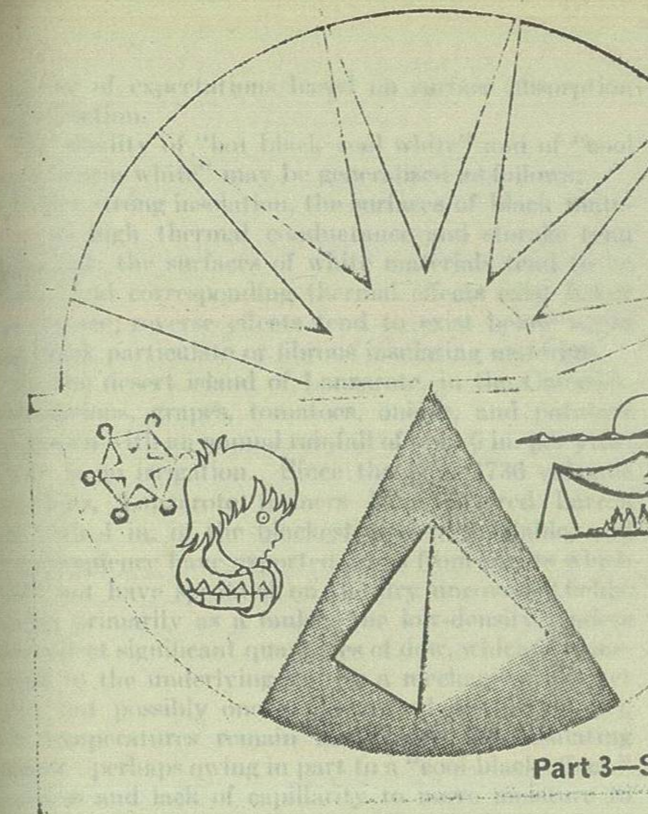

THE SOLAR ERA

Part 3—Solar Radiation: Some Implications and Adaptations

We are racing through fossil fuels, approaching limits of hydroelectric availability, and creating miniature suns. It is time to ask: Are obsessions concerning transmissible energy, plug-in convenience, "economics of scale," and conventionality retarding direct and effective use of solar energy? Here are some related thoughts and observations.

HAROLD R. HAY

"If man's ingenuity through the years had been directed to the utilization of solar energy instead of to the development of devices to consume fossil fuels, it is quite conceivable that we might today have a solar economy just as effective and efficient as our fossil-fuel economy. Ultimately, man will probably be driven to turn to the sun" [1].[1]

During the seven years since these challenging thoughts appeared in a survey of the energy resources of the future, environmental deterioration has increased the impetus toward solar orientation, but as yet there has been no major advance in that direction.

In marked contrast to man, nature has been an efficient gatherer and user of low-level solar energy for eons of time. Hydroelectric power, fossil fuels, habitability of polar countries, and much of life in all its forms are consequences of radiation collection by evaporating and circulating oceans. In fact, animal life as we know it owes its existence and development to adaptation to low-level solar effects. When animal life left the relatively constant temperature of the sea—and its UV-filtering effect—adaptation was required for the wide diurnal temperature range, drying winds, and broader radiation spectrum. Convenient rocks formed protective roofs and walls which served as radiation shields and offered, through heat capacity, lower daytime and higher nighttime temperatures. This adaptation, when rediscovered by man, resulted in a high degree of thermal control in houses made of earth, stone, or bricks. Man's ultimate achievement with capacity insulation was in the pyramids, the centers of which have nearly constant temperature throughout the year.

To reduce construction costs of capacity insulation, a water-shell structure is under investigation; it has possibilities for thermal comfort comparable to that protecting life in the sea and in amniotic fluids.

Sea-emerging animal life found white rocks cooler both day and night than black ones; thus life became responsive to effects of radiation absorption, reflection, and emission. This responsiveness was neurally reinforced upon man's walking on, or picking up, stones; eventually, he developed black-surface absorbers and white-surface reflectors of near-perfect efficiency. These were generally applied over conventional materials of high thermal conductivity; the impression grew that subsurface thermal effects corresponded to surface color.

Coevally, our emerging sea life may have taken refuge under black, spumaceous volcanic rocks and found them cooler day and night than nearby white pumice. Data are insufficient, but observations indicate that thermal effects under insulating materials may be the

[1] Numbers in brackets designate References at end of article.
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opposite of expectations based on surface absorption and reflection.

The duality of "hot black–cool white" and of "cool black–warm white" may be generalized as follows:

Under strong insolation, the surfaces of black materials of high thermal conductance and storage tend to be hot, the surfaces of white materials tend to be cooler, and corresponding thermal effects exist below the surface; reverse effects tend to exist below white and black particulate or fibrous insulating materials.

On the desert island of Lanzarote, in the Canaries, watermelons, grapes, tomatoes, onions, and potatoes are grown with an annual rainfall of only 6 in. per year. There is no irrigation. Since the 1730–1736 volcanic eruptions, Lanzarote farmers have covered barren soil with 4 in. of the blackest cinders available, and in consequence have exported crops from plants which could not have sprouted on the dry uncovered fields. Acting primarily as a mulch, the low-density cinders also collect significant quantities of dew, which is transferred to the underlying soil by a mechanism not yet clear, but possibly one of downward distillation [2]. Soil temperatures remain low under the insulating cinders—perhaps owing in part to a "cool-black effect." Coolness and lack of capillarity to move moisture to the surface seem to explain the exceptionally low evaporation from soil below the cinders.

Cool Black

Discussion of the cool-black effect caused Greek agricultural experts to consider it the first substantial justification for the 2000-year-old practice in Thessaly of burning wheat fields soon after early summer harvest. Throughout the world agricultural specialists have deplored this practice of burning straw, yet the objections cited (destruction of soil bacteria, loss of stem and leaf nitrogen, and wastage of a soil conditioner) were found invalid upon further study. Retaining validity within some regions is the need for the straw in erosion-control, and its possible industrial or low-grade fodder use.

The Greek agriculturalists had been puzzled by earlier emergence, faster growth, and greener color of plants in rows where straw had been piled more thickly prior to burning. Fertilizing effects were discounted because the soil was not deficient in ash minerals. Soil moisture retained by a cool-black effect of insulating ash could account for the growth differences. Another solar radiation phenomenon, however, was also involved. The impact force of early fall rains crushes the insulating ash to a thermally conductive pigment. Acting as a radiation absorber, this black pigment causes underlying soil to be warmer during cool weather. In nature, therefore, benefits may accrue from both hot-black and cool-black effects.

Supporting data for the cool-black effect stem from Australian studies showing that dark cattle exposed to strong insolation have lower rectal temperatures than lighter colored animals [3]. The explanation appears to be the fourth-power radiation law: Although the black hair tips of sheep had surface temperatures of 190 F, reradiation and induced convection dissipated the surface heat and served as an "automatic compensating mechanism" [4].

With native wisdom derived from a thousand years in the hottest desert in the world, the Tuareg tribe in the Sahara wears a thick blue or black outer garment over white cotton undergarments. Nomads of the Arabian desert live under a cool brown or black tent which excludes infiltration of heat-generating solar radiation. The dark color of the goat- or camel-hair tent results from animal adaptation for survival under intense solar radiation.

Warm White

To account for the white Australian cattle having higher body temperatures, a warm-white effect is postulated on the premise that though 60 percent or more of incoming radiation might be reflected and another portion absorbed and reradiated at the hair tips, the remainder is reflected from hair to hair in a downward course. Radiation converted to heat while within the insulating hair or upon reaching the skin would act to raise body temperature. It is common practice in hot dry countries to slaughter, in early summer, those young goats having much white coloration. White animals are more prone to sun scald during summer months than are dark-colored ones.

In the Arctic, the heat-collecting effect of white uniforms resembling fur was inconclusively reported by the military. A white synthetic pile on a black backing was covered by a white translucent film to prevent wind spillage of heat from between the white fibers. Radiation heat gain was not reported, nor was it clear if reflection and absorption of body-heat radiation accounted for the improved efficiency over the standard uniform. In this uniform, temperatures dropped from 90.5 to 86.5 F in 50 min versus 120 min for the white uniform [5]. Experiments with birds showed a reduced metabolism resulting from irradiation of white plumage; in these tests, black plumage had a greater effect [6].

In Scandinavian countries, low ambient temperatures are countered with clothing which leaves the hands and head as receptors for UV radiation vital to activate precursors for vitamin D needed for bone growth. Light reflection inward to the skin through the hair of "towhead" children, possibly supplemented by a fiber optic effect, may assure required UV absorption for bone development. Once this has been attained, it is not unusual for northern Europeans to develop moderate hair pigmentation, which may again be lost at an advanced age when bone weakness tends to occur. Applied to the dominant white coloration of Arctic animals, this theory would somewhat reduce the importance of white as representing adaptation for protective coloration.

One can also speculate about pigmentation as a genetic adaptation to solar radiation in the tropics. There, the hair of people subjected to strong insolation is normally black. In part, this may be to keep the head cool; over less hirsute portions of the body, it may act to partially absorb and dissipate radiation. As a heat collector, black skin is contraindicated, but it serves as a UV screen to prevent skin cancer. To offset the high thermal load induced by protective pigmentation, black skin may have more evaporative cooling provided by a greater number or activity of sweat glands per unit of area than has northerly adapted, sparsely pigmented skin.

If further studies establish the validity of the cool-black–warm-white hypothesis, the implications are many. It has been reported that metal surfaces under some white paints exposed to strong solar irradiation have temperatures higher than anticipated; paint porosity may be a factor. White high-density aggregate for asphalt roofs may be less desirable than black (acid-free) coke or similar materials. Loose black pile or boucle weaves may be cooler than denser weaves of lighter colored fabrics for hot dry regions.

A Lanzarote practice simultaneously uses reflectors and absorbers for human comfort. Stone houses are painted white to effect reflective insulation. Black low-density stone around the window opening as well as a thin layer of black cinders in lieu of a lawn are used to eliminate heat gain and glare from reflected radiation. In contrast, lack of adaptability by newcomers to desert regions causes unnecessary discomfort and expense.

Negative Energy

Sleeping patterns reduce man's consciousness of the equality of nocturnal radiation with solar radiation in the terrestrial diurnal energy balance. Natural "negative energy" has great potential for reducing our paradoxical use of air conditioners to convert energy into heat to produce cooling. Nature is less obtuse.

For natural air conditioning of man-made structures, economic heat storage is a prerequisite, with water the logical medium. Ceiling ponds are capable of maintaining comfortable temperatures throughout a normal year, in Phoenix, Ariz., without supplementary heating or cooling devices [7]. These ponds collect and store winter solar heat during the day and release it into rooms at night. In summer they collect and store infiltrated and internally generated heat during the day, then radiate it to the night sky. Movable insulation panels over the ponds operate as a thermal valve directing heat flow to produce desired thermal effects.

Because natural air conditioning works with the climate—not against it—the system flexibly utilizes and controls radiation absorption, reradiation, evaporation, and air movement. Winter heating results from exposing the ceiling ponds (enclosed in transparent plastic bags) to solar radiation. The room remains above the maximum ambient temperature. During nearly all of April and October, heat capacity alone holds room temperatures in the comfort zone—essentially within the comfort range obtainable with thermostatic control of conventional heating and cooling devices alternately used night and day in houses lacking heat-capacity insulation.

For summer cooling, nocturnal radiation is adequate with temperatures as high as 100 F; the ponds cool to the night sky although heat is received from both the underlying room and the overlying air. Radiation cooling plus evaporation of water flooded over the plastic-enclosed ceiling ponds maintain room comfort until outdoor temperatures exceed 105 F. Electricity is not needed until daytime temperatures surpass 105 F. Then a fan coil is adequate until temperatures rise over 110 F, whereupon additional use of a roof-pond blower will assure comfort during periods of relatively low dew point. High dew points with temperatures of 100 F require use of both the fan coil and the pond blower [7, 8].

The fan-coil unit transfers room heat to water circulating in three ponds which form the ceiling roof of the Phoenix room. The air blower is needed especially during hot humid periods when radiation heat loss is minimal and evaporation is retarded. The six adaptations to natural forces are used to develop a flexible natural air conditioning system requiring only minimal supplementary energy and devices in hot dry regions—none where comfort standards are not so narrow as those in the U.S.

Previous efforts to use natural forces with commonplace building construction failed to provide economic heating and cooling. Natural air conditioning calls for unconventional building design. Ceiling-pond economics are made favorable by deducting normal ceiling and roof costs from those of the ponds and movable insulation. The basic architectural style is indigenous to arid regions throughout the world—the result of thousands of years of man's adaptation to a highly adverse climate.

New plastics have greatly increased the feasibility of economic use of solar radiation. Most of the earlier forms of insulation would have to be hermetically sealed to prevent moisture uptake and loss of insulating value if used over ponds or exposed to rain. Established sandwich-panel technology using cellular plastics permits new and highly desirable types of construction—including exterior thermal insulation and internal heat-storage materials.

The aforementioned transparent-plastic pond bags and the underlying black liner for radiation absorption and for roof waterproofing may be of the films listed in order of increasing cost and resistance to deterioration by solar irradiation: polyethylene, polyvinylchloride, and polyvinylfluoride (PVF). A continuity of improved formulations and new resins assures better film life and economics for many applications of solar radiation.

Solar Stills and Water Heaters

The most satisfactory experience with solar stills to date has been with glass-covered types developed 100 years ago. Despite considerable research in recent years, there has been no improvement in yield and only a minor reduction in construction costs. Nonetheless, solar stills remain the cheapest means for desalting quantities of less than 50,000 gal of saline water per day in areas of reasonable sunshine. Production cost of about $3.50 per 1000 gal produced in a community still results, in substantial part, from a high capital investment. Such a system, which frequently occupies land better used for other purposes, necessitates dual piping for distilled water and for a second supply to meet nonpotable needs. It results in serious wastage of a costly product. Faced with such disadvantages, use of solar stills has been severely circumscribed.

Recently it was proposed that the initial cost of solar