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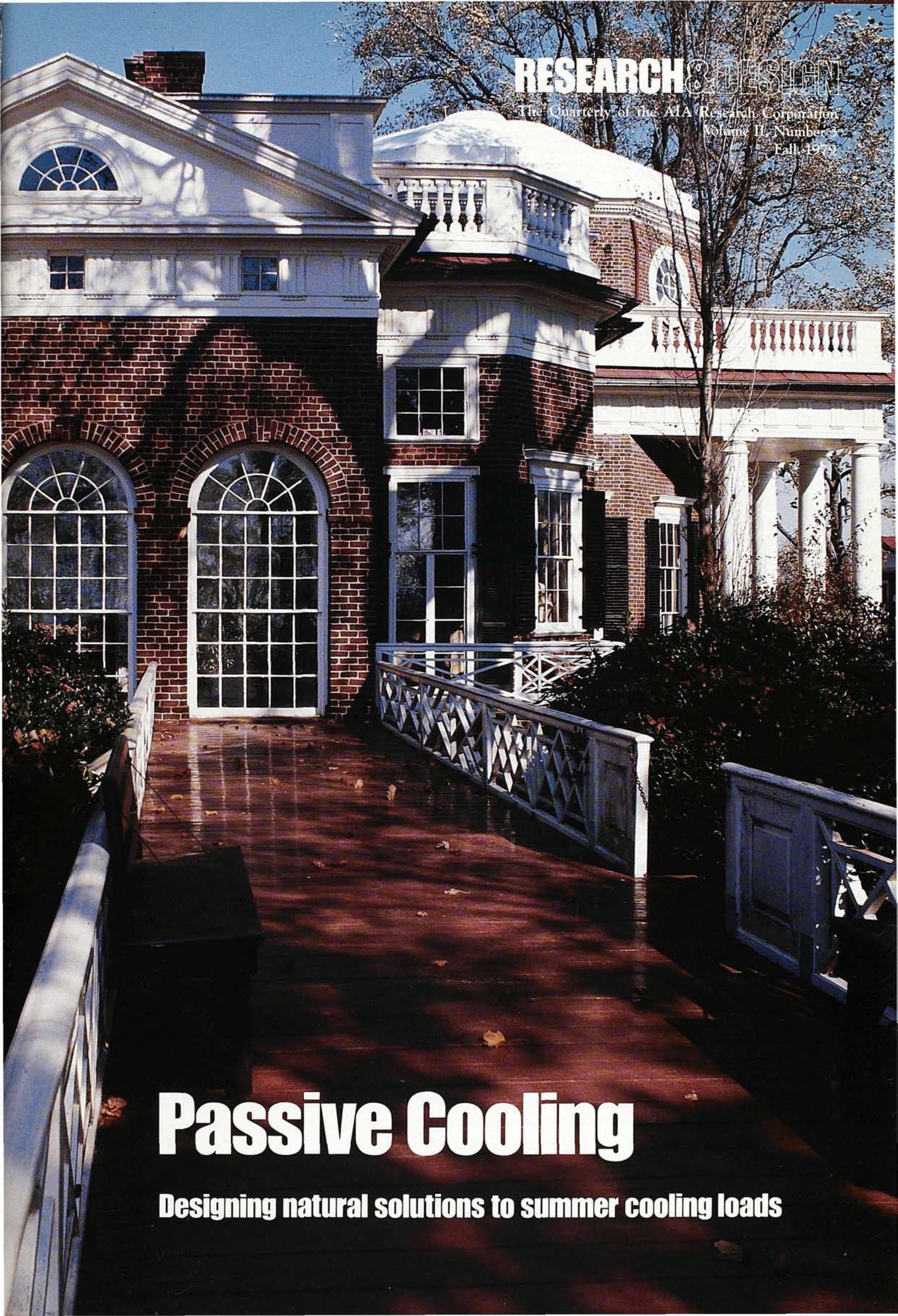

Passive Cooling

Designing natural solutions to summer cooling loads

COMMENTARY

One condition we've come to take for granted on a blistering summer day is the cooling relief of an air-conditioned office building or home. There are hot, muggy days on which most people would pay any price for the feeling of cool air on a perspiring forehead, and air-conditioning has made that feeling universally possible. The unfortunate question we're facing today is, given the escalating price of fuel and the possible interruption of supplies, can we really afford to pay "any price" for coolness?

Modern buildings have energy use characteristics that make cooling a major consideration in design. Cooling loads in residential design are, depending on the area of the country, often low. Still, users conditioned to cool comfort in the summer want those loads to be met. In non-residential design, cooling loads are larger and incurred more frequently. The designer must consider not only envelope-related solar gain, but the tremendous internal cooling loads generated by people, artificial lighting, and equipment—loads that often demand cooling year-round, and simultaneous heating and cooling for much of the year. As the cost of buildings operating in this energy-intensive mode soars, building owners look to building designers for solutions. And building designers, having worked in the mechanical conditioning context for the past 30 years, start looking for alternatives.

Most designers have become familiar with natural or passive design techniques which make maximum practical use of the sun for heating. Passive solar heating systems have a simplicity of concept, keyed to the annual motion of the sun, that we can easily imagine building designs responding to. Natural cooling, the reverse process, isn't so easily imagined. Rather than the purposeful collection, storage, and distribution of solar energy that heating involves, cooling requires the *dissipation* of heat from a building. But to where?

Three natural heat sinks exist in our environment—sky, atmosphere, and ground. Building designers have been using them for centuries, and we can use them today, but linking those heat sinks to our more sophisticated buildings and spaces is more difficult than passive heating. This issue of *Research & Design* is an introduction to the techniques of passive cooling, different and more difficult than those of passive heating. It is organized into three sections. The first is a brief overview of the processes of natural cooling and the design techniques that are being put to use in practice today. The second takes a look at some recent architectural projects around the country that integrate those techniques with actual building design. It includes both residential projects, where passive techniques stand a chance of meeting full cooling loads in many parts of the nation, and commercial projects, where taking advantage of natural forces can substantially reduce generally tremendous cooling requirements. The third offers a quick glimpse at some of the ongoing research into passive cooling design techniques. It includes several new announcements to be made at the fourth national AS/ISES Passive Solar Conference in Kansas City this fall.

The field is more complex than this issue of *Research & Design* can report, however, and it is growing. The U.S. Department of Energy has been exploring the potential of night sky radiative cooling, and has funded new projects for continued engineering development of that technology, for regional assessments of passive cooling's potential, and for demonstrations of passive cooling in residential and commercial buildings. Plans prepared by the Lawrence Berkeley Laboratories and the Solar Energy Research Institute call for an increasingly aggressive passive cooling program in 1980, involving a more thorough resource characterization, material and component testing, system studies, and building demonstrations. All of these activities will be directed at the development of tools to help designers predict the cooling performance of a wide range of passive cooling systems.

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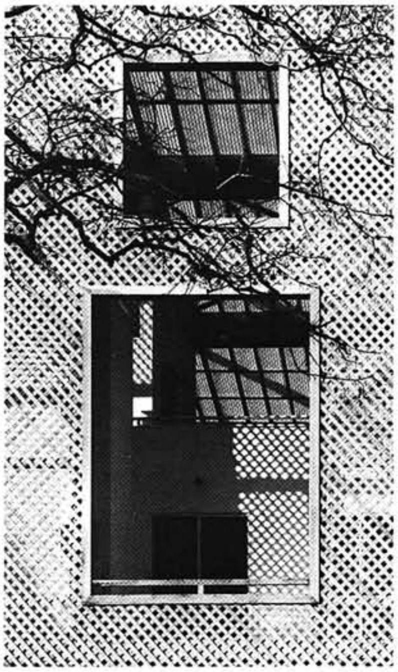

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Energy and architectural education.

4 **Passive Cooling**
The past summer, mild in terms of temperature, saw a harsh price hike from the OPEC nations and a major boost in the prime interest rate, both of which will send utility rates skyward in plenty of time for next summer's air-conditioning season. That's one reason more than a few architects are exploring ways to beat the heat as Thomas Jefferson did—naturally.

10 **Uncommon Sense**
Some recent architectural projects that let the forces of nature, aided and abetted by the forces of design, do most of the cooling.

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A look at some of the research that, with partial support from the federal government, is bringing science to an historically intuitive field.

The AIA Research Corporation

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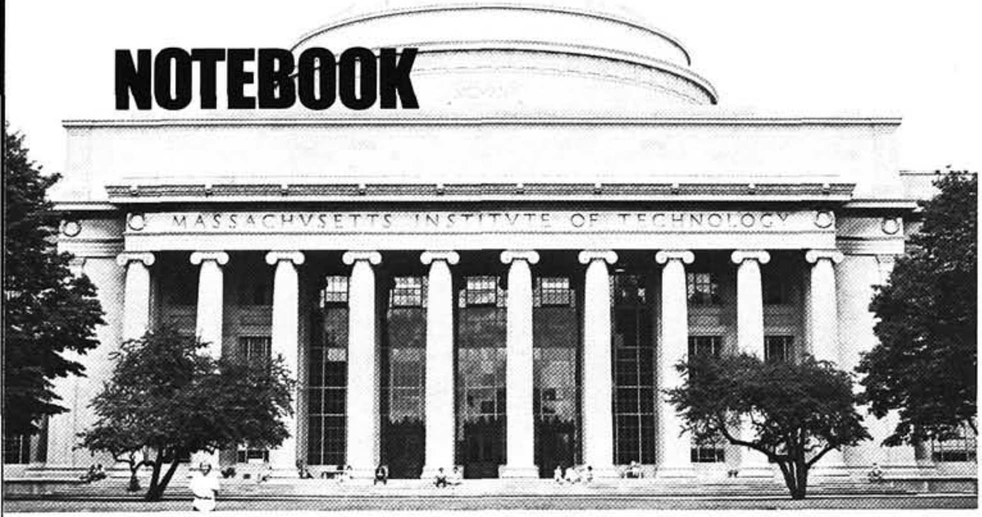
Cover: Photograph of Monticello by Robert Lautman.

NOTEBOOK



Above, MIT, site of this summer's energy institute for architectural faculty. At right, top to bottom: Faculty Ben Evans (VPI), Alan Brunken (Oklahoma State), Masami Takayama (IIT), and David Elwell (NJIT) in a design application session with instructing engineer Fred Dubin (second from right); speaker Ian McHarg (UPenn) with former student Arnie Aho (Mississippi State); lighting specialist William Lam describing his metered lighting model of TVA's new Chattanooga complex; faculty and consultants touring MIT's Solar 5 test house.

Energy and education: While students clamor for solar courses, researchers are gauging academic interest and design faculty are going back to summer school

Demand for energy-conservative buildings and architects capable of designing them has increased exponentially since the opening days of the energy crisis. With neither the crisis nor the demand showing signs of waning, the need for specialized training in energy conscious design has drawn particular attention, and not a few institutions are addressing the problem.

The central focus of concern is education in the nation's professional schools of architecture. In late 1977, reviewers of the U.S. Department of Energy's R&D efforts in passive solar design called the greatest barrier to professional competence in energy-conserving design the "lack of energy consciousness, thermodynamics, and integration of passive design thinking in the training and educational curricula of professionals and building trades." That important statement prompted DOE to take initiative on energy and education.

One of DOE's first actions was to hire the Princeton Energy Group, in Princeton, N.J., to survey a cross-section of the nation's architectural schools and gauge the level of their programs in energy conscious design. The survey, which involved interviews conducted late last year at 32 architectural schools where there were indications of at least some interest in energy-related training, produced some interesting results.

"Energy conscious, climate responsive, and passive solar design concepts are having an increasing impact" in architectural schools, the survey report says. "High interest is reported on the part of students," and schools are responding by "placing increased emphasis upon environmental technology as an adjunct to other design skills and issues." Studies in low-temperature thermodynamics and solar design "are receiving increased attention from both students *and* faculty."

But the survey found specific barriers. Schools are reluctant "to over-emphasize any particular methodology or technology." The degree to which energy issues have been integrated into design curricula "seems to depend on a small and select number of 'interested' faculty." Although most schools require courses in environmental control and HVAC in which the dynamic thermal performance of a building is introduced, "issues of active and passive solar design, if introduced at all, are not usually well developed" and are generally "taught from the perspective of a mechanical engineer." This pattern, says the survey report, "tends to reinforce a separation of professional roles, where engineers are brought in after the fact to provide complex mechanical systems necessary to make a building comfortable." And while there is academic research in progress that is beginning to quantify the links between energy and the generation of architectural form, "research faculty are [frequently] not the same faculty who teach studio . . . Few faculty have the full breadth of theoretical, analytical, and practical experience essential to communicate the concepts of passive solar design."

How to overcome these barriers? The Princeton survey team developed a set of recommendations from their research. First, develop "a coherent framework for the inclusion of passive solar design methods and concepts in the architectural design process," a curriculum that interfaces traditional methodologies and new technologies in an energy-conscious approach to building design. Second, develop "subject-oriented resource packages" to fit diverse course and studio needs. Among the subjects: basic building climatology, dealing "with fundamentals of heat transfer, human comfort, thermodynamic behavior of building types . . ;" site and microclimatology, "i.e., the influence of exterior natural and manmade environments on the internal thermodynamic behavior of buildings;" natural solar heating; natural cooling and ventilation; natural daylighting; analyses of historic design precedents; evaluations of energy-conscious construction details, and life-cycle costing.

In another educational effort, DOE already has in process a five-year program of summer institutes on energy conscious design for architectural faculty, the second of which took place this past August at the Massachusetts Institute of Technology. Conducted by the AIA Research Corporation and the Association of Collegiate

Schools of Architecture, the week-long session brought 45 design faculty from 22 of the nation's architectural schools together with leading architects, researchers, and educators in energy conscious design.

Largely the brainchild of John Cable, AIA, chief of DOE's Buildings Division, this summer's institute and the session held last year at Harvard focused both on changing teaching methodologies and on concepts and techniques of actual energy conservative building design —on the theory that existing architectural programs are studio-centered, supported by technical courses. DOE wants to work within that existing framework to raise energy consciousness.

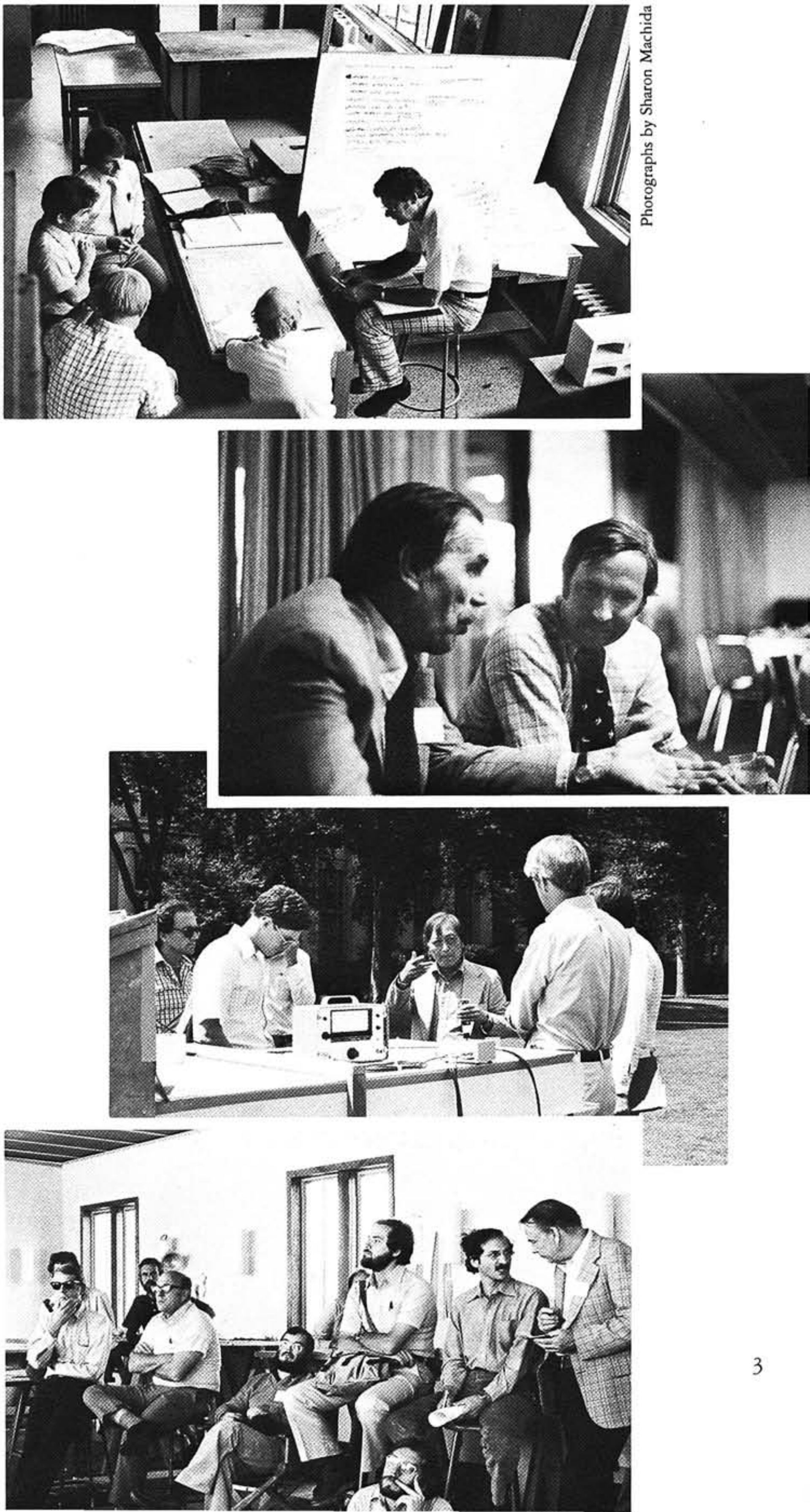
Faculty attending the MIT session had every opportunity to expand their consciousnesses, and according to some participants the cross-pollenation hoped for by DOE was surpassed. Six days intended for dialogue reportedly took on the intensity of a charrette.

Planner Ian McHarg opened events with a keynote address that took a biological approach to the interrelationships of the built and natural environments. With what one listener characterized as "his usual trenchant wit and at his usual breakneck speed," McHarg galvanized his audience with his conceptualization of the symbiotic links between climate and building, likening the evolution of building form to the evolution of an organism in its environment.

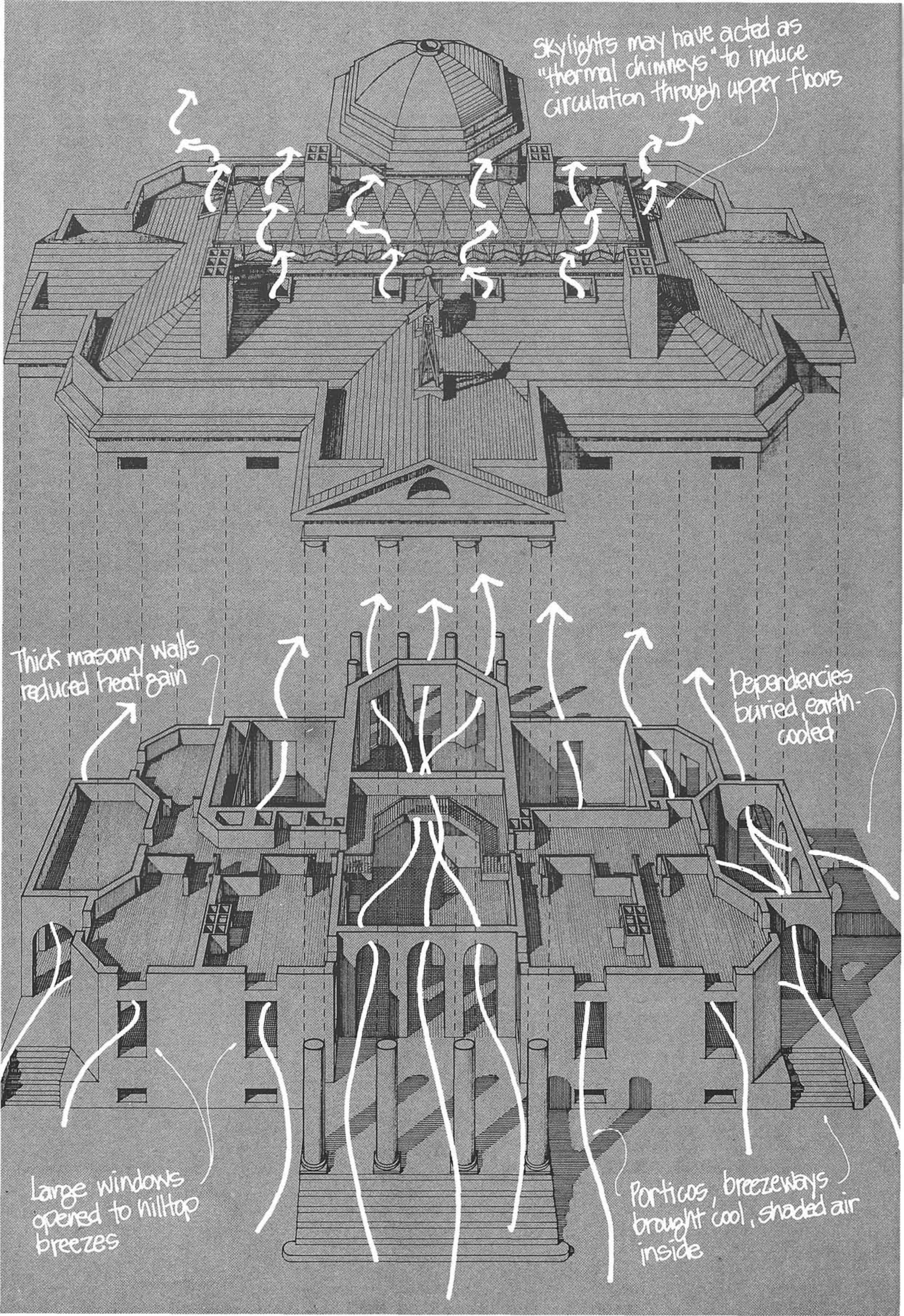
The dialogues began with presentations on three current energy conscious design projects that approach the state of the art: TVA's Chattanooga office complex, described by TVA, TAC, and CRS architects and by session instructors William Lam and Peter Calthorpe, whose daylighting schemes for the complex help make it one of the most advanced, energy-conservative large-scale projects in the nation; IBM's planned 44-story office building for midtown Manhattan, designed by Edward Larrabee Barnes Architects to function on a contingency basis without power from Consolidated Edison; and the Brookhaven Natural Thermal Storage House, a mixed-solution residential design by New Hampshire's Total Environmental Action and Brookhaven National Laboratory.

For the next three days, the faculty joined in theoretical presentations and technical sessions on energy evaluation, climate response, site analysis, building form, massing and configuration, layered envelopes, and lighting. In studio-replicating design application sessions and a panel discussion, they explored the problems of integrating the issues into their design studios. They heard architect Robert A. M. Stern, AIA/RC President Charles Ince Jr., and engineer Fred Dubin talk about design, research, and engineering approaches to energy use in buildings. They spent a morning in MIT's Solar 5 house touring an energy conscious solution to the taxing winters of Boston's climate. And they spent nearly every evening commandeering MIT slide projectors to present their own projects and approaches to each other—exactly the kind of cross-pollenation the session's organizers had hoped for.

Now the session's organizers will gauge how well the excitement generated by the week in Cambridge carries over to the educational curricula at design schools around the country.



Photographs by Sharon Machida


Skylights may have acted as "thermal chimneys" to induce circulation through upper floors
Thick masonry walls reduced heat gain
Dependencies buried, earth-cooled
Large windows opened to hilltop breezes
Porticos, breezeways brought cool, shaded air inside

Passive Cooling

Before energy was plentiful and air-conditioning omnipresent, designers came up with ingenious techniques for letting the forces of nature keep their buildings cool. Today's designers are relearning those techniques. And coming up with a few more.

It was in August, 1805, that Thomas Jefferson wrote to his friend Joel Barlow and invited him to Monticello. Barlow, one of Jefferson's successors as American minister to France, had just returned to New York from Napoleonic Paris. Eager for news, Jefferson urged him to visit Virginia directly. And, as friends eager for a visit will do, he added enticement to invitation, telling Barlow that "the mountains among which I live will offer you as cool a retreat as can anywhere be found."

August in Virginia was then and is today more closely the cruelest month than the coolest. Temperatures are high. The humidity is oppressive. In Jefferson's day August along the Potomac qualified foreign diplomats for tropical pay when they were posted to Washington, and August at Monticello, 120 miles to the south and west, was little cooler.

Yet Jefferson's Monticello was in fact a cool oasis in the heat of August—a condition due not to the mountains that Jefferson credited but to the architect himself. As he indulged in the "putting up and pulling down" he enjoyed in the years devoted to Monticello's design and construction, Jefferson employed not only the breadth of his knowledge and passion for Palladian design but techniques which were models of what we today call passive cooling.

Monticello's massive brick construction reduced heat gain over the long summer days, delaying transmission of that heat to the building's interior until late evening or night. The first plantation owner in Virginia to build on a hilltop instead of at a river's edge, Jefferson welcomed the breezes he found there into his home with spacious windows and a floor plan that maximized ventilation. He half-buried his outbuildings to preserve the view, keeping them cool in the bargain, and he linked those dependencies to the main house with covered arcades that, like his porticos, brought shaded air into the house at cooler than ambient temperatures. There is supposition that his narrow, skylighted interior stairways were "thermal chimneys" designed to induce air circulation within the house. If his skylights were operable—historians today don't know whether they were or were not—then the stairways served as sophisticated, thermally driven mechanisms for cooling the upper floors at Monticello. And if Joel Barlow had come to Virginia in the dog days of August, 1805 (he made the pilgrimage three years later) he'd have found his friend in relative cool, dry comfort, as promised.

What is most remarkable about Monticello, though, is not that Jefferson's cooling strategies worked but the fact that they stand up so well today. Jefferson came by his cooling intuitively, not scientifically. He was a student of architectural history, not a pioneer of environmental engineering, and his cooling strategies were largely by-products of the architectural styles he emulated and the practical lessons of a life lived in Virginia's climate. Yet an architect commissioned for a villa on the same site today would do well to equal Monticello's passive cooling performance. To succeed, chances are excellent that he or she would use Jefferson's strategies. Because for all the research activity in passive cooling today, for all the passive design projects recently built or currently underway, and for all of the years intervening between Jefferson and the present day, passive cooling hasn't changed that much.

That it *will* change, however, is a certainty. In an essay this summer, *Time* called the air-conditioner "a more pertinent symbol of the American personality than the car," and pointed out that the energy crisis has put both those cornerstones of the American way of life on waivers. Passive cooling will not send the last air-conditioner to the showers, to be sure. But its potential for reducing the presently awesome energy costs of mechanically cooling the nation has sparked architects, engineers, homebuilders, researchers, and the federal government to feverish exploration of passive cooling technologies.

What those explorers are finding is that most of the techniques that work have worked for centuries. We've just forgotten them. Now we're relearning them. More important, we're adding to them with the results of well-focused theorizing, careful testing and research, intelligent new applications in actual design and construction, and rigorous performance monitoring. All that adds up to a field that is fascinating not only for its potential

Drawings of Monticello courtesy of the Thomas Jefferson Memorial Foundation

impact on the way energy is used in cooling the nation's residential and commercial buildings, but for the way it blends the lessons of architectural history with the needs and solutions of the future.

Heat gain control

Controlling the heat a building gains from its environment is what passive cooling is all about. It is also what passive heating is about, and the relation between those two functions is crucial. Keeping unwanted heat out in the summer and drawing it in during winter are issues that should—in fact, must—be addressed hand in hand, for the simple reason that in either case the design of the building itself is the climate-control mechanism.

There are designers, it should be noted, who define passive cooling techniques as strategies which literally introduce coolness into a building without mechanical assistance, a definition that excludes design strategies which stop heat before it can enter and become part of the cooling load. While it's a definition that has real meaning, especially in its opposition to active mechanical cooling strategies, even its proponents agree that controlling heat gain is the essential first step in any attempt to cool buildings naturally, passively, through design itself.

If controlling heat gain is the first step in a passive cooling venture, then the adjunct corollary is learning as much as possible about the climatic conditions on site that produce unwanted heat, and a critical tool in that learning process may soon be on the way.

Early this year, participants in a national conference on climate and architecture recommended that federal researchers (specifically the Department of Energy and the National Oceanic and Atmospheric Administration's Environmental Data Service) develop a "building climatological summary" for each of the 138 areas around the country where major weather stations keep detailed climatic records. Each summary would concisely, graphically summarize year-round climatic conditions for its area, ranging from monthly temperature averages, humidity levels, and diurnal temperature swings to wind speeds and directions, sun angles, and cloudiness factors. With that kind of data, specific to the site, estimating cooling (or heating) load becomes relative child's play. So does controlling that load by orienting the building away from intense solar exposure, by using indirect daylighting in lieu of artificial lighting, by shading roofs, walls, and windows with overhangs, awnings, wingwalls, and vegetation, by adjusting surface/volume ratios, and by making intelligent materials selections for the "weatherskin."

If cooling load is still an issue when the designer has controlled as much heat gain as possible, these recommended climate summaries could become even more valuable weapons, because they can tell designers exactly what tools the climate itself will supply to bring conditions into the human comfort zone.

Human comfort is a function of four major variables: air temperature, air movement, humidity, and radiation, of which the mean radiant temperature of interior surfaces is the major factor. The metabolic heat generated by human activity and the amount of clothing worn are also considerations, but these the designer controls not at all, and can only anticipate with limited accuracy. The first four vari-

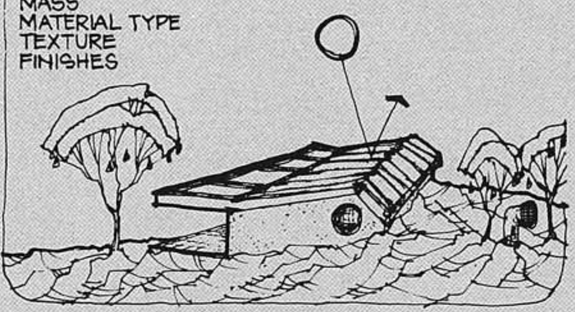
passive solar cooling

heat gain control

○ **SITE CONSIDERATIONS**
LOCATION
ORIENTATION
VEGETATION
LAND MASSING
MICROCLIMATE MODIFICATION

○ **ARCHITECTURAL FEATURES**
BUILDING EXPOSURE
SURFACE/VOLUME RATIO
SCREENS
SHADES
WINGWALLS
OVERHANGS

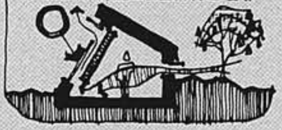
○ **WEATHERSKIN FEATURES**
INSULATION
GLAZING
MASS
MATERIAL TYPE
TEXTURE
FINISHES



direct loss

○ **NATURAL VENTILATION**

○ **INDUCED VENTILATION**



○ **OPENABLE WALLS**

○ **OPENABLE ROOF**

○ **TRANSPIRATION OF PLANTS**

○ **INTERIOR POOLS**

○ **DESICCANT MASS**

ables, the most important in the comfort equation, the designer can often control to substantial effect. With a summary of climatic conditions year-round, it becomes a relatively clearcut process to identify the climatic elements *in situ* which affect those variables negatively and which can be used through an intelligent design to combat the negative influences. Passive cooling amounts to weighing those elements and coming up with the appropriate mix of techniques to keep users cool, naturally.

The microclimate

If the best offense is a good defense, the best passive cooling strategy pays as much attention to the microclimate surrounding a building as to the building itself. Landscaping and vegetation can have a tremendous impact on natural comfort inside a building, affecting both summer cooling and winter heating loads, both of which should be considered in the physical design of a site.

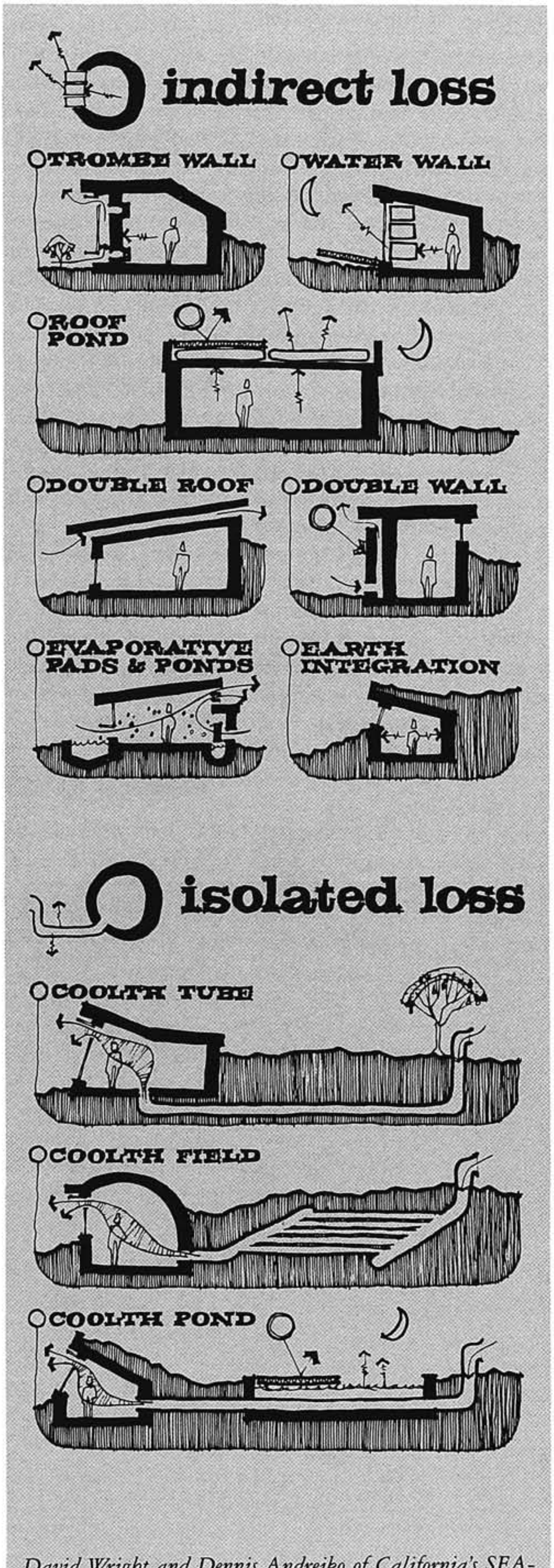
Massed earth is particulary effective as a windbreak. Earth berming can be used to deflect winter winds, to channel summer breezes into interior spaces, and to shape the air circulation pattern around a building.

Vegetation is an asset of greater worth. Evergreens make excellent windbreaks, and deciduous plants, shedding their leaves to allow the penetration of solar radiation in winter, in summer become complex cooling mechanisms. Deciduous leaves reflect infrared, heat-bearing energy and filter cool, green light to the ground. Combined with air movement, the evaporation of water into the air that occurs in plant transpiration has an evaporative cooling influence. The general effect in an area of massed vegetation is to keep temperatures in the shade a good 10-15°F lower than ambient—a particularly valuable phenomenon if that cooler air can be sent into the building.

Natural ventilation

The cooling value of air movement lies in its capacity to evaporate perspiration from the body and allow one to feel cool. Nowhere is that effect more celebrated than in the antebellum architecture of the Southeast. In Charleston, S.C., the breezes sweeping in from the ocean bring otherwise intolerable conditions down into the comfort zone (at least that of the acclimated resident) for much of a very long, hot summer. Those breezes are so powerful they have generated an indigenous architectural style: the single-house design peculiar to Charleston and common there faces the harbor, not the street, and draws its ocean air through a tree-shaded piazza and a broad veranda before channelling it through every room in a floor plan carefully designed for cooling. Like so much of the hot, humid Southeast, Charleston was designed with natural ventilation in mind.

In dry climates, however—climates averaging lower than 20 per cent relative humidity—the same process can dehydrate the body and, if not eased by evaporative cooling, cause radical discomfort. Where ventilation is a wise cooling technique, and where summer winds regularly occurring at five miles per hour or greater make it effective, buildings should be sited for summer wind exposure, opened with louvered, vented, transomed, and windowed walls, and planned for through-ventilation.



David Wright and Dennis Andrejko of California's SEA-group developed these excellent conceptual illustrations of passive cooling techniques. The direct, indirect, and isolated loss breakdown mirrors the gain matrix of passive solar heating.

Induced ventilation

Where natural ventilation is desirable but, lacking wind, not possible, a building can be designed to induce its own ventilation by duplicating the temperature stratifications that are the source of wind itself.

As air warms, it rises, seeking its way upward (and out of an enclosed space) and drawing cooler replacement from below. By using sunlight to heat an isolated pocket of interior air to greater than ambient temperatures and controlling its escape, a building can generate air circulation and maximize the influx of cooler air.

The most effective application of this natural law is a "thermal chimney," a solar-exposed enclosure tall enough to generate maximum air flow and massive enough to retain heat and power the system into the evening hours. Other solar design elements usually associated with passive heating—thermosiphon systems, indirect gain greenhouses, and trombe walls—can be used to the same cooling effect. The optimal system draws its replacement air from the coolest possible location, a planted, shaded area to the north or an underground air pipe or storage chamber.

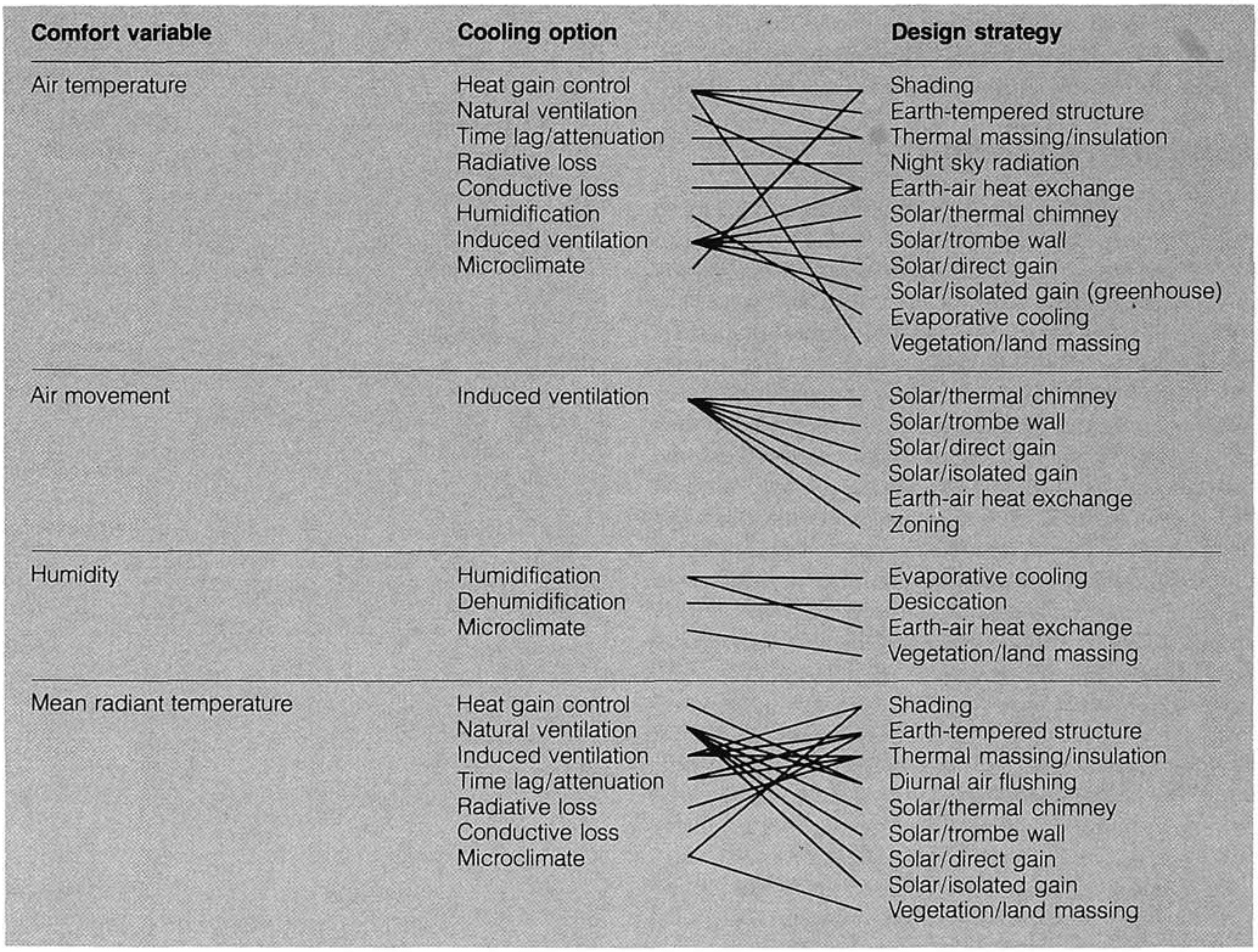
Evaporative cooling

Swamp coolers, fountain courts, and atrium pools are all applications of evaporative cooling, a particularly powerful technique in climates of low relative humidity. When a body of water is placed in a hot and relatively dry space, the water evaporates into the air and increases humidity. In the process it turns sensible heat into latent heat, literally lowering the temperature of the air at a rate equivalent to 1,000 BTUs lost for every pound of water added to the air.

Evaporative cooling can also be put to work to cool a radiative roof deck or any other radiative surface in contact with interior spaces. If a roof is sprayed with water, evaporation cools the roof surface, encouraging its absorption of heat from the interior and the dispersal of that heat into the atmosphere.

Effective as it can be, an evaporative cooling strategy mandates certain considerations: Water must be available in quantity to supply an evaporative system, and since such systems are most effective in dry climates, water supply can be a problem. It is a strategy that requires shade as well, since it is the air's heat, not solar heat, that the process is capable of modifying. And a cooling strategy employing evaporation should be joined with ventilation for the most efficient distribution of cool, humidified air.

Source of discomfort is linked with appropriate cooling options and design strategies—stressing the applicability of several strategies to a single variable—in this chart by researchers Donald Elmer, Mo Hourmanesh, and Fuller Moore.



Desiccant cooling

In regions of high humidity, where moisture in the air actually prevents the body from cooling itself evaporatively, desiccant cooling is a valued traditional strategy. Dehumidifiers have replaced the salt barrels that were once ubiquitous in the Southeast, but before energy was harnessed and plentiful, desiccant salts were effective coolers to which the only drawback was the need to throw them out once they were saturated.

Passive cooling in regions of high humidity remains a problem today, and desiccant solutions remain the focus of research and current design experimentation. One new hybrid system in use rotates two desiccant salt plates, one of which is inside the living space absorbing moisture from the air while the other, already saturated, is outside in the sunlight losing its moisture through evaporation and being readied for reuse. Another system combines induced ventilation to bring air from underground over an activated charcoal desiccant and cool the interior with dry air. As the air warms and exits high on the south wall, it passes over the saturated desiccant plate, spurring the evaporative process.

The selection of activated charcoal over desiccant salts in the latter system is the product of research, which is rampant in this particular area; one chemical researcher reports that coconut husk charcoal may be the most effective natural desiccant available. The real frontier in desiccant research, however, as in other areas of passive design, is to develop a system capable of cooling buildings larger than residential scale.

Night sky radiation

Radiative cooling is an indirect heat-loss process that involves exposing interior spaces to the heat sink of a massive body of water or masonry, then exposing the mass to the planetary heat sink of a cool, clear night sky. The mass absorbs heat from the interior, and then releases that heat—in the same process that maintains Planet Earth's thermal equilibrium—to the skydome. The only caveat in the process is that it is most effective where the diurnal (day-night) temperature swing is in excess of 20°F and where the night sky is relatively clear (radiative losses to the vast heat sink of deep space are impeded by the greenhouse effect of cloud cover).

Masonry massing is the key to such historic examples of radiative design as the puebloes and Spanish missions of the Southwest, but since the invention of Harold Hay's patented Skytherm system attention has been focused on using roof-sited water as the radiative mass. In a typical roof-pond (or thermo-pond) building, bags or bins of water on the roof are covered with moveable insulation during the day to absorb heat from the interior spaces below. At night the insulation is removed and the heat stored in the water is released to the cool skydome. Other systems designed along the same lines use floating insulation which can be immersed in the roof pond at night, or stationary insulation over which the water is piped at night. In any configuration, radiative cooling is popular in both the research and design communities because it doubles for heating in winter; the exposed mass absorbs solar radiation by day and, insulated from the sky, transmits heat to the interior spaces by night. The strategy's efficacy as a cooling technique can be improved by sprinkling waters on the rooftop water containers to add evaporative cooling to the radiative effect.

Time lag cooling

Like radiative cooling, time lag cooling takes advantage of the thermal absorption, reduction, and lag characteristics of mass, and requires the same 20-35°F diurnal temperature swing to be effective. Where the conditions are right, time lag cooling has been around for centuries.

The principle is that the transmission of heat through mass—stone, concrete, adobe—is both delayed and attenuated over time. Depending on the material and the thickness of a massive wall, the delay can stretch from two to 12 hours, and the greater the lag the greater the attenuation of heat transmitted. Thus less heat reaches the interior spaces, and it doesn't arrive until late evening or night, when ambient temperatures have dropped and the exterior wall is radiatively cooling. By night's end the wall is again a cold barrier to the daytime onslaught of insolation. Exterior sheathing, insulation, or shady vegetation will add to that barrier, further flattening the diurnal curve that ironically is both the nemesis of comfort where time lag strategies are appropriate, and the key to the time lag cooling effect.

Earth cooling

Warm in winter, cool in summer, the earth is where mankind first sought shelter, and for good reason. Below the frostline, ground temperatures remain remarkably stable, hovering around the average annual air temperature, usually in the range of 50-65°F. At shallow depths, ground temperatures actually fluctuate with the seasons, but the much smaller fluctuations come as far as three months behind schedule. Thus the earth not only attenuates extreme air temperatures, but acts as a maximal time lag device, carrying winter coolness well into late spring and summer warmth into late fall.

Underground or earth-integrated construction, the common way of exploiting the moderating influence of the earth, takes advantage of both these virtues, and putting part or all of a building below grade reaps substantial cooling (and heating) benefits. There are, however, problems, not the least of which is the cost of excavation. Soil erosion, soil instability, and ground water are also crucial considerations.

Another method for taking advantage of Mother Earth is to pre-condition air by running it through subterranean cool pipes before it enters the building, or by storing it in a below-grade rock storage chamber before use. The hazards of such methodology—cost, condensation, and ground water in particular—are no less real than in earth-integrated construction. But the field is undergoing considerable research and experimentation aimed at defining and overcoming these particular difficulties, and at quantifying the feasibility of numerous earth-cooling design strategies, including the tapping of cool underground water supplies for radiative and evaporative cooling applications.

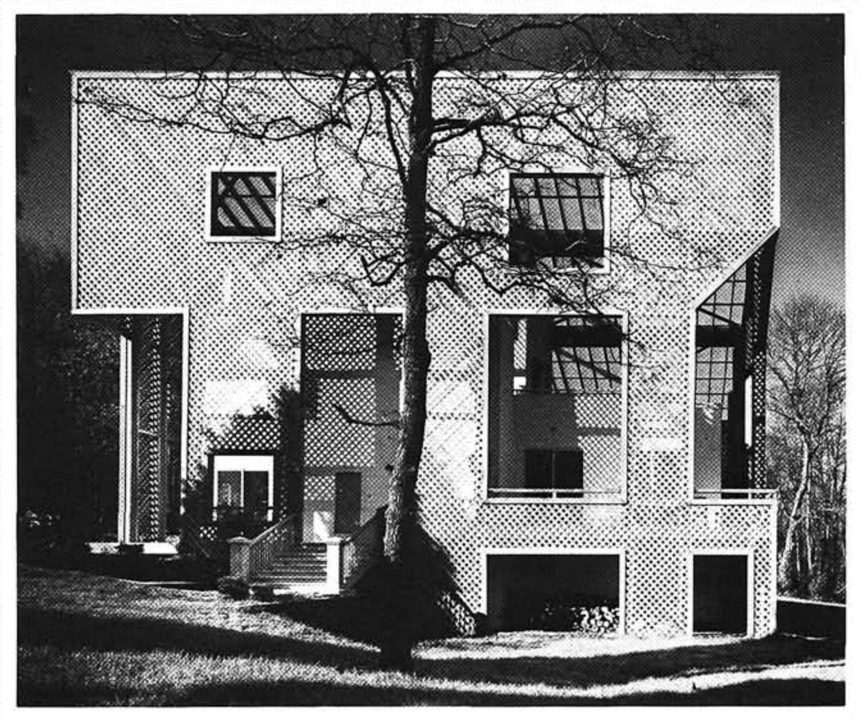
—Kevin W. Green

Uncommon Sense

A look at 14 recent architectural projects whose designers have blended contemporary research and the lessons of history to meet summer cooling loads naturally.

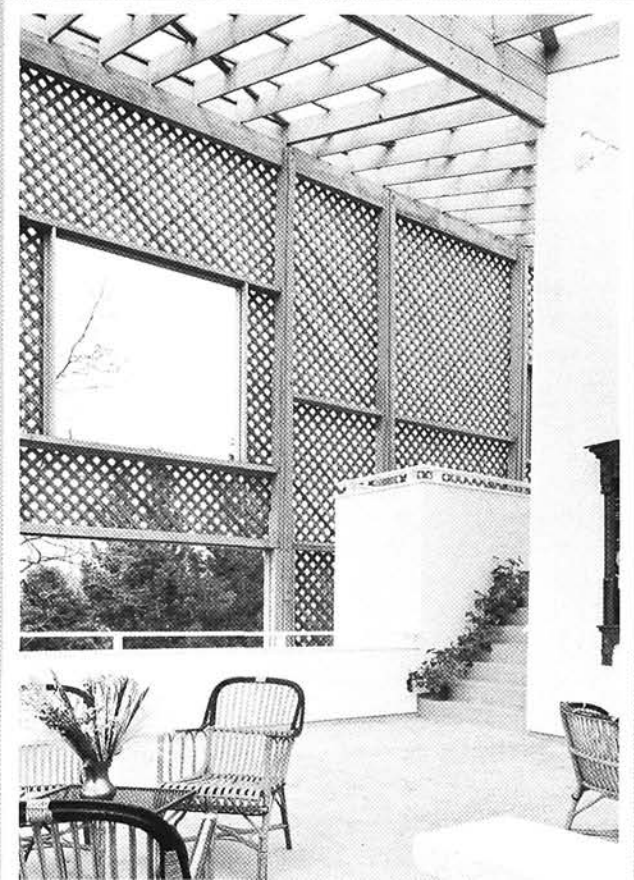
A cool, contemporary porch on the Potomac

MLTW/Turnbull Associates took a striking approach to the traditional porch and shading solutions to southern summer heat in this frame residence for the Potomac River Valley in Virginia. The house itself, white inside and out, sits within an outer "porch house" sheathed in natural redwood lattice and covered with a translucent plastic roof. The super-scaled openings to the east and north *(right and below)* frame views. The porch house forms a cool air space around the inner house during Virginia's summers. The multilevel exterior decks, shaded by the latticework and cooled by the breeze, were intended for summer living and sleeping.



Cervin Robinson

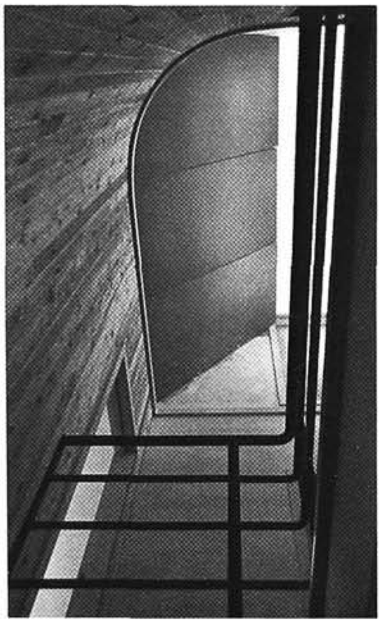
Cervin Robinson



Rob Super

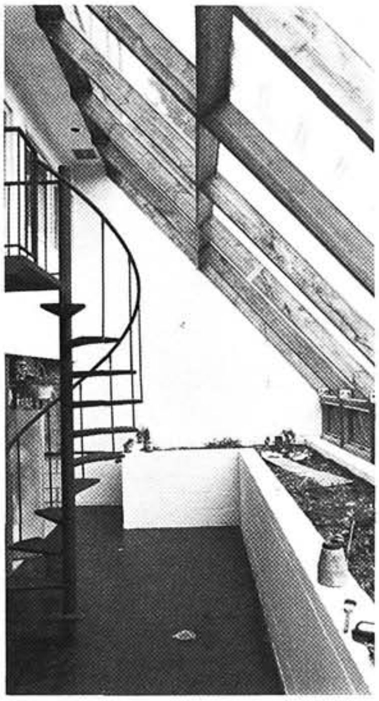
Honors for a northern solution

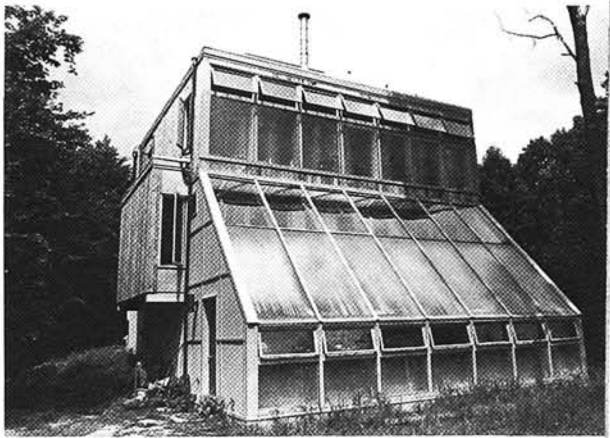
Simplicity, energy independence, and frugality were the virtues cited when this Hopewell, N.J. house *(below)* by Vinton Lawrence and Harrison Fraker of the Princeton Energy Group was selected for a HUD passive solar home award last year. Natural ventilation meets most of the summer cooling load—the house sits partially buried near the crest of a hill. When natural breezes are insufficient, solar-heated air rising through the greenhouse/solarium (which is flanked by an 800-gallon water wall for thermal mass) and up through the cupola serves to induce ventilation. A duct fan also recirculates cool air.

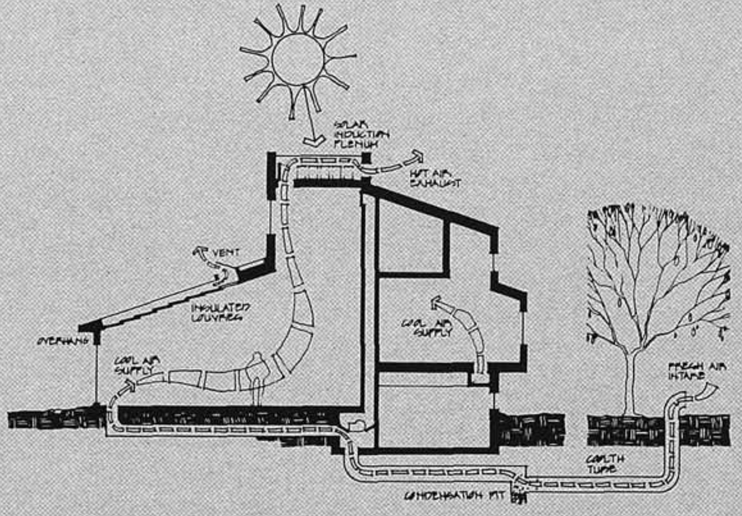


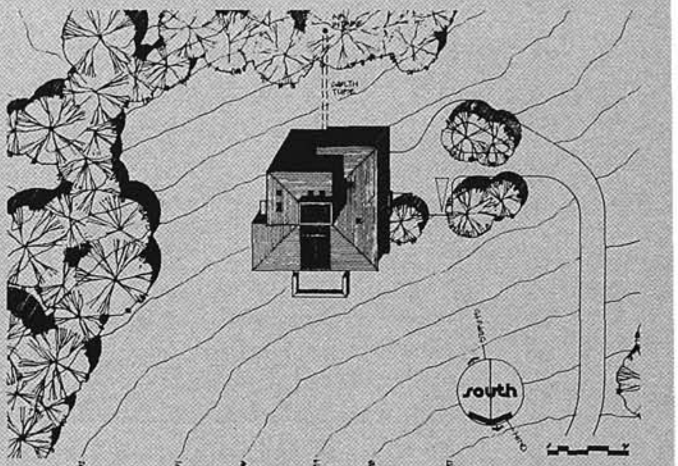
Traditional schemes for the bayou country

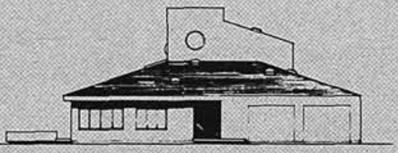
Texas architect Andrew Samson drew heavily on traditional notions for his home on the banks of the Buffalo Camp Bayou *(above)*. The V-shaped "dog-run" house is broken with a central breezeway for summer ventilation by the prevailing breezes off the bayou. The breezeway culminates in a wide, two-story solarium, vented at its peak, that draws hot air up and out and encourages air circulation. Tree-shaded and wrapped with porches, the house sits on pilings for cooling underfloor air circulation, and its tin roof reflects most solar radiation. Insulation, high ceilings, and transomed doors (salvaged, like the flooring, from old buildings) add to cooling efficiency.

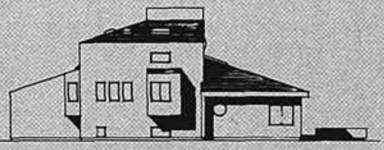








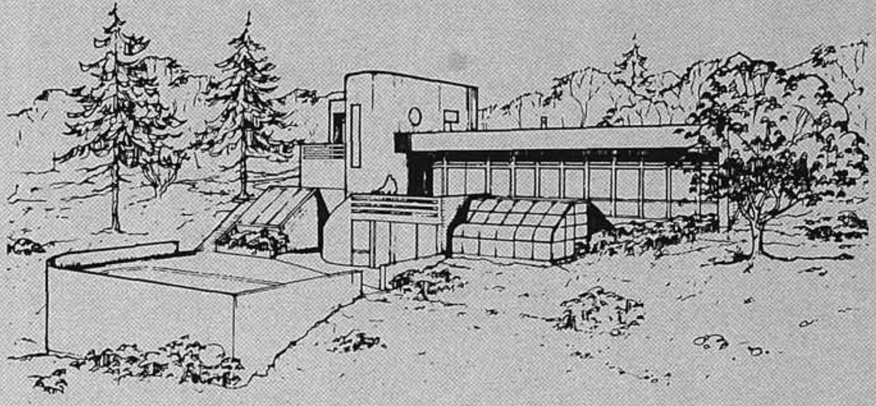

East

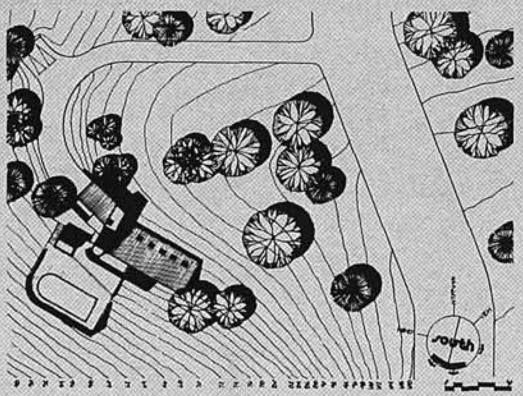

West

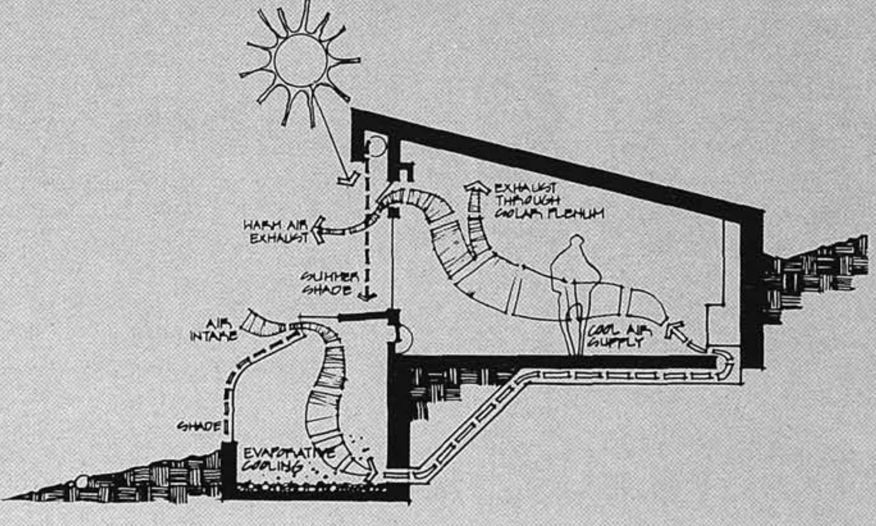

South

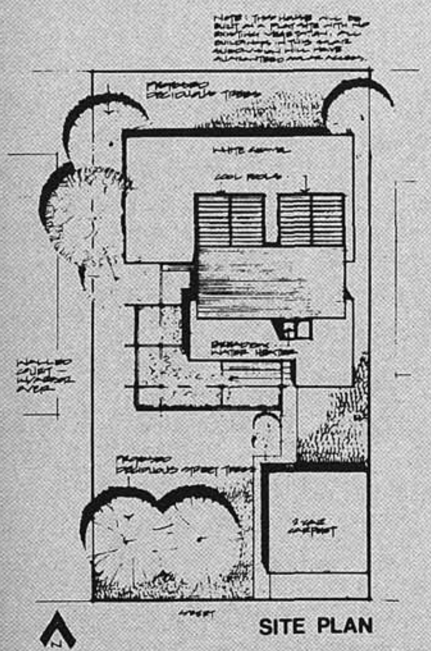
From California, two by SEAgroup . . .

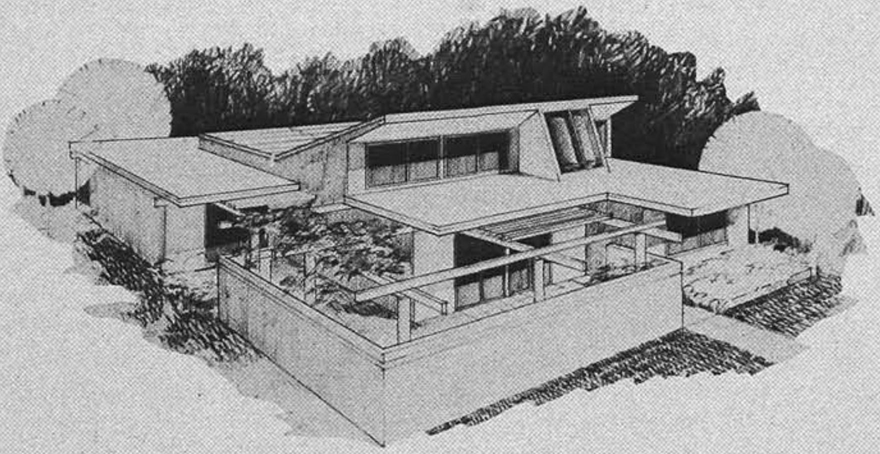
Headed by architects/authors David Wright and Dennis Andrejko, California's SEAgroup (for Solar Environmental Architecture) has been designing passive buildings around the country for several years. The J. Davis residence *(above)* for Hutchinson, Kansas helps meet its cooling load by drawing cool, shaded exterior air through a lengthy "coolth tube" and into the house. The air circulation is solar-induced at the massive roof plenum. The Sayre residence *(below)* in Applegate, Calif., was designed for similar cooling, with air being drawn into an evaporatively cooled greenhouse (the gravel floor is saturated), through an earth tube, into the living space, and out through a warm air exhaust and the tall solar plenum that induces the air flow. Costs on the owner-built home altered the design, however. When finished, the swimming pool remained, the greenhouse and the earth tube did not. Such problems are not uncommon, and SEAgroup and other designers have become adept at non-energy cost-cutting.

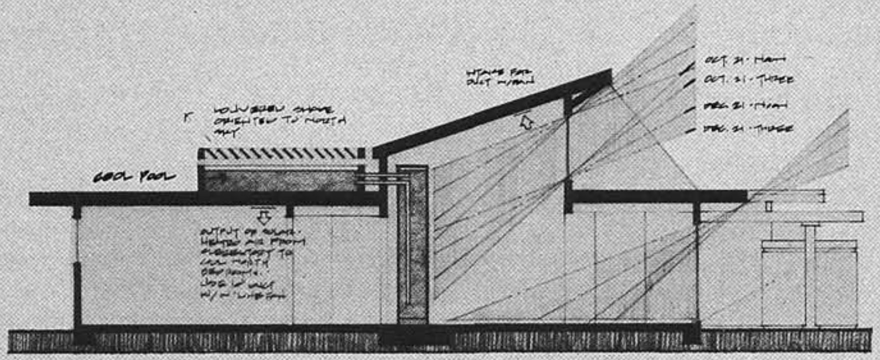






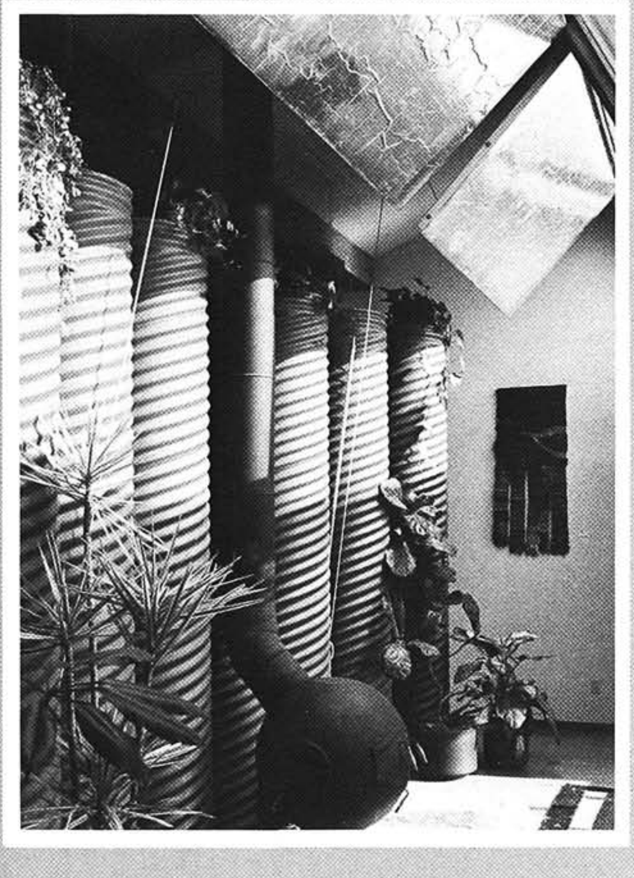






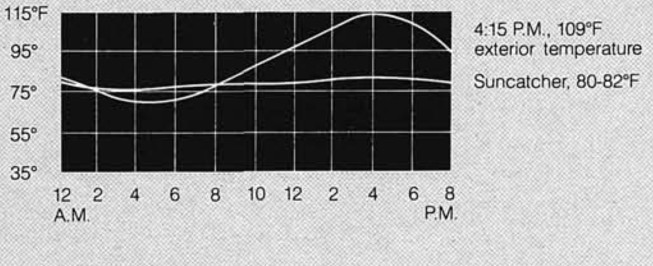
. . . And two by Living Systems

Another California design firm, Living Systems, headed by John Hammond, has also been at passive design's leading edge for several years. Hammond's work with roof-ponds and water-walls led to the design of the Suncatcher house *(below)* in Sacramento as a display home for Pacific Gas & Electric. The unusual geometry of the roof lines shades windows from the summer sun and bounces direct insolation away from the angled and shuttered clerestory. In winter, insolation enters to strike the water thermal storage wall *(below, left)*. The building's cooling performance on a record-breaking August day, charted below, speaks for itself. The firm's Cool Pool One design *(above)* reworks the same design to add radiative cooling. In a natural cycle, cool water flows from the roof-pool down into the interior water wall, cooling the living area; as water in the wall picks up interior heat, it rises back to the pool for cooling exposure to the sky. Louvers above the cool pool are north-oriented.



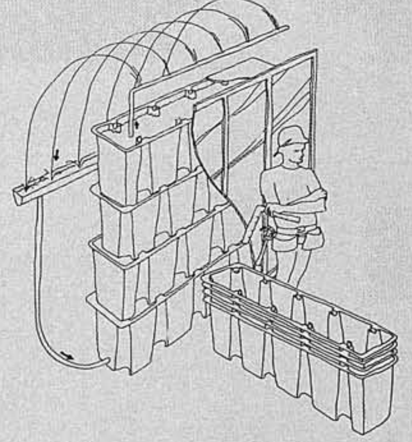
Suncatcher summer performance

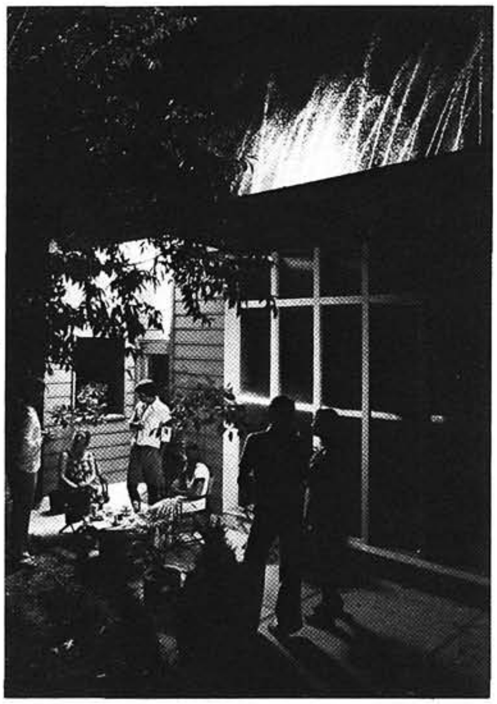
All-time PG&E/SMUD record for power consumption, due mainly to mechanical air-conditioning systems.

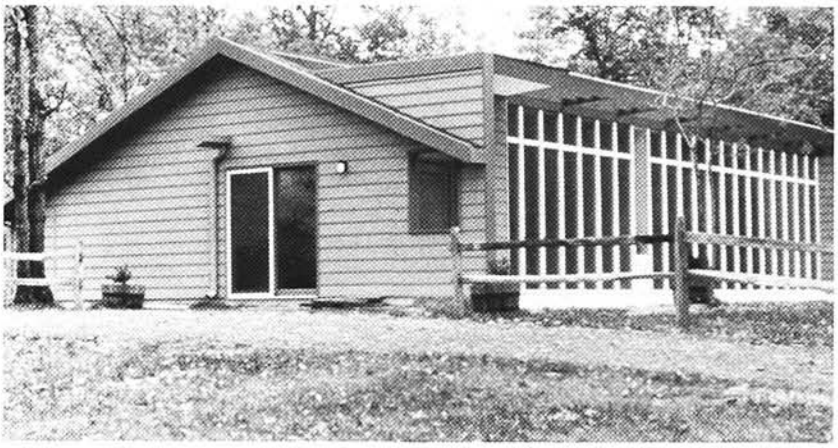


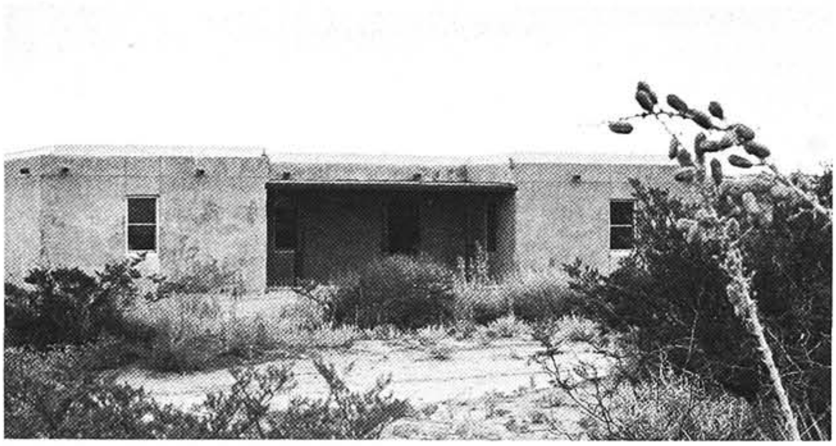
Cooling for a water-trombe wall

Tim Maloney heads One Design Inc., an enterprising Winchester Va. firm involved not only in design but in product development and limited manufacturing. Maloney came up with the unique system at right to keep the water in his thermal mass wall cool enough to draw sensible heat from interior air by spraying the water through cool night air *(left)* and channelling it back into his water-wall.

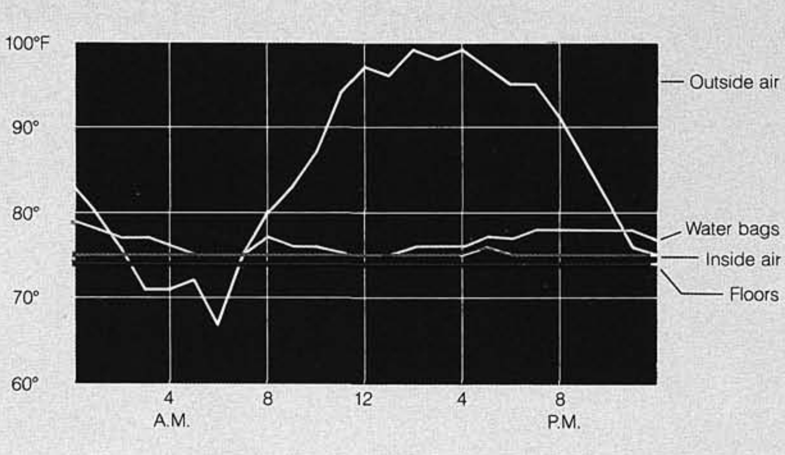






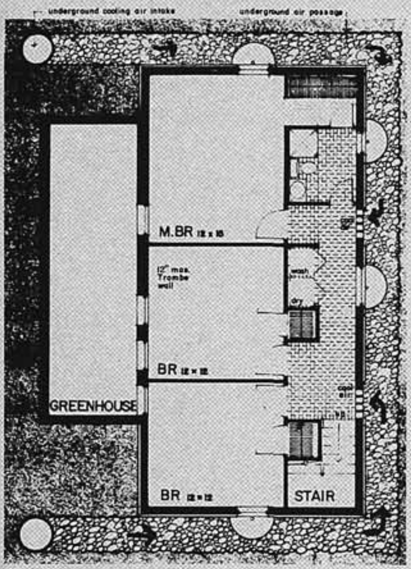


Temperatures on June 16, 1979



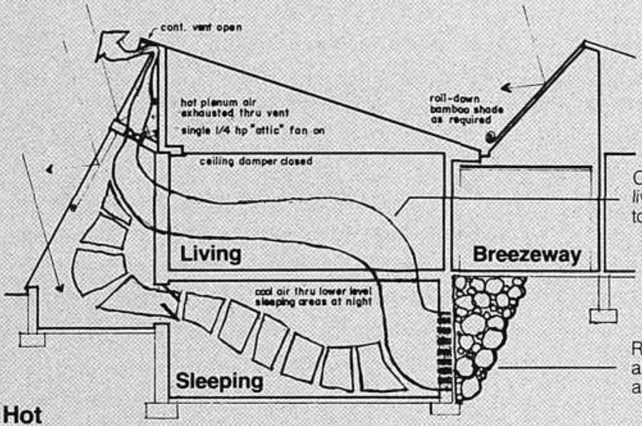
Radiative testing in New Mexico

Thomas R. Mancini, mechanical engineer at New Mexico State University, helped design and build this 1,850-sf residence as a test facility, not a home. But testing of the building's patented Skytherm roof-pond heating/cooling concept was no more important a requirement than producing a house acceptable to homebuyers, which is why the low, masonry building on the Las Cruces campus echoes traditional Southwestern styling. Built of precast concrete wall panels coated with exterior polyurethane foam insulation, it also echoes the thermal performance of its adobe ancestors. Coupled with the roof-pond's radiative cooling, minimized glazing (all double-pane), and an interior thermal mass, it appears capable of meeting all of its rigorous cooling load (chart, left). Five custom-made water bags comprise the roof pond; stock insulation panels on garage door tracks roll back to a rear roof overhang for night sky exposure.



Moore's house for all seasons

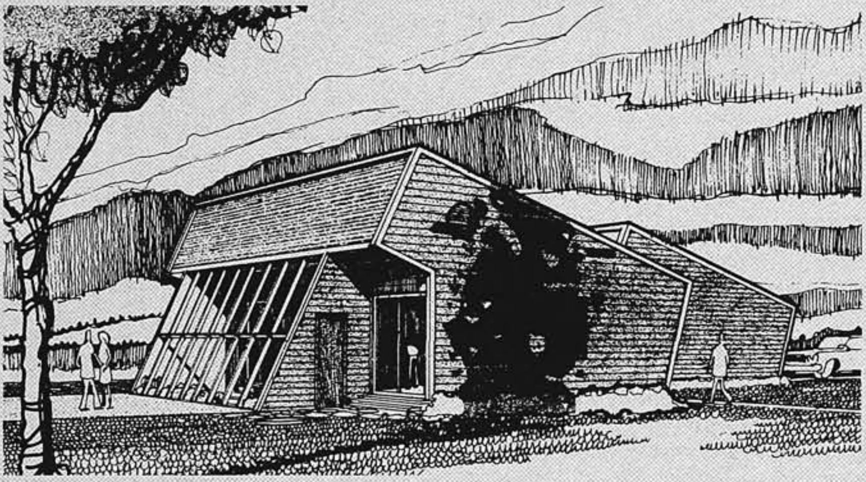
Another HUD passive solar home award winner, this 1,600-sf southwestern Ohio house was judged capable of meeting almost all its cooling requirements naturally. Designed as a house for all seasons by Fuller Moore of Miami University in Oxford, Ohio, the building is partially buried and thermally layered so that the lower sleeping spaces stay cool. In warm weather, an attic collector space above the south-facing, shaded greenhouse acts as a thermal chimney, pulling cool air from a sizeable underground rock storage area through the house. When temperatures are hot, a small attic fan aids the thermosiphon effect.

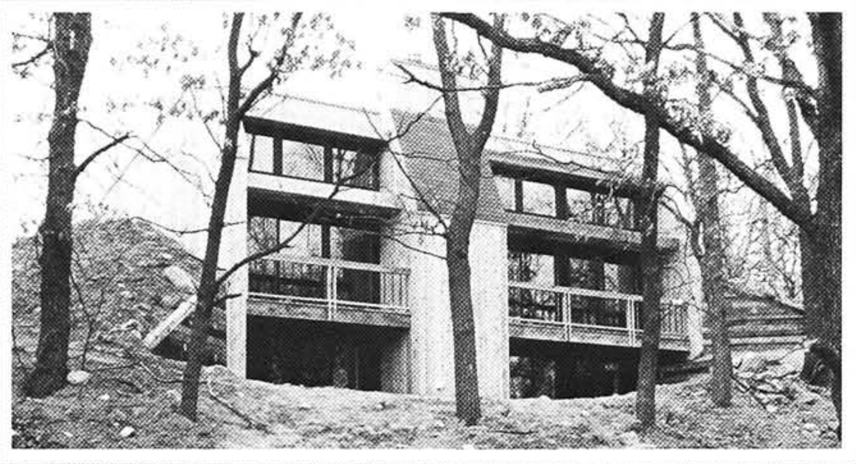


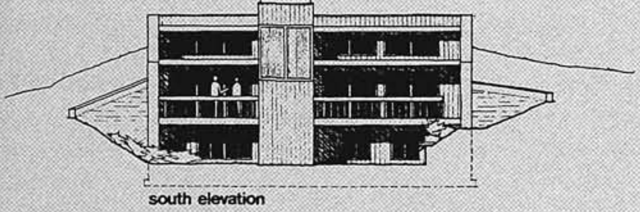
Cool air through upper level living areas during day, to greenhouse through door

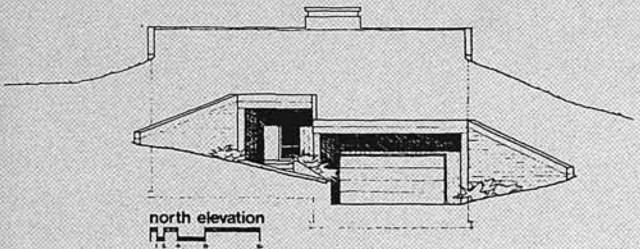
Rock-filled underground air passage cools and dehumidifies air

Hot
Passive plus fan



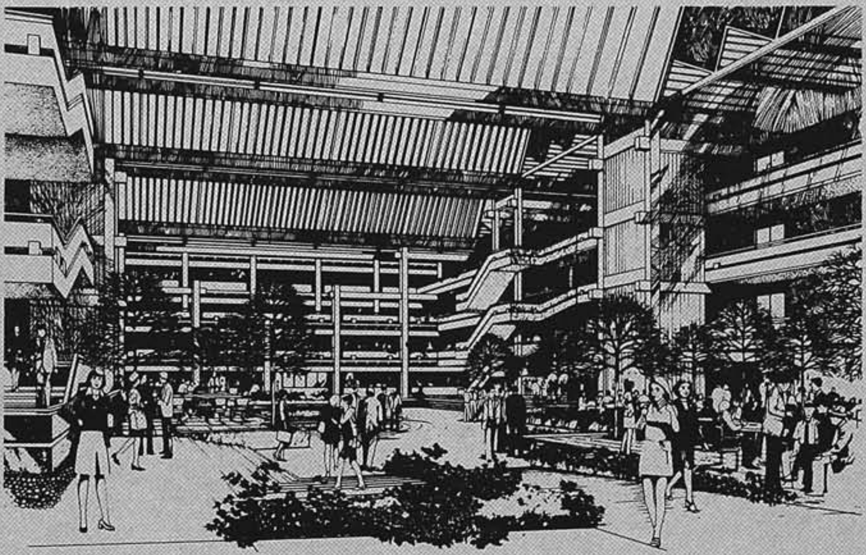






Earth-integration for a short summer

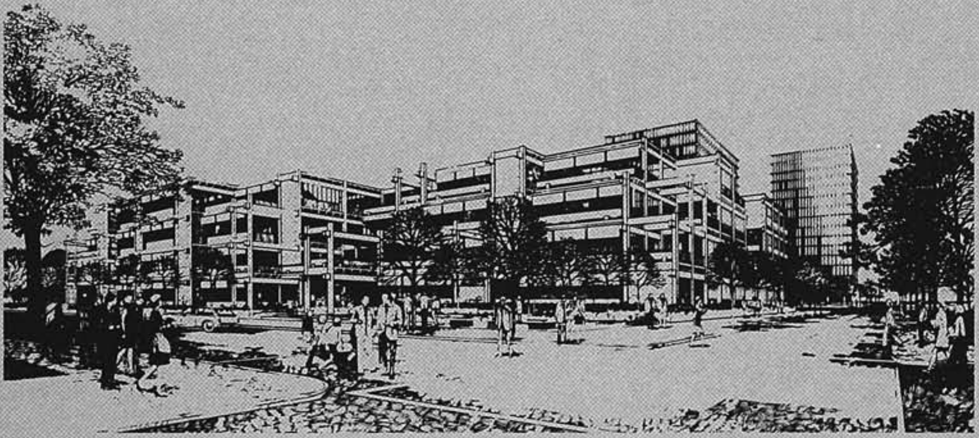
Yet another HUD award winner, this house by Tom Ellison and John Carmody was designed for Burnsville, Minn., 15 miles from Minneapolis. Its summer cooling load doesn't amount to much, but surrounding earth temperatures averaging around 45°F and four-foot overhangs on the south do the job completely, assisted by north-south through ventilation.

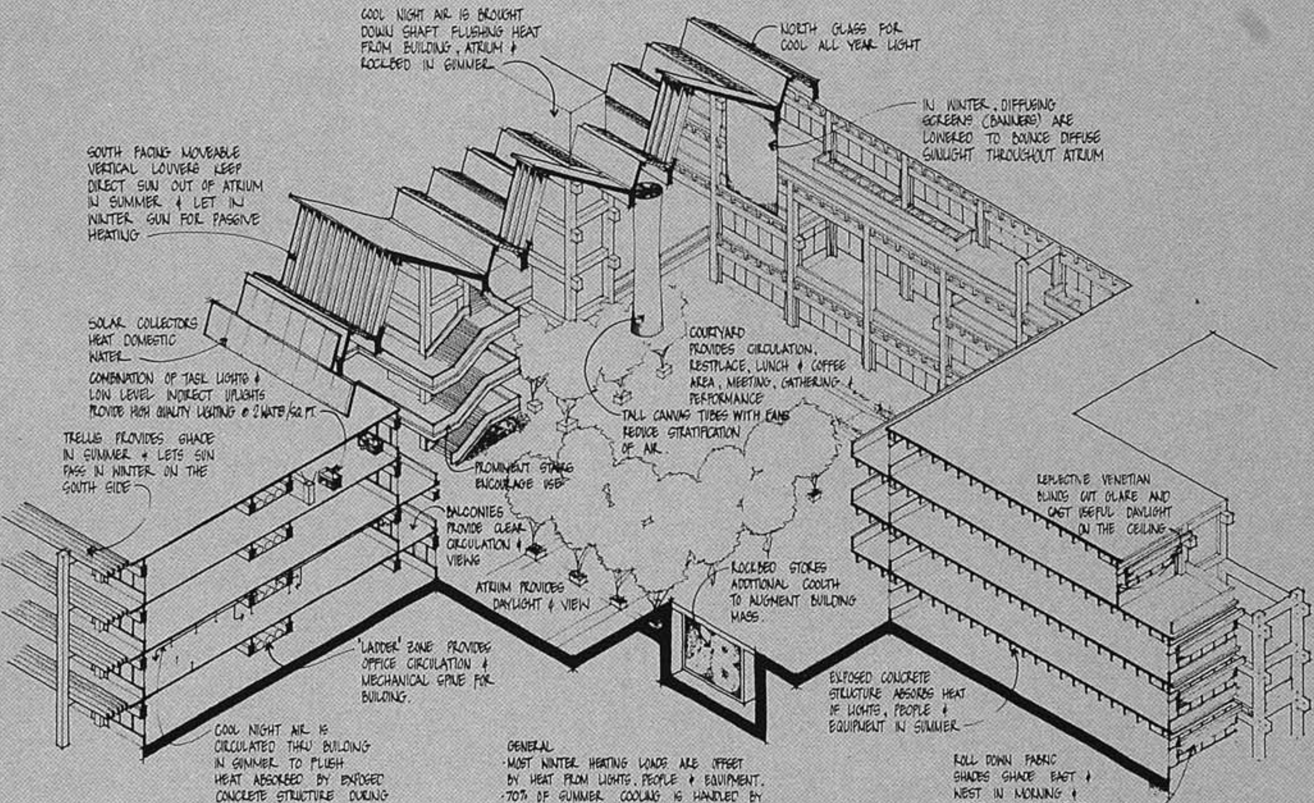


Site One: Cooling at non-residential scale

Site One, the new California state office building designed by the Office of the State Architect and a host of consultants, is the first in a growing crop of large-scale, non-residential projects that, while not totally passive, are impressively designed in that direction.

Before design began on the four-story, 207,000-sf Sacramento building, the architects undertook a now-model climatic study of the site that suggested several techniques for reducing and meeting a year-round cooling load. The thermal mass of the concrete structure should keep mean radiant surface temperatures low and absorb heat generated by people and equipment during the day; at night, when area temperatures drop significantly, the ventilation system will flush cool night air through the building. Sensor-activated window shades on the east and west, trellises on the south, and better insulation and double-glazing on exterior walls and windows should reduce heat gain.

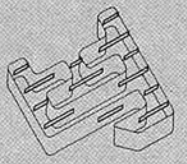


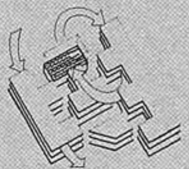


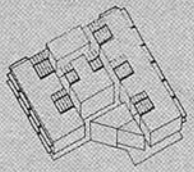
GENERAL
-MOST WINTER HEATING LOADS ARE OFFSET BY HEAT FROM LIGHTS, PEOPLE & EQUIPMENT.
-70% OF SUMMER COOLING IS HANDLED BY 'NIGHT VENTING.' THIS VENTING CIRCULATES SACRAMENTOS TYPICAL COOL NIGHT AIR THRU THE BUILDING LOWERING THE TEMPERATURE OF THE CONCRETE STRUCTURE & STORING THE 'COOLTH' FOR THE NEXT DAY. THE ROCKBED 'THERMAL BATTERY' MEETS 23% OF THE ANNUAL COOLING LOAD.

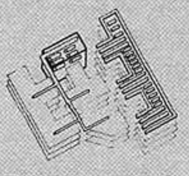
Checkerboard atria for an office building

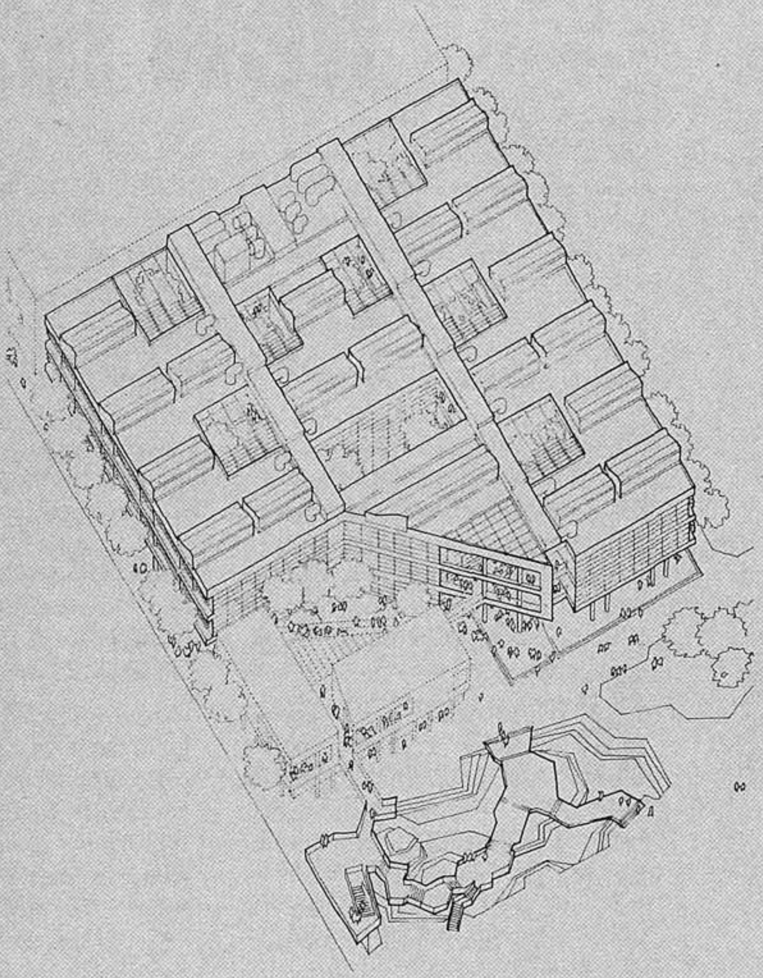
SOL-ARC, the energy consulting and design division of Berkeley's ELSF Architects, is responsible for this cooling-loaded state office building for San Jose, Calif. Relatively small at 125,000-sf, sited along a new pedestrian mall, and home to 22 different state agencies, some of them used daily by the public, the building called for a particularly user-conscious as well as energy-conscious solution. SOL-ARC kept the building at three stories to encourage stair use and created a checkerboard pattern of eight courtyards that give separate identity and entry to each state agency. The courts also admit enough daylight (together with north light monitors) to eliminate ambient lighting needs for a third of the building, reducing energy consumption and heat generation. Louvered sunshades and fabric awnings protect the courts and the building perimeter from direct solar gain while admitting diffuse light.


Daylighting


Rockbed and thermal mass

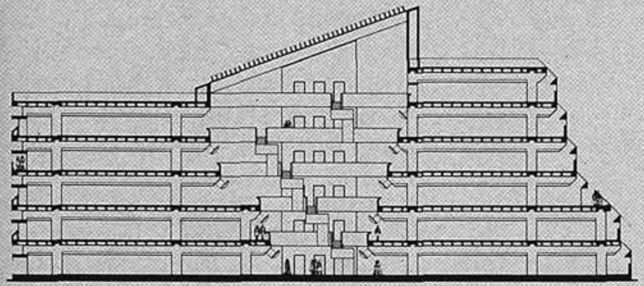

Sunshading

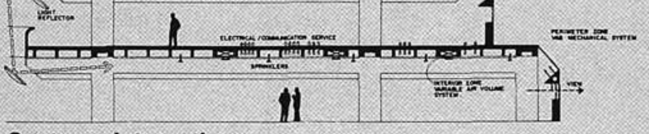

Energy control systems



TVA's natural strategies for humid Chattanooga

The Tennessee Valley Authority and its energy consultants expect to cut energy requirements by 70 per cent on its planned 1.3 million-sf Chattanooga office complex, where humidity and latent heat are tremendous burdens. A lithium-bromide chemical dehumidifier will handle latent heat actively. Ground water circulated from a 59°F underground aquifer will remove some excess building heat. Natural ventilation will aid sensible cooling. And a masterful daylighting scheme bounces natural light into a central atrium through computer-controlled reflective/insulating louvers and then into high-ceilinged interior spaces for ambient light.


East Elevation



Systems Integration

New Research

More subtle and complex than passive heating, and less likely to fully meet loads, passive cooling is posing an irresistable challenge to architectural researchers.

Notwithstanding the general successes of passive cooling design applications, there are research efforts underway on several fronts that stand to improve cooling technologies substantially.

At Trinity University in San Antonio, researchers are concentrating on what many designers call the last barrier to nationwide effectiveness for passive design—cooling in the hot, humid states of the southeast and south central U.S., where close to two-thirds of the nation's air-conditioning occurs every year. The real barrier to comfort in those regions is high humidity and the *latent* heat held in the moisture in the air. With ventilation's inability to fully meet cooling loads there, and with the current lack of sophisticated desiccant techniques, the barrier is nearly unassailable. So Trinity researchers have focused instead on reducing *sensible* heat—the air temperature read on a thermometer—to comfortable levels with radiative cooling techniques. The research includes monitoring heat loss radiated to the sky through infrared-transparent windscreens, measuring the atmospheric radiation received on horizontal and north-tilted surfaces, and measuring the heat dissipated by dry-surface and wet-surface (sprinkled for an additional evaporative cooling effect) roof ponds. It's the data from the latter tests that may prove to be most important, because it is being used to confirm computer simulations which indicate that radiant losses from a wet-surface roof pond can meet the entire *sensible* cooling load of a residence, even in the Southeast. Based on this research, the Trinity group will tell participants in the 4th National Passive Solar Conference in Kansas City this October that now, "in every part of the nation, natural processes can supply sufficient sensible cooling to produce comfortable temperatures in well-designed residential and commercial buildings."

That announcement has greater meaning for architects in regions with minimal *latent* heat difficulties, since sensible cooling there can often meet full summer cooling loads. In the South, especially along the Gulf coast, where latent heat can make up as much as 55 per cent of the cooling load, passive cooling remains problematic. The Trinity group is planning to continue its work with two new test residences on which they will make side-by-side performance comparisons of different passive systems, working to overcome the humidity barrier.

The Kansas City conferees will hear more about radiative cooling, and a possible breakthrough, from researchers at the Desert Research Institute in Boulder City, Nev. There the focus is on "the more exotic side" of radiative technology—selective radiative surfaces capable of radiating more heat to the night skydome (and to the daytime sky) than black-body (thermo-pond or other non-selectively surfaced) radiators.

The object of DRI's research has been to identify a high-emittance surface which emits radiation in the 8-14 micron wavelength—a frequency known as the "atmospheric window" through which the selective surface can "see" past the atmosphere (which under cloudy conditions can bring night radiative cooling almost to a halt) and radiate its heat directly to the vast heat sink of deep space. At Kansas City, researchers W. C. Miller and J. O. Bradley will announce that a radiator surfaced with anodized, electro-polished aluminum appears to improve on black-body radiative performance by 17-55 per cent, depending on the radiator's operating temperature. They will assert that a selective radiator of this type has been shown capable of meeting the full cooling requirements of a typical Las Vegas residence under severe cooling conditions. And they will report that the radiator performs in the daytime as well; radiator panels covering a roof and faced north, away from direct insolation, can reach equilibrium (when absorption and radiation are in balance) at temperatures 11°C lower than ambient, significantly lowering cooling load.

The aim of the DRI work is not to develop selective surfaces for radiative application only in desert conditions, however; radiation to a clear desert sky can be powerful enough to form ice on a wet surface when ambient temperatures are above 50°F. The real challenge to radiative performance lies where cloudy conditions frequently incapacitate current radiative technologies.

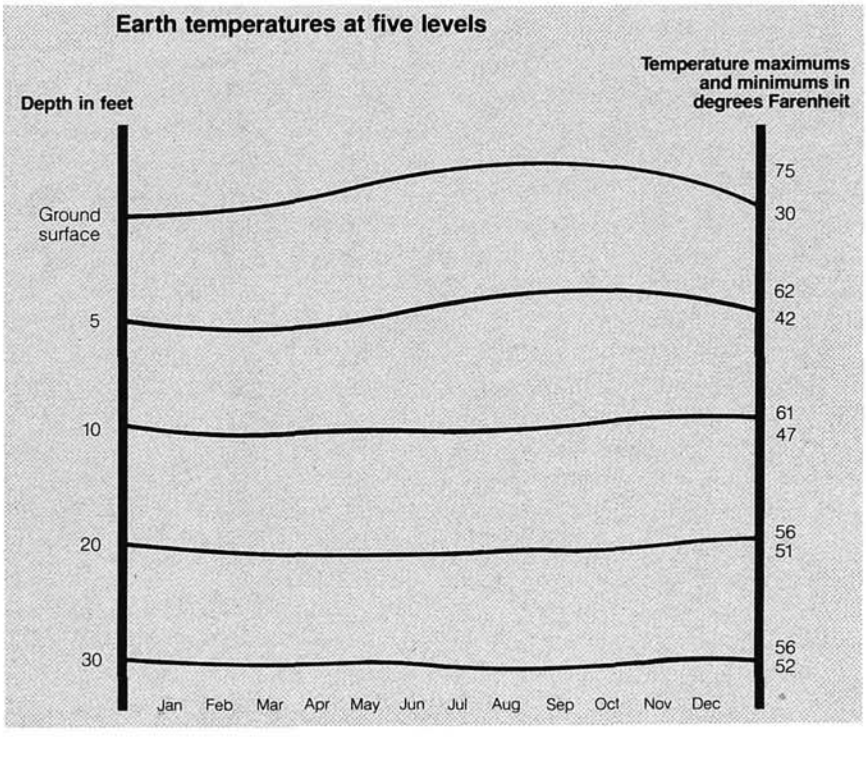
Earth cooling techniques are receiving nearly as much research attention as radiative. At the National Bureau of Standards in Gaithersburg, Md., researcher T. Kusuda has led the field in establishing such basic tenets as the fact that temperatures ten feet blow the ground surface usually hover around the annual air temperature, that seasonal temperature swings at that depth are both radically attenuated and occur months behind surface swings, and that the variables of ground cover, ground water circulation, and moisture content largely determine the heat source and heat sink characteristics of the earth. Urban surface coverings of black asphalt, for example, can raise earth temperatures at depth as much as 15°F above normal.

The applications of this new research are intriguing. In the farm country of the Midwest, a group of enterprising Christians in Nora Springs, Iowa have founded the Lord's Power Co. Inc. (LPC) and developed an earth-air exchange system they call Terra-Therm for passively heating and cooling livestock containment buildings. Through standpipes tall enough to rise out of snowdrifts, their system draws air down through long, buried earth tubes and back up to a barn interior for distribution. In summer the air is cooled to comfort levels (levels that are crucial to milk production, calf health, and other issues) as heat dissipates into the cooler earth. The air is dehumidified as well, since the earth tubes are installed on slight grade and moisture condensing out of the cooling air runs down to a sump for periodic removal. LPC's Terra-Therm marketer, Borchert Midland Inc., did $5 million in business this year and looks for $30 million next. "It's so dadblamed simple," says LPC's Rock Leier. "That's why it's so successful in the marketplace."

Researchers at the Princeton Energy Group in New Jersey are trying to quantify the potential of earth-air cooling by instrumenting two earth-pipe test units and measuring temperature differential at inlet and outlet. One of the test units is a 20-foot length of polypropylene pipe, one foot in diameter, buried four feet deep. Monitored this past August when earth temperatures at that depth were 60-65°F, the pipe achieved a peak cooling effect of 5,000 BTUs per hour—the equivalent of a small air-conditioner—and an average cooling effect of 2,500 BTUs per hour over five days. The second test unit, a field of eight intake-manfolded parallel pipes, each 40 feet long, six inches in diameter, buried four feet deep, produced a peak cooling effect of 15,000 BTUs per hour and an average or 8,700 BTUs per hour—enough to meet 70 per cent of the cooling needs of a 2,300-sf builder's house in New Jersey, by the researchers' estimation.

Effective as those results may seem, researchers want more data on earth-cooling technologies. The single-pipe test unit studied in Princeton raised adjacent soil temperatures 13°F during its week-long operation, something some researchers feel would detract from the unit's performance over longer periods. The substantial difference between peak cooling figures and average cooling figures, over a relatively short time, tends to back up that belief, so more research will be done in the area, involving longer tests and probably involving a system that alternates air flow through numerous pipes in long (up to 500 feet) fields to allow earth temperatures to cool. According to researcher Conrad Chester of Oak Ridge National Laboratory, the potential for organism growth in humid earth-air pipes and underground rock storage chambers is also an upcoming subject of research.

One ground-based and traditional cooling technique is not only controversy free but appears particularly promising for an upcoming application. Commissioned for the design of a new town center for Soldiers Grove, Wisc. (population 514), Rodney Wright of the Chicago-based Hawkweed Group Ltd. found a 30-year-old ground water cooling system in a nearby tavern called the Brass Horn. A brass and bronze "sand point" pierces the high water table beneath the tavern, filtering cool water from sand and sending it up for circulation through cooling coils in the barroom. Air blown over the coils apparently kept the bar so cool that, together with overhangs, earth berms, natural ventilation, tree shade, and night air flushing, Wright will use the high water table under the Soldiers Grove site to meet the small town's relatively low cooling load the same way the Brass Horn


Earth temperatures at five levels

T. Kusuda's research at the National Bureau of Standards charted both the attenuation and seasonal lag of earth temperatures at varying depths. Average air temperature is usually the mean.

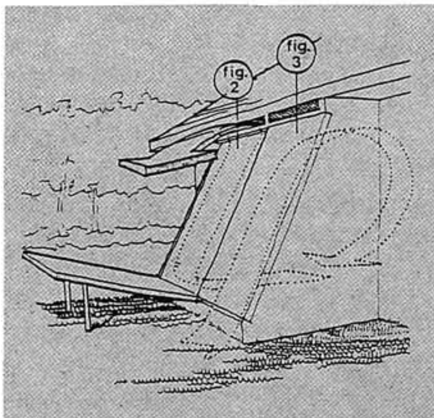


Fig. 1 Air path through system

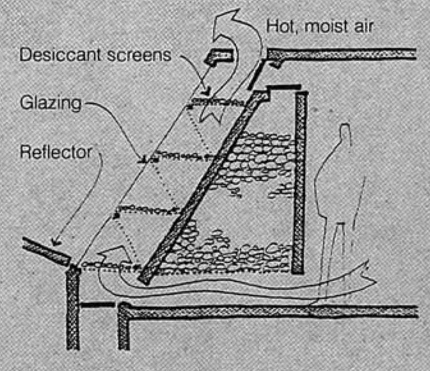


Fig. 2 Desiccant regeneration

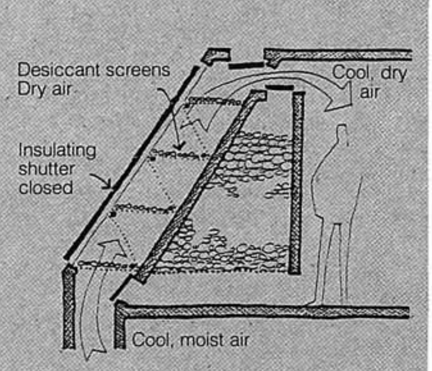


Fig. 3 Desiccation mode

Moore's thermally-driven dessication scheme drys humid air for interior circulation and regenerates already saturated desiccants simultaneously, in separate chambers.

keeps its patrons cool.

Wisconsin's cooling problems don't begin to approach the difficulty of those in the humid South, where desiccation appears to be the only passive process capable of reducing humidity and the burdens of latent heat. A number of researchers are studying desiccant techniques, including Israel's Baruch Givoni, recently at UCLA. Fuller Moore, architect and educator at Miami University in Oxford, Ohio, has developed a "dual desiccant-bed humidifier with solar-heated regeneration" that could have a major impact on desiccant cooling.

Designed for small-scale residential application, the system places trays of an activated charcoal desiccant in a glazed, rock-bin solar collector with two separate chambers, each with a hinged, insulating cover. In one chamber, cover open, solar radiation combines with air drawn through the collector by thermal effect to dry out and regenerate desiccant trays saturated with moisture drawn from the air. In the other chamber, insulating cover closed, air from a shaded outside location or from underground is drawn over the moisture-absorbing trays and into the living spaces, dry and cool.

Shading, like salt-barrel desiccation, is a traditional cooling solution in the South, though not generally considered sufficient to meet full cooling loads. Today vegetation for shading has become one of the most interesting subjects of research. Geoffrey Stanford, director of the Greenhills Center in Cedar Hill, Texas, envisions whole buildings, in fact whole cities, shaded with growth reminiscent of the Hanging Gardens of Babylon.

Shade trees can take 30 years to mature, Stanford says. Certain vines, pruned and trained upward, take only three. He has experimented with vine growth and come up with a recommended shading strategy for a single-story residence. Plant Baco black no. 1 grapevines 12 feet apart, he suggests. Plant them ten feet out from the south wall, and water them five feet further out to bring roots away from the foundation. Build a rooftop trellis 12-14 inches off the roof surface, and train the vines to cover the trellis (first year growth is 15 feet). The air space between roof and trellis will allow ventilation, encourage plant transpiration, provide an insulating air buffer above the house. With both wall and roof shaded, Stanford projects temperatures 20°F lower than ambient inside the house.

Growth rate for some vines, according to Stanford, means vines can be cut back annually to allow winter building insolation. New growth will supply shade by summer.

Vine	Perennial	Annual	Dense shade	Dappled shade	Max. ht. in feet
Frost sensitive					
Milkvine	●			●	25-50
Hyacinth bean		●	●		No data
Chayote	●		●		30-80
Moonflower		●	●		25-50
Morning glory		●		●	20-40
Okra vine		●	●		20-40
Potato vine	●		●		30-60
Coral vine	●			●	50-100
Frost hardy					
Carolina jessamine	●			●	50-80
Cross vine	●			●	50-80
Red honeysuckle	●			●	30-60
Mustang grape	●		●		60-150
Baco black No. 1	●		●		60-150
Wisteria	●			●	60-150
Milletia	●		●		No data
Undesirable					
Trumpet vine, English ivy, Kudzu, Virginia creeper, Poison ivy					

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Recommended Reading

The best sources for information on passive cooling are most often the best sources on passive design in general, and they can all be said to belong in every practitioner's library. A few titles:

Baruch Givoni's **Man, Climate, and Architecture** is generally regarded as the best text on climate-responsive design and considered worth its $50 price. Givoni documents the interaction of climate, physiology, the thermal properties of building materials, and the effects of design strategies from an analytical, practice-oriented approach. The 483-page book is available from International Ideas Inc., 1627 Spruce St., Philadelphia, Pa. 19103.

For the climate data essential to passive design, Victor Olgyay's 190-page **Design with Climate** is the seminal work. Olgyay's development of the bioclimatic chart defines the impacts of dry and wet bulb temperatures, relative humidity, solar gain, ventilation, and mean radiant surface temperatures on human comfort. It's available for $28.50 from the Princeton University Press, 41 William St., Princeton, N.J. 08540.

O. H. Koenigsberger's **Manual of Tropical Housing and Building, Part One: Climatic Design** is an important and deceivingly titled volume. A step-by-step practice manual, its discussions of fundamental design principles extend beyond tropical climates. It's available for $11.50 from Longman Inc., 19 W. 44th St., Suite 1012, New York, N.Y. 10036.

For a basic approach to passive design, **Natural Solar Architecture: A Passive Primer** by architects David Wright and Dennis Andrejko is difficult to beat. Graphic, non-formulaic, and easy to understand, the 245-page hand-illustrated book is available from AIA Publications (order no. 3M322) for $7.95, $7.15 to AIA members.

Architect Edward Mazria's **Passive Solar Energy** is a considerably more comprehensive introduction to the field, deemed by some to be the best available. It's in such demand that AIA Publications is currently out of stock and the book is being reprinted. By mid-autumn copies should be available again for $24.95, $22.45 to AIA members (order no. 3M399).

To stay in touch with the leading edge of research and design in passive cooling, stay in touch with the American Section of the International Solar Energy Society (AS/ISES). DOE researcher Donald Elmer heads the group's Passive Cooling Standing Committee and puts together an invaluable, quasi-quarterly newsletter that does an excellent job of keeping up with and slightly ahead of the field. Bibliographies on cooling information are also periodically produced. Contact AS/ISES at McDowell Hall, University of Delaware, Newark, Del. 19711. AS/ISES also publishes hefty proceedings of each of its national passive solar conferences; volumes 2 and 3 contain several reports on state-of-the-art cooling research efforts and applications.

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