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ABSTRACT

This is an update of the 1973 edition of a guide for energy conservation in schools. This Educational Facilities Laboratories publication is an information source for teachers, school administrators, school maintenance personnel, school designers, or anyone interested in conserving energy in schools. Topics discussed include: (1) life-cycle costing; (2) establishing an energy management program; (3) changes in operation and maintenance practices; (4) modernizing existing schools; (5) waste-heat recovery; (6) insulation; (7) solar applications in existing schools; (8) new school design needs; and (9) solar energy uses in new schools. A summary and recommendations are also provided. (MB)

THE ECONOMY OF ENERGY CONSERVATION IN EDUCATIONAL FACILITIES

REVISED

A report from EFL

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FOREWORD

The original edition of *The Economy of Energy Conservation in Educational Facilities* was published in July 1973. Although only five years have passed, 1973 was another era in terms of the national energy crisis. Since then we have experienced an oil boycott, severe periodic shortages of fuel, several unpleasant winters, huge jumps in the cost of energy, increasing dependence on foreign oil imports, and a worldwide economic recession. These lamentable events led to attempts to formulate and implement a national energy program that, at least, resulted in a new federal agency. They also generated on a nationwide scale an increased awareness of energy conservation measures that can be taken in planning new buildings and in operating existing buildings.

This revised edition updates the developments in energy conservation for educational facilities that have occurred since 1973. A great deal has happened, and most of it is due to the inventiveness of school districts and colleges and the organizations that serve them. The original theme of the book is more relevant today than ever before: saving energy in educational facilities permits cost avoidance (a term introduced since 1973) and helps prevent the erosion of programs and services. And now we must add a further theme: saving energy is vital to the national interests. We cannot retain and improve the society we have developed over 200 years if we don't all tackle the problem. For education not to do so would be an abdication of a traditional role of national leadership.

To gather, distill, and present the information in the first edition of *The Economy of Energy Conservation*, EFL

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retained C.W. Griffin, a civil engineer who wrote EFL's *Systems: An Approach to School Construction*. An informal panel of specialists advised EFL during the development of the research for *Economy* 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, a federal energy administrator. Three members of the EFL staff contributed to the revised edition, Alan C. Green, Sy Zachar, and Steven Bedford.

The 1973 report had an orange cover—and became known as "EFL's little orange book." The 1978 edition has the same color cover, and with the assistance of grant support from the Exxon Corporation we're pleased to update and reissue "EFL's little orange book."

EDUCATIONAL FACILITIES LABORATORIES

INTRODUCTION

However you view it, the educational enterprise in America is dramatically extensive. Education is the primary activity of 64 million Americans, one out of every four; it accounts for 8% of our Gross National Product; and we expend in the neighborhood of $120 billion in its support. More to the point of this report, the physical plant to house the educational enterprise is estimated at about 7 billion sq ft of space or 260 sq miles of building. The energy bill for heating, cooling, and lighting public schools (including kitchens and equipment) is now $3.2 billion per year. One of the reasons for this gargantuan total is that energy costs have increased over 100% in the last five years.

No other cost in the educational budget has taken such a dramatic leap. And, this increase means that energy costs are consuming a steadily increasing share of the educational budget at a time when the whole educational enterprise faces severe financial problems. Thus when the total budget is limited, any increases in energy costs have to be paid at the expense of library resources, maintenance and upkeep of existing buildings, and special programs. All of which reduces the opportunity for education to remain vital and inventive.

As more people become aware of the trade-off in programs and services for energy, the necessity for conserving energy in educational facilities gains wider attention. Unfortunately, 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

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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 of the rest of the world.

There is also the clear impact of energy costs on international economics. The United States imports almost half its oil, and in 1977 the $45 billion spent on oil was by far the largest contributing factor to the nation's $27 billion trade deficit. The economists tell us that such trade deficits weaken the dollar, increase inflation, jeopardize the economy, and increase the chance for economic recession.

It is in our culture to assume that a national problem can be resolved by new technology, and thus a few years ago optimists hoped that technology would solve the energy crisis by presenting us with new, cheap, easily available and less polluting sources of energy. But now it is apparent that 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. There is no short-term solution on the technological horizon. We must simply learn to conserve energy.

Conservation in educational facilities is necessary on two levels—financial and spiritual. The financial objective has been delineated: to reduce the erosion of programs

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and services. On a spiritual level, education must contribute to the national resolution by providing an example of stewardship and by teaching the students—who are the citizens of the future—how to cope with this vital concern.

Some of the coping techniques will take time to materialize. We have lagged in energy conservation techniques, partly because the building industry did not develop any and partly because building owners were preoccupied with capital costs as opposed to operating and maintenance costs. School and college administrators are often handicapped by ill-informed guardians of the public treasury who minimize highly visible capital costs while burdening the public with needlessly heavy operating and maintenance costs for the 40 year life of a building.

Hopeful signs

- Some, but far from all, school districts and colleges have initiated well-organized and effective energy conservation programs.
- There is a body of experience and information on conservation techniques available to draw on. The engineering and design professions have sharpened their skills; building codes and standards are being modified to reduce their effect on energy use, new technology in solar energy, heat recovery, and cogeneration is being developed and is beginning to reach cost effective levels, energy conservation services are available such as those provided by the higher education Energy Task Force (managed by a consortium of the Association of Physical Plant Administrators, National Association of College

and University Business Officers and American Council on Education), and the Council of Educational Facility Planners, energy audit programs such as EFL's Public Schools Energy Conservation Service (PSECS) are available at low cost; rarely a day passes without a conference, workshop, or seminar dealing with energy conservation in educational buildings.

- State governments have entered the scene often, admittedly, to benefit from federal largesse. But at least all states have "energy offices," and most state education departments have initiated programs and in many cases the two are even talking together. Some states, notably New York, North Carolina, Colorado, Ohio, Utah, and New Mexico have organized energy conservation services for local school districts.

And, of course, the federal government is very much in the act. The crisis of 1973 lead to the formation of the Federal Energy Office, then the Federal Energy Administration, then the Energy Research and Development Administration, and most recently the gathering of all of the federal programs into the Department of Energy. The Educational and Health Care Facilities Energy Efficiency Act of 1977 encouraged, but not mandated, education to be incorporated in state plans. Later, the FEA supported the development of EFL's PSECS as well as other information and demonstration projects, notably the 10 schools energy demonstration program administered by the American Association of School Administrators.

The proposed National Energy Act is an important piece of legislation for the educational sector. Under it, $900 million will be available over a period of three years for schools, colleges, and hospitals to undertake audits and then to cover up to 50% of the costs of modifying their facilities to save energy. DOE is supporting the effort in many ways, ranging from the development of curriculum materials to the funding of solar and other new technology demonstrations. The U.S. Office of Education has entered the scene through the formation of the Energy in Education Action Center.

But, for all of this activity, one undeniable truth remains. Within the educational enterprise, energy conservation occurs in school buildings only when local boards and administrators are committed to the need and when they provide the leadership for local conservation efforts.

The Economy of Energy Conservation in Educational Facilities is intended to encourage the organization and support of local conservation efforts and to provide organizers and their professional staff and consultants with information and guidance. The report is straightforward in its message: conservation is in the national interest, and it is imperative for the economic well-being of schools and colleges. And, conservation can be initiated at three levels: in the operation of existing facilities, in planning improvements and additions to existing buildings, and in the design of new facilities.

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 basis of first cost only is destined to become an ever bigger folly as the energy crisis intensifies and fuel costs rise. In these days of rapidly escalating building costs (up 212% nationally between 1965 and 1978), 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 on "Life-cycle Costing" for a formal economic analysis displaying longterm 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 economics 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, who was 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. Energy savings up to 30% can be achieved with 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 $4.4 billion total school construction market in 1977. 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.

PLANNING AN ENERGY MANAGEMENT PROGRAM

The cost of energy is rapidly becoming a major expense item: costs have doubled in the last five years and are predicted to double again in the next five years. Although the cost of oil, gas, and electricity is beyond our control, we can limit the amount of energy used in schools and thereby control the overall costs of energy for a building. Limiting consumption is generally called energy conservation, but it can equally well be called energy management. As such, energy becomes a responsibility of school administrators to be treated the same as any other resource managed by a school system.

Most energy management will be related to the building shell and its electrical and mechanical systems. But it is also closely related to how the building is used.

The largest user group in a school is the students, and the primary user group is the teachers. Since energy management will involve environmental changes, the school's commitment to energy management must be explained to the teachers and students, and their ideas and concerns must be taken into account.

Energy management begins at the top

No sustained energy management program can exist without a commitment from the school board (or board of education). The superintendent must know that good management of fuel and utilities is expected of him, and that his board members know that energy management is also part of their responsibility.

The development and implementation of an energy management program will require a team to do the nuts and bolts work at each school. This energy team in most instances will consist of the following: the assistant superintendent for business affairs, the chief of plant operations for the district, the building custodian, and the principal. In addition, one technical person should be made part of the team and he could be from the local utility company. The team should be part of its school's energy management committee, which should represent teachers, students, food service staff, school board, PTA, and include an engineer or member of the physical plant staff of the local college or university.

Establishing an energy management program

Because energy management is a new technique, members of the committee should find that a problem solving approach makes a good introduction. The approach discussed below is partly based on work done by John Blossom, P.E., President of Ziel—Blossom & Associates. See chart on page 16.

Step 1. Define the goal The goal in this case would be to establish an energy management program.

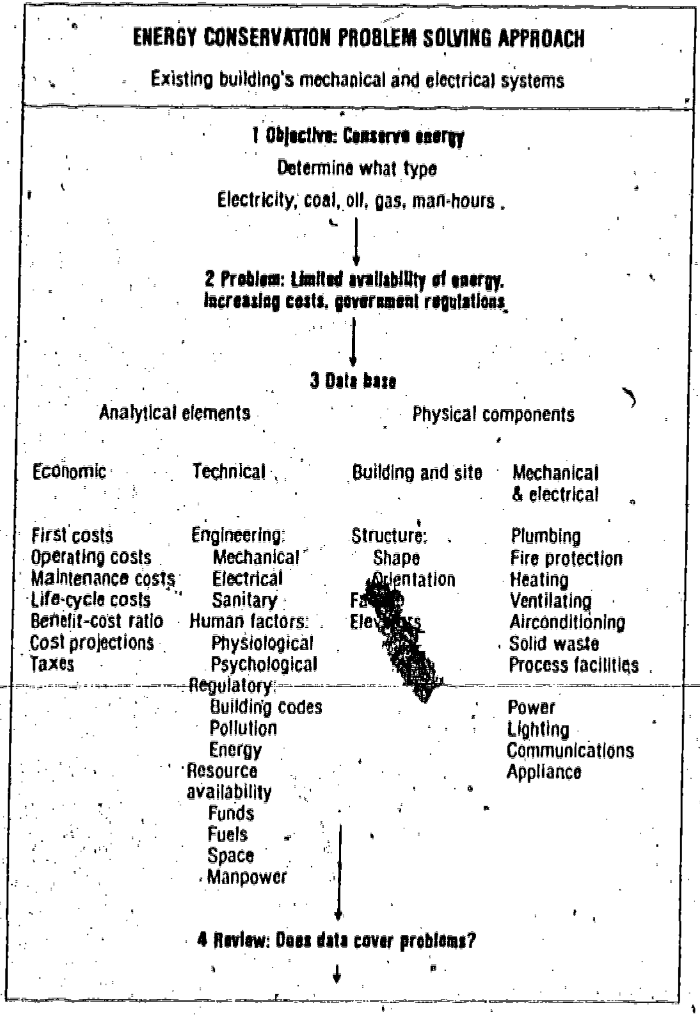
Step 2. Define the problem Do not assume that everyone will see the problem in the same way. Some will see it as a problem of cost, others of consumption, and still others of the building shell and its mechanical system.

Step 3. Establish the data base Establishing a data base is the most time-consuming task, but it will be a learning experience for those involved for they will discover a great deal about their school. Data required includes:

- How much energy does the school use, both electrical and fuel? What fuel is used and how is it measured? What does it cost? What's a kilowatt? What's a Btu?
- What is the area involved? How much energy does the school use per sq ft? What is the energy cost per sq ft?
- What is the enrollment? How much energy is used per student and what is the cost per student?
- What are the climatic influences? How many degree days does the region have? Is it a very windy region? Does it have lots of sun? How many days does the building require cooling?
- What are the operating characteristics of the school? Length of the school year? Operating hours of the building? How much of the school is occupied after class hours, by whom, and until when?
- What are the physical characteristics of the school building? Its age, construction, mechanical system, orientation, and architectural style?

These figures provide handles for analyzing much of the information needed. They also provide a basis for direct comparison of energy consumption among schools. The energy consumption per pupil and per square foot will provide basic clues for understanding the way energy use differs among school buildings, grade levels, and program offerings. The age, construction, orientation, architectural style (e.g., use of glass) all affect energy usage.

The second part of making a data base is to take an energy audit. An audit implies an exactness of account-



ENERGY CONSERVATION PROBLEM SOLVING APPROACH

Existing building's mechanical and electrical systems

1 Objective: Conserve energy

Determine what type

Electricity, coal, oil, gas, man-hours

↓

2 Problem: Limited availability of energy, increasing costs, government regulations

↓

3 Data base

Analytical elements

Economic
- First costs
- Operating costs
- Maintenance costs
- Life-cycle costs
- Benefit-cost ratio
- Cost projections
- Taxes

Technical
- Engineering:
  - Mechanical
  - Electrical
  - Sanitary
- Human factors:
  - Physiological
  - Psychological
- Regulatory:
  - Building codes
  - Pollution
  - Energy
- Resource availability
  - Funds
  - Fuels
  - Space
  - Manpower

Physical components

Building and site
- Structure:
  - Shape
  - Orientation
- Fa[illegible]
- Ele[illegible]

Mechanical & electrical
- Plumbing
- Fire protection
- Heating
- Ventilating
- Airconditioning
- Solid waste
- Process facilities
- Power
- Lighting
- Communications
- Appliance

↓

4 Review: Does data cover problems?

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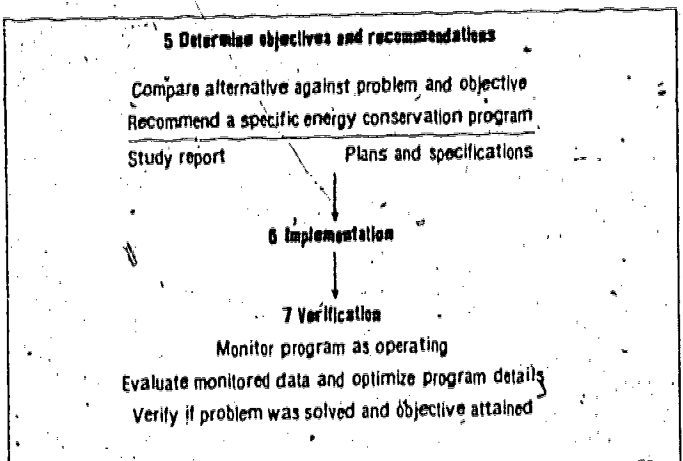


Based on material from Heating/Piping/Air Conditioning magazine, January 1975

ing that is not always possible or necessary. It is simply a determination of how much, where, and how effectively a building uses energy. The first audit should be a walk through the building by the energy team. This may be the first time that some members have been in the boiler room or basement. Their walk should follow the flow of heating, cooling, and hot water through the building. Questions should be asked: What does this do? Why is this on? Where does this lead? What time does it go on and off? Is all equipment either on or off? How many air changes does the gym have? How much air is going through the cafeteria? All day?

After familiarizing itself with the building, the team is ready to undertake a more detailed audit. For this, any school can receive help for a modest fee from the Public Schools Energy Conservation Service. PSECS was developed by EFL in cooperation with the Federal Energy Administration (now Department of Energy) to provide school personnel with the information base necessary to establish an energy management program. A school fills out a form detailing the physical characteristics of the building and its electrical and mechanical systems, how the building is used, and its present energy consumption. The forms are processed by EFL in a computer program that prints two reports which are sent to the school. One report outlines the possible energy savings and the low-cost measures by which they can be achieved. These are simple steps that can often lead to savings in the neighborhood of 30% a year. The second report details capital modifications to the building shell and its electrical and mechanical systems that would reduce energy consumption. The report shows the cost of the modifications, the savings in dollars and fuel, and the payback period of each investment.

A district can request a district-wide audit and receive a summary report of each school audited. The costs for PSECS is low, less than $100 per school. The service is run by EFL on a nonprofit basis and will soon be operated by several state education departments. Check with your state official.

After using a PSECS audit and achieving an energy reduction between 20% and 30%, a school can hire a professional engineer to make a much more detailed survey of the building, its systems, and consumption. When the energy management goal is to reduce energy consumption an additional 20%, the use of a professional audit for a fee of $10,000 or more becomes cost effective.

(For more information on audits see *Energy Sourcebook* from the Council of Educational Facility Planners, 29 West Woodruff Avenue, Columbus, Ohio 43210.)

Step 4. Review The review process is important because it connects the data with the original goal and problem statement. And, it will reveal whether enough is known about the problem to begin planning. The review process should end with the energy management committee establishing goals that the energy team will be charged with carrying out. One of the goals might be to reduce energy consumption in each school by 20% in 12 months.

Step 5. Determining objectives and recommendations This step develops the objectives and recommendations necessary to implement the goals established in the previous step. The objectives might follow the energy use patterns of the facility so that there would be specific objectives for reducing electrical consumption and fuel consumption. Each will require different actions, although in some instances they will coincide. For example, reducing the number of air changes will save both fuel and electrical consumption.

To start the committee off, it may be beneficial to run a brain-storming session in which all value judgements are suspended. All ideas, sane and crazy, are thrown onto the floor and listed. No comments are made about the suggestions; they are just listed. At the end of the session all the suggestions are reviewed by the group. Many will be dropped. Those that are kept become the recommendations.

Step 6. Implementation What actions should the school and district take first? Before answering this the energy team will have to ask four basic questions about each recommendation or proposed action: How much energy is lost by not taking action? What is the potential annual cost saving based on current operating and maintenance costs? What is the cost of the action? What is the payback period?

Note: Payback time = first cost ÷ estimated yearly savings. For example, a $1,000 time clock that can save $500 a year pays for itself in two years. The shorter the payback period, the better the investment. Efforts should be directed first towards high payoff (quick payback) and low cost projects, second, towards projects that have payback periods of six months to two years, and third to projects that require large investments which often must be repaid with bond revenue.

After evaluating the potential maintenance and operation savings of the noncapital projects and the investment merit of capital projects, the energy team must assign priorities to the order in which the project should be implemented. Then the team should assemble the package of projects that will be used to meet the goal. It should assign responsibility for carrying out the projects to the people with the expertise or experience to carry out the work.

Step 7. Verification, monitoring, and evaluation As in any educational effort, monitoring and evaluation are necessary to insure that the goals of the program are met. They provide a feedback, similar to the review process in Step 4, for the energy management committee and team to judge if their program is on track, what components are or are not working well, what changes can and should be made. The district might find that it was easier than expected to meet the target goal of dropping energy by 20% within the year and they should lower it to 30%. Areas that are not providing the anticipated reduction should be looked at to find why they are not working. Was the data base incorrect, the action inappropriate, or was the targeted reduction too high?

Plotting the energy consumption is useful in graphically depicting the progress made. As the energy consumption lines begin to drop, it dramatizes the progress made to date and clearly shows the distance to the goal. Energy graphs should be displayed in a prominent place to show the school community the work that has been done and remind them that they are part of the process.

Training

It may be necessary for members of the administrative and support staff to attend workshops or training sessions. The costs, if any, will usually be minimal compared with the savings in manpower effectiveness and energy usage. A good energy management program should have a measurable payback period in terms of manpower and energy consumption effectiveness. One member of the team, probably the assistant superintendent for business affairs, should be assigned to locate, or, if necessary, develop training programs for the district's staff.

Resources for training include the following:

- State Agencies. Each state has a State Energy Office and a State Education Department that has an office responsible for energy conservation in school buildings. Each agency should be able to either provide direct assistance in establishing a training program or know where such training is available in the state.
- Energy extension service. Each state is establishing with federal assistance energy offices similar to cooperative extension services. They are administered by the state universities.
- Utility companies. Most utilities can provide a variety of energy management services and technical assistance. They have had to train their own staff in energy management and may share their talents with schools.
- Community colleges. Many two-year colleges have established programs relating to energy management, including courses on the electrical and mechanical systems of buildings. The district should consider paying the fees of their plant staff who attend. If the community college does not have energy related programs, the district should ask the institution to establish them.
- Colleges or universities. Since higher education institutions use three to four times as much energy per student as public schools, they have been very active in developing conservation programs. You may receive help from the physical plant department and/or the school of engineering, school of architecture, or the science department.
- Hospitals. Hospitals are the most energy intensive of all institutional buildings. Most have initiated some energy management programs, and your local hospital may share its experience with the school district.

Sharing management resources

Unlike other facets of managing the educational enterprise, energy management is not specific to education. There are many opportunities for sharing resources and ideas and embarking on joint ventures with other non-profit institutions. The effectiveness of the schools' own efforts can be enhanced by the cooperative use of local and state resources. For example, schools and hospitals working together can ask more of the community college in establishing training programs for plant personnel. A program established and supported by the major institutions of the community is in a much better position to seek funding from state and federal sources. Finally, the visibility of the schools' effort (in a time when schools are less popular) cannot help but enhance their image as an effective user of tax dollars.

Eventually, (barring unusual supply problems) energy management should become "just another" cost controlling operation. After experience is gained and all the staff members are trained and comfortable with the responsibilities, it should become a routine operational task.

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 56 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 56, 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 operation 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.

Partial 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 electrically 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 ⅛-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).

Airconditioning 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 incorporate 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 former 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."

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 $16,000 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.

38 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) $5,000-$6,000 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, or installing shading devices outside the windows. Modernization generally puts high first-cost components at a competitive disadvantage compared with the same items when they are 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 economics

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 building 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.[6] 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 combination 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.

Another technique for reducing energy consumption in HVAC systems is called the economizer cycle and it requires cool outside air to be introduced to an airconditioning system instead of cooling and recirculating the warmed up inside air. Naturally this will not work if the outside air is humid, and for this reason the economizer cycle has little application in areas such as Florida. Controls can be installed that test the humidity and temperature of the outside air and will not allow it to enter the system when it is too warm or humid. An additional set of controls prevents outside air being introduced at the start of a cooling or heating day until the desired interior temperatures are reached.

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/demand 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

48 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 8 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.

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.)

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.

Tightening the envelope

A heated or cooled building requires some of its air to be exhausted and replaced by outside air. If the HVAC system is regulated properly, an economical amount of air will be exchanged. However, if unwanted hot or cold air leaks into the building, the HVAC system will have to compensate and thus burn more energy. The steps to stop air leaks are often called tightening the envelope.

Obviously the main places for a building envelope to leak are around the windows and doors. Air can infiltrate around the frames if the caulking dries out and leaves a space between the metal or wood frame and the surrounding wall. Obviously, these should be recaulked. And, air can leak between the frames and doors or opening windows. Weather stripping can provide a seal for these moving parts.

Main entrances with one set of doors between an entrance lobby or hallway will always admit outside air whenever the doors open. To offset this loss a building requires a vestibule with a sealed chamber between two sets of doors. The vestibule must be sized for the traffic flow or else both sets of doors are likely to be open at the same time.

Cold outside temperatures can chill the interior of a building if the metal window and door frames conduct the cold through the walls. Good metal frames have thermal breaks in them to insulate the interior face of the frames from the exterior. If window frames do not have thermal breaks, they will have to be replaced.

Heat and cold can also be conveyed through convection that occurs when window glass is heated or cooled thus affecting the temperature of the air on the other face. One solution is to double glaze the windows—add another sheet of glass and leave an air space between it and the original sheet. Ideally this air space should be a vacuum, but vacuums, like ideals, are hard to maintain.

Another solution is more dramatic! Replace the glass with insulated panels. Before considering this technique be sure to check that sufficient windows are not blanked off to meet the code requirements that specify the ratio of glazing to floor area.

52 Some HVAC systems, particularly in old buildings, expel interior air through gravity-operated exhaust vents. Unfortunately many of these vents allow excessive amounts of air to leave the building and the HVAC works overtime to compensate. Fortunately the flow can be reduced with pressure-activated dampers inside the vents. The result carries a bonus for the building since the interior air pressure builds up sufficiently to stop outside air entering through the customary leaks in the building envelope. With infiltration reduced—therefore no drafts are felt—the comfort of the building is increased.

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 to 50 ft-candles reduces energy consumption by 90%.

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 fixture) 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.

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. Addition 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.

Using the sun's energy

Adding solar energy systems to existing buildings generally costs $10 a sq ft more than in new buildings. If you are thinking about adding a system you should consider the following: Does the building already conserve energy? Is the building shell adequately insulated? It should be at least the equivalent of an electrically heated school. Is a solar energy system compatible with the existing system? Solar systems often provide heat at a lower temperature than conventional systems and so require larger radiator or convector heating surface areas. A water system is not always compatible with a steam system because two different kinds of radiators are required. Is there a place to put the collectors? If the collectors are placed on the roof, structural modification can add $2 to $4 per sq ft to the price of a system. Plumbing costs are also increased by breaking through existing walls, roofs, and floors. If collectors are placed on the ground, make sure the pipes into the building are well insulated. Make sure no buildings or trees will block the sun's rays.

Equipment currently available is a reasonable long-term investment, but the cost is expected to drop as more solar energy systems are built. But why wait for the perfect system to arrive? The longer you wait to make a decision concerning solar energy, the more money you are going to spend on fuel from a nonrenewable source. If you can save money now, why wait?

How solar energy is converted

The simplest form of solar heating is called direct or passive and it converts sunlight into thermal energy within the space to be heated. The most common technique is to install large south-facing windows that trap direct solar radiation during winter daylight hours. Some of the building's heat is stored in the masonry walls and is given back to the room when the sun goes down.

This elementary system provides adequate comfort in a climate with few cloudy days or periods of intense cold such as northern Arizona and New Mexico. In a climate less ideal, more elaborate methods are required, such as thick masonry walls to store heat, large expanses of south glazing, movable insulation (including thick curtains), and carefully located ventilators. In the summer when direct sunlight is not wanted, an overhang is provided on the windows to shade them from the high sun. Incorporating direct solar heating into the design of a building does not require an increase in initial cost or maintenance costs.

There are drawbacks to this approach in that great amounts of south-facing glass can cause overheating, glare, and damage to furniture. In buildings with massive heat-storage walls on the south side, views are impaired and enjoyment of the southern exposure is limited. The other form of solar heating is the indirect system which converts sunlight into thermal energy outside the spaces to be heated and cooled. Such systems require a means of collecting the sunlight, storing its heat until needed, and then distributing it.

The heart of the indirect system is the solar collector, which gathers the solar radiation and intensifies it to heat water or air that can be stored and piped into a conventional heat distribution system. There are basically two types of collectors in an indirect system: the concentrator and the flat plate.

The concentrating collector usually consists of a highly reflective curved surface which focuses sunlight on a radiation absorbing area. These collectors can easily obtain temperatures above 250F. They are trough- or dish-shaped and require a tracking system that must follow the sun because they can only collect direct radiation.

Flat plate collectors have a more universal application because they absorb diffuse as well as direct sunlight. The collectors are, in simple terms, large trays of water or air covered with glass to create a "greenhouse" that heats the fluid. The surface of the tray is coated with an absorbent material to soak up the sun's rays and intensify the heat transferred to the water or air. The plates are usually about 4 ft by 8 ft. They can be mounted on a roof or on the ground and are tilted roughly perpendicular to the sun to capture the most direct radiation. Insulation on the back of the collectors prevents heat loss to the air.

The heated fluid is carried from the collector into a storage area where it is held until it is needed. In an indirect system using water, the storage area consists of a large tank capable of holding up to a few days' worth of heat for the entire building. Heat from an air system usually is stored in large bins of stones.

In a water storage system, heat is transferred to the rooms by direct convection, circulating the storage tank water through baseboard convectors, or coils in hot air ducts, or by fan coil units. Domestic hot water can be preheated by routing cold feedwater through the storage tank and then heating it up to 140F by gas. A typical solar heated air system transfers heat to the dwelling spaces by a conventional forced warm-air system.

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.
- Solar energy.

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.)

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.

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 shading 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

Airconditioning is the major building subsystem suitable 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

74 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.

Revised requirements for building codes

Building codes have sometimes obstructed attempts to design energy conserving HVAC systems for buildings. To remedy this situation ASHRAE developed a new set of criteria, ASHRAE Standard 90-75 "Energy Conservation in New Building Design," so that local government agencies that write building codes would have up-to-date criteria for revising their codes.

The new standard recommends that the percentage of glass required in codes be lowered, insulation be greatly increased, and lighting and HVAC systems reduced. If the recommendations are followed, school buildings could be built with, on average, about 40% less capacity in heating systems and 30% less in cooling systems. A school built to the new recommendations would use 70 cents less on energy per sq ft in a year than a new school built to the traditional code specifications.

Even if a city or county does not adopt the ASHRAE recommendations there is no reason why a school district should not voluntarily embrace 90-75. A school built to 90-75 would exceed all the requirements of a city's old code.

Initial costs would be about the same. The reduced amount of HVAC equipment would lower the cost of the building, but since the design requires more detailed analysis of the future requirements, the extra engineering time will offset lowered equipment costs.

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.

78 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."

Solar Energy

If you are considering building a facility that will use the sun to meet some of its energy requirements, a few guidelines should be kept in mind. Any cost comparisons with fossil-fuel heating and cooling systems should be based on life-cycle costs, not just initial costs. Make no mistake, solar energy installations are not cheap.

The success of a solar installation depends on a good heat-conserving structure. The building shell should [illegible] heavily insulated to obtain an insulation factor of R15 for the walls. (A typical 1950s brick school has a factor of R4, and buildings designed to meet the School Construction Systems Development (SCSD) standards in the 1960s are up to R6.) Windows and door area should be minimized (about 12% of the exposed perimeter) and should be protected from the wind by the use of fins or recesses. The perimeter of the building should be kept to a minimum to reduce heat loss.

A standard for a well-designed solar building is that it only needs about 10 Btu/sq ft/hr to keep it at a comfortable temperature in winter. A school without energy conserving features often requires four to five times that amount of heat.

Climate and location affect the suitability of a schoolhouse for solar energy. In most parts of the country there is not enough solar radiation to economically provide the building with all the heat it needs. Conventional systems must be incorporated into the design to provide additional heat or cooling. For instance, in the Northeast it is not economical for solar heating to provide 100% of a school's heating requirements, but 50% is a reasonable expectation.

To provide the most economical mix of conventional and solar heating methods, the solar energy system must be sized with consideration for the available money, the fuel inflation rate, and the system component cost. If a system is too small, solar energy cannot be economically introduced because of the fixed costs of controls, pumps, and other components that have a minimum size no matter how small the collector system.

If a collector takes over a large amount of the load, it will work at full capacity for only a small part of the year; thus its load factor for the rest of the year becomes too small to be economical. Rules of thumb are no substitute for engineering calculations, but a simple guide for an indirect system is that collectors equal to half the floor space will provide about 70% of a building's heat requirements.

Installed systems can cost anywhere from $10 to $75 per sq ft of installed collector. This includes the price of tanks, pumps, heat exchangers, piping, and thermostats. The average cost is around $20 per sq ft. In new construction a solar energy system can represent from 3% to 5% of the total building cost. About 1% of the building cost covers increased structural expenses for supporting the collectors on the roof. Collectors represent almost 50% of the total cost of a heating and cooling system. This is mainly because few, if any, collectors are mass-produced. As more buildings become solar, industry will mechanize and collector prices will drop. If you can't afford a complete system, consider installing everything but the collectors. Later, if your area runs out of fuel, you will be able to add collectors.

Generally, most systems that cost over $25 per sq ft will not pay for themselves in energy saving within the 20- to 30-year life of a bond. A well-designed system can produce energy that is competitive in price with the cost of electrical energy as a heat source over a 10- to 15-year span. In the near future, with improved technology and rising fossil-fuel prices, solar heat will be competitive with oil and gas heat.

At present, solar hot water heating is the most cost-effective of all low-temperature solar applications. This is because the initial investment is small and hot water is used throughout the year. This heavy and constant use gives a larger load factor than in a solar space heating system that stands idle all summer.

If the building also requires cooling, solar assisted heat pumps provide a very economical approach. These systems have projected payouts in 10 years, primarily because of the small collector size and improved performance.

Maintenance and operating costs usually represent about 1% of any mechanical heating system cost. Some systems require more maintenance than others to protect them from corrosion and dielectric difficulties. Solar systems that use water must be protected by antifreeze solutions or have automatic drain down systems that switch on when night approaches. Initial costs can be high because contractors add contingencies to cover their lack of experience in this field. In a study by Westinghouse, contractors were rated second only to power companies in order of resistance to the idea of solar energy.

The problem of sun rights must be solved before solar energy can be fully accepted. No established legal rights to solar radiation exist. The closest anyone has come to granting solar rights is in Great Britain. The old English doctrine of "Ancient Lights" gives the landowner the right to receive the customary amount of light and air. The U.S. courts, however, have specifically repudiated this doctrine. Although there are no specific laws governing solar rights, there are legal principles such as zoning, law of nuisance, easements, and pollution control laws which may be applicable to the problems.

SUMMARY AND RECOMMENDATIONS

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/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 su[illegible]) useful life.

Benefit/cost analysis form[illegible] 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/LIFE-CYCLE (LONGTERM) COSTING OF BUILDINGS

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 debt, 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 [illegible]00 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

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 5¼% interest rate.

Debt service constant table

	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 [illegible] additional capital cost ($115,090)
[illegible] 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

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

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

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

$n = 4$ 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

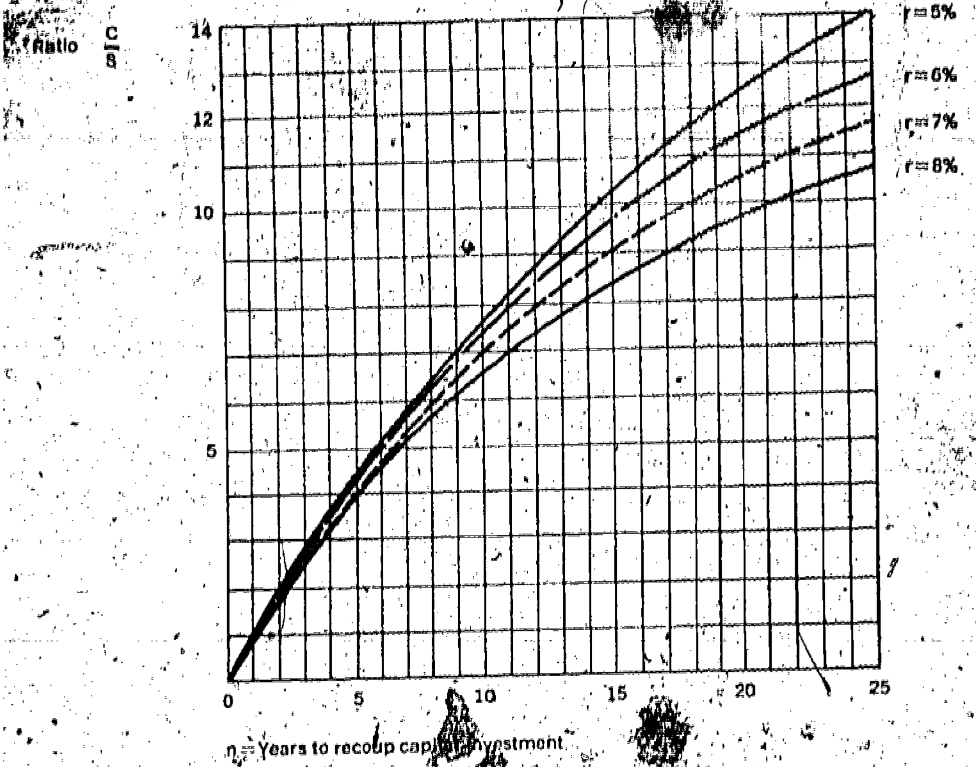
HVAC System A

Annual O&M cost = $118,660

HVAC System B

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

Time to Recoup Capital Investment
Graphical Solution



Difference, S, = \$118,660 − \$95,040

$$S = \$23{,}620$$

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

Present worth of 20-year difference = \$ 23,620 x 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

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

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.

PUBLICATIONS

The following publications are available from EFL, 850 Third Avenue, New York, N.Y. 10022.

An Approach to the Design of the Luminous Environment A fully illustrated technical report based on research to lower lighting levels in buildings without affecting lighting performance. Published by the New York State Construction Fund. Available from EFL. (1976) $8.00

Arts and the Handicapped: An Issue of Access Gives over 150 examples of how arts programs and facilities have been made accessible to the handicapped. A great variety of programs are included, from tactile museums to halls for performing arts, for all types of handicaps. Special emphasis on the law, the arts, and the handicapped. (1975) $4.00

The Arts in Found Places An extensive review of where and how the arts are finding homes in recycled buildings, and in the process often upgrade urban centers and neighborhoods. Over 200 examples, with special emphasis on "do's and don'ts." (1976) $7.00

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

Communications Technologies in Higher Education Twenty-one profiles that were distributed during 1975-76 in Planning for Higher Education update most of what has happened in this field during the last decade. Available from Communications Press, Inc., 1346 Connecticut Avenue, N.W., Washington, D.C. 20036. $13.95 casebound; $7.95 paperback; $7.00 looseleaf packet, plus 50¢ shipping charges per order.

Four Fabric Structures Tentlike or airsupported fabric roofs provide large, column-free spaces for physical recreation and student activities at less cost than conventional buildings. (1975) $3.00

The Graying of the Campus Guidance on program planning and environmental management for making postsecondary education universally available to older Americans. (May, 1978) $6.00

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

Housing for New Types of Students Colleges faced with declining enrollments from the traditional age group should widen their constituency by modifying their accommodations for senior citizens, those over 25, those under 18, the handicapped, married, single parents, etc. (1977) $4.00

Memo to Ambulatory Health Care Planners A general guide to making health centers more humane and flexible. Changing types of services should be anticipated and new partners in the delivery of social services sought. (1976) $2.00)

The Neglected Majority: Facilities for Commuting Students Advocates making college facilities more amenable and available to students who do not live on campus. Includes examples of facilities for studying, eating, leisure, shopping, resting, recreation, etc. (1977) $4.00

New Places for the Arts Provides descriptions of several dozen recent museums, performing arts facilities for theater or music, and multiuse centers built especially for these purposes. Includes names of the consultants involved. (1976) $5.00

Patterns for Designing Children's Centers A book for people planning to operate children's centers. Summarizes and illustrates all the design issues involved in a project. (1971) $3.95

Performance Guidelines for Planning Community Resource Centers A guidebook to help users articulate their requirements for a community center. Published by American Institute of Architects Research Corporation. (1976) Available from EFL. $7.50

Physical Recreation Facilities Illustrated survey of places providing good facilities for physical recreation in schools and colleges—air shelters, shared facilities, and conversions. (1973) $3.00

The Place of the Arts in New Towns Reviews approaches and experiences for developing arts programs and facilities in new towns and established communities. Gives insights and models for the support of the arts, including the role of the arts advocate, the use of existing space, and financing. (1973) $3.00

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, reachout schools, etc. Lists hundreds of sources. (1972) $2.00

Reusing Railroad Stations Book Two Advocates the use of abandoned stations for combined public and commercial purposes, including arts and educational centers, transportation hubs, and focal points for downtown renewal. Explains some of the intricacies of financing that a nonprofit group would have to understand before successfully developing a railroad station. (1975) $4.00

The Secondary School: Reduction, Renewal, and Real Estate An early warning of the forthcoming decline in enrollment in high schools, and suggestions for reorganizing schools to prevent them from becoming empty and unproductive. (1976) $4.00

Space Costing: Who Should Pay for the Use of College Space? Describes a technique for cost accounting the spaces and operating and maintenance expenses to the individual units or programs of an institution. (1977) $4.00

[illegible] a guide to economical ways to provide better [illegible] illustrates techniques for improvement [illegible] changes, the remodeling of old dorms, new [illegible] and government financing. (1972)

[illegible] Options and Opportunities Tells how [illegible] closed schools by widening educational and [illegible] career and special education programs. [illegible] local enrollment projections, how to decide [illegible] (1976) $4.00

[illegible] **Who Are Interested in Making the Arts** [illegible] Describes arts programs and facilities that have been designed to overcome barriers to children, the [illegible] handicapped. Contains an enrollment card for a free information service. (1976) Free

Cooperative Use of Resources for the Arts Describes cooperative planning and gives examples of joint use of resources. (1978) $2.00

New Places for the Arts, Book Two Lists about sixty museums, performing arts facilities, and multiuse centers. Includes brief descriptions, plans, and names of consultants. (1978) $3.00

Technical Assistance for Arts Facilities: A Sourcebook Where arts groups can find help in planning arts facilities. Lists federal, state, and private sources. (1977) $2.00

Newsletter

EFL Reports... A periodical on financing, planning, designing, and renovating facilities for public institutions. Free

FILMS

The following films are available for rental at $9.00 or for purchase at $180.00 from New York University Film Library, 26 Washington Place, New York, N.Y. 10003. Telephone (212) 598-2250

New Lease on Learning A 22-minute, 16mm color film about the conversion of "found space" into a learning environment for young children. This 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.

The City: An Environmental Classroom A 28-minute, 16mm color film, produced by EFL in cooperation with the New York City Board of Education, shows facilities and resources in and around the city in which effective programs of environmental education are under way.