lamps, nearly 80% of consumed lighting energy ends up as waste heat. Moreover, reductions in lighting levels produce amazing energy savings. Dropping an illumination level from 150 50 ft-candles reduces energy consumption by 90%.

40 There are two obvious methods for reducing the electrical energy consumed in lighting. Local switching, enabling occupants to turn off part of a room's lights is available at a negligible increase in wiring costs. Another obvious method is to design lighting for specific local tasks instead of uniform general levels. According to Stein, designing individual study carrels for local illumination of 70 ft-candles (the recommended IES standard for general classroom lighting) would cut lighting power requirements by 80%.

Lighting consultant William M. C. Lam, of Cambridge, Mass., cites several other techniques for restricting high illumination levels to specific local spots where they are needed. In drafting rooms, table-anchored, swivel-armed fluorescent lamps provide flexibility. They also provide better individual glare and shadow control than general high-level ceiling lighting. Incandescent lamps still have their local lighting uses. Movable track fixtures permit the movement of luminaires to different locations where they are needed.

The Illuminating Engineering Research Institute (IERI) recommends the use of photoelectric switching to combine natural and artificial lighting to best advantage.

"High-low" ballasts offer still another means of effecting relatively large economies at extremely slight additional capital investment, according to Lam. For about 10% additional first cost for lighting fixtures, high-low ballasts (individually switched at each fix-

ture) allow a building owner or the occupants to select the lighting level in each part of each room whenever the furniture or use is rearranged. The savings are particularly great in modular buildings where flexibility is achieved through a uniform layout of lighting fixtures. If only the fixtures located over desks were operated at "high" and all others at "low", the average lighting load in a typical building may be reduced by 50%, with additional savings in extended lamp life. There would also be a more comfortable and attractive environment.

If high-low ballasts were required on all government financed projects, the ballasts would become competitively priced and the additional first cost would be offset by operating savings in weeks instead of months.

Many experts are questioning lighting criteria. The basic standard for school lighting is reading hard pencil on cheap, gray foolscap. Why, asks Stein, choose such an arbitrarily difficult task? Why can't the student use a softer, more legible pencil, or even better paper? Visual perception is extremely sensitive to the quality of reading material. With everything else constant, 8-point Bodoni type can be read with the same ease at 2 ft-candles as No. 2 pencil writing at 63 ft-candles.

It is, of course, convenient to have uniform general lighting levels throughout an entire academic space. But in view of the economic and social costs of such tremendous energy waste we may have to compromise.

42 The New York Chapter of the American Institute of Architects agrees with other experts that a 25% reduction in electrical lighting energy consumption is in order.

Several new technological improvements are available to cut the energy consumed by lights. Cooling fluorescent fixtures via the air-or water-cooling heat recovery techniques discussed later in this report appreciably raises their efficiency; an ordinary 40-watt fluorescent lamp operating in 77F air produces 14% more light than the same lamp operating in 100F.

Operating fluorescent lamps at higher frequencies than the standard alternating current 60 cycles per second also raises lighting efficiency. At relatively high lighting levels, raising the frequency to 3,000 cycles per second can cut operating costs by 15%. Despite its higher initial cost, high frequency lighting nonetheless merits investigation by the school designer.

Use of large glass areas to cut the need for artificial light poses a perennially debated problem. Does the saving in lighting energy justify the added cost for heating and cooling accompanying the larger heat losses and gains through the glass? Mechanical engineers tend to favor the use of opaque well insulated walls with minimum glass area. Architects and lighting consultants sometimes tend to favor the potential light-energy savings attainable through well designed and shaded glass. (Among their liabilities, large glass areas increase maintenance costs — for replacement of broken glass, for washing, and for blinds and other natural light

controls.) Each case requires individual study by the architect and his consultants.

Waste-heat recovery

Perhaps the most productive energy conservation technique is the recovery of waste heat, which is usually rejected to the atmosphere, but could be used elsewhere in a building. Among the most productive waste-heat reclamation techniques are the following:

- Recovery of lighting heat loads.
- Exhaust heat recovery.
- Total energy plants. (See next chapter.)
- Heat pumps.

Schoolrooms produce an unusually high heat gain, often requiring cooling even when outdoor temperatures fall below 20F. This is because of their dense occupancy, roughly three times that of a typical office. Light troffers can heat the ceiling plenum to temperatures exceeding 120F, and the consequent heat gain ranges between 50% and 80% of the heat gain from human occupants. During cold winter weather, removal and recovery of this light-generated heat saves energy in two ways: by reducing classroom cooling and heating loads; and by reducing total energy consumption by transferring the excess heat to other areas that need it.

Removal of this light-generated heat can be accomplished by two techniques: piping cooling water through jackets in the lighting troffers, or exhausting room air through aircooled fixtures into the ceiling plenum.

 Of the two techniques, water cooling is inherently the more efficient. Connected to an evaporative cooler, the water-cooled lighting fixture reduces the required capacity of the airconditioning system's refrigeration equipment as well as fan horsepower and duct size. Aircooled fixtures do not reduce required cooling capacity, because they are part of the airconditioning system, not, like the water-jacketed fixtures, incorporated into a more efficient, independent system of their own.

Potential economies through light-generated heat recovery are indicated by a San Diego office building equipped with combined water-cooled lighting and airconditioning troffers. In return for $20,000 additional cost for the special light fixtures and $50,000 for improved thermal insulation (in this case, double-glazing), the owner saved $100,000 in reduced airconditioning and air-handling equipment. And in addition to this net $30,000 capital saving, he will perennially benefit from lower operating costs. Heat exchangers designed to recover normally wasted exhaust heat can reduce winter heating energy consumption by 30%-35% and summer airconditioning energy consumption by 15%-20%. These exhaust heat exchangers come in four basic kinds: rotary wheel exchangers; water-cooled, coil (run around) exchangers; heat pipe banks; and air-to-air exchangers. Each kind can provide all the fresh air intake preheat needed either in winter or summer.

The rotary wheel exchanger has several advantages. Strategically located to intercept adjacent airstreams and packed with heat-absorbing material (for example,

aluminum or stainless steel shavings), a rotary wheel heat exchanger can directly transfer heat from the exhaust to the supply airstream. It can, moreover, recover both sensible and latent heat (i.e., the heat contained in the phase change of atmospheric water vapor). A coil exchanger can recover only sensible heat. Thus it is less efficient in effecting summer cooling savings. As a major drawback, the rotary wheel exchanger requires the same location for supply and exhaust ducts.

For smaller or existing installations, the coil exchanger offers the advantage of heat transfer between supply and exhaust ducts in widely separated locations. Finned coils are installed in both ducts, and the heat-conveying water is simply pumped from the exhaust to the supply duct.

Heat pipe banks and air-to-air heat exchangers are more exotic techniques that merit investigation by mechanical engineers.

The heat pump offers still another method of recycling waste heat. Like the refrigeration unit in a conventional airconditioning system, the heat pump comprises three basic components: compressor (the system's prime mover); an evaporator (the cooling component); and a condenser (the heat-rejecting component). The heat pump differs from normal airconditioning in its reversibility, which allows it to recover the normally wasted heat rejected by the condenser and use this reclaimed energy for winter heating.

 The heat pump's reversible cycle depends on an intricate, four-way valve that can reverse the basic cooling cycle. In this reversed cycle, the outdoor condenser (heater) becomes an evaporator (cooler), and vice versa, the indoor evaporator becomes a condenser heating the interior. During the heating cycle, reversed refrigerant flow extracts heat from the outdoor air and yields it indoors at the condenser.

If, for some reason, the decision has been made to heat and cool electrically, the heat pump is the most efficient method. Because it draws a large part of its energy from outside air, well water if available, or condensed water in a closed loop system, a heat pump can be 2.5 to 6 times more efficient than other electrical heating methods. Electrical resistance heat is inherently far less efficient than the heat pump because the generation, transmission and distribution of electrical power loses about 60% of the potential energy of the fossil fuels that produced the power. The heat pump is especially efficient for southern climates when outdoor air is used, but if well water or condensed water is used, heat pumps can sometimes compete with more conventional heating and cooling techniques in northern climates.

A case in point is a Kimberly, Wis., high school, where mechanical engineer Walter R. Ratai combined a heat pump with an ingenious light-generated heat recovery system to reduce annual heating and cooling costs below the estimated fuel cost for heating with a conventional unit ventilator system. Moreover, the design reduced capital costs by an estimated $150,000. Addi-

tion of cooling boosted total construction cost by $180,000. But the compact design made possible by cooling cut $330,000 from general construction, electrical, and plumbing costs.

Because of the heat recovery system, the Kimberly school requires no additional heat when the outside temperature is above 23F. (At this equilibrium temperature, excess heat drawn from interior areas is circulated in the cooler peripheral areas.) When temperatures drop below 23F, the heat pump extracts supplementary heat from 54F water in a 650-ft-deep well. Removal of classroom air through the lighting fixtures reduced required cooling capacity by 10% and fan power by 25%. By removing 70% of total light-generated heat from the classrooms, the engineer enhanced the efficiency of the heat pump and the lamps, which (as noted previously) operate more efficiently at cooler temperatures.

PLANNING NEW SCHOOLS

Starting out with a new building obviously offers the greatest opportunity for energy conservation. With the clearly stated goals of energy conservation and life-cycle costing in the architectural program, a school building's energy consumption can be reduced by up to 50% compared with a conventionally designed building. In addition to the techniques discussed previously, new construction offers several means of energy conservation that are generally impracticable (or less practicable) for existing buildings. Among these are:

- Compact building shape.
- Multi-use occupancy.
- Total energy.
- Wall shading.
- Automatic controls.
- Improved mechanical design.
- Improved electrical design.

Compact building shape

Building shape plays a basic role in the energy required to heat and cool a building. Since heat gains and losses are transmitted through walls and roofs, the designer should attempt to minimize these surface areas. As an indication of the heat loads imposed during hot weather, the temperature of a grey slag roof can reach 175F. Sprawling, single-story schools maximize roof areas.

Energy conservation thus reinforces rising land costs to favor more efficient, compact building shapes. The trend

toward year-round sessions with its consequent need for airconditioning further enhances the advantages of the compact, multistory building shape. A mere indication of practicable surface area reductions — a three-story, double-loaded classroom corridor wing requires 35% less building-surface area than a single-story building of equal volume. A compact design also reduces plumbing and electrical costs, through shortened runs for pipe and conduit.

Other siting factors may sometimes outweigh compact building shape as an energy-conserving measure, according to Stein. Skillful exploitation of prevailing winds, topography, and trees, a sheltered solar exposure, or other natural features may enable an architect to design less compact shapes that may ultimately prove more efficient than simple minimization of the building's area/volume ratio. Relying on natural ventilation for hot weather cooling may require toleration of occasional discomfort on calm days. Nonetheless, imaginative exploitation of natural features is a largely ignored ancillary method to be used in conjunction with building shape as a major energy-conserving technique.

Building orientation affects airconditioning energy requirements. A rectangular building with a 2.5 length/width ratio absorbs considerably less solar heat if its long axis is aligned in an east-west instead of a north-south direction. (The sun bakes east and west walls longer and more ferociously than even a south wall, which can be more readily shaded and which intercepts solar rays at less direct angles.)

50 Multi-use occupancy

Closely related to building shape as a factor in energy conservation is the multi-use building, a design technique of increasing relevance, especially for the central-city school. Skyrocketing land costs, coupled with short supply, inspired design of the earliest multi-use school-office and school-apartment structures built during the mid-1960s. Energy conservation adds another advantage to multi-use buildings, especially for school-apartment buildings. Incorporating a school and residential apartments in a single structure affords an excellent opportunity to reduce the overall surface area/volume ratio below that of two separate structures. And with their staggered peaks in airconditioning demand, the school and apartment have complementary energy demands. The flattened demand curve permits lower total plant capacity and the greater operating efficiency of running equipment closer to capacity.

Multi-use projects offer an opportunity for schools to exploit the potential economy of *total energy* (discussed below). What is needed for total-energy economy is complementary uses of energy. A project under study by the Fairfax County (Va.) School District would consolidate the energy plants for an elementary school and a shopping center. According to Ed Stephan, the total energy plant serving the school-shopping center complex would have two turbines, designed to operate on either kerosene or diesel fuel (which could be altered as supplies and prices vary to favor one fuel or the other).

Total energy

Total energy, the on-site generation of electric power along with other building energy needs, is basically a heat recovery method that can cut operation costs in special circumstances. Schools of widely-varying size — from 330 to 2,300 students — and widely separated geographical locations have been equipped with total energy plants.

The heart of a total energy plant is a gas or oil-fueled engine or a gas-fueled turbine that drives the electrical generator. Waste heat from the power generator is recovered for heating or cooling. Under the most favorable circumstances (which seldom occur), this waste heat more than doubles the thermal efficiency of the total energy plant — from about 30% to 70%. (Gas-fueled turbines offer even greater efficiency as well as greater pollution abatement than gas or oil-fueled engines.)

Operating economy in a total energy plant depends on the use of surplus generating heat as the energy source for an absorption refrigeration machine. An absorption chiller replaces the conventional compressor-evaporator refrigerating cycle with an absorptive-evaporator cycle. In the absorber chamber, a salt (lithium bromide) solution accelerates the evaporation of water from the evaporator chamber to which it is connected. (The salt solution has a lower vapor pressure than the pure water.) Waste steam from the power generator keeps the process going, by boiling away excess liquid in the absorption chamber, thus maintaining correct salt concentration.

52 Absorption chillers use more of the fossil fuels than electrically-driven refrigeration units of similar capacity, but their operating costs may be lower depending upon the relative fuel and electrical costs. When powered by the waste-heat from total energy electric generators, they offer even greater operating savings. And their maintenance costs are similarly low.

Though not a generally economical solution to a single school building's energy problem, the total energy plant merits consideration as part of multibuilding complexes or multi-use projects.

To exploit the potential economies of total energy, a project must satisfy three basic criteria:

- It must have high, fairly constant energy demand during most of the day, over most of the year, both for electric and waste-heat power. (This criterion eliminates total energy for schools on a nine-month schedule.)

- It must have heating or cooling demands that are both simultaneous and roughly proportional to lighting and other electric power demands.

- Gas (or oil) fuel rates must be competitive with prevailing electric rates.

Wall shading

Here is another basic, yet often neglected, technique for reducing a building's energy consumption. New York City architect Manfred H. Riedel says wall shad-

ing has become almost a lost art among modern architects; they simply use power instead of ingenuity to provide interior comfort. Each wall of a building may require a different treatment, depending on its exposure. To capitalize on glare-free natural lighting, the best exposure for a wall with large glass area is north (like artists' studios). It also reduces summer airconditioning loads. Planting trees along a west wall provides shade in summer, when the trees are in leaf, and admits sun in winter when solar heat gain may help. Canopies, projecting mullions, louvers, and solar glass screens can drastically reduce solar heat gain.

There are several techniques for reducing solar heat gains, and even losses, through glass. Shaded glass admits only one-quarter of the radiant heat admitted by unshaded glass exposed to sunlight. Double-glazing (two layers of glass with an insulating air space between) prevents winter heat loss as well as summer heat gain. Double-glazed, shaded, heat-absorbing glass reduces heat gain by about 85%. Reflective glass cuts heat gain by one-third or so.

The principle of reflective heat rejection is exploited in the design of a 20-story building for Loop College in downtown Chicago. Designed for minimal glass area by the Office of Mies Van der Rohe, the opaque walls of this building will be painted a heat-reflective metallic silver.

Automatic controls

ditioning is the major building subsystem suit-

 able for automation. It can be monitored by a central control console where an operator can start and stop equipment; read and automatically record temperature, humidity and flow conditions; reset the air and water temperatures; and receive and acknowledge alarms. The system can be computerized to obtain greater energy conservation, thereby lowering the operating costs, and it can assist the preventive maintenance program.

One simple means of conserving airconditioning energy is an "economy cycle" that shuts down the refrigeration machines and takes in outside cooling air when temperatures drop to 55F. The economy cycle depends on automatic dampers on the supply fan opening to the outside. The cool outside air mixes with return air in needed proportions to achieve the desired temperature. In the most sophisticated control systems, empirical data on solar heat absorbed hourly by sun-baked walls is fed into the computer for correlation with the volume of chilled water required to produce comfortable temperatures. The computer can be programmed for the following tasks:

- More economical operation of pumps, fans, compressors, and related subsystem equipment.
- Immediate detection of overheating, overcooling, or other subsystem failures.
- Surveillance and control of faulty equipment.
- Closer detection and consequently quicker correction of deviations from desired comfort levels of temperature and humidity.

Automatic control devices can produce significant energy savings in other building subsystems — notably elevators, which can be shut down and restarted by time clock devices.

Central control systems can often be amortized in less than five years, through big savings — not only in fuel and labor costs, but in lengthened equipment life.

Improved mechanical design

Many mechanical engineers have remained as unconcerned as building owners about energy waste. First-cost economy in mechanical design has long been the general rule. Few manufacturers could even supply data on the operating characteristics of their equipment at partial loading, information essential for long-term operating economy. Mechanical engineers have tended to overdesign HVAC equipment for two reasons: to satisfy peak loads, and to hedge against substandard construction such as poor door fittings and loose window seals. This wasteful practice assures unnecessarily high energy consumption at normal heating and cooling loads.

Several changes in traditional design practices can achieve much greater operating economy:

- Use of energy flow analysis, not peak demand, as the basic design philosophy.
- Design for *adaptability*, not *flexibility*, as the basic criterion.
- Design for lower thermal environment standards.

Energy flow analysis is a tool already used by leading design firms to replace the crude conventional practice of simply designing the HVAC system for peak heating and cooling loads. Under this philosophy, the mechanical engineer is a member of the preliminary design team; he points out the impact of architectural design on the building's total energy requirements – for lighting, electrical equipment, heating, ventilating and air-conditioning, etc. Instead of merely specifying equipment to meet the architect's design, the mechanical engineer offers alternative schemes that will minimize energy consumption.

Computer-calculated programs for comparing alternative energy systems are in use by the larger mechanical engineering firms. One such program is ACCESS, "Alternative Choice Comparisons for Energy System Selection." Sponsored by the Edison Electric Institute, this program enables the engineer to compute estimated life-cycle costs for *all* the building's energy-consuming systems. It weighs such factors as demand as well as consumption.

The American Society of Heating, Refrigerating, and Airconditioning Engineers (ASHRAE) has been conducting surveys of energy consumption in an instrumented building. ASHRAE's analysis of building heat gains and losses, in addition to such basic factors as the building materials' thermal-insulating qualities, accounts for such often ignored factors as shading, orientation and heat-gain lag due to the building materials' heat capacity. According to Royal S. Buchanan,

ASHRAE technical director, use of these sophisticated energy-requirements calculations should result in substantially lower operating costs.

Another set of computer programs, developed by the Gas Industries Research Section, expands the scope of the ACCESS and ASHRAE programs. Called Ecube, this energy analysis grew out of a program designed for detailed feasibility studies of total energy.

The Ecube program answers such questions as the following: How much refrigeration-supplied cooling energy can be saved by using an economizing outside air cycle? How does energy consumption vary with different thermal-insulating values for the building skin? How much additional energy is required for various levels of humidification? What is the thermal efficiency of different systems? How much of the recoverable waste heat can be used? What size units are best? And the crucial question — which system minimizes the long-term owning cost: System A (high first cost, low operating cost); System B (low first cost, high operating cost); or System C (moderate first cost, moderate operating cost)?

Design for adaptability instead of flexibility is a philosophy advocated by Dubin. Designing spaces for the maximum airconditioning and lighting loads can waste great quantities of energy. Designing them for the capability of modification to these maximum loads is far more economical.

Standards of thermal comfort may have to yield a little

 under the impact of the energy crisis. Significant quantities of energy could be saved merely by lowering interior winter temperatures and raising summer temperatures from the 75F mid-point of the 73F to 77F range defined as "thermal comfort conditions" by ASHRAE. Raising the summer temperature from 75F to 78F could cut energy consumption for the airconditioning by about 10% in the average airconditioned building. Similar savings could be realized by lowering interior winter temperatures. Cold-blooded occupants could readily adapt simply by wearing heavier clothing.

According to Dubin, many other buildings (including schools) could be designed for atmospheric conditions that are exceeded only 5% of the time instead of the 2.5% criterion in current use. This relaxed design would allow spaces to become warmer or cooler only about 50 hours a year more than current standards allow. In view of the added efficiency which would be achieved through regular operation of the HVAC system closer to capacity, the slightly reduced standard of comfort seems a bargain.

Ventilating standards set in the days before modern technology cause needless problems. Most codes require excessive quantities of outdoor ventilating air. But flooding buildings with huge quantities of outdoor air raises capital and operating costs — for additional heating and cooling capacity, and for energy to temper outdoor air and fanpower to move it. Today, where fresh air is required to dilute stale, odorous indoor air, charcoal-activated filters, or even ultra-violet lamps can often produce better results at big savings.

Heat captured from heat-producing equipment and exhausted directly to the outdoors offers another means for conserving energy. In a research project for the Veterans Administration, mechanical engineers Dubin-Mindell-Bloome Associates reduced the airconditioning load by more than 25% through direct exhaust of kitchen and laundry air. Significant, if less spectacular savings could be effected in schools by similarly designing exhaust systems for direct rejection, instead of throwing this additional load onto the building's HVAC system.

Improved electrical design

Apart from lighting, electrical design offers relatively slight opportunities for energy conservation. With its constantly increasing use of electricity — for radio, TV, slide and movie projectors, teaching machines, signal and PA systems — the school should, nonetheless, exploit all energy-economizing opportunities. Basically, these opportunities involve more efficient distribution and power-demand limiting devices.

Because of higher line losses at lower voltages, use of higher voltage transmission reduces a school's electric bill. As part of its energy-conservation program, the General Services Administration now purchases electrical power at 13,800 volts and distributes the service at this relatively high voltage to local substation transformers located throughout a building. These transformers reduce the voltage to 277/480 volts for fluorescent lighting, heavy equipment, power and distribution.

 A second set of transformers steps the voltage from 480 to 120/208 volts, for receptacles and miscellaneous equipment — typewriters, adding machines, cleaning equipment, etc.

For large buildings, electric utilities add a "demand" surcharge to their basic rates, for installing and maintaining service facilities larger than required for normal service. To eliminate demand surcharges, a Permissive Load Control (PLC) can reduce electric bills by up to 20%, merely by disconnecting loads that are not immediately vital to a building's operation. When vital service (non-deferrable) load reaches a predetermined power level, PLC temporarily disconnects deferrable loads. Essential services include lights, general heating and cooling, elevators, and cooking ranges. Deferrable services include domestic hot water heating, corridor and stairwell heating and cooling, swimming pool heating, and snow-melting heaters, which are disconnected in reverse order.

Inefficient use of electrical power, for which most utilities raise rates, is another candidate for correction with widespread design possibilities. Induction motors that drive fans, compressors, blowers, pumps, and the like, sometimes exhibit a low "power factor". (Some electrical devices, such as lights, are free of this particular power drain.) Many utilities penalize customers whose electrical equipment operates at an average power factor below a specified percentage (typically 85%), and this practice is expected to grow.

Capacitors installed on these underused power lines raise power factors and reduce power losses, by correcting voltage/current imbalances. In some instances, savings in averted power factor charges can pay off the capital investment for capacitors within two years.

New construction thus affords the designer an entire spectrum of energy-conserving techniques embracing those specifically discussed in this section plus other techniques discussed under "Operations and Maintenance Changes" and "Modernization of Existing Schools."

SUMMARY AND RECOMMENDATIONS

62 Regardless how it is expressed in a local community, the energy crisis is no future threat; it is a current reality that will certainly intensify. This intensifying crisis will be marked, at worst, by fuel shortages and power brownouts and blackouts; at best, by rising energy costs. School administrators should lose no time instituting energy conservation programs incorporating the following steps:

1. Review O&M personnel for their qualifications to cope with the increasingly sophisticated mechanical-electrical equipment going into schools.

2. Analyze energy consumption in existing schools, to identify sources of energy waste.

3. Include energy conservation as a major part of an architectural program for modernization or new construction projects.

4. Use life-cycle costing (or some variant that weighs O&M costs) to replace initial cost as the sole basis for contract awards for mechanical and other energy-consuming subsystems.

APPENDIX I/LIFE-CYCLE (LONGTERM) COSTING OF BUILDINGS

For a building where the owner pays O&M costs as well as capital costs, there are three basic techniques for computing life-cycle (longterm) costs:

1. Benefit/cost analysis.
2. Time-to-recoup capital investment.
3. Direct comparison of life-cycle costing for alternative systems of building or subsystem(s) useful life.

Benefit/cost analysis formalizes the decision confronting an owner who must decide whether a capital improvement is economically justified. In more sophisticated applications, a benefit/cost analysis can also provide a rational basis for choosing among alternatives, after the go-ahead decision has been made.

Virtually every decision that one makes entails, at least subconsciously, some form of benefit/cost analysis. We are constantly balancing costs — in time, money, or effort — against benefits — in saved time, or simply in satisfaction. All costs and benefits must be reduced to a monetary value and the ratio computed. If benefits exceed costs, i.e., the benefit/cost ratio exceeds 1, then the project is economically justified.

The second method, *time-to-recoup capital investment*, merely calculates the time required to recoup the original capital investment through annual O&M savings, which are used to pay the annual debt service required to amortize a loan for the capital investment. If this time is less than the estimated useful life of the added building component, then obviously the investment is economically justified.

APPENDIX I/LIFE-CYCLE (LONGTERM) COSTING OF BUILDINGS

64 For *life-cycle cost comparison*, in its simplest method, one can simply reduce all costs to a total annual cost for the useful life of compared alternatives. Total annual cost (owning cost) comprises two basic categories:

1 Amortization (principal and interest) of capital cost amount, normally financed by bond issue.

2. Estimated annual O&M expenses.

In the simplest case of comparing alternative systems with equal useful lives, the lowest total annual cost among Systems A, B, and C is easily identified. But when the systems have different useful lives, the problem becomes more complicated. All costs must be reduced to the same useful life, and amortization cost reduced to a *uniform* annual level. Suppose, for example, that a central HVAC system with 20-year useful life is compared with a packaged HVAC system with 10-year useful life. If the packaged HVAC system requires anticipated cost replacement of 70% of its originally installed equipment after 10 years, the annual cost of a capital recovery fund necessary to finance that cost over a 20-year useful life must be added to the basic amortization cost to equate comparative costs.

The most common error in life-cycle costing involves attempts to compare initial *cash* investment with annually paid *charges*. One cannot, for example, claim that a $100,000 cash investment is paid off in 10 years if it cuts O&M costs by $10,000 a year. At 6% interest, it takes more than 15 years to recoup that initial investment. Interest charges always apply, for the simple reason that borrowed money always carries a charge for

its use, and unused, or saved money always carries the potential of earning interest.

In keeping with this principle, convert future savings to a "present-worth" basis. The "present-worth" concept reduces future savings to a common basis with current savings. This conversion is necessary because a dollar saved today is worth considerably more than a dollar saved some years from now. (At 6% interest, a dollar saved today is worth twice as much as a dollar saved 12 years from now.) The present-worth formula takes account of these future interest losses.

As a further means of insuring fair, consistent cost comparisons, reduce comparative costs for alternative systems to an annual basis. Even though a school district may treat operating and capital costs differently, such distinction must be ignored in analyzing what the school *should* do for longterm economy. If, after a cost comparison has been made, the capital cost of the chosen system exceeds the bond limit, the school board may be forced to reject the most economical alternative. But this is a *legal*, not an economic, constraint and should be clearly recognized as such.

Comparison of HVAC systems for Chantilly High School

A. Benefit/cost analysis

Total first cost System A	$1,123,100
Total first cost System B	$1,238,190
System B exceeds System A by	$ 115,090

APPENDIX I/LIFE-CYCLE (LONGTERM) COSTING OF BUILDINGS

Annual O&M Cost	System A	System B
Maintenance & repair	$ 24,000	$18,420
Energy (electric)	$ 94,660	$67,000
Total O&M	$118,660	$85,420

System A exceeds System B by $ 33,240

Assume a 20-year useful life for each system and a 5½% interest rate.

Debt service constant table

Years, n	Interest rate, r 4.0	5.0	6.0	7.0	8.0	10.0
5	0.2246	0.2310	0.2374	0.24389	0.25046	0.26380
10	0.1233	0.1295	0.1359	0.14238	0.14903	0.16275
15	0.0899	0.0963	0.1030	0.10979	0.11683	0.13147
20	0.0736	0.0802	0.0872	0.09439	0.10185	0.11746
25	0.0640	0.0709	0.0782	0.08581	0.09368	0.11017
30	0.0578	0.0651	0.0726	0.08059	0.08883	0.10608
40	0.0505	0.0583	0.0665	0.07501	0.08386	0.10226

Table footnote

d = Debt service constant, a factor that multiplied by the total loan amount, or total principal, yields the annual debt service payment.

$$d = \frac{r(1 + r)^n}{(1 + r)^n - 1}$$

in which r = interest rate
n = number of years to repay loan

Compute the debt service constant, d, for 5½% interest from the formula or interpolate between values of 5% and 6% in the table; d = .0837

Amortization cost, D, for additional capital investment

$D = .0837 \times \$115{,}090$

$= \$9{,}620$

$$\text{Benefit/cost ratio} = \frac{\text{Annual O\&M saving}}{D} = \frac{\$33{,}240}{\$\ 9{,}620}$$

= 3.4 (a tremendous advantage for System B)

B. Time to recoup investment

To find how long it would take to recoup the additional $115,090 capital cost investment required for System B, assume that the entire $33,240 O&M saving is applied to paying off a loan for $115,090 for n years at 5½% interest.

$$n = \frac{\log \left[\dfrac{S/rC}{S/rC-1}\right]}{\log (1+r)}$$

In which C = additional capital cost ($115,090)

S = annual O&M saving ($33,240)

r = .055 (interest rate)

n = number of years to pay off capital debt with an annual debt service payment equal to S, which in this example is $33,240

$$n = \frac{\log\left[\dfrac{33{,}240 / .055 \times 115{,}090}{(33{,}240 / .055 \times 115{,}090 - 1)}\right]}{\log(1 + .055)}$$

$$= \frac{\log \dfrac{5.25}{4.25}}{\log 1.055} = \frac{\log 1.235}{\log 1.055}$$

$$= \frac{.0917}{.0233}$$

$$n = 4 \text{ years}$$

For a simple graphical solution to such problems, use the chart on page 69. Simply compute the ratio, C/S, and find its intersection with the curve for the correct interest rate. The graph will present solutions of more-than-sufficient accuracy for most practical problems.

Warning: In computing C (additional capital cost), you must include *all* costs associated with the improvement, not merely the contract cost for the component itself. These additional costs include architectural-engineering fees, additional financing or legal fees, and so on.

C. Total longterm saving

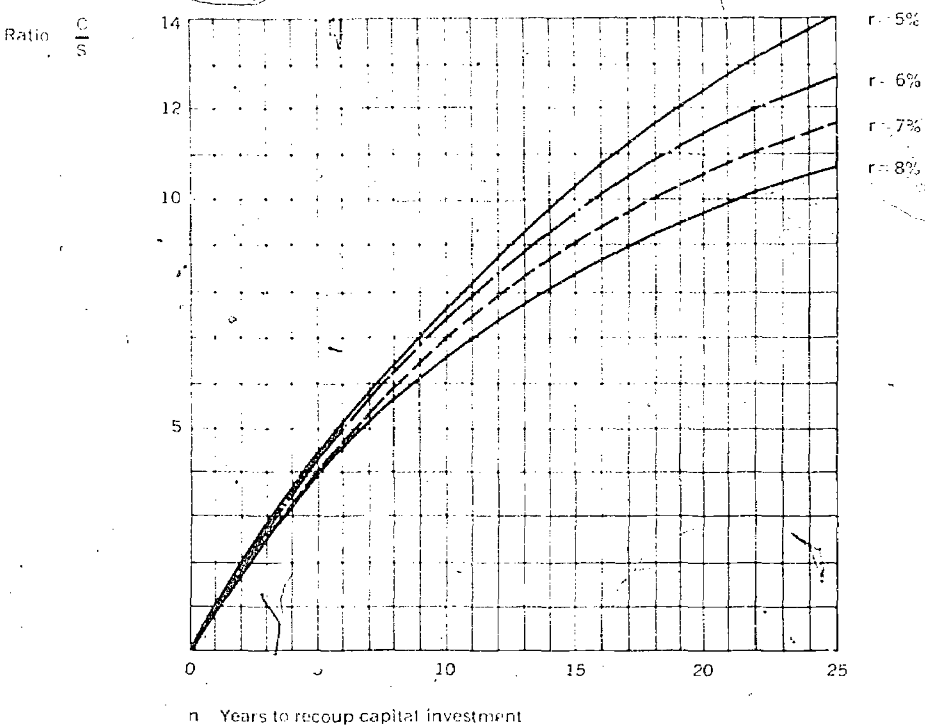
HVAC System A
Annual O&M cost = $118,660

HVAC System B

Annual O&M cost =	$85,420
Additional amortization	$ 9,620
Total	$95,040

APPENDIX I LIFE-CYCLE (LONGTERM) COSTING OF BUILDINGS

Time to Recoup Capital Investment
Graphical Solution



 Difference, S, = \$118,660 – \$95,040

$$S = \$23,620$$

$$\text{Present worth} = S\left[\frac{(1+r)^n-1}{r(1+r)^n}\right] = 23,620\left[\frac{(1.055)^{20}-1}{.055(1.055)^{20}}\right]$$

$$\text{Present worth of 20-year difference} = \$\ 23,620 \times 11.95$$
$$= \$282,000$$

D. Cost-saving with rising fuel rates

Assume that energy costs rise at an annual rate of 7% (geometric progression). What would be the total 20-year saving?

Annual energy cost: System A \$94,660

System B \$67,000

If the energy cost rises g% per year, the following formula holds:

$$\text{Present worth of total energy cost} = F\frac{a(a^n-1)}{a-1}$$

In which F = Original (year 0) annual fuel cost

g = annual rate of fuel increase (starting with first year's cost = F(1+g)

n = number of years

r = interest rate

$$a = \frac{1+g}{1+r}$$

APPENDIX I/LIFE-CYCLE (LONGTERM) COSTING OF BUILDINGS

System A

Energy cost	= $94,660 x 23.29 =	$2,205,000
Maintenance	= $24,000 x 11.95 =	$ 287,000
First cost	=	$1,123,000
Total "present worth"		$3,615,000

System B

Energy cost	= $67,000 x 23.29 =	$1,560,000
Maintenance	= $18,420 x 11.95 =	$ 220,000
First cost	=	$1,238,000
Total "present worth"		$3,018,000

"Present worth" of 20-year cost saving for System B = $597,000.

APPENDIX II/BACKGROUND TO THE ENERGY CRISIS

The rising U. S. energy consumption trend displays two alarming characteristics:

- Total consumption is currently doubling every 15 years (see chart).
- Electrical energy consumption (roughly one-quarter of the total) is doubling every 10 years.

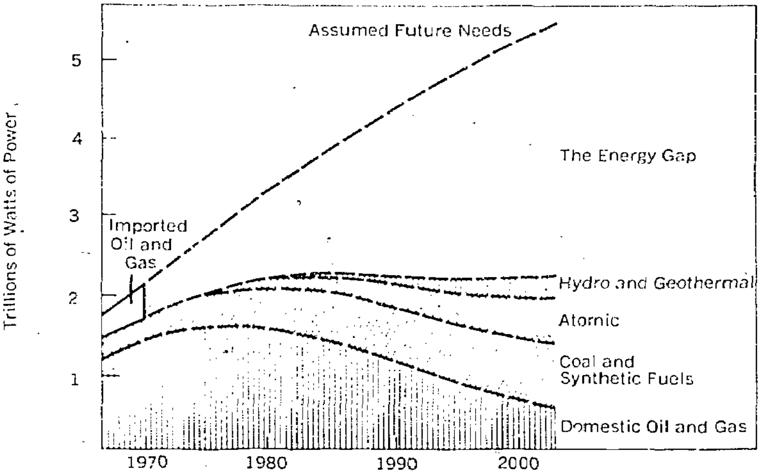
According to a Federal Power Commission projection, this 7% annual rise in electrical energy demand will continue over the next few decades, with 1980 demand double that of 1970, 1990's nearly doubled again. Blackouts, brownouts, and other power interruptions are already signaling trouble.

In addition, the projection of steeply rising energy costs over the next decade highlights the desperate need for energy conservation starting now. These rising costs are assured by our dwindling supplies of readily recoverable fossil fuels, which will remain our chief energy sources far into the foreseeable future.

A federal interagency staff has proposed a national goal of 15% reduction in U. S. energy consumption by 1980 (see chart). The proposed program would comprise the following energy-conserving measures:

- Use of improved thermal insulation in buildings.
- Adoption of more efficient airconditioning systems.
- Changes in transportation modes (from highway to rail, freight shipment, from automobile to mass transit commuting, from air to ground).
- Shift to more efficient industrial processes.

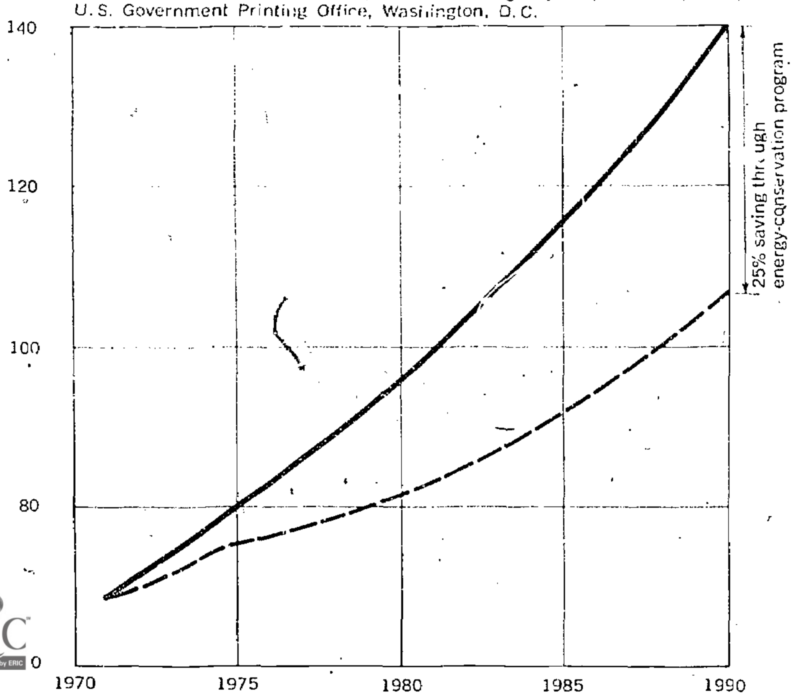
Projected U. S. Energy Gap



Taken from *The Energy Crisis* by Lawrence Rocks and Richard P. Runyon. © 1972 by Lawrence Rocks and Richard P. Runyon. Used by permission of Crown Publishers, Inc.

Total Annual U.S. Energy Consumption (in Btu x 10^{15})

Source: *The Potential for Energy Conservation*, Interagency Staff Study, Executive Office of the President, Office of Emergency Preparedness, 1972, U.S. Government Printing Office, Washington, D.C.



APPENDIX II/BACKGROUND TO THE ENERGY CRISIS

A half year after the publication of this report, there was still no indication that the government would promulgate these goals.

Technological outlook for the future

In the early days of nuclear power development, optimists dreamed of electric power so cheap and plentiful that it would not pay to install switches to turn lights off. These dreams have long since faded, as a host of practical difficulties have impeded the development of fission reactors. Nuclear power today accounts for less than 2% of our electric energy (less than ½% of our total energy output). Fossil fuels — oil, natural gas and coal — currently account for more than 96% of our total energy output, and they will supply at least three-quarters of our total energy for the next 30 years.

During the past two decades, most R&D work on alternate energy supplies has focused on nuclear power. But several alternative energy sources — notably gasification of coal and geothermal steam — promised earlier practical results than new nuclear energy techniques. Though restricted geographically to the western part of the U. S., geothermal steam (evaporated and heated by hot rocks under the earth's crust) could satisfy 5% of the total current U. S. electrical energy demand for 50 years. But the federal R&D funds for geothermal steam totaled a trivial $700,000 for fiscal 1972. Internal Revenue Service rulings discourage prospecting for this low-polluting energy source.

In contrast with geothermal steam, which promises

early delivery of usable energy, nuclear power generation has been tortuously slow in proving its practicability and safety. Conventional fission reactors (i.e., reactors whose heat derives from the splitting of uranium atoms) pose a host of problems: disposal of radioactive wastes; low level, radioactive leakage; the catastrophic (if unlikely) hazard of runaway melting of the nuclear core; thermal pollution of cooling streams; and the limited supply of U-235. (U-235 remains the energy source for current reactors because of the even greater difficulties with "breeder" reactors.)

The fusion reactor is a potential energy source that could satisfy the world's energy needs for millions of years, while minimizing the hazards posed by fission reactors. It is fueled with deuterium (heavy hydrogen) atoms, which are in plentiful supply in the oceans. Fusion of deuterium atoms into helium atoms releases tremendous quantities of heat energy, as a source of steam for driving the same turbogenerators used in a conventional fossil-fuel plant.

But the practical obstacles are monumental. For two decades, nuclear fusion research has focused on the problem of magnetically confining the core "plasma" (ionized gases) at virtually interstellar temperatures, ranging up to 100 million F. The ultra-hot plasma cannot be allowed to touch the combustion chamber walls which would cool the gaseous ions below the torrid temperatures required to sustain the fusion reaction. Because of this formidable technological problem, the fusion reactor appears commercially impractical at

least until the year 2000, despite some encouraging recent experimental progress in confining the hydrogen plasma at 25 million F.

For varying reasons, other non-nuclear solutions appear fairly remote.

The fuel cell, used in the Apollo spacecraft exceeds the efficiency of conventional thermal power plants by 50%. But for an economically competitive terrestial application, it requires large scale gasification of coal for fuel, and this process appears to be some years away.

Magnetohydrodynamics (MHD) generates electricity directly from hot ionized gases flowing at supersonic speeds between the poles of a magnet at fuel cell thermal efficiency. But MHD has lacked the research effor required for its practical achievement.

Solar radiation may eventually become a nonpolluting, energy-conserving power source. As explained in the text, the solar radiation impinging on a schoolhouse roof could supply several times the winter heating needs. Energy cost rises within the next few years could cover the cost of capturing, storing and conveying this energy to the building interior.

Tidal energy, though proven technologically, is not yet proven economically. It is, moreover, limited to a few suitable sites and is therefore insignificant on a national scale. Conventional hydroelectric power offers a similarly small opportunity for economical expansion of waterpower. The best dam sites have already been ex-

ploited. Thus, despite projected increases in the use of nuclear energy and the possibilities inherent in non-nuclear energy sources, we must look for continued dependence on fossil fuels, at least in the immediate future.

Cultural obstacles to resolving the energy crisis

Formidable as they are, the technological obstacles pose fewer difficulties than the cultural obstacles to solving the energy crisis. Despite the flood of publicity on the energy crisis, much of the energy industry continues marching toward the brink while a few isolated voices call for retreat.

For example, high lighting levels squander energy in two ways: they consume great quantities of energy to produce the light itself, and light-generated waste heat increases cooling and ventilating loads on the HVAC system. Yet in a recent magazine article, the Electrification Council (an organization representing electrical industry contractors, manufacturers, and utilities) cited reasons for increasing lighting levels to six or seven times the minimum levels recommended by the Illuminating Engineers Society. Never once did this article mention the drawbacks of such profligate energy use. High lighting levels were recommended for locker rooms because they "promote cleanliness and order."

Some building codes promote energy waste. Wall glass is a notorious means of increasing heat gains and losses, thereby maximizing heating and airconditioning loads. Yet some building codes require minimum window

 areas of 25% of the floor area for any academic room in the school.

Energy waste in the form of gross overheating remains as much an American characteristic today as it was during Dickens' first visit here. Urban apartments are often overheated to an extent requiring open windows to cool rooms to comfortable temperatures even in the coldest weather. Such overheating is not unknown in American schools.

The socially shortsighted and costly policy of rating first cost above longterm overall owning cost is another deeply ingrained habit. Window airconditioners graphically display penny-wise, dollar-foolish consumer behavior. According to an Electric Energy Association survey, one nationally marketed window unit comes in a 230-volt model that doubles the energy consumption of a slightly more expensive 115-volt model of identical cooling capacity. At New York City electrical rates, the roughly $30 (10%) saving in the 230-volt unit's first cost is consumed in one year's additional operating cost. Yet most airconditioning manufacturers produce similar energy-wasting models designed to satisfy shortsighted consumers' obsession with first-cost economy.

Our energy-wasting habits are institutionalized in public financing policy. Municipalities are encouraged to minimize initial cost regardless of longterm cost, by the prevailing policy of limiting capital expenditures with bonding debt ceilings. No such limitation is placed on operating costs, which are paid directly by annual tax

revenue. The same philosophy of limiting school bond issues, while allowing operating budgets free rein, encourages wasteful longterm school design.

American energy-wasting habits are, however, finally coming under effective challenge. As a portent, the Federal Housing Administration's (FHA) thermal-insulating requirements will reduce energy consumption for the average FHA-financed house by about one-third, at great longterm savings to owners. California will require higher thermal insulation for new residential construction, starting in 1974. Public service commissions—out of self-interest if not social improvement—are becoming increasingly aware of the need for energy conservation. And, it seems that conservation efforts may not remain voluntary. The New York State Public Service Commission is currently investigating limiting use of a utility's power for electric heating or airconditioning to buildings that meet prescribed thermal-insulating standards.

Such legal goads will not be necessary for prudent building owners. They will act voluntarily to conserve energy because the virtual certainty of continued energy cost escalation makes energy conservation an economic necessity. Building owners who persist in wasting energy will almost certainly pay a high price for their intransigence.

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REPORTS

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Career Education Facilities A programming guide for shared facilities that make one set of spaces or equipment serve several purposes. (1973) $2.00

Design for ETV—Planning for Schools with Television A report on facilities present and future, needed to accommodate instructional television and other new educational programs. (1960, revised 1968) $2.00

The Early Learning Center A Stamford, Conn., school built with a modular construction system provides an ideal environment for early childhood education. (1970) $0.50

Educational Change and Architectural Consequences A report on school design that reviews the wide choice of options available to those concerned with planning new facilities or updating old ones. (1968) $2.00

Environmental Education/Facility Resources Illustrates where and how students learn about the environment of communities and regions using existing and designed facilities. (1972) $2.00

Found Spaces and Equipment for Children's Centers Illustrations of premises and low-budget materials ingeniously converted for early education facilities. Booklet lists general code requirements and information sources. (1972) $2.00

The Greening of the High School Reports on a conference on how to make secondary school healthy. Includes the life-styles of adolescents and ways to accommodate them, open curriculums and alternative education programs. (1973) $2.00

Guide to Alternatives for Financing School Buildings Chart and book explore conventional and unconventional routes for financing school construction. Includes case histories. (1971) $2.00

High School: The Process and the Place A "how to feel about it" as well as a "how to do it" book about planning, design, environmental management, and the behavioral and social influences of school space. (1972) $3.00

The Impact of Technology on the Library Building A position paper reporting an EFL conference on this subject. (1967) $0.50

Joint Occupancy How schools can save money by sharing sites or buildings with housing or commerce. (1970) $1.00

Patterns for Designing Children's Centers A book for people planning to operate children's centers. It summarizes and illustrates all the design issues involved in a project. (1971) $2.00

Physical Recreation Facilities Illustrated survey of places

Places and Things for Experimental Schools Reviews every technique known to EFL for improving the quality of school buildings and equipment: Found space, furniture, community use, reach out schools, etc. Lists hundreds of sources. (1972) $2.00

Places for Environmental Education Identifies types of facilities needed to improve environmental education. (1971) Single copies free, multiple copies $0.25

The School Library: Facilities for Independent Study in the Secondary School A report on facilities for independent study, with standards for the size of collections, seating capacity, and the nature of materials to be incorporated. (1963) $1.25

Schools for Early Childhood Ten examples of new and remodeled facilities for early childhood education. (1970) $2.00

Schools: More Space/Less Money Surveys the alternatives for providing school spaces in the most economical manner. Includes extending school year, converting spaces, sharing facilities, open campus, etc. (1971) $2.00

Student Housing A guide to economical ways to provide better housing for students. Illustrates techniques for improvement through administrative changes, remodeling old dorms, new management methods, co-ops and government financing. (1972) $2.00

Systems: An Approach to School Construction Documents the industrialized techniques and materials of systems construction. Systems are essentially an erector set from which a school may be built to suit the demands of any community. Includes case histories. (1971) $2.00

FILMS

The following films are available for rental at $7.50, or for purchase at $125.00 from New York University Film Library, 26 Washington Place, New York, N. Y. 10003. Telephone (212) 589-2250.

New Lease on Learning A 22-minute, 16mm color film about the conversion of "found space" into a learning environment for young children. The space, formerly a synagogue, is now the Brooklyn Block School, one of New York City's few public schools for children aged 3-5.

Room to Learn A 22-minute, 16mm color film about The Early Learning Center in Stamford, Connecticut, an open-plan early childhood school with facilities and program reflecting some of the better thinking in this field.

NEWSLETTERS

BSIC/EFL Newsletter A periodical recording developments in the systems approach to building educational facilities. Free

ning for Higher Education A periodical produced jointly the Society for College and University Planning. Free