Background

Evaporative Cooling

- Cooling of a body through the process of evaporation. When water turns from liquid to vapor, its latent heat rises as heat is absorbed from its surroundings.

"1 gram of water --->(evap) 0.6Btu/lb.F"

"1 lb of water --->(evap) 890 BTU @95(F)"

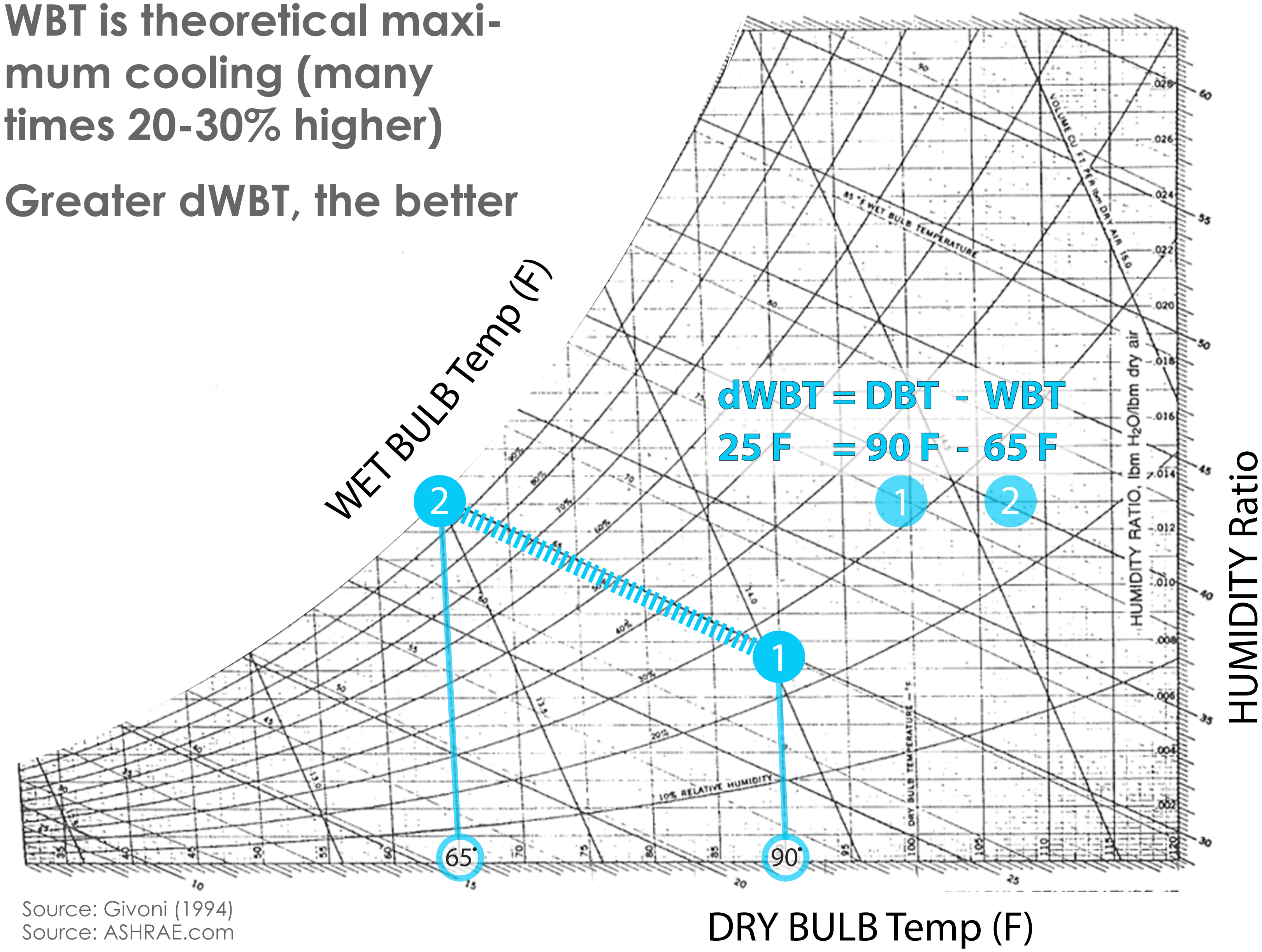
Adiabatic Process

- Total energy (sensible + latent) is kept constant

Cooling Process

- When water evaporates without external heat gain the Dry Bulb temp decreases, its Moisture Content increases, and the Wet Bulb stays the same

- **WBT is theoretical maximum cooling (many times 20-30% higher)**
- **Greater dWBT, the better**



Source: Givoni (1994)
Source: ASHRAE.com

Feasibility

Things to Consider

- Relatively cheap and not energy intensive
- Requires abundant water supply
- High Air Velocity
  - May cause Drafty conditions
  - Allow fresh air into space, increasing IAQ
- Increases indoor humidity levels
  - consider damage to building materials and personal items

Appropriate for Hot and Dry Climates

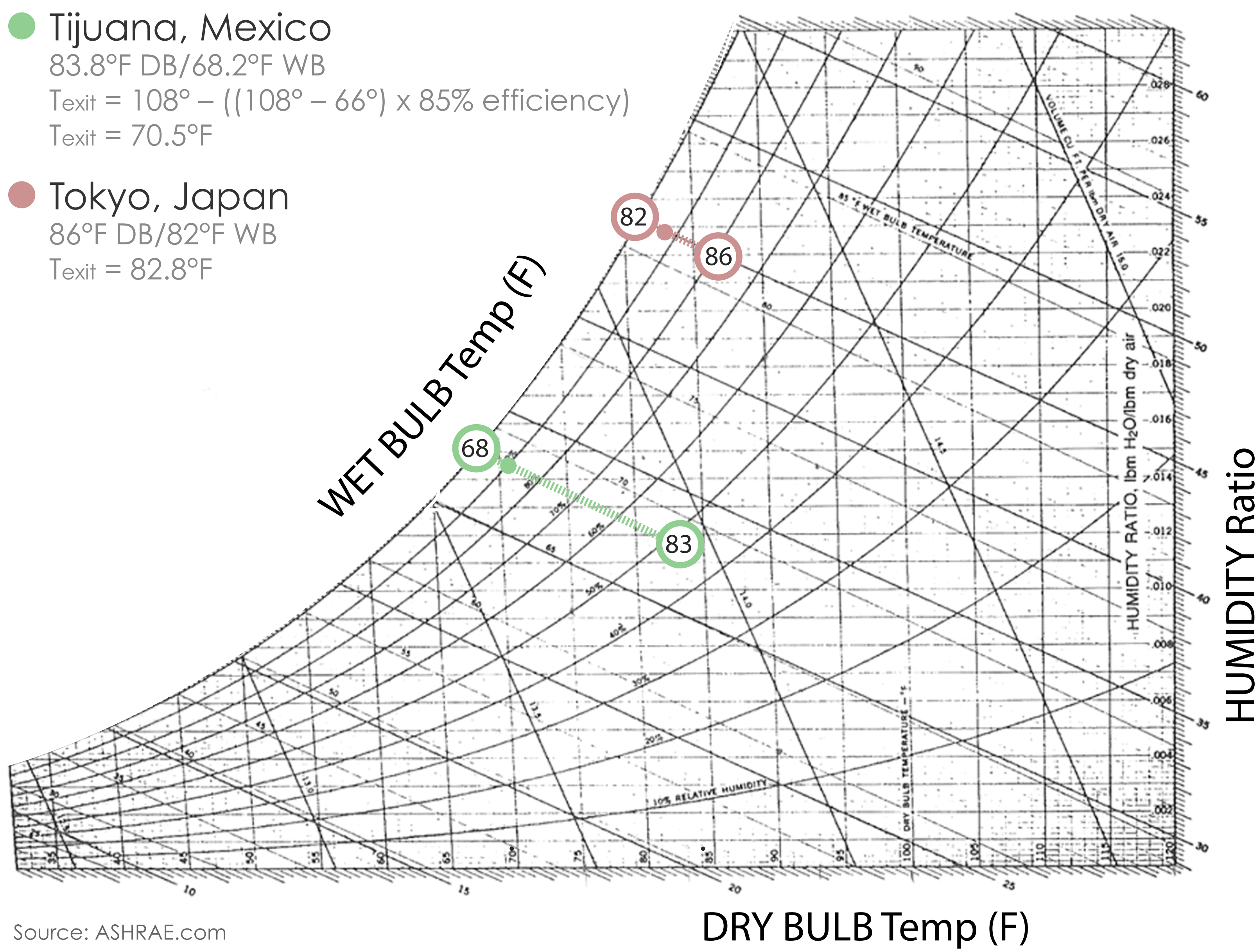
- Western/Mountain States & Northern Mexico
  - Popular in Denver, Salt Lake City, Tucson, and Fresno
- Not appropriate for Hot and Humid Climates
  - July/Aug Monsoon Rains in Northern Mexico

Rule of Thumb

- Typical dWBT (arid region) = 18-27 (F)
- Typical dWBT (desert region) = 27-36 (F)
- Assume 85-90% efficiency
- Cooled Air is (6-8) (F) higher than ambient WBT
- WBT < 72(F)

Texit = DBT – ((DBT – WBT) x E)

- Tijuana, Mexico
  83.8°F DB/68.2°F WB
  Texit = 108° – ((108° – 66°) x 85% efficiency)
  Texit = 70.5°F
- Tokyo, Japan
  86°F DB/82°F WB
  Texit = 82.8°F



Source: ASHRAE.com

Swamp Cooler

Mechanical Evaporative Cooling Systems

Things to Consider

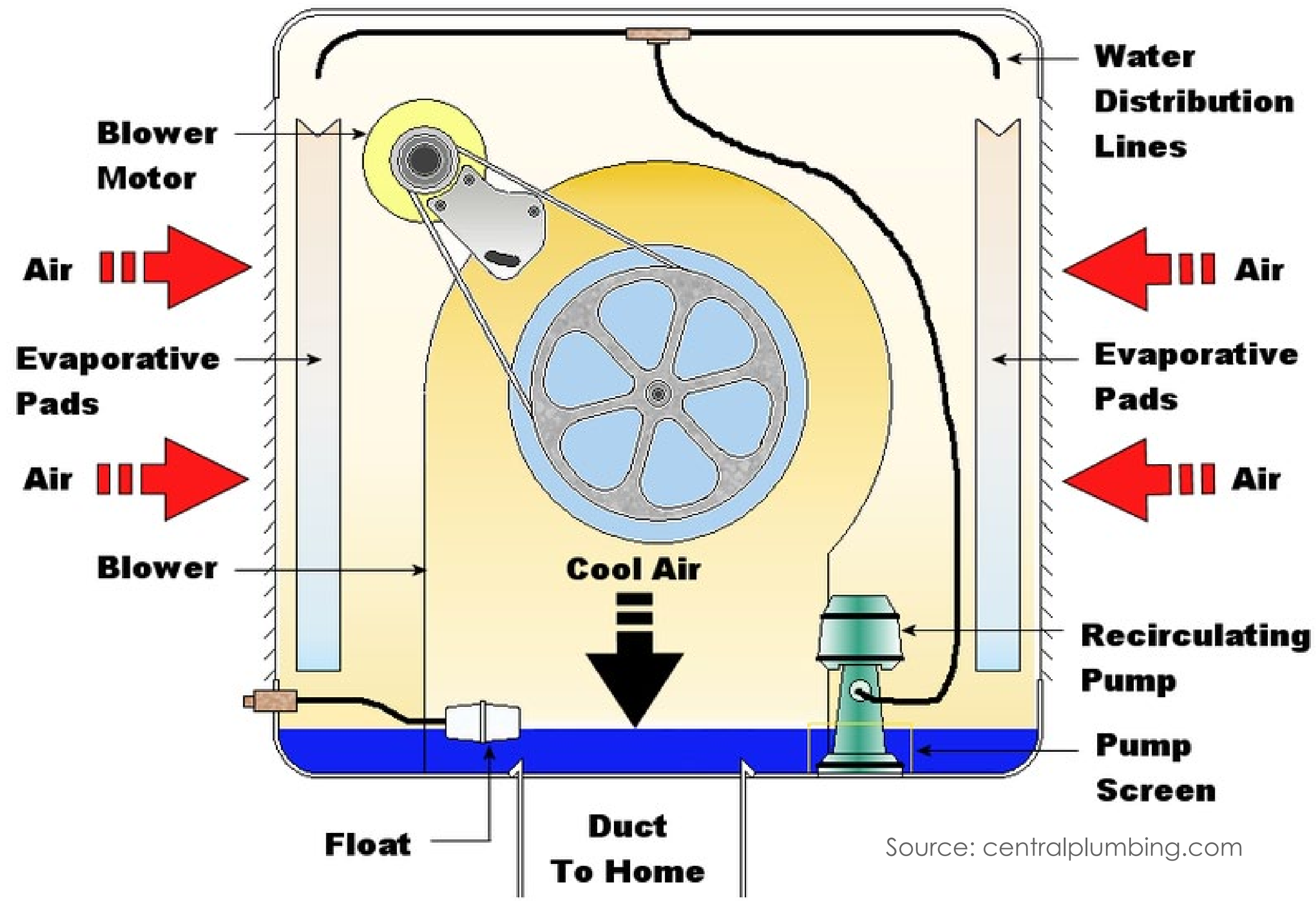
- 75% less energy than traditional AC
- Simple design requires little main-tenance
- Simple installation
- In dry areas added humidity can be comfortable
- Pads filter air
- High air velocity allows for good circulation and IAQ
- New 2 stage swamp coolers
  - require higher upfront cost
  - performance comparable to traditional AC

Description

- Hot Dry outdoor air passes through damp pads and into building by a fan
- Water is continuously circulated through the pads by a water pump and distribution line.

Sizing

- CFM (air) = Room Volume (ft^2) / 2
  - For large or multi-room buildings divide evenly to allow more even distribution
  - Can be integrated into traditional AC Ducting

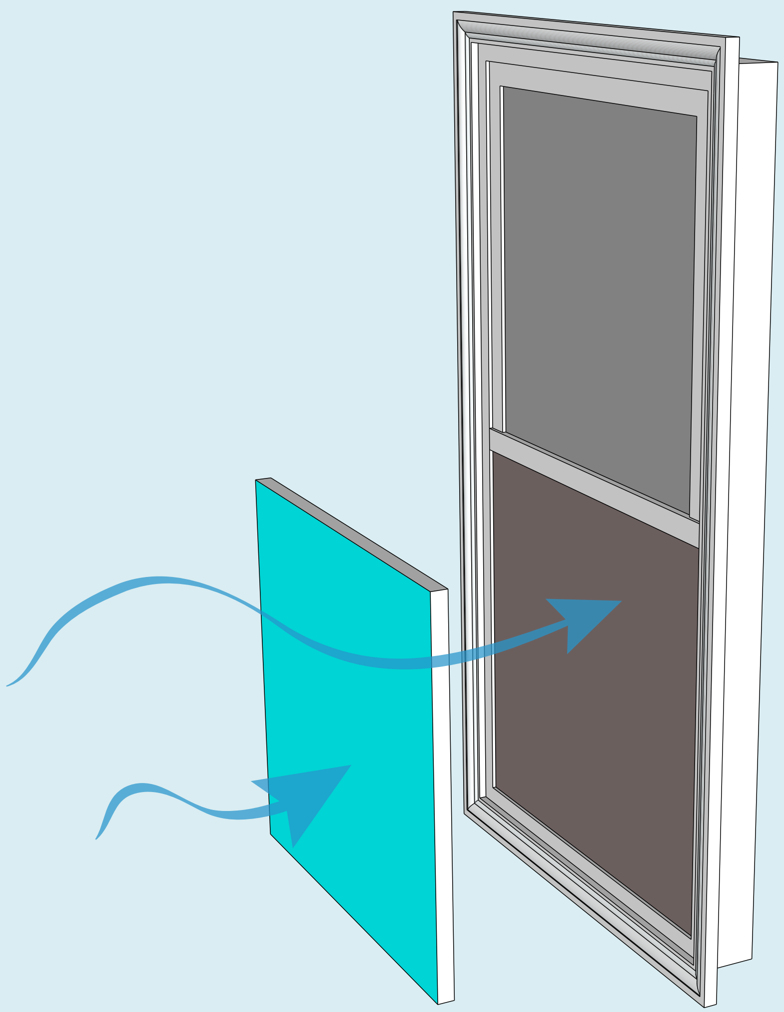


Source: centralplumbing.com

Homemade
Evaporative Cooling Systems

Window Pads

- Wet fiber pads installed on wind facing windows
- Manually or Mechanically Wetted
- Water through pad can be collected and recirculated or used to irrigate crops.



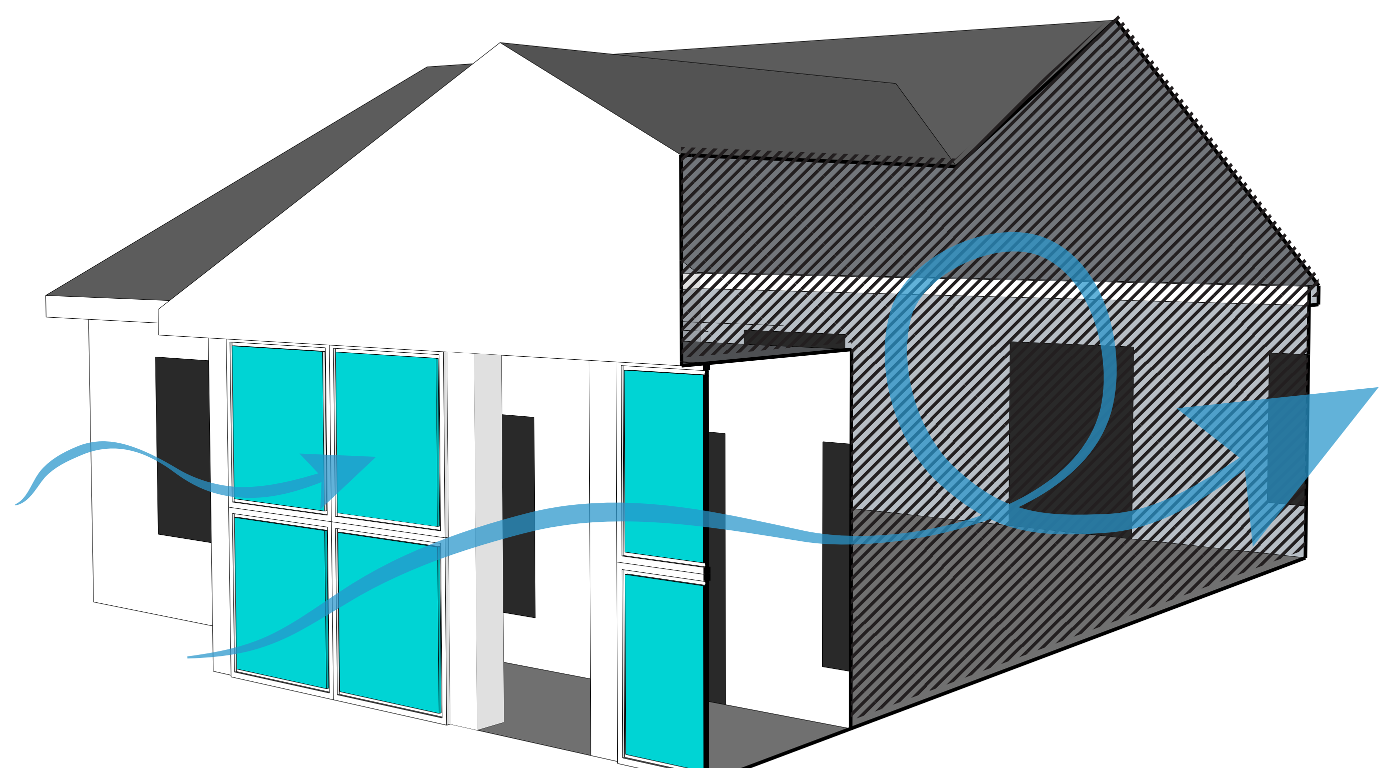
Evaporative Porch Walls

- Evaporative pads will slow down air penetration considerably through windows
- Using an **enclosed** porch allows greater volume
  - Greater volume when passed through smaller door and window openings will increase Velocity

  V(wind velocity) = Q(flow volume) / A (Opening Area)

Things to Consider

- Requires reliable prevailing winds
- Efficiencies will be 40-50% of mechanical coolers
- Very cheap and little to no overhead
- Serve as air filter in dry dusty areas
- Blocks view through window
- Can be designed intelligently and aesthetically



Cooling Towers

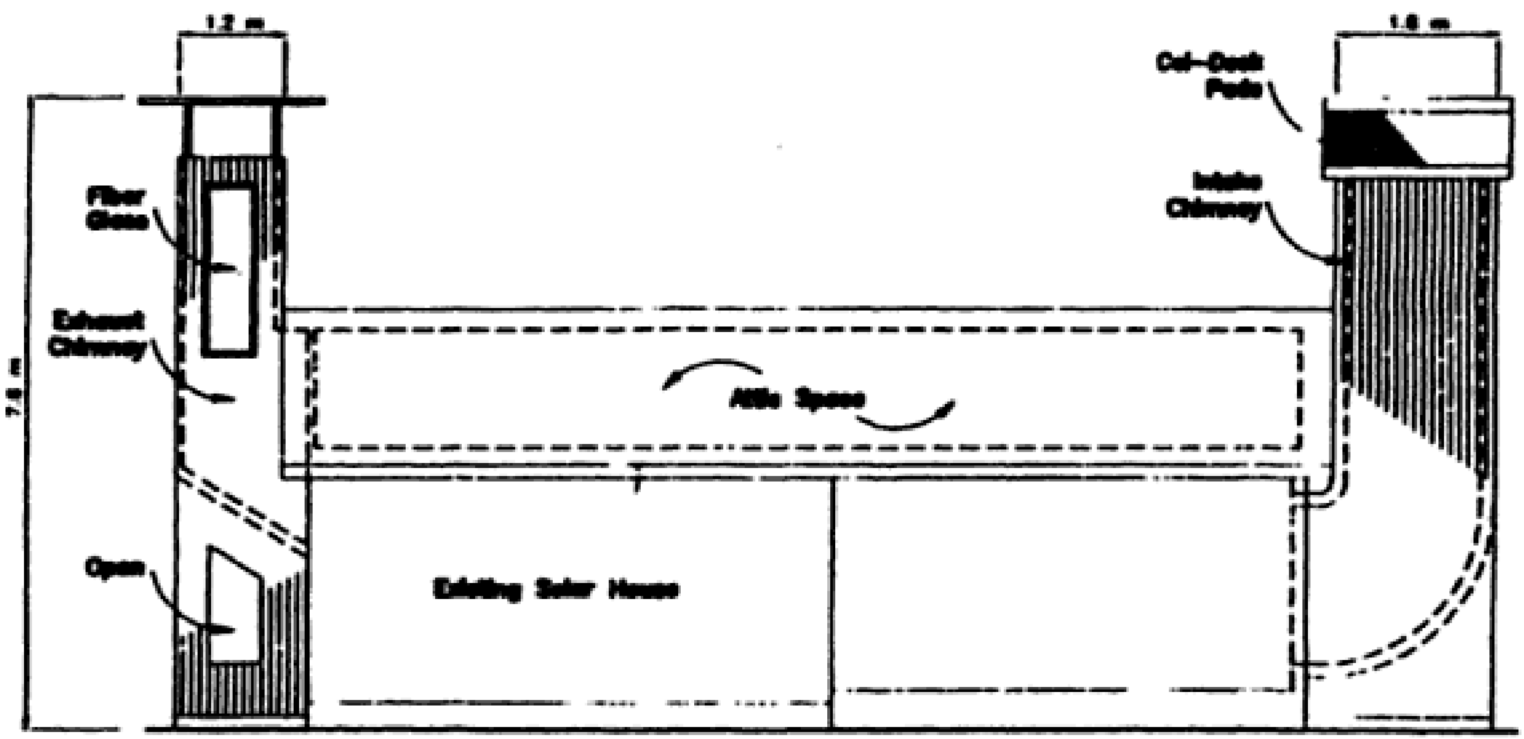
Wetted Pad Towers

- Ambient air enters the tower at the top, is cooled by the evaporation of water, and leaves the tower at the bottom.
  - Cooler air is Denser than Warm air and falls
- Wetted cellulose pads are saturated with rigidifying and antirot compounds
- Water is collected at bottom to be recycled via pumps
- Can be fan powered to increase air flow
- Often times a solar chimney is used to encourage air circulation

Case Study (Cunningham & Thompson 1986)

- University of Arizona's Environmental Research Laboratory in Tucson, Arizona, USA
- Did *not* utilize fan unit
  - Water Pump only source of power use
- **1.8 x 1.8 m** Cross Section Tower; **7.6m** tall; attached to **100sqm** insulated structure
- Tested August 22-23, 1985

- Data:
  - DBT: 40.6 C
  - WBT: 21.6 C
  - Texit: 23.9 C
  - IAT: 24.6 C
  - V (air speed): .75 m/s
- Analysis:
  - 16 C drop in temp (40%)
  - Giovani Analysis (1991) shows little benefit of Solar Chimney and ambient wind speed
  - dWBT is greatest passive factor



South Elevation

Source: Chalfun (1998)

Cooling Towers

Sizing

- Q=0.033 x Aevap x sqrt(H x (DBT-WBT))

ASHRAE Ventilation Rates

Day Care	17 cfm/person
Classroom	13 cfm/person
Multi Use Hall	8 cfm/person

TABLE 5-1. EFFECT OF TOWER'S HEIGHT AND PADS' AREA ON AIR FLOW

Tower Height		*Pads Area*		*Air Flow Rate*	
(m)	(ft)	(m^2)	(ft^2)	(m^3/s)	(cfm)
2.0	6.6	1.0	10.8	0.190	6.7
4.0	13.1	1.0	10.8	0.268	9.5
6.0	19.7	1.0	10.8	0.329	11.6
8.0	26.2	1.0	10.8	0.379	13.4
2.0	6.6	2.0	21.5	0.379	13.4
4.0	13.1	2.0	21.5	0.537	19.0
6.0	19.7	2.0	21.5	0.657	23.1
8.0	26.2	2.0	21.5	0.759	26.8
2.0	6.6	4.0	43.0	0.759	26.8
4.0	13.1	4.0	43.0	1.073	37.9
6.0	19.7	4.0	43.0	1.315	46.4
8.0	26.2	4.0	43.0	1.518	53.6
2.0	6.6	6.0	64.5	1.138	40.2
4.0	13.1	6.0	64.5	1.610	56.8
6.0	19.7	6.0	64.5	1.972	69.6
8.0	26.2	6.0	64.5	2.277	80.4

Source: Chalfun (1998)
Source: Givoni (1994)

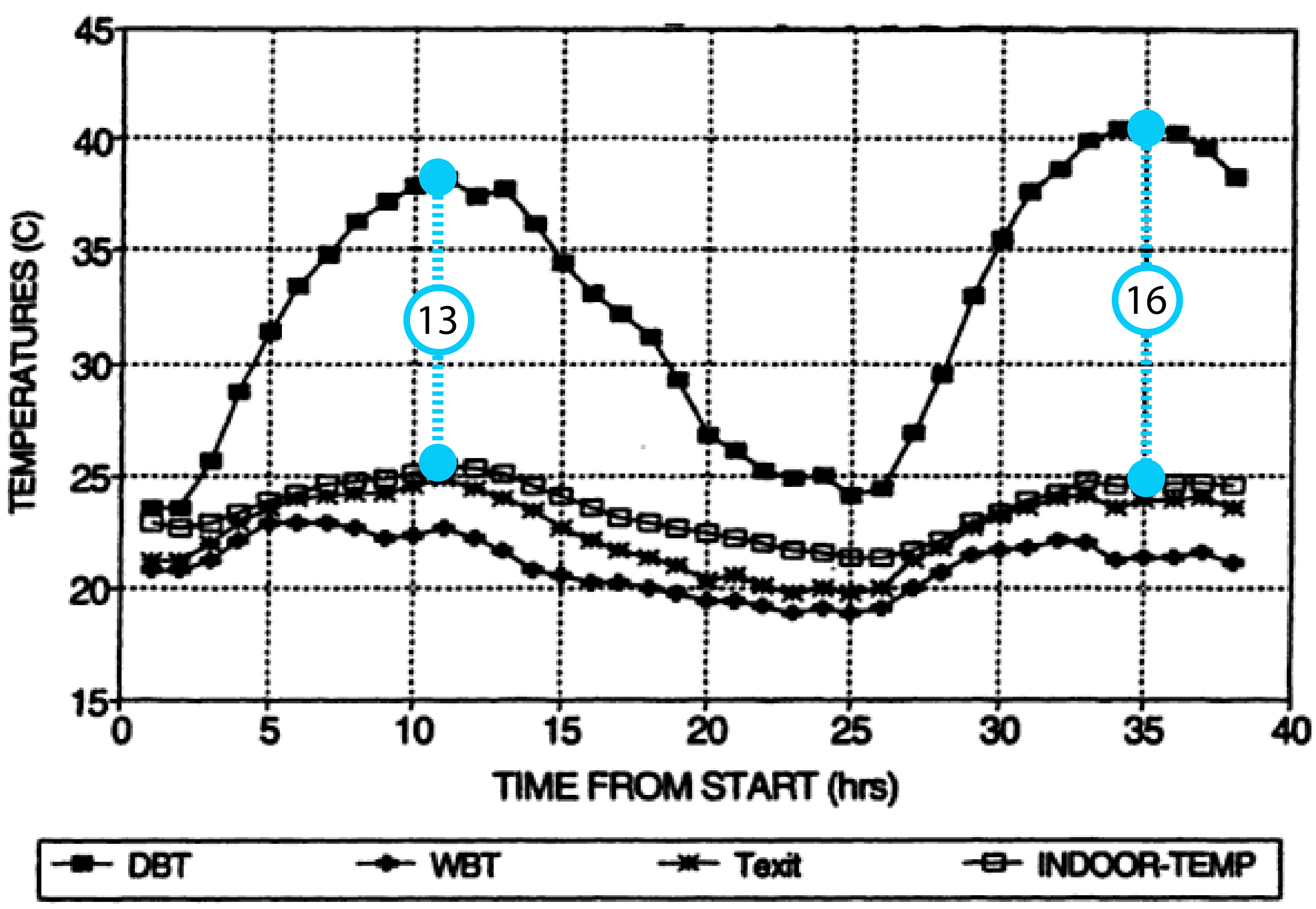


FIGURE 5.6 Performance of Cunningham and Thompson's tower.

Source: Chalfun (1998)

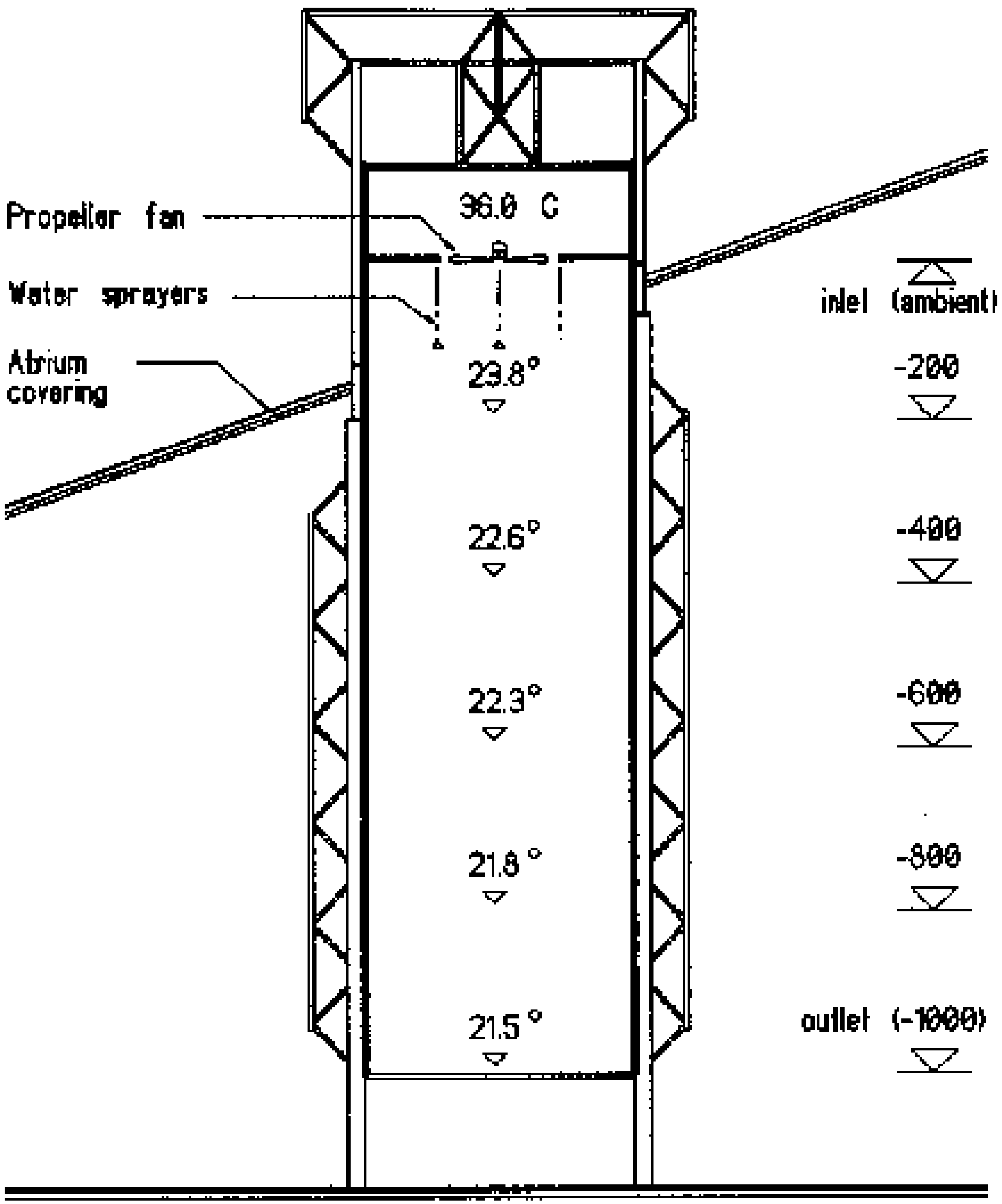
Shower Cool Towers

Description

- Developed by Givoni at the 1992' Seville Spain Expo
- Fine water drops sprayed down tower
- Trap aira and creates a stream of cool air traveling down the tower
- Evaporation cools the air enroute down the tower
- Pumps cycle the water back to the top

Case Study

- University of Negev Cooling Tower Study (1996)
  - Isreal Highlands
  - 10m^2 cross area, 10m tall
  - Forced & Passive ventilation
  - 85-95% WBT achieved
  - 10-15 C Temp drop
  - 8-12 C in first 2m
  - Peak cooling of 100kW
  - Used 1-2m3/day of water



Source: Pearlmutter, (1996)
Source: Givoni (1994)

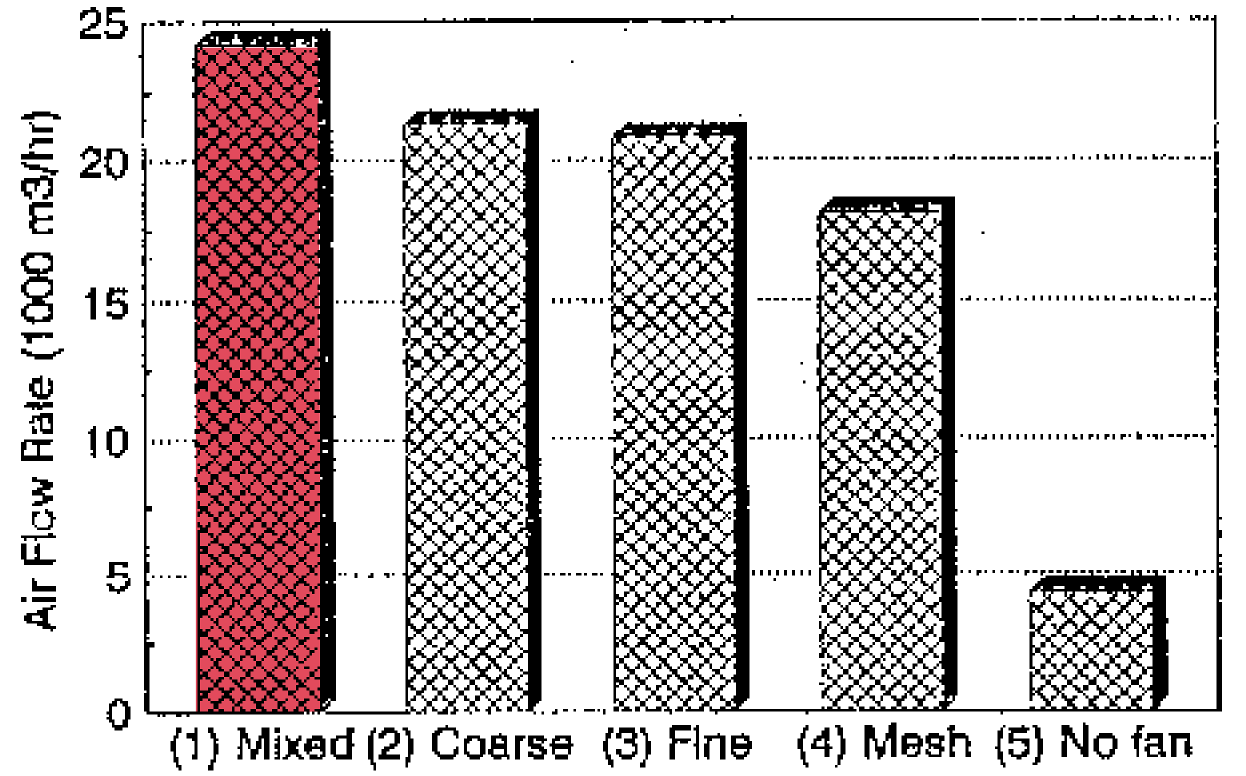
Shower Cool Towers

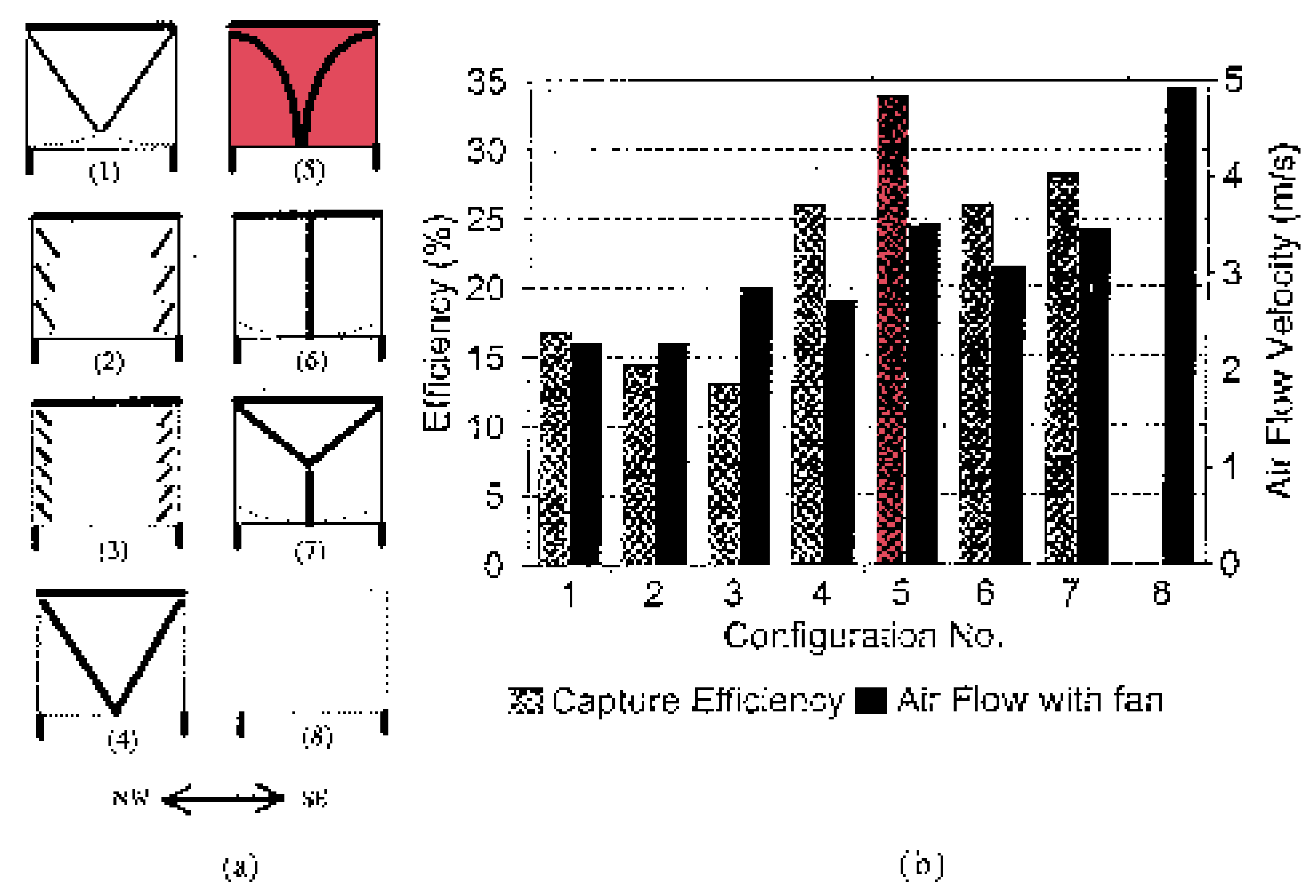
Analysis

- Since most cooling is done by 2m, air speed is limiting reagent in cooling ability.
- Mix of fine and coarse spray created fastest air flow.
- Once saturation is reached only way to increase cooling effect is to increase air flow.
- Fan forced or air scoops

Things to Consider

- Design Integration of the tower
- Theoretically if tower is tall enough and drops small enough all water can evaporate, allowing space below to be useable





Source: Pearlmutter (1996)

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What is a roof pond?

Roof ponds are considered to be an effective strategy for cooling buildings without the use of mechanical equipment. The evaporative cooling strategy acts as a "thermal sponge". This "sponge" absorbs heat from a room in which it is covering through the interior of the ceiling. The regions that would render roof ponds useful are desert areas or other areas with great differences between wet bulb temperature and dry bulb temperature.

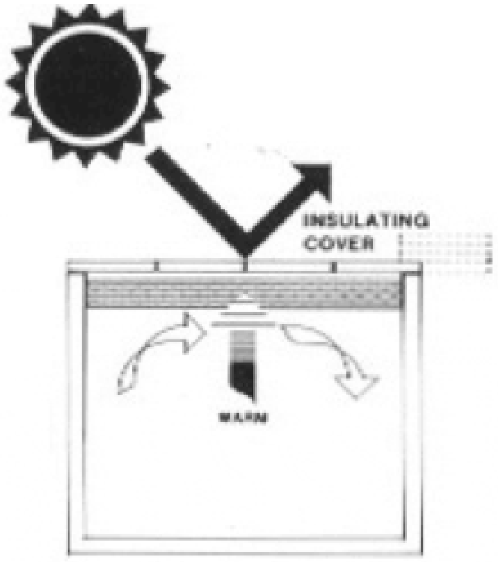
Types of roof ponds

There are a variety of roof ponds used today. Some of these are as follows however only the types most related to our site will be discussed:

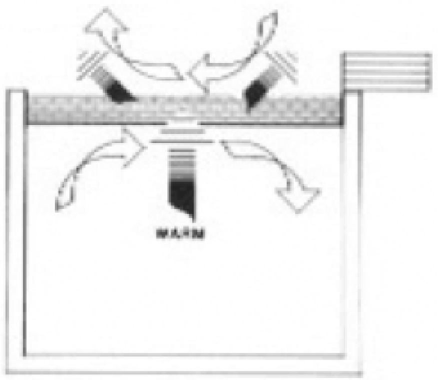
- Uncovered with sprays
- Uncovered without sprays
- Covered with sprays
- Covered without sprays
- Skytherms
- Walkable pond
- Wet gunny bags
- Cool pool
- Ventilated roof pond

Concerns

Architects and clients express concerns due to water leaking phobias and structural reinforcement even though it yields one of the most stable interior temperatures.



Day



Night

Typical diagrams

In most cases, the roof ponds are covered during the day and allow for the water to absorb the heat from the room. At night, the pond is uncovered releasing the heat collected from the day into the night sky.

Residential Application

House in Atascadero, California may be an early example of roof-pond structures. Throughout the years, this structure has demonstrated stability in temperature. To prove its success, Harold Hay designed the house without south-facing windows.

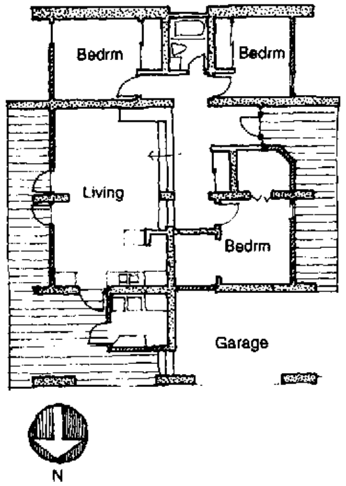
The Design

The residential structure is designed with a roof pond that has movable insulating panels. During the day, the panels are closed especially in summer. At night, the panels are opened. The water is stored in plastic bags which rest on metal decking.

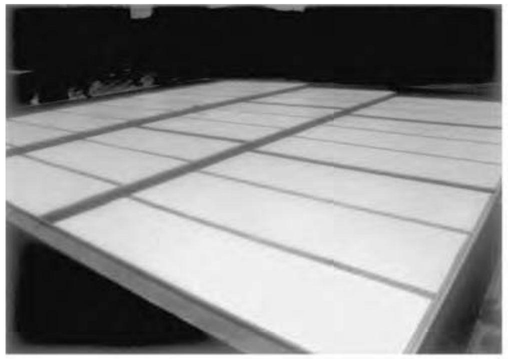
Atascadero, California

The city is raised on an elevation of 991 feet. In July, the average temperature is 93 degrees Fahrenheit while in January, the average low is about 32.9 degrees. The location also has moderate humidity.

(a)



(b)

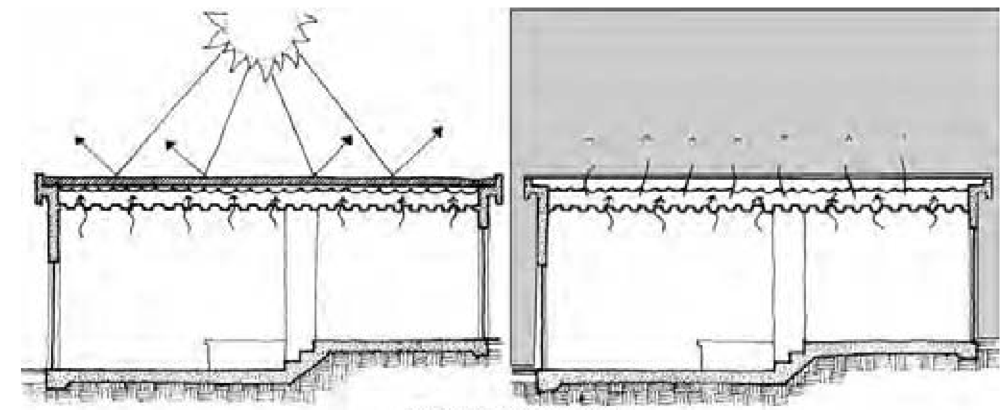


(c)

(d)

Diagrams

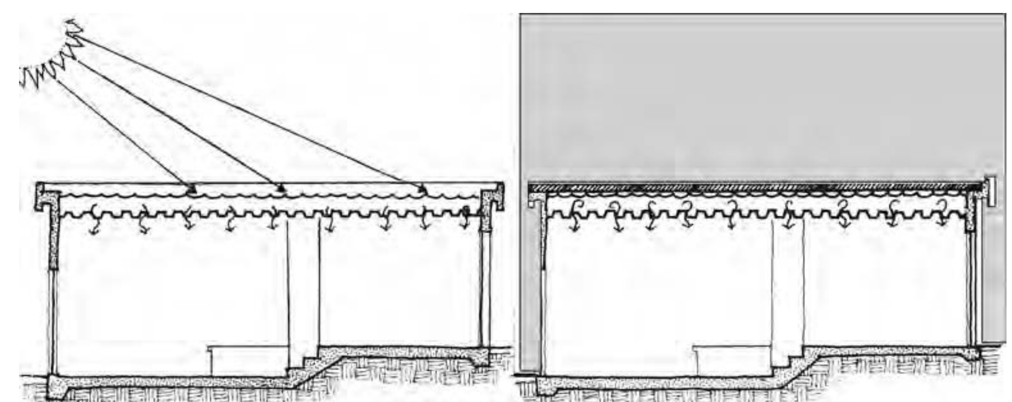
The diagrams at the right demonstrate how the roof pond on the Atascadero house operate during the summer months. During this time, we would like to cool the building, especially with temperatures in the 90's. To do so, roof panels cover the roof pond and reflect sunlight away from the building. At night, the panels are opened and the heat collected from the interior environment is transferred from the roof pond to the night sky.



Roof pond cycle in summer

(e)

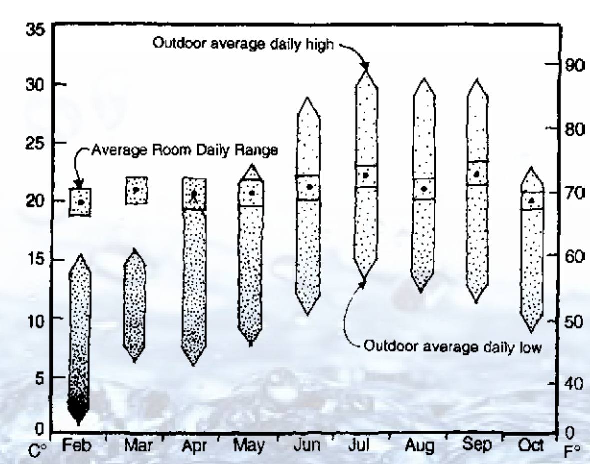
The following diagram demonstrates how the roof pond operates during the winter months. During this time, we would like to heat the interior space. In doing so, the panels are removed during the day to capture the heat from the sun and closed at night. This allows for the heat captured to travel into the interior of the house, thus heating the space.



Roof pond cycle in winter

(f)

The following chart represents data collected throughout the year. It analyzes the outdoor temperature, both high and low, and compares it to the average room daily range achieved by the Atascadero home. It is evident that the house maintains a stable temperature throughout the entire year.



(g)

Fig. 8.22 (Continued)

Advantages

The pond makes a majority of the roof.
Process may be reversed for cooler months.
Can be modified to be inexpensive.
Dependant from the orientation of the building.
Brackish water can be used.

Disadvantages

Lack of experience by the construction company.
Extra attention and time devoted to water proofing roof.
Can be easily interrupted by other buildings or trees.
80 degrees Fahrenheit is the max temperature the pond will succeed.

Calculations

Minimum required sizing of the pond in ft.^{2} pond per ft.^{2} floor area.

Pond min. temperature = Max daytime temperature - Mean daily range

Pond Δt = Pond maximum of 80 degrees Fahrenheit - Pond minimum temperature

Allowable heat stored (daily) = (.7)(pond Δt)(pond depth)(62.5 lb/ft.^{3} water)(1 Btu/lb^{o}F)

Sample Calculation

EXAMPLE 8.6, PART A An office building in Albuquerque, New Mexico, is to be cooled by a roof pond 4 in. deep. An hourly heat gain of 15 Btu/h ft^2 is assumed (excluding heat gain through the roof), somewhat more than the Oregon office building of Example 8.1.

SOLUTION

For Albuquerque:

Maximum temperature = 91°F (Table B.5)
Mean daily range = 25.3F° (Table B.5)
Minimum (night) temperature = 91 – 25.3 = 65.7°F

Therefore:

Pond Δt = 80 maximum – 65.7 minimum = 14.3F°

Pond storage capacity for building heat
= 0.7(14.3°)(0.33 ft)(62.5 lb/ft^3)(1 Btu/lb °F)
= 206 Btu/day ft^2

The required pond size, then, is

$$\frac{15\ \text{Btu/h ft}^2 \times 9\ \text{h/day}}{206\ \text{Btu/day ft}^2} = 0.66\ \text{ft}^2/\text{ft}^2\ \text{floor area (or } 0.66\ \text{m}^2/\text{m}^2)$$

Therefore, a 4-in. (102-mm) pond covering 72% of the one-story building's floor area will be approximately large enough to cool the building. (If the entire ceiling is desirable as a cooled surface, then a slightly shallower pond of greater area could be used. However, the sliding insulation panels must be stacked somewhere beyond the edge of the roof pond.)

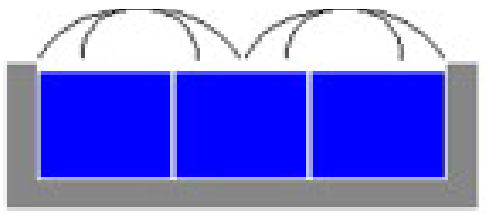
$$\text{Roof Pond Size} = \frac{\text{Building total heat gain per day (Btu/day ft.}^2\text{ floor area)}}{\text{Pond allowable heat stored per day (Btu/day ft.}^2\text{ floor area)}}$$

Focus Areas

With the variety of roof ponds available today, the few most beneficial to our site are:

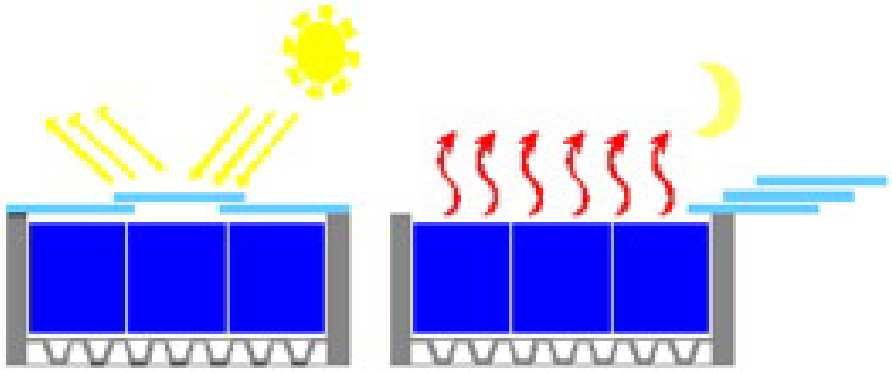
Covered without sprays
Skytherms
Wet gunny bags
Ventilated roof pond
Walkable pond

Covered Without Sprays



Provides a cooling affect at most times.
Known to have negligible fluctuations in temperature.
The covers/panels provide an airspace between the panel and pond, which does not affect the performance.

Skytherms



Must have a metal deck to support a roof.
4-10 inch bags must be used.
Temperatures below 86 degrees Fahrenheit can be maintained as log as DBT are above 104 degrees Fahrenheit.
Recorded a reduction in heating demand by 86% in the climatic conditions of Shiraz

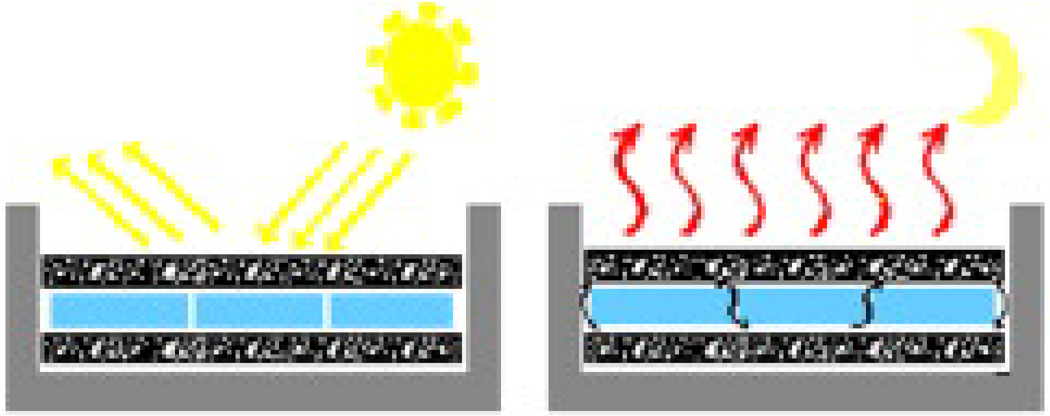
Wet Gunny Bags

Gunny bags rest on mesh with polystyrene strips.
The most efficient depth is 8 inches.
Performs better than a pond with movable insulation.
Spraying system may be essential due to no heat dissipation at night.

Ventilated Roof Pond

Provides a secondary insulation roof over the pond.
A permanent airflow is established enhancing effects.
Can be applied with a tilted roof (maintained wet lower surface)
Must close and open the openings for operation
The need of two roofs is a disadvantage in terms of construction and cost

Walkable Roof Pond

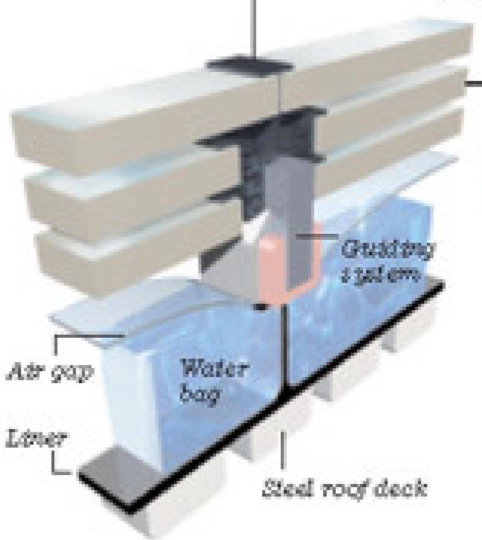


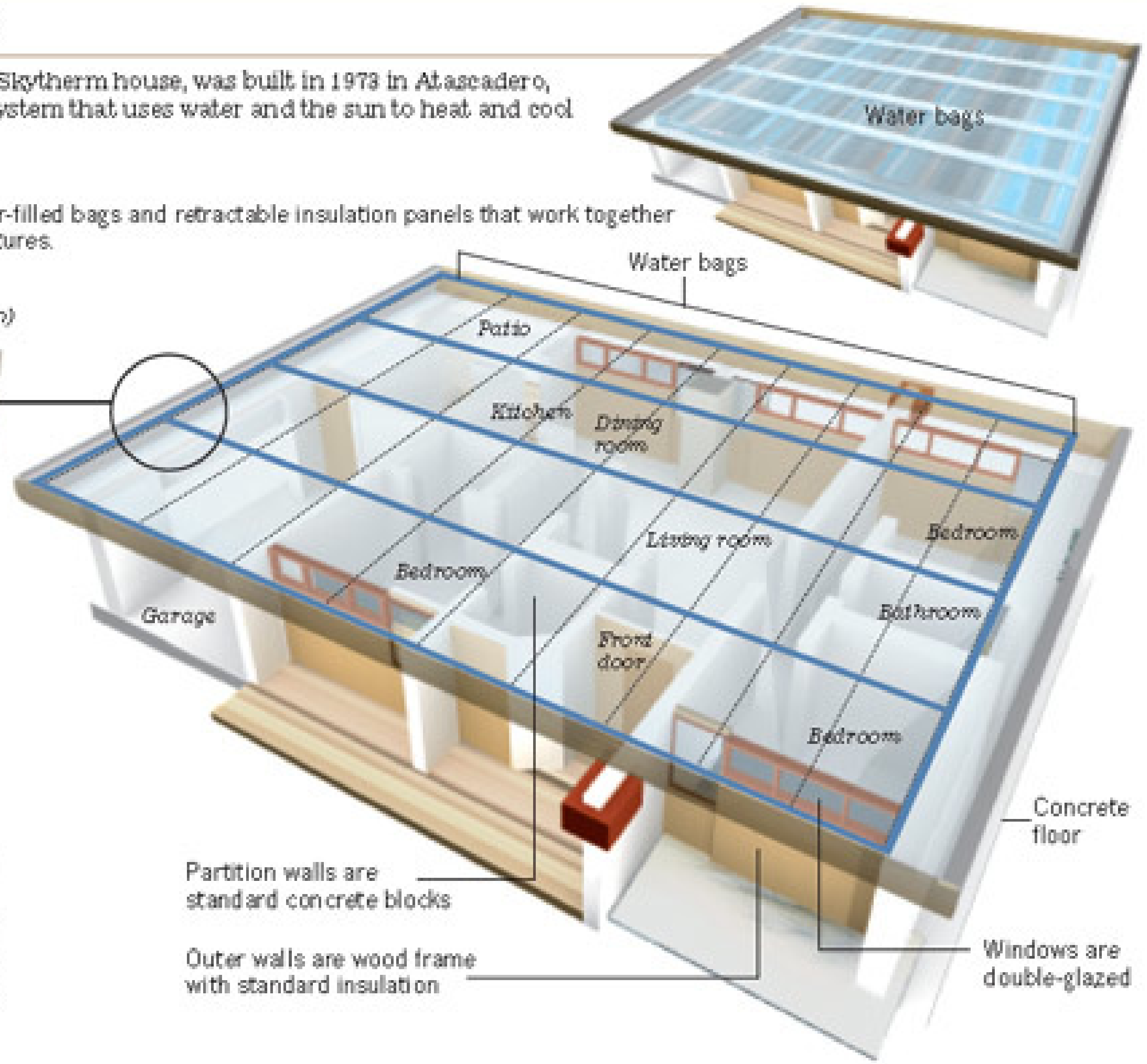
Insulation is embedded into pond.
Buildings with reinforced concrete flat roofs in desert areas may utilize this design.
Advantage is the ability to create useful areas on the roof

Sun + H_2O = comfort

An early Harold Hay invention, the Skytherm house, was built in 1973 in Atascadero, Calif., to demonstrate a roof-pond system that uses water and the sun to heat and cool without electricity.

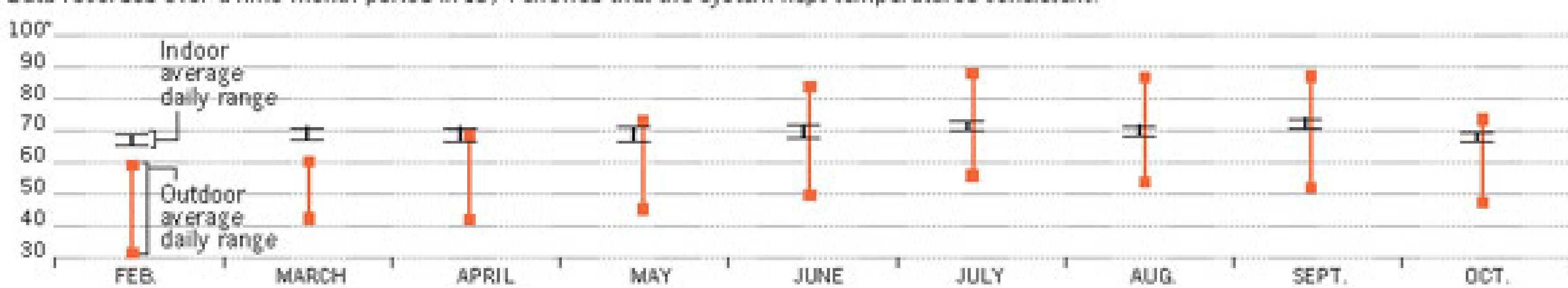
The roof pond
A steel roof deck holds four long, water-filled bags and retractable insulation panels that work together to maintain consistent indoor temperatures.





How it works
Summer: In daytime, the covered roof keeps heat out and the indoor space cool. At night, exposing the water bags radiates heat into the air.
Winter: The uncovered roof draws heat in during daytime and the covered roof maintains it at night.

Comfortable indoor temperatures
Data recorded over a nine-month period in 1974 showed that the system kept temperatures consistent.



Source: Energy Department

Lorena Iñiguez Los Angeles Times

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