# Application of Passive Cooling in a Tropical Climate

P. Boon-Long

Department of Mechanical Engineering
Chiang Mai University, Chiang Mai 50002, Thailand.

## ABSTRACT

*A brief review of passive radiation cooling is given. Calculation results relevant to the climate of Thailand are presented, and possible applications of passive cooling in the agriculture area are discussed. Results of experiments conducted in the mountains of northern Thailand indicated that the concept has potential, particularly for short-term storage of vegetables and some temperate zone fruits, and for precooling. Three factors are identified which need to be considered before any use of passive cooling methods: for what purposes, at what location, and during which seasons.*

## INTRODUCTION

Passive cooling can be achieved by several methods, for example through ventilation, shading, evaporation, radiation and earth-contact. Some methods can be used during the entire day, while others occur only during the night. In this paper, attention will be focused on the second type only, which is usually called nocturnal or night cooling. This occurs mainly through radiation and evaporation. Special emphasis will be placed on application of nocturnal cooling in the warm, humid climate of the tropics.

A basic principle of nocturnal cooling is shown in Fig. 1. In this figure, a cold-storage mass, for example a shallow water pond, is placed on the roof of a room. A piece of movable insulation panel is installed over the cold-storage mass. During the night the insulation panel is removed, thus exposing the mass to the surroundings. Heat will be transferred from the mass to the surroundings by radiation and possibly evaporation, thereby lowering its temperature. In the morning the insulation panel is replaced, to prevent heat from being transferred into the cold-storage mass during the day. The room below will be kept cool by natural-convection heat transfer between the cool underside of the roof and the room air. This method is entirely passive, in that no energy input is required for operation, except a minimal amount for removing and replacing the insulation panel twice a day.

Since the method described is entirely passive, its performance will therefore depend heavily on the local surroundings, particularly the ambient air temperature and humidity, cloud cover, and wind conditions. A dry and cool-night climate with clear skies is very favourable for radiation and evaporation cooling, while the warm and humid conditions found in the tropics are the opposite. Thus, use of a passive-cooling method for any purposes should be preceded by a careful study of the local climate and the intended usage.

As previously mentioned, the effectiveness of passive cooling in a tropical climate is much more limited than in a dry and cool region. However, as will be described later in this article,

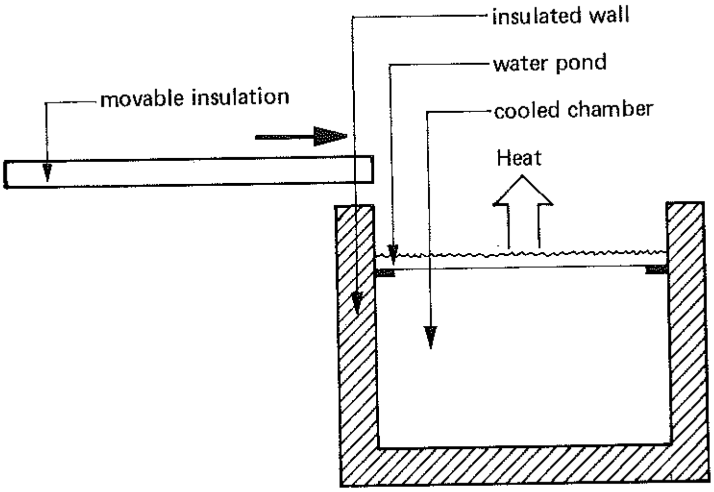

Fig. 1 Room for nocturnal cooling

passive cooling can still be very useful in a tropical surrounding if properly applied and with full recognition of its limitations. One potential application is in agriculture, in which at least three different uses appear to be feasible:

1. Passively-cooled storage for certain fruits and vegetables.
2. Precooling of some fruits and vegetables before storage.
3. As a growth chamber for certain types of produces, for example Champignon mushrooms.

The advantages of passive-cooling methods in developing countries are their simplicity, low cost, both in construction and in maintenance, low-energy usage, and good utilization of local resources. The main disadvantage is that they depend strongly on the local environment, which means the location of installation and the seasons they are to be used in.

At least three factors must be kept in mind when planning to use passive cooling:

1. Type of usage, which will dictate the conditions required inside the passively-cooled room. For example, to store a certain variety of pears, the storage conditions required are approximately 18°C and 85-95% relative humidity. To produce comfort for people, however, the conditions required would obviously be quite different.
2. Location of usage, and
3. Time of year that the room needs to be used.

From the second and third factors, an estimate can be made of the conditions that can be produced inside the passively-cooled room. These conditions can then be compared with the conditions required in 1. A good match would at least indicate a relatively good chance of success for that particular application.

Comfort cooling (air conditioning) theoretically can be achieved by nocturnal cooling methods as well, even in a tropical climate. However, it must be accompanied by some form of air dehumidification, otherwise the resulting microclimate will be much too humid for human comfort.

## THEORY

An extensive review of radiation cooling was made recently by Givoni[1]. This article is recommended for readers who are interested in further pursuing the subject. In addition, Haisley[2] and Bowen[3] provided a collection of detailed information, both theoretical and experimental, on many passive cooling works. Here, only a brief review of radiation cooling will be made.

Consider first a black radiator placed horizontally at ground level at night, and originally at the same temperature as the ambient air. In Fig. 2, a typical spectral intensity of radiation emitted by the atmosphere, which would be all absorbed by this black radiator, is shown. At thermal equilibrium, the radiation absorbed by the black radiator must be equal to the radiation emitted by it. In other words, the area under both curves must be the same. Since the atmospheric radiation spectrum has a dip in intensity approximately between 8-13 μm, it follows that the spectral radiation intensity curve of the black radiator must be lowered (i.e. the radiator must be at a lower temperature), in order to ensure equal areas under the curves at thermal equilibrium. This means the black radiator will be colder than the ambient air (assuming for simplicity that no other heat transfer mechanisms are present). The phenomenon is generally called radiation cooling.

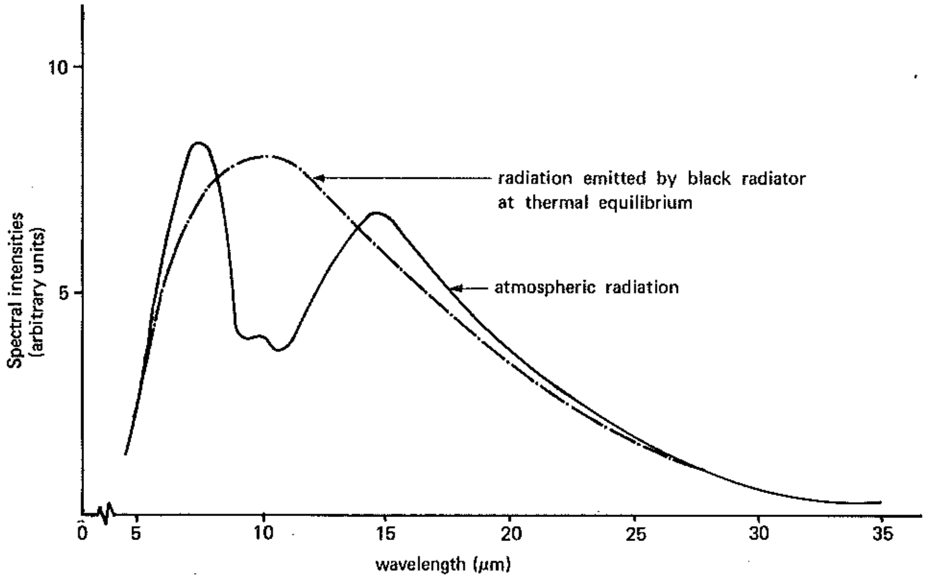

Fig. 2 Spectral radiation intensities versus wavelength

Radiation cooling can be further enhanced by taking advantage of the 8-13 μm dip ("transparency window") in the atmospheric radiation spectrum. Suppose a radiator can be made which radiates only in the 8-13 μm wavelength region, and in none other, the emissivity of such a radiator would be as shown in Fig. 3. Equivalently, it may be said that this radiator would absorb radiation only in the 8-13 μm range, and in none other. Thus it will absorb atmospheric radiation only in the wavelength range in which the atmospheric radiation intensity is lowest. At the same time, however, it will emit radiation just like a black radiator in this same wavelength range. Therefore,

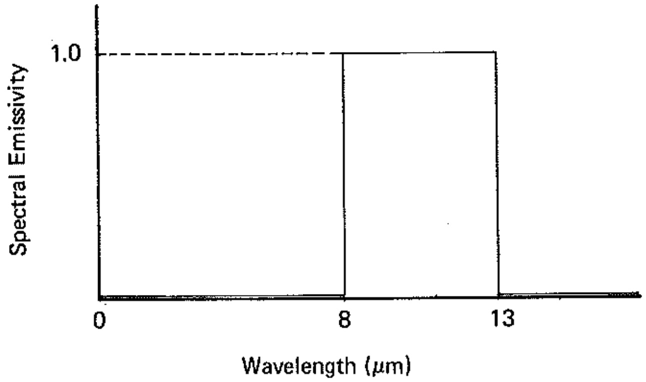

Fig. 3 Spectrum of an ideal selective surface

it can be expected that the temperature of this ideal "selective" radiator should be even lower than that of a black radiator (under the same assumption that no other heat transfer mechanisms are present). Spectral characteristics of some real "selective" surfaces are shown in Fig. 4.

Following the above discussion, the equilibrium temperature of any radiator can then be estimated if two things are known: the spectral characteristics of the radiator under consideration, and the atmospheric radiation at that time and at that location. The first item can be found in many works on radiation heat transfer; the second must be calculated for each location of interest.

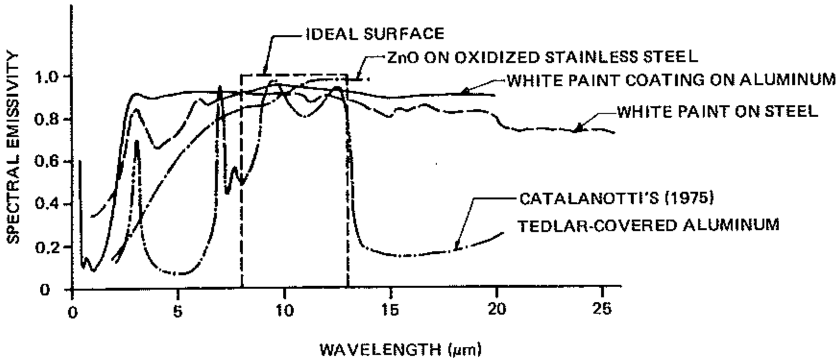

Fig. 4 Spectral characteristics of real selective surfaces.

For a tropical climate such as Thailand's, the author has calculated atmospheric emissivity for the four provinces for which necessary data are available, namely, Bangkok, Chiang Mai, Ubon Rajathanee, and Songkla. Details of the calculation processes are described elsewhere[4]. In this paper, only the results will be presented, as Tables 1-4. From the tables, it can be seen that, even in such a humid climate, there is still potential for selective radiation cooling in the atmospheric transparency window, especially at Chiang Mai in the north and Ubon Rajathanee in the northeast.

From the tables, atmospheric radiation flux for each city and for any month of the year can be calculated. Average net radiative cooling rates from a radiator can also be calculated. A sample

**Table 1**
**Calculated spectral atmospheric emissivity for Bangkok**

| Month | Monthly-averaged temperature (°C) | Spectral hemispherical emissivity 8.5-12.0 $\mu$m | Total hemispherical emissivity |
|---|---|---|---|
| January | 21.9 | 0.68 | 0.92 |
| February | 22.8 | 0.66 | 0.92 |
| March | 25.5 | 0.74 | 0.93 |
| April | 25.6 | 0.84 | 0.96 |
| May | 26.0 | 0.91 | 0.97 |
| June | 25.9 | 0.91 | 0.98 |
| July | 25.8 | 0.91 | 0.97 |
| August | 25.3 | 0.92 | 0.98 |
| September | 25.3 | 0.90 | 0.97 |
| October | 24.7 | 0.87 | 0.97 |
| November | 22.9 | 0.74 | 0.94 |
| December | 22.6 | 0.76 | 0.94 |

Note: Spectral emissivity at wavelengths 5-8.5 $\mu$m and 12-35 $\mu$m is unity.

**Table 2**
**Calculated spectral atmospheric emissivity for Ubon Rajathanee**

| Month | Monthly-averaged temperature (°C) | Spectral hemispherical emissivity 8.5-12.0 $\mu$m | Total hemispherical emissivity |
|---|---|---|---|
| January | 19.1 | 0.54 | 0.89 |
| February | 21.2 | 0.49 | 0.88 |
| March | 24.7 | 0.61 | 0.90 |
| April | 24.7 | 0.68 | 0.92 |
| May | 26.0 | 0.75 | 0.94 |
| June | 25.2 | 0.88 | 0.97 |
| July | 25.2 | 0.83 | 0.96 |
| August | 25.0 | 0.88 | 0.97 |
| September | 25.1 | 0.83 | 0.95 |
| October | 23.4 | 0.74 | 0.93 |
| November | 20.5 | 0.61 | 0.91 |
| December | 20.4 | 0.59 | 0.90 |

Note: Spectral emissivity at wavelengths 5-8.5 $\mu$m and 12-35 $\mu$m is unity.

**Table 3**
**Calculated spectral atmospheric emissivity for Songkla**

| Month | Monthly-averaged temperature (°C) | Spectral hemispherical emissivity 8.5-12.0 μm | Total hemispherical emissivity |
|---|---|---|---|
| January | 24.8 | 0.75 | 0.94 |
| February | 23.9 | 0.63 | 0.91 |
| March | 24.1 | 0.70 | 0.93 |
| April | 25.3 | 0.83 | 0.95 |
| May | 24.9 | 0.89 | 0.97 |
| June | 24.9 | 0.87 | 0.97 |
| July | 24.0 | 0.83 | 0.95 |
| August | 24.2 | 0.85 | 0.96 |
| September | 23.9 | 0.84 | 0.96 |
| October | 24.2 | 0.88 | 0.97 |
| November | 24.2 | 0.89 | 0.97 |
| December | 24.7 | 0.77 | 0.94 |

Note: Spectral emissivity at wavelengths 5-8.5 μm and 12-35 μm is unity.

**Table 4**
**Calculated spectral atmospheric emissivity for Chiang Mai**

| Month | Monthly-averaged temperature (°C) | Spectral hemispherical emissivity 8.5-12.0 μm | Total hemispherical emissivity |
|---|---|---|---|
| January | 14.1 | 0.42 | 0.87 |
| February | 14.4 | 0.42 | 0.86 |
| March | 17.9 | 0.43 | 0.87 |
| April | 21.7 | 0.61 | 0.91 |
| May | 23.6 | 0.75 | 0.94 |
| June | 24.4 | 0.81 | 0.95 |
| July | 23.9 | 0.81 | 0.95 |
| August | 23.7 | 0.78 | 0.94 |
| September | 23.4 | 0.75 | 0.94 |
| October | 22.1 | 0.70 | 0.93 |
| November | 19.7 | 0.60 | 0.90 |
| December | 17.7 | 0.49 | 0.88 |

Note: Spectral emissivity wavelengths 5-8.5 μm and 12-35 μm is unity.

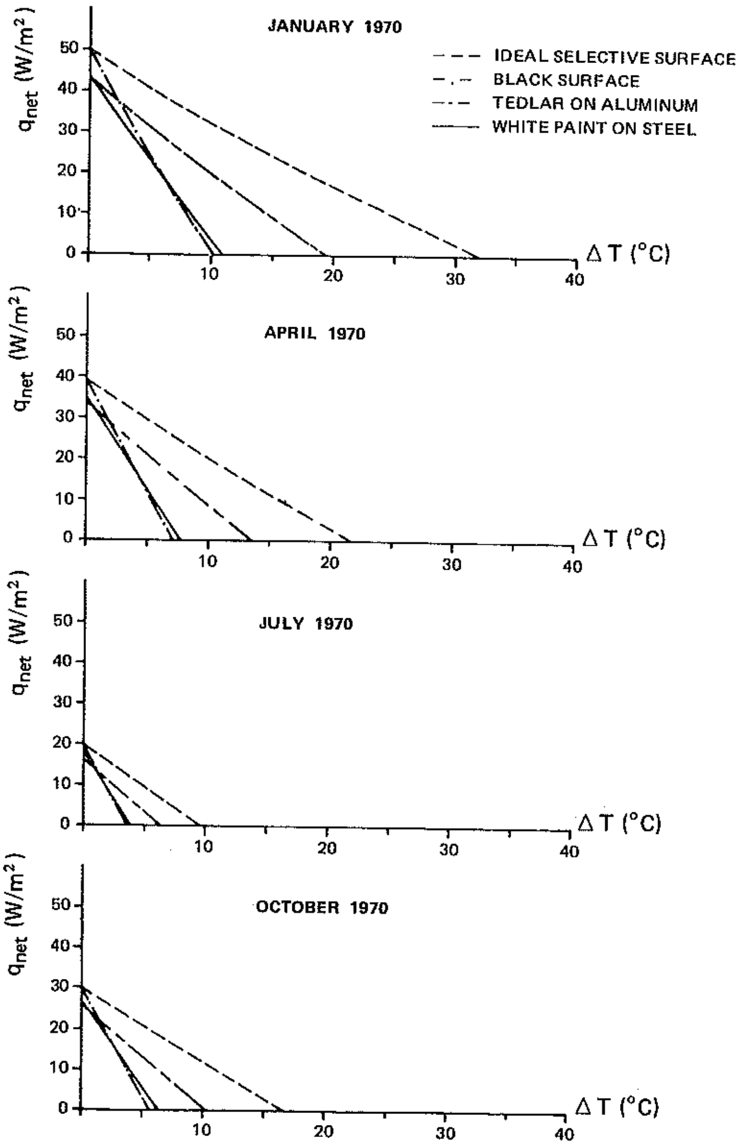

Fig. 5 Radiative cooling rate for Chiangmai as a function of difference between ambient and surface temperatures (ΔT).

of the results of such calculations for Chiang Mai is shown in Fig. 5, in which net radiation heat fluxes from four types of radiators are plotted against the temperature differences between ambient air and the radiators (ΔT). As radiator temperature drops (i.e. ΔT increases), the net outward radiation heat flux decreases. The temperature difference at zero net heat flux is the theoretical equilibrium temperature, at which point emitted radiation equals absorbed radiation, in the absence of conductive or convective heat gain. Real temperature difference at thermal equilibrium would of course be smaller. Another point which should be noted is that the radiation flux depends strongly on seasons, ranging from approximately 50 $Wm^{-2}$ in January to less than 20 $Wm^{-2}$ in

July.

The above discussion represents a brief summary of the theory behind radiation cooling. In practice, however, several factors combine to render the theoretical equilibrium temperature unattainable. One is conductive and convective heat gain into the radiator, as previously mentioned. Another is that, once the radiator temperature drops below the dew point of the ambient air, condensation occurs on the radiator surface, and significantly reduces the net outward radiation flux. These factors must be borne in mind when utilizing radiation cooling.

## EXPERIMENTAL RESULTS

Experiments conducted at Chiang Mai, Thailand, during the winter (dry and cool period) indicated that the maximum temperature depression that could be obtained from a white-painted radiator (Fig. 6) was 9°C below ambient, under a clear sky. During the wet season, however, the temperature depression obtained was only 1-2°C, due to the very humid climate. At any rate, it should always be possible to cool down the radiator (or the cold-storage mass in the case of direct cooling) at least to the minimum ambient temperature at night.

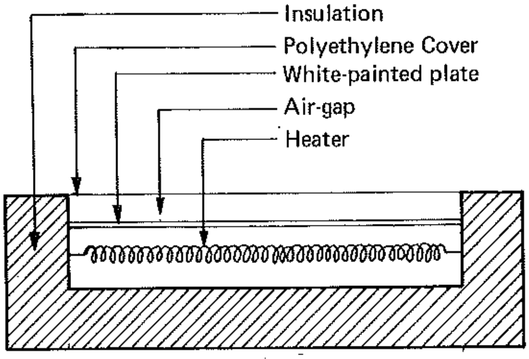

Fig. 6 White-painted radiator for experimental tests

Radiant heat flux measurements were made using a heat flux meter shown in Fig. 6. In this device, an electrical resistance wire was used to maintain the radiator plate temperature at the desired level. At steady state, heat flux supplied to the resistance wire, minus corrections for convection and conduction heat losses, was assumed equal to the outward radiant heat flux. Results obtained at Chiang Mai during a night in August showed large hour-to-hour fluctuations in values, as shown in Fig. 7. This was due mainly to the moving clouds, ambient air humidity, presence of rain, and wind conditions. During the winter, however, when the night sky was mostly clear, a consistent heat flux which averaged 40-50 $Wm^{-2}$ was obtained from a simple white-painted radiator at ambient temperature.

It is the personal opinion of the author that, in this tropical climate, theoretical estimates of atmospheric radiation, effective sky temperatures, or radiative cooling fluxes are of limited use, due to the highly variable sky conditions (clouds, rain, smoke etc.) during most of the year. If at all possible, an experimental measurement should always be made at the location of interest, and during the time of interest, in order to evaluate the feasibility of using passive cooling for the intended purposes.

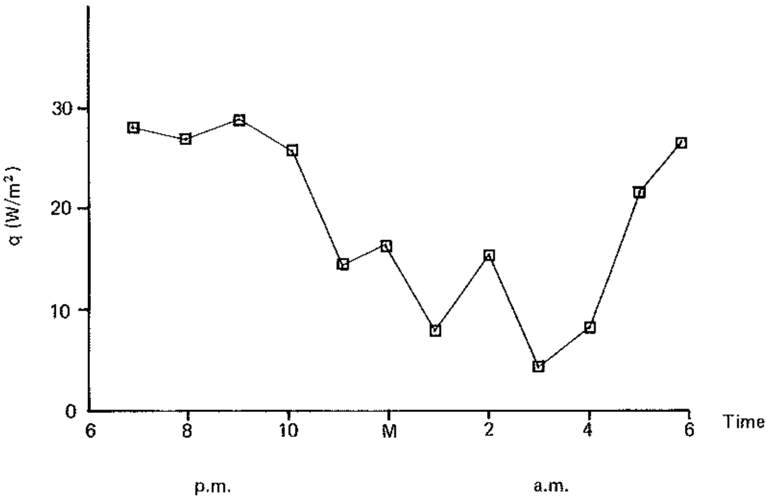

Fig. 7 Net heat flux from the radiator in Fig. 6 on a particular night

## APPLICATION OF PASSIVE COOLING IN AGRICULTURE

As previously mentioned, current efforts at Chiang Mai to utilize passive cooling in agriculture center on three possibilities:

1. for storage of produces such as fruits and vegetables,
2. for precooling, and
3. as a growth chamber for small plants which prefer cool, humid conditions.

To evaluate the feasibility of the first application, six passively-cooled scale models, each 1 x 1 x 0.8 m, were built and placed at three mountain locations for long-term monitoring. The models were of two types, roof-pond and white-painted radiator (Fig. 8). For the latter, which did not have built-in thermal storage capacity, small plastic bags containing water were placed inside the models, to serve as cold-storage mass. Data were taken over a one-year period. The results could be summarized as follows:

a. It was always possible to cool down the roof pond water to the minimum night time ambient temperature, and beyond, provided that the water depth did not exceed approximately 0.1 m (4 in).

b. Temperature inside the cooled chamber could also be lowered to the minimum night time ambient temperature. With proper insulation (at least 0.05 m of fiberglass insulation), diurnal fluctuations of temperature inside the cooled chamber could be limited to 2-3°C.

c. The white-painted radiator roof with polyethylene cover produced lower surface temperature than the roof pond, especially in the winter. However, in actual application what really matters is the cooling of the cold-storage mass, not just the radiator surface. Considered in this light, the white-painted radiator tested could not match the performance of the roof-pond. This was because heat must be transferred from the cold-storage mass to the radiator, and then from the

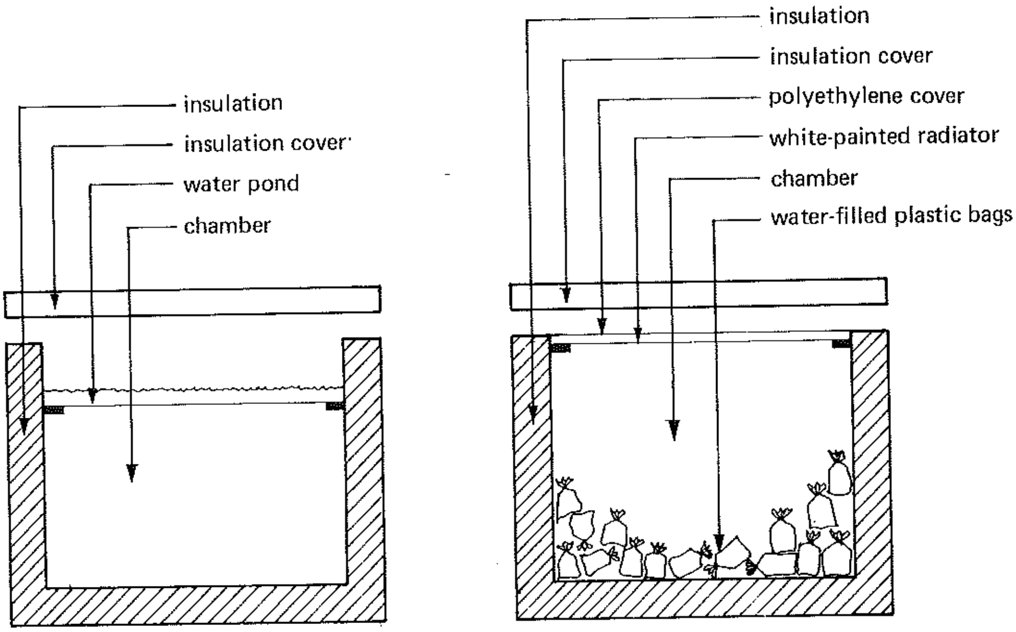

Fig. 8 Experimental chambers of passive cooling tests

radiator to the surroundings, whereby in the case of the roof-pond, the cold-storage mass (water) was cooled directly.

d. Other configurations of white-painted radiator/thermal storage mass were also tested, one of which is shown in Fig. 9. In this case, the cold-storage mass was in direct contact with the finned underside of the white-painted radiator, to improve heat transfer rates outward. Another was designed after Givoni[5], as shown in Fig. 10. This design sought to eliminate the relatively costly movable insulation, by having a fixed insulation layer immersed in the pond. However, experimental results showed that none of these designs could equal the performance of the open roof-pond, under the tropical conditions tested.

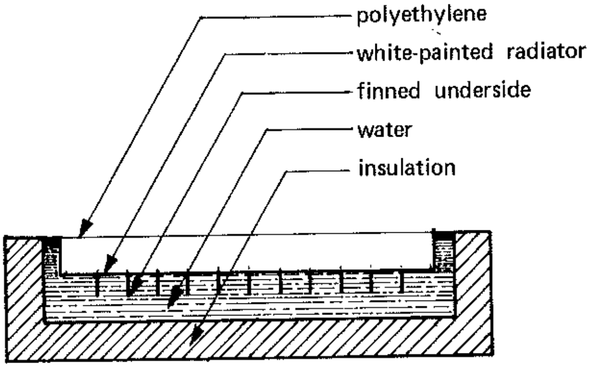

Fig. 9 Experimental radiator with heat transfer fins

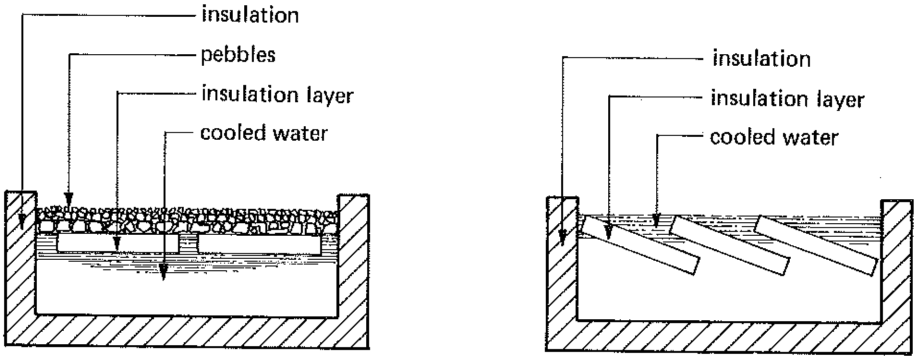

Fig. 10 Experimental radiator with fixed upper insulation layer.

After the results from the scale models were evaluated, a full-sized 3 x 3.5 x 2.5 m roof-pond room was built at Doi Ang Khang, Chiang Mai Province, for actual test storage of fruits. The room is shown in Fig. 11. Extensive shading was used in the design, to minimize heat gain into the room during the day. The walls were a double layer of concrete blocks, with approximately 5 cm gap in between. The depth of pond water was 0.1 m. The room is now being tested for storage of pears and persimmons.

Precooling, the second possible application of passive cooling in agriculture, was studied but not yet tested. The basic design is simply a shallow water-pond on the ground, with movable insulation on top. Pond water would be cooled at night. During the daytime the pond would be covered with insulation, and the cooled water would be drawn off to use in hydro-cooling of produces before packing and shipping. A full-scale test of this concept is being planned.

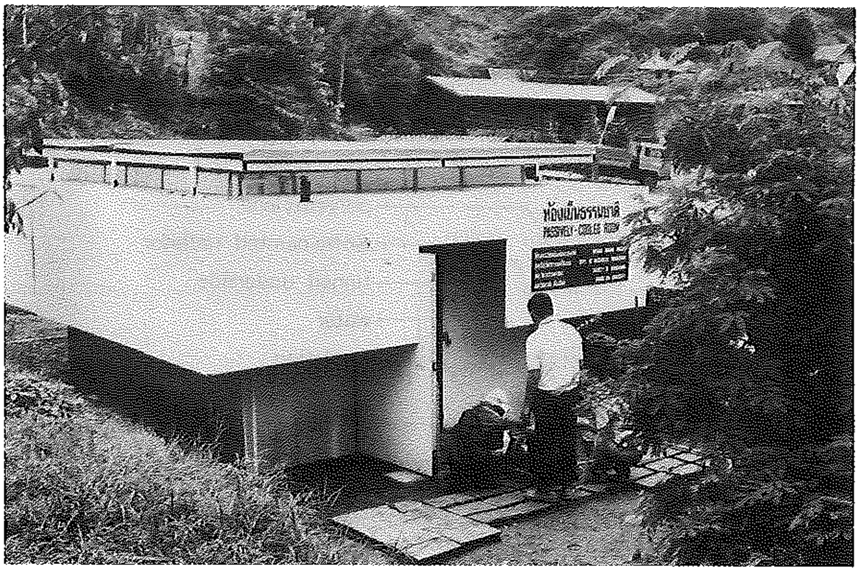

Fig. 11 Roof pond room for food storage.

The third possibility, that of using passive cooling in growth chambers, is being tested at Huay Thung Chao, also in Chiang Mai Province, for growing Champignon mushrooms. Normally, Champignon mushrooms can be grown in Chiang Mai only once a year in the winter, when ambient temperature is sufficiently low. By using a passively-cooled chamber, however, it is hoped that they can be grown two or three times a year, since conditions inside the chamber will always be cool and humid, with little diurnal fluctuations. If this is possible, the growers' income would be significantly increased; marketing the additional mushrooms very likely would not be a problem at this stage, as current demand for Champignon mushrooms in Thailand far exceeds supply. To test this concept, a 3 x 3.5 x 2.5 m roof-pond room was therefore constructed, with double side walls and movable insulation panels. Small ventilation holes were provided. The mushrooms will be grown in wooden trays, each 0.75 x 0.75 m, placed on shelves on both sides of the room. In addition, a conventional thatched-hut growth chamber with the same dimensions was also constructed, for comparison of mushroom yields with the passively-cooled chamber (Fig. 12). Tests are currently underway, with the first batch of mushrooms scheduled to be commenced in July 1983.

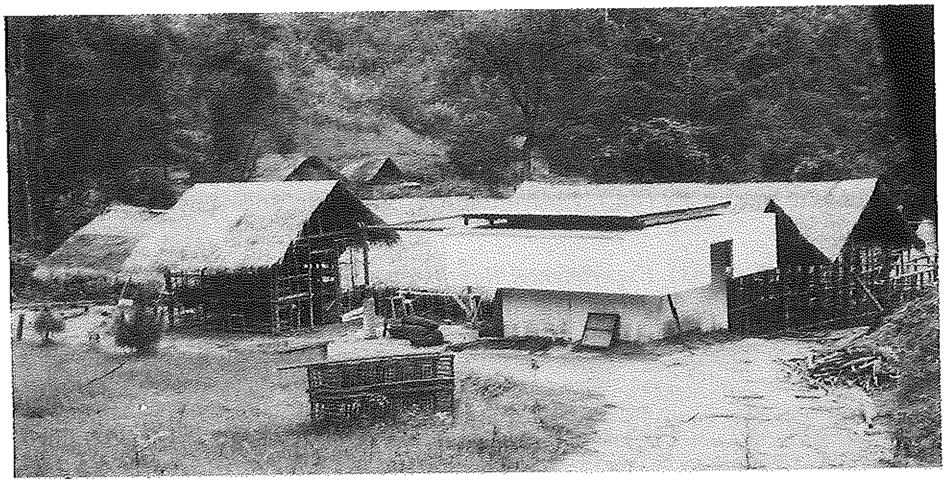

Fig. 12 Roof-pond room for growing Champignon mushrooms.

It should be noted that the passive method of cooling described so far will always produce humid conditions inside the cooled chamber. This is because the air temperature is lowered but moisture in the air is not removed, as is the case with conventional refrigeration units. Therefore, in applications in which a low-humidity storage condition is needed, some means of air dehumidification must be used. This could be achieved through a conventional compression-type dehumidifier, or some other low-energy systems, for example a system with solar regeneration. A system of the latter type has also been tested at Chiang Mai, using solid silica gel as the desiccant. Early results show that the system could lower relative humidity inside the cooled chamber to the 40% level, using approximately 2.1 kg of silica gel for each 100 g of water removed per day, provided that the daily solar insolation exceeds roughly 18 $MJm^{-2}$. Further work on this system is being conducted. A more detailed description of the system has been presented elsewhere[6].

## CONCLUSION

Application of passive cooling in the tropics appears to have a real potential, especially in agriculture where cool, moist air conditions are needed for many purposes. However, to utilize this concept effectively, it must be recognized that passive cooling usefulness depends on at least three factors previously mentioned: for what usage, at what location, and during which time of the year. More work needs to be done to assess the potential of passive cooling in various real applications.

## REFERENCES

1. GIVONI, B. (1982), Cooling by Longwave Radiation, *Passive Solar Journal,* Vol. 1, No. 3, pp. 131-150.
2. HAISLEY, R. (Ed.), *Passive and Hybrid Cooling Notebook.* (1981). Florida Solar Energy Association, Coral Gables, Florida.
3. BOWEN A. and others (Ed.), (1981). *Passive Cooling.* American Solar Energy Society, Boulder, Colorado.
4. BOON-LONG, P. (1981). Calculations of Longwave Spectral Atmospheric Emissivities and Potential of Selective Radiation Cooling for Chiang Mai, Thailand, *J. Sci. Soc. Thailand,* Vol. 7, pp. 147-153.
5. GIVONI, B. (1981). Experimental Studies on Radiant and Evaporative Cooling of Roofs. In A. Bowen and others (Ed.), *Passive Cooling,* American Solar Energy Society, Boulder, Colorado.
6. BOON-LONG, P. (1983). *Experimental Results on a Solar-Heated Dehumidification System Using Solid Desiccant.* Paper presented at Solar World Congress, Perth, Australia, August 14-19, 1983.