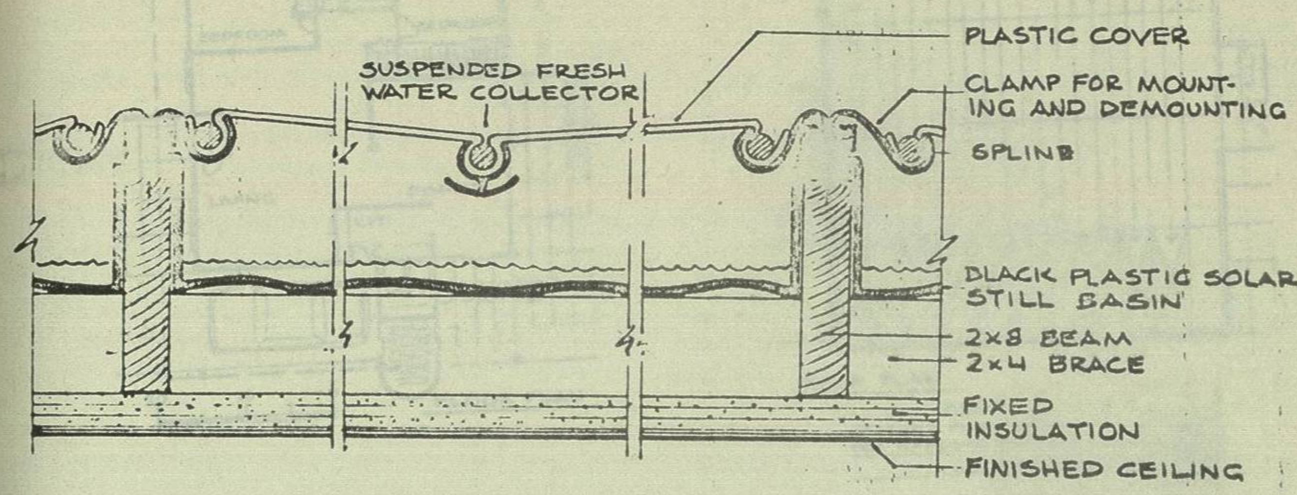


Fig. 1 Plastic rooftop solar still for desalination of water.

desalination might be fully offset by using a still for the ceiling and roof of a building [9]. Modular stills, producing 25 to 30 gal/sq ft/year of distilled water, would be placed between ceiling beams; this would simplify the leveling to obtain shallow brine depths conducive to high yield. Insulation under the still, also essential for high yield, would form the ceiling. Several still designs are available with costs approximating those of conventional roofs. Plastic pipes and fittings would be used not only for the stills but also for bringing saline water to the building and for conducting concentrated brine away in a sewerage system.

Plastic is the preferred cover material for roof stills. The inherent safety hazards of glass almost preclude its extensive use on roofs in densely populated areas. Even with costly framing, which would make it uneconomic for desalination, some breakage of glass must be expected during construction, use, and maintenance. Glass shards might pierce the solar-still liners and cause flooding of an underlying room. Building codes and insurance rates could prove restrictive for glass-covered roof stills.

Fig. 1 illustrates a new solar-still design that is adaptable as a roof and is expected to correct many shortcomings of previous stills. The rigid basin, of molded black ABS resin, would be supported by 2- by 4-in. braces between ceiling beams. The transparent cover film is shown fastened in S-clamps engaging protrusions and seals on the sides of the stills. Seals of adjacent stills would be parts of an extrusion covering the beam and waterproofing the roof. The weight of the center-suspended condensate collector contributes to the vapor seal and shapes the V-cover so that distillate drains to the collector. Stretching the cover tighter at one end produces slope for drainage of condensate and of rain. Each is removed in tubing slipped over portions of the collector and each is conducted to separate storage.

Advantages of this design, other than eliminating glass-cover hazards, include:

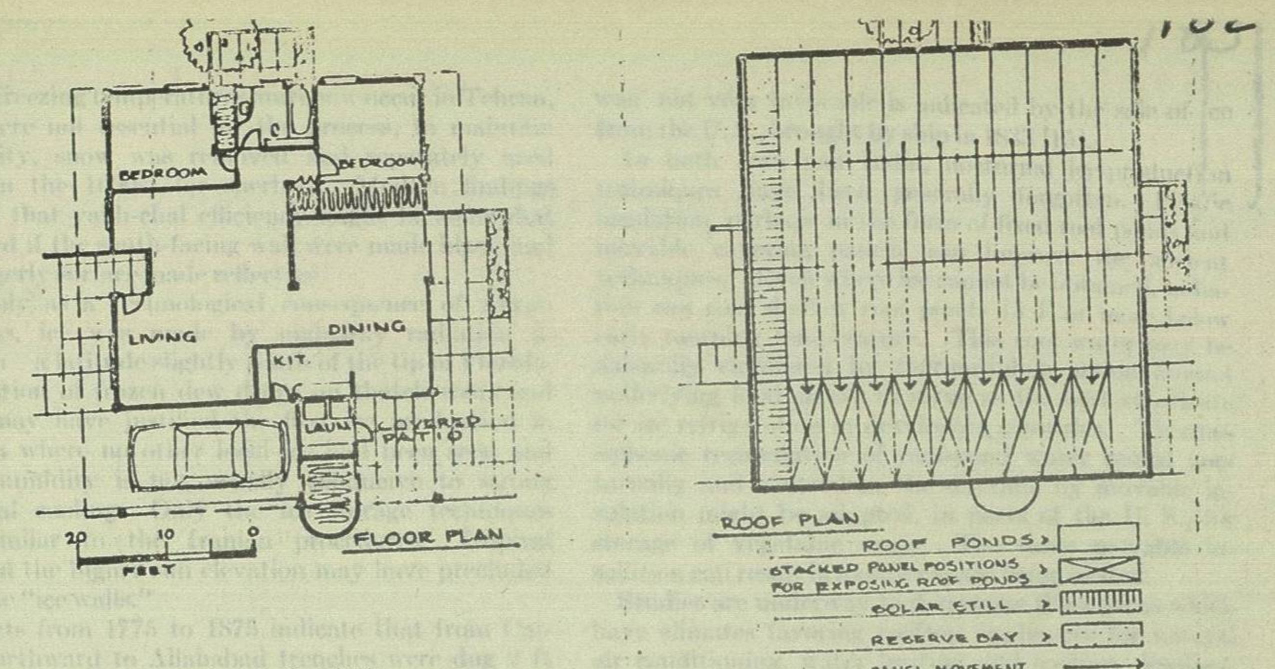
- Prefabrication
- Quick assembly
- Ease of access to the basin for annual cleaning of salts, if required
- Cover replaceability, if cleaning or patching is needed
- Minimal vapor leakage at seals
- Division of the cover into two panels, thereby reducing wind flutter and film embrittlement.

Accidental cover damage would, at most, allow rain to drain into the condensate collector. Annual inspection and servicing charges might offset the lower capital cost and interest resulting from crediting usual ceiling and roof costs. Product-water costs are not expected to differ greatly from those of desalination at a community distillation plant.

Previous economic analyses of solar stills having covers of 10-ft-wide 4-mil PVF used film prices ranging from 27.6 to 44.3 ¢/sq ft. These included high charges for special width and thickness, for sandblasting one side to produce wettability, and for shipment to distant islands. With 54-in-wide 1.5-mil untreated film costing only 3 to 3.5 ¢/sq ft, 2-mil thickness is about 4 ¢, and 4-mil PVF should sell for 8 ¢/sq ft if a substantial market for this thickness develops. A new liquid wettability treatment[2]—successfully used on plastic greenhouse covers—is claimed to last the life of the plastic and to cost less than 0.5 ¢/sq ft applied. On a wholesale basis, the price of 4.5 or 8.5 ¢/sq ft offsets the longer average life obtainable with single-strength B-quality glass costing 16 to 20 ¢/sq ft and having higher packing, transport, and breakage charges.

Sandblasted 4-mil PVF has given four to five years of service in large solar stills of a design which tended

[2] Sun Clear, a product of Solar Sunstill, Inc., Setauket, N. Y.



Courtesy of Environmental Planning Consultants, San Luis Obispo, California

Fig. 2 Floor plan of naturally air conditioned house and roof plan indicating movement of insulation panels to expose roof ponds. Also shown: rooftop solar still and reserve bay usable as solar water heater.

to shorten film life by creating severe local stresses. Design factors sometimes caused failures after only one or two years. Because PVF still covers tend to yellow after four to five years of exposure, there is little need for a longer mechanical life unless UV inhibitors can reduce photodegradation. Elimination of abrasive wettability treatments and reduction of unsupported cover widths (to minimize flutter, crystallization, and wind damage) should assure a five-year life for either 4- or 2-mil film. A three-year service for a 2-mil V-cover, weakened by sandpapering and inadequately fastened, has already been demonstrated. PVF covers have produced the highest yields ever reported for large solar stills [10].

Fig. 2 illustrates the manner in which solar stills, solar water heaters, and natural air conditioning ceiling ponds can serve as a roof. Movable insulation panels retard nocturnal heat loss from these energy collectors. The same technology, and interchangeable parts, can produce cold water and ice.

Yakh-chals

We are reminded in a well-qualified engineering textbook that, neglecting evaporation, radiation to outer space could freeze water in shallow insulated trays when the ambient air temperature is 630 R or 170 F; back-radiation and moisture condensation from surrounding air greatly lower this temperature. Desert conditions are the most favorable for strong natural cooling [11].

Prevailing attention to the economic consequences of animal comfort is resulting in studies of natural thermal phenomena. The development of sun-shading devices for animals resulted in the observation that whenever possible the animals preferred the north shade of tall reflective walls. This response was related to radiation cooling from the south side of their bodies to the wall and reflection to "cold spots in the sky" at a right angle to the sun [12]. Later studies not only found that white sloped-toward-the-north surfaces are indirect daytime heat sinks but also that black, fully shaded, northerly oriented walls achieve surface temperatures higher than those of the surrounding air [13].

Natural air conditioning of rooms by daytime radiation to the cold sky has not been studied to the extent which seems justified. Although the lowest temperature in a cloudless sky is constantly changing its daytime position, this change did not vary greatly during the hot period of the day from 60 deg above the horizon at the location of the studies. Structures with windows sloped to take advantage of this cold sink might minimize heat load in polar-oriented rooms. Care would probably be needed to prevent excessive nighttime cooling.

Archaeological evidence exists that thousands of years ago "ice walls" were built in the deserts of the Middle East. These were mud walls running east–west, with basins on the north side in which water was frozen by nocturnal radiation. Known as yakh-chals, Fig. 3 [14], these devices are still used in remote parts of Iran. Their ancient shapes varied from single walls to three-sided high walls with the east–west wall five times the length of the end walls built at right angles to it.

Until 15 years ago, yakh-chals of different shape provided ice for Tehran. These were earth walls nearly 6 ft thick at the base and tapered to 8 in. at 25 to 30 ft in height. Frequently, two to four parallel walls 450 to 700 ft in length had end walls of lower height. Distance between the main walls was related to solar incidence to keep the enclosed ground shaded during the winter ice-making months. Air stratification caused temperatures to vary from that of ambient air near the top of the walls to subfreezing temperatures at ground level.

Clear water was flooded over the level area to gradually build up ice cakes of excellent clarity. These cakes were moved to covered pits where they were frozen into larger blocks by pouring on ice water. Although freezing temperatures and snow occur in Tehran, these were not essential for the process; to maintain ice clarity, snow was removed and separately used (early in the 1600s) for sherbets. Modern findings indicate that yakh-chal efficiency might be somewhat improved if the south-facing wall were made black and its northerly surface made reflective.

Possibly as a technological consequence of Aryan invasions, ice was made by night-sky radiation in Calcutta a latitude slightly south of the tip of Florida. Observation of frozen dew drops on thatch roofs and leaves may have justified the first ice production in Calcutta where no other local ice had been seen and where humidity is not usually conducive to strong nocturnal cooling. Only the ice storage techniques were similar to the Iranian procedures. Tropical rains and the higher sun elevation may have precluded use of the "ice walls."

Reports from 1775 to 1875 indicate that from Calcutta northward to Allahabad trenches were dug 2 ft deep and allowed to dry. Then insulation—such as sugar cane, corn stalks, or straw (a "black-looking" kind was "reckoned better for the purpose than wheat straw")—was added to within 6 in. of ground level. From December to mid-February winds were carefully observed. When they came gently from the northwest (even though warmer than the more humid prevailing air), unglazed shallow plates were placed in the trenches. Water was added in the plates to a depth expected to freeze, frequently 0.5 in., sometimes 1.5 in. Evaporative cooling lowered water temperature to a point where radiation caused freezing. Ice crystals appearing in some plates were thrown across the other plates as nucleation.

Ice was made in this manner when air temperatures were 43 or 47 F. The ice was carried to pits, pounded to a mass, watered, and frozen into a solid block. With the surface insulated and further covered by a thatched building, the ice lasted into the summer months. Some factories produced 120 tons per season; others made as much as 10 tons per night. That the economics was not very favorable is indicated by the sale of ice from the U. S., brought by ship in 1833 [15].

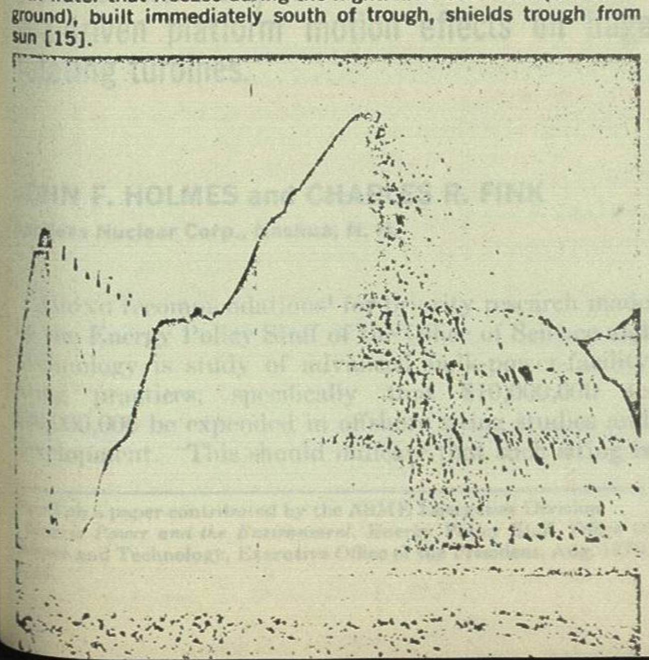


Fig. 3 Yakh-chal: Conical building (center) stores, below ground level, ice blocks cut from trough dug in ground and filled, in winter, with water that freezes during the night. Mud-brick wall (left background), built immediately south of trough, shields trough from sun [15].

In both Iran and India, nocturnal ice-production techniques have been generally forgotten. Plastic insulation, perhaps in the form of fixed roof ponds and movable covering panels, can improve the ancient techniques. Even where ice cannot be obtained, radiation can cool shallow roof ponds 15 F or more below early morning temperature. This cool water may be naturally circulated by thermosiphon action around underlying food chests to serve as the best substitute for ice refrigeration in developing countries. Thermosiphonic recirculation of roof-pond water cooled nocturnally and covered in the daytime by movable insulation might be adapted, in parts of the U. S., for storage of vegetable crops. The same movable insulation can result in another space being heated.

Studies are underway to determine those areas which have climates favoring rooftop appliances for natural air conditioning, water heating and cooling, desalination, and ice production. Present plastics make these processes feasible for use in some climatic regions today. Experience gained in these areas, aided by further improvements in plastics and by additional studies of diurnal energy forces, will extend the range of applicability.

Extensive use of radiation-collecting and -dissipating devices in the American southwest is closer to realization. The disposition of the people, the need for new housing and cities, and the search by major companies for new markets may finally accelerate use of natural energy forces.

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