

# Indirect Evaporative Cooling with an Outdoor Pond

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## Abstract

This paper describes the performance of an indirect evaporative cooling system which consisted of an insulated water tank, cooled at night, and a test cell with the cooled water circulating through pipes embedded in its concrete roof. Several configurations of the system were analysed (e.g. with and without night ventilation, different hours of cooled water circulation within the roof, etc.). This paper explains the results when the cooled water was circulated inside the roof continuously during 24 hours. Predictive formulas are proposed to calculate average and maximum temperatures and the results are indicated. The performance of these systems is a function of the average Wet Bulb Temperature, permitting to determine with more precision the applicability of these systems in different climate zones.

## INTRODUCTION

The cooling potential of this system is mainly by indirect evaporative cooling combined with convection and radiation to the sky. Since cooling of the building occurs without elevating water content in the air, this system is suitable in places with high relative humidities.

## ANALYSIS: EXPERIMENT SET UP

The pond is 274.32 cm wide by 274.3 cm long and 91.44 cm high. Insulation panels surround it with a resistance of 1.94 m<sup>2</sup>K/W (R11 in USA). The initial water level of the pond was 45.5 cm (18"), for a volume of 11.2 m<sup>3</sup>. The test cell is 125 cm. Wide, 140 cm. high and 255 cm long. Its walls are plywood outside and fibreglass inside. The roof is 10 cm thick concrete with embedded tubing for cooling and two inches of insulation on its external layer. There are 193 concrete blocks (19x9x5.5 cm.) inside the cell. These characteristics create an insulated cell with thermal mass.

Measurements through the data acquisition system include DBT, solar radiation, wind speed, WBT, air and ceiling temperatures inside the cell, pond's water temperature, and inlet and outlet temperatures of the water. Because of space limitations, this paper is limited to the system when the cooled water was circulated within the roof during 24 hours.

## RESULTS

Results from two series performed during the summer of 1999 in the University of California at Los Angeles, are analysed in this paper: the test cell under floating conditions without operation of the cooling system (Sep 24-Oct 23), and the cell with tube cooling during the 24 hours (July 2–17). Daily patterns are analysed to generate predictive equations for the cooling condition.

## Continuous Pond Cooling

### Maximum Temperature

When the cooling system was operating, the maximum dry bulb temperature inside the test cell was found to correlate best with the average wet bulb temperature. The equation to determine maximum DBT inside the test chamber is a direct function of the average WBT:

$$(1) T_{mx} = WBT_{avg} + \Delta t$$

Where:

T<sub>mx</sub>: Predicted maximum dry bulb temperature inside the chamber in a particular day

Δt: Average elevation of the indoor maximum above the outdoors' average. In this case Δt = 4.4 K.

WBT<sub>avg</sub>: Average Wet Bulb Temperature for the day.

If we include the effects of Solar Radiation:

$$(2) T_{mx} = WBT_{avg} + \Delta t + k (GS_{avg} - S_{avg})$$

Where:

T<sub>mx</sub>: Predicted maximum dry bulb temperature

Δt: Average elevation of the indoor maximum above the outdoors' average. In this case Δt = 4.4 K.

WBT<sub>avg</sub>: Average Wet Bulb Temperature for that day.

K: Ratio of the daily changes of the indoor maximum temperature to the daily rate of change of the average solar radiation (0.0058 in our case).

GS<sub>avg</sub>: "Grand average" of the daily average solar radiation

S<sub>avg</sub>: The value of solar radiation for the series

Equation (2) for this series would be:

$$(2) T_{mx} = WBT_{avg} + 4.4 + 0.0058 (GS_{avg} - S_{avg})$$

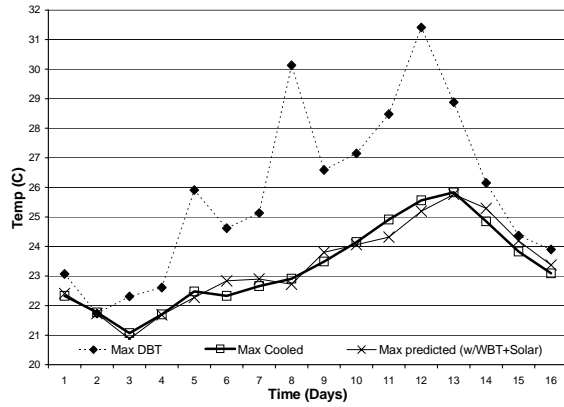


Fig 1. Predicted and measured maximum values inside the test cell with 24-Hour Pond Cooling.

*Average Temperature*

To determine average DBT inside the test chamber we can also apply Eq. (1) but in this case  $\Delta t = 3$

If we take into account the effects in the building due to the solar radiation we apply Eq. (2) and determine that in this case  $\Delta t = 2.9$  and  $k=0.0019$ . Then for this test cell and under these conditions Eq. 2 takes the following form:

$$DBT_{cell} = AvgWBT + 2.9 + 0.0019 (GS_{avg}-S_{avg})$$

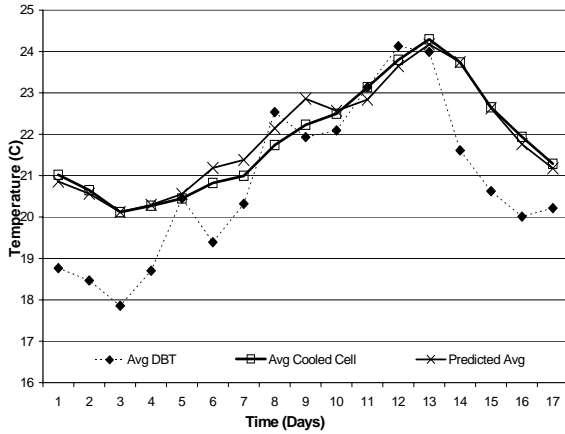


Fig. 2: Predicted and measured average values inside the test cell with 24-Hour Pond Cooling.

Predicted values for average and maximum temperatures follow the recorded values (Figs 1 & 2), validating the equations. The correlations for the cooled cell were  $R^2=0.9188$  for the maximum temperature as a function of average WBT and  $R^2=0.9534$  as a function of average WBT and average solar radiation. For the average temperature the correlations were  $R^2=0.9639$  as a function of average WBT and  $R^2=0.97$  as a function of average WBT and average solar radiation. Thus, even though there is an improvement when the effects of solar radiation are accounted for in the formula, the average wet bulb temperature is, by itself, an effective indicator of indoor maximum and average temperatures.

*Floating Condition*

The maximum temperature inside the test cell with floating conditions, correlated closely to the outdoor average as indicated in the equation proposed by Givoni [1] for buildings without cooling (Eq.3). To determine the average temperature, a similar equation (Eq. 4) was used, but in this case the previous day average DBT was used (TavgPD) instead of the same day average. This is probably due to the time lag effects on daily average temperatures.

$$(3) T_{mx} = GT_{avg} + \Delta t + k1 * (T_{avg} - GT_{avg})$$

$$(4) T_{avg} = GT_{vg} + \Delta t + k * (T_{avgPD} - GT_{avg})$$

**CONCLUSION**

Results were compared after applying the equations for the floating and cooling conditions to the same time period (Table 1). In the cell with the floating condition, without the cooling system, and with mass, insulation and colour acting as thermal regulators, the indoor maximum temperature is an average of 2.6 K below the outdoor maximum and the average temperature is 2.2 K above the outdoor average. When cooling is applied to this same cell, the maximum temperature inside the cell is lowered by an additional 1.3 K, to 3.9 K below the outdoor maximum, while the average temperature is now only 0.6 K above the outdoor average. These values indicate that an indirect evaporative cooling system, such as this pond can be combined with thermal mass and other bioclimatical measures, to passively cool a building.

Table 1. Comparison of Indoor- Outdoor Temps

Parameter (C)	Outside Dry Bulb	Cell with no cooling	Cell with pond Cooling
Maximum	28.1	25.5	24.2
Average	20.9	23.1	21.5

The indoor temperature in the building with no cooling is a function of the outdoor average temperature and when the building is cooled with the pond, it is a function of the average outdoor wet bulb temperature. This helps to determine the applicability of evaporative cooling systems under different climate conditions.

**REFERENCES**

1. B. Givoni, 'Minimum Climatic Information Needed to Predict Performance of Passive Buildings in Hot Climates'. PLEA 99 Conference. (Brisbane, September 1999), 197-202.

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