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ABSTRACT

This pamphlet advocates air conditioning to improve educational productivity. The physiological effects of thermal environment are explained and educational experiments cited to substantiate the benefits of air conditioning in promoting learning. The necessity and economy of air conditioning for schools with large open-space learning areas and for those with year-round usage is emphasized. Air conditioning as part of a school's modernization process is also discussed. (MLF)

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Airconditioning for Schools

EA 003 490

A report from
Educational Facilities Laboratories
477 Madison Avenue, New York, N.Y. 10022

Foreword

This report certainly is not impartial: It advocates that the interior climate of schools should be made more comfortable. EFL's motive in advocating airconditioning for schools is simply to improve the productivity of education by helping the teachers to teach and the learners to learn.

Trying this philosophy out in conversation often draws impassioned dissent from taxpayers who say they carry a large enough burden of municipal support without adding the luxury of airconditioning a school. To refute this argument is easy, but to do it sympathetically requires a little time to assemble the facts in an orderly process. So, EFL retained C.W. Griffin, Jr., an engineer who is an experienced writer on construction and the environment, to tell about the economics of airconditioning, the physiology of cooling bodies, the relation of learning to thermal comfort, and the integration of airconditioning into modernization projects.

In olden days, schools were designed for a single function: to teach the young. More recently, schools have recognized an obligation to the community to provide facilities useful to adults when school was not in session.

An emerging concept in this country, Western Europe, and Australia, is that the schoolhouse should be a gathering place for people, not just children. A good place for men of all ages, of all seasons, in all seasons. Thus, cooling the schoolhouse—the Community Center—is neither economically imprudent nor a proper cause for cultural guilt that we brought comfort to children and teachers before we had to.

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Why Aircondition Schools?

A quiet revolution highlighted by two massive modernization programs is transforming the North American school environment. In Houston and Dallas, renovation programs incorporating the airconditioning of nearly 400 schools will seal these buildings against outside heat, humidity, and noise. In Florida, airconditioning has become mandatory for all new schools, from kindergarten through high school; no school designed without airconditioning qualifies for a bond issue.

Though greatest in the southern states, the value of airconditioning is gaining recognition all over North America. To maintain a comfortable thermal environment in most states requires mechanical cooling during 35% of more of the 1 100 hours that most schools are open from September through June.

In its increasing popularity for schools, airconditioning is merely following a familiar historical evolution in which yesterday's luxury becomes today's necessity. In the nineteenth century, central heating was an exclusive luxury for the rich; in the twentieth century, it is commonplace and necessary for an acceptable standard of living.

Airconditioning, with its major distinguishing feature of mechanical cooling, is in a transitional stage. To the typically prosperous American in his various roles as worker, shopper, hotel guest, homeowner, theatergoer, and even motorist, airconditioning is becoming a necessity. (The majority of even low-priced new cars sold in the United States are airconditioned.) But to this same American, in his role as taxpayer, airconditioning for schools may still rank as a luxury. After all, *his* school wasn't airconditioned. Why can't the teachers and kids endure a few hot days in late spring and summer? With local taxes still climbing, why spend public money frivolously?

The frugal taxpayer's attitude is understandable. But is it prudent? Ultimately, the Spartan attitude toward airconditioning schools may prove expensive. With rising standards of comfort, plus increasing summer use of schools, will many U.S. communities accept a primitive thermal environment throughout the 40-year expected life of a school built in 1970? When America's first high school, Boston Latin, was built in 1635, the right to be warm was well established. More than three centuries later, the new right to be cool is being born. Construction of an unairconditioned office building has become unthinkable, and it may be true of schools within the next decade. Long before the year 2010, the school board will probably decide to install airconditioning. And when it is added as an afterthought, airconditioning always costs more than an original installation.

A major change in the plan shape of schools over the past decade has promoted airconditioning of schools. For several reasons, notably rising land costs and new learning space requirements, compact school plans are replacing the sprawling corridor or finger plans so popular in suburbia during the 1950's. With its typical layout of classrooms flanking a central corridor, the finger plan is adapted to natural cross ventilation, through operable windows opened during hot weather. But compact, open-plan schools cannot be naturally ventilated. Moreover, because the daily heat gains from human occupants and lighting are not dissipated through exterior walls, interior areas of compact schools require year-round cooling, even in northern climates with ambient temperatures below 55F. Thus the compact, open-plan school is normally airconditioned, but at a total building cost roughly equal to the total cost of an unairconditioned finger-plan school.

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Schools in cities have an additional need for airconditioning since it permits windows to be kept closed which keeps out noise and dirt. Thus students can concentrate better on their work, and the cost of cleaning can be reduced.

Physiological Effects of Thermal Environment

Before the advent of airconditioning in the early twentieth century, heating of air was usually the sole means of controlling the interior thermal environment. Even the cave men burned heating fires in winter. Mechanical ventilation came fairly recently, and, in a still bigger recent step it was understood that cooling the air removed large quantities of water vapor that aggravated the oppression of summer heat. Only in the last two decades, however, has airconditioning technology been scientifically attuned to the physiological mechanisms controlling human comfort and well-being. Air temperature is only one factor contributing to human comfort, and not always the most important. In varying degrees, under different conditions, human comfort also depends on three other factors:

- Air motion
- Temperature of surrounding surfaces
- Relative humidity

Each of the four basic determinants of the thermal environment plays a different role in dissipating body heat. In both winter and summer, the human body adjusts for a kind of controlled cooling. Whether at total rest or engaged in the most frenzied physical activity, human bodies constantly dissipate heat, and the basic problem in designing the thermal environment is to control the rate of heat dissipation. For comfort, and even for health, body heat must not be dissipated too fast (as in an unheated building in winter) or too slowly (as in an uncooled building in summer).

The physical mechanisms through which body heat is rejected are *convection, radiation,* and *evaporation.*

Convection depends on air temperature and air motion. With its basic blood temperature of 98.6F and a skin temperature normally around 92.5F, the body loses heat to the normally cooler surrounding air at a rate determined by the air flow. The cooler the surrounding air and the faster it moves, the greater the heat dissipated through convection. Obviously, if the air temperature exceeds 92.5F, no convective heat loss can occur.

Radiation depends on a similar physical principle—i.e., all bodies radiate heat at a rate dependent on their temperatures. Radiative heat losses depend on the temperature of surrounding surfaces. Surface temperatures, in turn, depend largely on insulation of walls and roof (for the top floor in a building). In winter, to offset the cooler surface temperatures, a poorly insulated building requires warmer air temperature than a well-insulated building, and conversely, in summer, a poorly insulated building requires cooler air temperature.

Evaporation, the final factor in dissipating body heat, supplements radiation and convection. Evaporation is a highly effective cooling process, in which water expelled by the sweat glands dissipates body heat through perspiration.

The importance of perspiration as a heat-dissipating mechanism grows with rising air temperature. Below 60F, the pores are closed, and little or no heat is dissipated through perspiration. But, when interior air and surface temperatures reach 95F (max. skin temperature), evaporative losses become the sole means of dissipating body heat.

Several variations in the human body's he dissipating mechanisms complicate the design of a good thermal environment. In winter, radiative heat losses are important, and comfort depends on heated air and good building insulation to keep surrounding surfaces warm. However, in summer, when the blood vessels actually open to facilitate heat dissipation, the comfortable indoor temperature rises toward 80F. Humidity control then becomes the critical factor.

In addition to the complexities of maintaining a comfortable thermal environment for the dissipation of body heat, there are important secondary factors vital to health and comfort. Atmospheres with relative humidity less than 20% dry out skin and nose and throat passages, causing irritation and even promoting sinus infection. The comfortable relative humidity in winter is between 30% and 70%, so in extremely cold weather humidification is required.

As still another function, a modern airconditioning system reduces atmospheric dust, odors, and bacteria. Noxious fumes, odors, and dust produced in laboratories and shops must be eliminated by direct exhaust ventilation; kitchen heat and odors are best dissipated by separate exhausts placed directly above the kitchen space. Filtration can remove gaseous as well as solid pollutants; dilution with liberal masses of fresh air abates odors.

Other forces are battled by the architect and his mechanical consultant. Additional energy gains —from increased lighting levels, from solar radiation through glass walls, or from computers or operating machines—increase interior heat loads. Among the variables that affect airconditioning design are local climate, prevailing winds, site topography, and building orientation. To produce an educational environment satisfying modern standards of thermal control, an architect needs a full panoply of airconditioning tools.

Thermal Environment and Learning

The benefits of airconditioning in promoting learning are substantiated by an accumulating mound of evidence. Recognition of the thermal environment as a direct factor in the learning process lagged behind recognition of acoustics and lighting. But many experiments conducted in the United States and Europe have established the connection between airconditioning and academic achievement. Students tested in these experiments displayed reduced mental efficiency at temperatures above and below the comfort range. Some of these experiments lack scientific rigor. Nonetheless, the theory that a properly airconditioned environment aids learning is established beyond reasonable doubt.

One of the earliest and most convincing experiments substantiating this theory was conducted in 1962 at the University of Iowa. In one room of a specially built, two-room research school, researcher Charles Peccolo established ideal conditions: 70-74F temperature range, 40-60% relative humidity, and 20-40fpm (feet per minute) air motion. The other classroom simulated an unairconditioned classroom. Temperature varied from 72F to 81F, relative humidity from 33% to 75%, air motion from 5 to 10fpm. The teacher could open windows and adjust a thermostat. Two groups of 44 fourth-grade students, matched in intelligence, home background, age, and sex, worked in these two classrooms at three mental tasks: reasoning, new concept formation, and clerical routine.

After three weeks of this work, the children in the airconditioned room displayed greater progress than their less comfortable counterparts. In reasoning tasks, they demonstrated greater improvement in completing mazes and designs, solving mathematical problems, and determining relations among words. They also demonstrated greater improvement in clerical tasks requiring quick recognition and response. Moreover, for the reasoning tasks, the superiority of the airconditioned room as a learning environment increased during the course of the experiment.

(Learning new concepts, measured from written tests following film showings, indicated no significant differences between the two groups.)

In a more rigorously controlled experiment at Kansas State University, 72 college students, subjected to controlled temperatures ranging in 6-degree increments from 62F to 92F, learned most easily, and with minimum error rate, at 80F. (Relative humidity remained constant at 45% throughout all tests.)

Significantly improved at the 80F temperature were the following indexes of learning performance: (a) time to complete assignment; (b) reduction of error rate; and (c) effort required to learn (subjectively judged).

Researchers R.D. Pepler and R.E. Warner, of Dunlap & Associates, attribute the relatively high optimal temperature to the experiment's timing. The experiment was concluded in October, before the onset of cold weather. Thus the students had apparently remained adapted to summer weather, physiologically attuned to higher temperatures. The researchers also speculate that exposure periods longer than the 1-hour sessions used to measure performance would have accentuated the performance differentials between comfortable and uncomfortable temperatures.

In cooler Sweden, researchers found children more sensitive to high temperatures, a fact also explained by children's natural preference for lower temperatures than adults. In tests conducted at the National Swedish Institute for Building Research on a group of 10-year-olds, performance declined in language learning, arithmetic ability, spelling, reading speed, and comprehension at temperatures ranging from 81F to 86F. Moreover, the degree of learning loss was found greatest among those who work closest to the limit of their mental capacity.

A more recent and more ambitious Dunlap & Associates experiment, elaborately designed to eliminate extraneous factors, correlated airconditioning with improved academic performance at elementary, junior-high, and high-school levels. Staged at two roughly one-month intervals, in late spring and early autumn, this experiment demonstrated the benefits of airconditioning in the moderate Portland, Oregon, climate.

Academic achievement was measured in sixth-grade spelling, seventh-grade social studies, eighth- and ninth-grade Spanish, and in high-school Latin, general mathematics, and geometry. Extraneous conditions were standardized wherever practicable: spelling tests were given at the same time in the airconditioned and the non-airconditioned school; Spanish was taught by the same teacher in both junior high schools.

A curious ancillary discovery emerged from this experiment. Smaller temperature variations (2F or 3F) affected academic performance more in the airconditioned schools than larger temperature variations (8F to 10F) in the non-airconditioned schools. People accustomed to a thermally controlled environment apparently become more sensitive to temperature changes than those adapted to a more naturally variable environment, according to the report author, R.D. Pepler. A good airconditioning system, offering rigorous control of the thermal environment, is apparently needed to exploit the full potential of improved academic performance.

Other tests, too numerous to cite, buttress these findings. Industry has long been convinced that airconditioning improves both office workers' and plant workers' efficiency. Environmental quality can probably improve office workers' productivity by 15%, suggests Dr. Harry Johnson, Director of the Life Extension Institute in New York. Relieving plant workers of the dulling burden of high temperature and humidity reduces accidents in light assembly tasks. Some school districts aircondition machine shops, automobile shops, and other vocational areas where a cool 67F has been found best for safety.

As partners with the students in the learning process, teachers have not been scientifically studied for the effect of different thermal conditions on teaching performance. But their attitudes toward airconditioning and its effects on the learning process have been surveyed, and not surprisingly the teachers overwhelmingly *affirm* that airconditioning aids the learning process. And if a happier teacher is a better teacher, then airconditioning will predictably improve teacher performance: 96% of 177 teachers surveyed in the cool Portland, Oregon, area favored airconditioned classrooms.

Los Angeles' striking teachers expressed their preference in stronger terms, demanding airconditioning throughout the school system as part of a settlement of last spring's strike. They didn't win their demand, but the Board of Education is considering airconditioning schools in the flight patterns of Los Angeles Airport. Damping the highly disturbing jet noise requires closed windows, which would make airconditioning mandatory.

Cooling Northern Schools

In addition to direct psychological and physiological benefits, airconditioning forms an indispensable part of a truly modern school. Toronto's Study of Educational Facilities (SEF) systems-building program offers an instructive case history. It demonstrates the need for airconditioning in schools adaptable to rapidly changing educational techniques.

The first SEF building system is designed for the large open-space learning areas needed for individualized instruction and team teaching. Long-spanning structural framing allows great flexibility in spatial division without obstructive interior columns or bearing walls. Relocatable partitions, electrical distribution, lighting coffers, and ceiling panels all permit flexibility for bold educational experimentation in varying-sized spaces, designed for anything from mass lectures for 150 students to small seminars for 10 or fewer.

Airconditioning is incorporated in the SEF building system for two basic reasons:

• The large interior areas require artificial cooling when outside temperatures rise above 55F.

• Prospective year-round use of the new schools, anticipated long before their 40-year expected lives are over, would make cooling necessary for the hot Toronto summers.

Systems-built schools, and even modern schools built via the conventional construction process, illustrate the interdependence of different building components in creating a good interior environment. In a noisy central city, it is pointless to spend money for acoustical ceilings, sound-damping partitions, and carpeting—all precisely designed to control noise—without also including the airconditioning that would allow windows to be closed in warm weather.

Artificial lighting is similarly associated with airconditioning. The vagaries of natural light—solar glare and endless variation depending on the season and the weather—have made architects increasingly dependent on artificial lighting to satisfy rising standards of visual performance. Airconditioning dissipates the heat generated by these rising levels of lighting energy. And the windowless walls with which airconditioning works best not only promote more uniform lighting; they drastically reduce heat gains and losses through the walls.

For SEF, the elimination of airconditioning would have weakened the entire systems-building concept. Without airconditioning, the architect is forced into the corridor plan, the finger plan, or some minor variation on the theme. Unairconditioned classrooms must have at least one exterior wall surface for natural cross ventilation, generally across two classrooms flanking a central corridor. This plan destroys most options for flexible space division. Without the large interior areas characteristic of the compact open-space school, the potential for educational experimentation is seriously curtailed. The static egg-crate school, with its fixed, uniform classroom cells lining two sides of a central corridor, architecturally expresses an outmoded, static concept of education. A school board's decision not to include airconditioning virtually condemns the architect to design an eggcrate school. It may be destined for early obsolescence as the new teaching philosophy spreads.

Airconditioning Economics

If compact and corridor-plan schools are to be compared for cost, airconditioning must be considered. Since ventilating equipment must be installed in a compact plan, it is not a major step to add cooling at the same time. The cost of adding mechanical cooling to heating and ventilating, during the design state, is roughly 7% of total building cost. But, the architectural economies of compact design often outweigh the added cost of airconditioning. Both the traditional corridor plan and the later finger plan have a higher peripheral wall-to-floor area ratio than a compact school; they may contain 15% more wall area than a compact layout. At $180 or more per lineal ft, these walls are an intrinsically expensive element. Moreover, with operable windows required for natural ventilation, they add an item of perpetual maintenance expense. They also increase heating expense to offset heat losses through the large weather-exposed wall areas and through the larger glass areas required when operable sash is needed. As still another increasingly important saving, the compact school reduces land costs, now rising at an average annual rate of 12%.

Perhaps the best authenticated case history involving the competitive economy of a compact, airconditioned school vs. a naturally ventilated, finger-plan school occurred in Pinellas County, Florida, in 1961. Two approximately equal school buildings were built at about the same time to allow accurate cost comparison.

At $699,000 Oak Grove Junior High, a compact, airconditioned junior high school designed for 930 students, cost $15,000 less than Pinellas Park, an open-campus school designed for an identical enrollment. Pinellas Park, with its slightly larger floor area, cost slightly less on a unit-area basis —$9.56 vs. $9.92 per sq ft. But the lower per-pupil cost for Oak Grove, $752 vs. $768 for Pinellas Park, made the construction cost roughly equal. Although these costs are obsolete by today's inflated standards, their relationships are nevertheless revealing.

What offset the additional $68,000 cost for Oak Grove's airconditioning was a roughly equivalent savings in structural framing, walls, windows, and doors. These costs were reduced by the compact design and the elimination of natural ventilation. At Oak Grove, the $125,000 cost of these components barely exceeded 60% of the same components at Pinellas Park.

Like the capital costs, operating costs also proved to be nearly equivalent after two years of continuous, year-round operation (September, 1961, through September, 1963). Maintenance cost for Oak Grove's airconditioning and Pinellas' heating and ventilating were roughly equal, but the unit energy costs for Oak Grove's airconditioning was higher by $0.35 per pupil per year. (With increasing enrollment in the underpopulated Oak Grove, even this trivial difference would have diminished.)

In addition to the basic economies, the compact design yielded several ancillary, less easily measured economies:

- Less glass breakage (in fewer windows).
- Less fencing, security lighting, and other safeguards against vandalism.
- Lower installation and maintenance costs for storm drains.
- Less damage by humidity and airborne dust to clocks, shop tools, projectors, and other equipment.
- Elimination of blackout curtains or Venetian blinds required to darken rooms used for audiovisual instruction.

The 12-Month School Year

Faced with the problems of capital outlay and saturated bonding programs that preclude new buildings, some districts are experimenting with year-round use of their schools to avoid split sessions or shared classrooms. The pressures for year-round use of schools are intensifying. Proponents include school boards seeking to reduce construction budgets and industrialists trying to avert the massive summer vacation exodus. A company with several hundred employees faces a difficult task wedging vacations into a three-month pe.iod. The growing popularity of winter sports and vacation trips to warmer climates has reduced the attraction of summer as a universal vacation season.

"Year-round use of schools will come," says John Rankin, Assistant Technical Director of Toronto's SEF program. "The three-month summer vacation is a vestige of a vanished agrarian economy, which required the children's aid working the crops. A 12-month school year is better attuned to urban society."

A $3.5-million airconditioning program for 30 existing schools in Clark County, Nevada (Las Vegas), was completed in 1969, largely because of the prospective conversion to a 12-month school year. "We expect to be on a 12-month schedule in five years," says county superintendent Kenneth Guinn.

A financially pressed St. Louis suburb recently completed an experimental program demonstrating educational benefits of a 12-month school year. "Children tend to forget much less over 3-week vacation periods than over the 3-month summer vacation," says M. Gene Henderson, superintendent of the Francis Howell School District.

A tripling of school population over the past decade had forced the district to choose between split sessions or the 12-month school year. New construction was barred because the district had reached its legal bond-issuing limit.

A year's trial of the 12-month schedule enabled this district to accommodate 60 classrooms of students in only 45 classrooms at Becky-David Elementary. By overlapping the four quarters, the school's administrators kept at least one-quarter of the school's total enrollment on vacation at any one time. Current plans call for staged shifting of the district's 4,000 elementary and junior-high-school students to the 12-month schedule. Airconditioning of these year-round schools has high priority, but it can't be done until the district chooses to find the money.

Cities without current plans for conversion to the 12-month schedule nonetheless report increasing summer use of their schools. In 1969, 82,000 schoolchildren attended summer school in Cleveland; by 1970, the number had grown to 90,000, 60% of the 150,000 total school enrollment. Michael Marcase, Philadelphia's Deputy Superintendent for Planning, attributes his city's increase in summer enrollment more to optional enrichment programs than to make-up courses for failing students. In addition to the normal summer make-up or supplementary work, urban schools are now offering adult education, Head Start, and other remedial programs during the summer. Community use of schools is also increasing, further justifying public investment in creating a comfortable educational environment.

As still another economic benefit, airconditioning protects an increasingly heavy school investment in sophisticated audio-visual equipment that is sensitive to varying temperature and humidity. Many modern schools have a TV studio for closed-circuit use and a computer control for distribution of educational tapes to receivers in learning laboratories, classrooms, and libraries. Study carrels are equipped with miniature TV receivers and stereotape recorders. The same electronic marvel that shows the TV football fan an instant replay of a dazzling pass pattern shows his children an instant replay of a light-refraction experiment. To assure proper operation of this new panoply of instructional aids, the architect must often provide a more rigorously controlled thermal environment than is required for human comfort.

Magnetic and video tapes demand especially narrow atmospheric controls for proper functioning. In high temperatures, magnetic tapes may stick to reels, and dust particles in unfiltered air can cause visual "dropouts" on video tapes or cause computer errors. The required temperature range of 68F to 78F roughly parallels human comfort limits, but relative humidity should fall within a much narrower range (40-50%) than the 30-70% tolerated by human occupants.

Though not quite as fastidious as electronic equipment, musical instruments may retaliate with sour notes if not accorded proper environmental treatment. A clarinet, factory-tuned at 72F, may be untuned by temperature variations expanding and contracting the metal parts. Pianos are especially vulnerable to humidity changes. With varying atmospheric moisture, the sounding-board expands and contracts, and shifting strings strike discordant notes. Stringed instruments may warp and even crack in unhumidified storage rooms during cold continental winters. Altogether, musical instruments may represent a $100,000 investment for a school.

Airconditioned Modernization

Airconditioning is, of course, most economically installed with the original construction; it always costs more when added later. Yet the market for airconditioning existing schools is already roughly one-quarter the size of the new school market and can be expected to keep growing every year. The added airconditioning is often part of an over-all modernization program, including improved lighting and possibly movable partitions and furnishings.

Like airconditioning of new schools, these renovation programs have two basic aims:

• To improve the quality and comfort of the learning environment.

• To exploit the construction and operating economies made possible through airconditioning.

The major impetus to school modernization programs is the accelerated rise in construction costs, now proceeding at a national rate of about 12% a year. Voter resistance to bond issues has forced school administrators to turn to renovation as an economic alternative to replacing obsolete schools with new buildings. With new schools costing $35,000 to $40,000 per classroom vs. $5,000 to $6,000 for renovation, an annual airconditioning of 10,000 existing classrooms makes economic sense. By 1975, under new pressures for year-round school use, plus the predictably escalating cost of building construction, the market for airconditioning existing schools should climb to 15,000 classrooms a year.

The added architectural flexibility contributed by airconditioning applies to renovation as well as new construction. With airconditioning included as part of the renovation work, the architect can remove partitions, rearrange rooms, and fill in windows without fear of destroying natural ventilating patterns. He can locate bandrooms or libraries in the interior, without requiring tremendous quantities of uncooled ventilating air.

The simultaneous expansion, modernization, and airconditioning of a San Diego elementary school illustrates the great economy of filling in open spaces in a typical finger-plan school. This modernization-addition cost 28% less than the state-aid formula price ceiling, an index of current local school building costs.

Built in 1959, Rios Elementary's growing enrollment required the addition of 14,000 sq ft of classroom space to the existing 22,000 sq ft. In addition to simply adding space, the Rios administrators also wanted to transform the space into a flexible, open environment adapted to new instructional techniques. By adding merely 110 ft of wall, La Jolla architect Clyde Hufbauer enclosed an additional 13,200 sq ft. To enclose a square plan of equivalent area would have required four times the length of wall. Removal of interior partitions and former exterior wall segments gained the equivalent of 16 standard classrooms. With new, sound-absorbing carpeting, improved lighting, and nine roof-mounted airconditioning units (installed at a cost of $1.53 per sq ft), the renovated Rios school can now accommodate the latest techniques of team teaching and individualized instruction

Without airconditioning, such a conversion would, of course, be totally impracticable. The large interior areas, lacking adjacent window walls for natural ventilation in San Diego's warm climate, would have been unusable without mechanical cooling. The learning areas will, in fact, require mechanical cooling at least 90% of the time.

In the spring of 1970, Dallas started a $41 million, seven-year renovation program focused on relighting and airconditioning 6,000 classrooms in 170 schools. Estimated owning and operating costs for the added airconditioning and the nearly tripled lighting levels totals 3.3% of the annual school system operating budget.

The relighting-airconditioning combination is a natural partnership for economical, concurrent installation. With its six 500-watt silver-bowl incandescent fixtures furnishing a mere 26 ft-candles, the typical Dallas classroom is grossly underlighted. The inefficient incandescent lights also add a high heating load (equivalent to 20 students) to each classroom. By replacing these incandescents with fluorescent lights providing 67 ft-candles, the architect simultaneously reduces the lighting heat load from 0.85 to 0.37 tons of refrigeration. The $270 per classroom saving in airconditioning equipment cost equals the fluorescent lighting cost. Substitution of fluorescent lights will cut an estimated $61.20 from the annual classroom lighting bill and another $6.30 from the airconditioning operating bill.

An even larger renovation program in Houston will ultimately aircondition all 226 of that city's public schools at an estimated cost of $46 million.

The most instructive feature of Houston's program is the strategy formulated for establishing the schedule and the quality for the program. Working with the Houston school board, architect Bruce Wallace of McKittrick, Drennan, Richardson & Wallace, established the following principles:

1) Give high priority to schools planned for conversion to 12-month schedule.

2) Match design life of airconditioning system to projected remaining life of building.

3) Replace heating systems with high maintenance costs as soon as practicable with new

heating-cooling plants (to reduce high interim maintenance costs).

4) For schools scheduled for expansion within five years, schedule airconditioning installation to coincide with addition.

5) In general, schedule airconditioning concurrent with planned remodeling.

New Products for Better Environment

Within the past decade the airconditioning industry has developed a wide range of equipment suitable for both new and existing schools. The airconditioning industry has, in fact, taken a building industry lead in adopting nationally recognized testing and performance standards for its equipment. Now under development by the American Society of Heating, Refrigerating, and Airconditioning Engineers (ASHRAE), standard classification of airconditioning systems should assure purchasers that they are getting specified flexibility and environmental control. Moreover, technological progress has kept airconditioning cost escalation below over-all building cost escalation, chiefly through increased factory fabrication.

The basic airconditioning equipment comprises boilers (for heating), chillers (for cooling and dehumidification), mechanical sprays (for humidification), fans and ducts for conveying conditioned air, filters for cleaning air, pumps and pipes for conveying chilled or heated water. Despite many sophisticated sub-classes, this equipment can be assembled into only three basic methods of airconditioning: *all-air*, *all-water*, and *air-water*.

In *all-air* systems, central fans distribute the centrally cooled or heated air through a duct network serving the various building spaces. In *all-water* systems water is pumped to coils that heat or cool locally supplied air flowing over them. *Air-water* systems are combinations of all-air and all-water airconditioning. Like the all-air systems, they have centrally distributed air, but the major part of the thermal load is balanced by heated or cooled water.

Each basic type of airconditioning has its many sub-species and its own special advantages. With short duct runs, all-air systems are usually best for performance and for economy. Thus they are generally suited for compact schools, whose relatively short distances do not require excessive fan power. For finger or cluster plans, with their peripheral spaces and long distances from a central plant, an air-water system may be best. (Water can be more efficiently and economically conveyed over long distances than air.) The most popular school heating technique throughout the 1960's has been the unit ventilator. It draws in outside air, filters it, and forces it across a water-heated coil and into the room through a sill-level grill. Circulation of chilled water thro gh the heating coil or through a second coil enab... the unit ventilator to be converted into a true airconditioning unit if controls are added.

Though central heating and refrigerating and fan assemblies have traditionally been favored as the most economical, durable methods for air-conditioning large buildings, a new trend has developed largely in response to the systems-building trend started by California's School Construction Systems Development (SCSD) program, initiated in the early 1960's. In response to the performance specifications for that program, several airconditioning manufacturers marketed packaged rooftop systems designed with previously unavailable flexibility. Unlike the more conventional air conditioning systems, these simplified packaged systems feature so-called direct-expansion refrigeration, thus eliminating water as an intermediate cooling medium. (In these basically all-air systems, air passes directly over the refrigerant coils instead of chilled water coils.) They also dispense with the cooling towers often used to cool the heated chilling water in large central systems. Compact forced-air condensers liquefy the heated refrigerant gas before it flows back to the compressor to start the cooling cycle anew. Through a complex of multizone mixing boxes and flexible, removable duct segments, the winning SCSD airconditioning became the first of many commercially available packaged airconditioning systems adaptable to a broad range of room sizes and space changes.

Built for new durability, packaged airconditioning systems exploit the faster, more economical, and often more dependable quality of factory prefabrication and assembly. With the older central airconditioning systems still competing, there is a wide variety of airconditioning available for today's new school construction market.

Today's airconditioning products are also adaptable to renovation work. Where an existing school has good existing heating ducts, cooling coils can sometimes be added for local room control. For small buildings, self-contained unit ventilators may be best. Central chilled water may be best for airconditioning large existing buildings. Rooftop units can serve interior classrooms and wings of one-story buildings. These units offer several advantages: they may require no ducts; they allow flexibility in relocating rooms; and they can require less specialized skill to install than central airconditioning.

The belated recognition of airconditioning as a basic factor shaping the educational environment has left a tremendous market of unairconditioned schools. Only 8% of the nation's 1.8-million classrooms are airconditioned. Because of excessive age or some basic building handicap, about one-quarter of the unairconditioned classrooms are not worth airconditioning. But the remaining 1.2-million classrooms constitute a roughly $5 billion market for airconditioning existing schools. At its roughly $4 billion annual rate, new school construction annually adds about a $300 million potential market, which is still only partially exploited at the 30% current rate of airconditioning new schools.

Carpeting may offer an instructive parallel for the needed airconditioning breakthrough, according to EFL President Harold B. Gores. In 1956, says Dr. Gores, carpet sales to schools totaled $50,000. By 1966, in response to the need for a quieter environment and reduced floor maintenance, the 1956 mini-market had expanded to a respectable $99 million.

"Carpet manufacturers suddenly realized that U.S. schools had 100,000 acres of hard, noisy, slippery floors," says Dr. Gores. "This was a big factor in the carpeting revolution. Perhaps the airconditioning revolution will really start when the industry discovers the 900,000 acre-feet of unairconditioned school space."

Educational Facilities Laboratories, Inc. is a non-profit corporation established by the Ford Foundation to help schools and colleges with their physical problems by the encouragement of research and experimentation and the dissemination of knowledge regarding educational facilities.

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