Modeling a Radiant Cooling Test Cell with Different Ua Values

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ABSTRACT:

Metal roofs cool down quickly, during the nights, acting as an effective nocturnal radiator directly above the living space. However, during the daytime hours the indoor temperatures in buildings with such often uncomfortably hot. Operable hinged **interior** insulation plates under the roof can reduce greatly the daytime heating without interfering too much with the cooling effect of such roofs during the nights. A model of this system (a test cell) was constructed and tested at UCLA. The main variable in the experimental series was the UA value of the walls of the cell. This paper describes the development of formulas that recreate the indoors maximum temperatures of a test cell with such a cooling system.

Conference topic: Methods and tools for design-assistance
Keywords: radiant cooling, housing, passive cooling, bioclimatic architecture

1. INTRODUCTION

In many developing countries corrugated metal or asbestos cement roofs are very common. During the nights the low-mass roof cools down rather quickly, acting in effect as an effective nocturnal radiator located directly above the living space. The indoor night conditions in such buildings are often more comfortable than in buildings with high-mass roofs. However, during the daytime hours the indoor climate in buildings with such roofs is often uncomfortably hot, as the un-insulated lightweight roofs have much higher temperatures than massive concrete and lightweight insulated roofs.

Installing centrally hinged interior insulating parallel plates under the roof can reduce greatly the daytime heating without interfering too much with the cooling effect of such roofs during the nights. When the plates are in a horizontal position (closed), during the daytime, they form a continuous insulation layer under the roof, minimizing the heat flow into the interior space. During the nights the plates should be turned into a vertical position, enabling radiant and convective heat flow from the interior space to the ceiling, which is cooled by the long-wave radiation to the sky.

A model of this system (a test cell) was constructed and tested at UCLA. The main variable in the experimental series reported in this paper was the UA value of the walls of the cell. Detailed description of the model and the experimental performance of this system is reported in another paper in this Conference (Laroche and Givoni 2002).

2. DEVELOPING THE FORMULAS

In developing formulas for predicting an indoor temperature parameter of interest, e.g. the indoor daily maximum temperatures, the first issue is to find out what parameter of the outdoor climate could best serve as a basis for predicting the indoor maximum. This means analysis of the patterns of the relationship between the daily outdoor maximum, average and minimum temperatures, as a set, and the indoor maximum. This analysis can be preformed visually by plotting the indoor parameter of interest over the background of the outdoor daily maximum, average and minimum temperatures. Once this relationship pattern is observed it is a relatively simple matter to express it in a formula.

This paper describes the development of formulas that recreate the indoors maximum temperatures measured at the upper level of the test cell when cooled by such a cooling system. As the heat gain/loss (UA Value) of the test cell was changed in the various experimental series, separate formulas had to be developed for each configuration of the test cell.

The following sequence will be repeated for each UA value of the test cell: For each series with a given UA value, the daily indoor maximum will be graphed over the background of the outdoor maximum, average and minimum temperatures. The observed pattern of relationship between the indoor maximum and the outdoor parameters will be described and expressed in a formula.

First Series: UA=4.6 W/sqm.K

In this series (October 2000) all the walls, as well as the door, were highly insulated, yielding a UA value of 4.6 W/sqm.K. Figure 1 shows the daily outdoor temperatures and the indoor maximums during this series.

The indoor maximum was closely related and slightly (about 0.7 oK) below the outdoor average. The day to day changes in the indoor average were smaller than the corresponding changes in the outdoor average. Also, as the daily swing (difference between the maximum and the minimum) was larger, the drop of the indoor maximum below the outdoor average was slightly larger. This pattern can be expressed by the formula:

$$T(in)max=Tavg-0.7-+(1.2-0.1167*(Tmax-Tmin)) \; 0.1168(Tavg-GTavg)$$

when GTavg is the period's average of the DBT average.

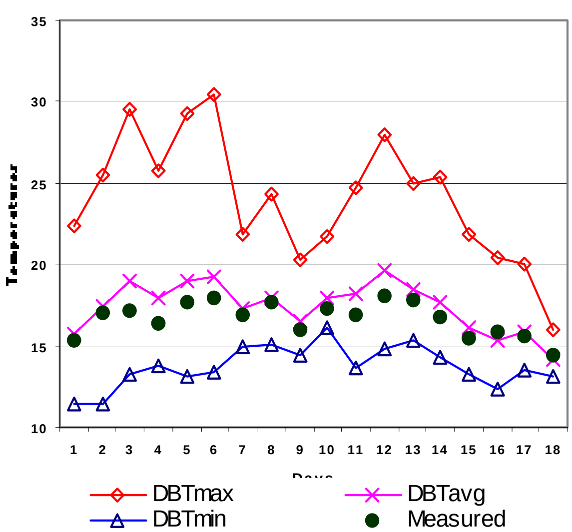

Figure 1: Daily outdoor temperatures and indoor maximums with the UA of the cell is 4.6 w/sqm.K

Figure 2 shows the DBT average and the measured and computed indoor maximum temperatures.

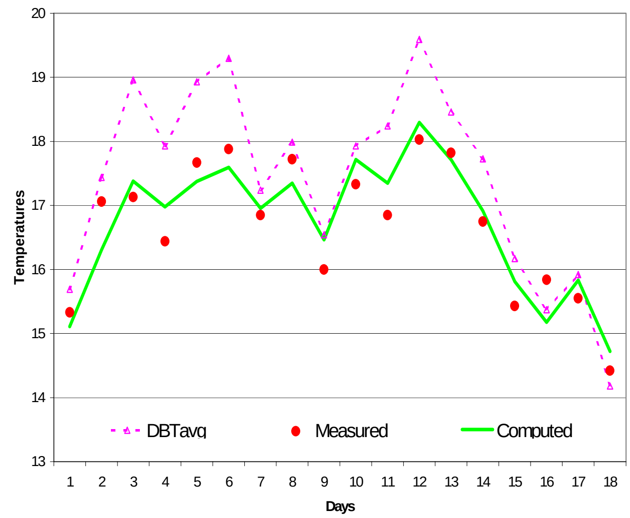

Figure 2: Daily measured and computed indoor maximum temperatures and DBT average.

Second Series: UA=8.1 W/sqm.K

In this series (June 2001) the insulated door of the cell was replaced by a PVC sheet, thus increasing the UA value of the cell to 8.1 W/sqm.K. Figure 3 shows the daily outdoor temperatures and the indoor maximums during this series.

Figure 3 shows the daily outdoor temperatures and the indoor maximums during this series (June 2001). The indoor maximum follows the outdoor average, with an average elevation of 2 oK.. The day to day changes in the indoor maximum are slightly smaller than the corresponding changes in the outdoor average. The diurnal swing throughout this series was almost constant, so its effect could not be evaluated.
The formula representing this pattern is:

$$T(in)max=GTavg+2-(-0.105*(Tmax-Tmin)+1.3)$$

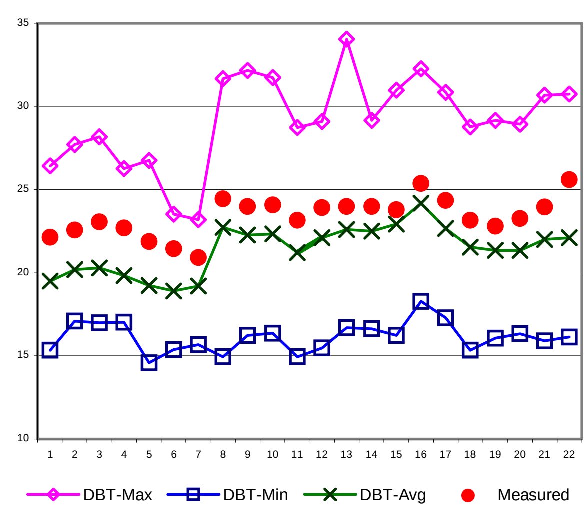

Figure 3: Daily outdoor temperatures and indoor maximums with the UA of the cell is 8.1 w/sqm.K

Figure 4 shows the DBT average and the measured and computed indoor maximum temperatures.

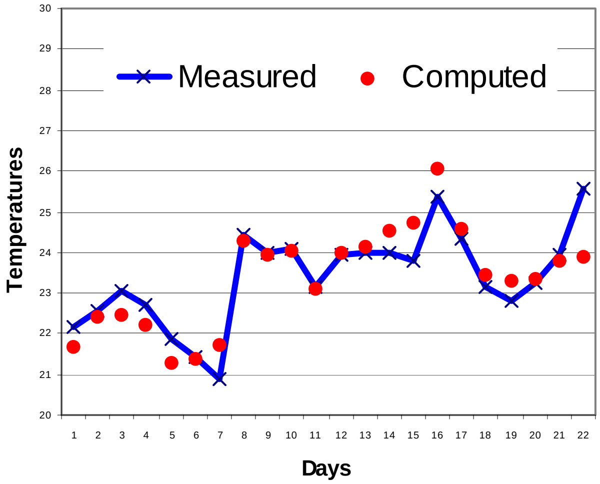

Figure 4: Daily DBT average and the measured and computed indoor maximum temperatures.

Third Series: UA=10.5

In the third series(December 5-January 10) part of the insulation from the east and north walls was removed, increasing the UA value of the cell to 10.5 W/sqm.K.

Figure 5 shows the climate data and the indoor maximum temperatures during this series.

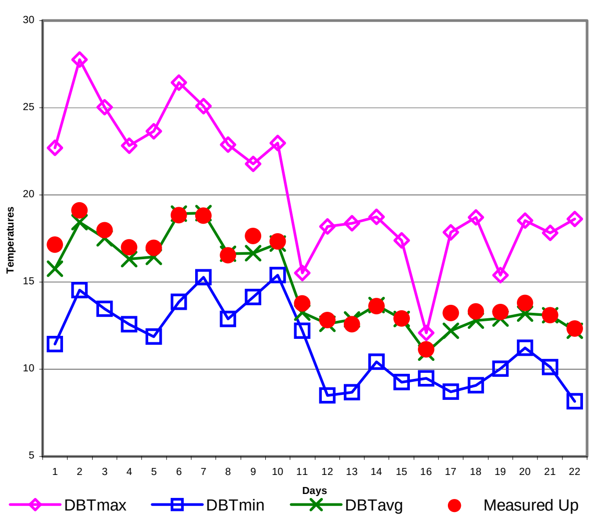

Figure 5: Daily climate data and the indoor maximum temperatures during the second series.

It can be seen that during this series the indoor maximum has followed very closely the daily outdoor average temperature, with an average elevation of 0.3 oK.

The formula expressing this observation is:

T(in)max=Tavg+=.35

Figure 6 shows the daily DBT average and the measured and computed indoor maximum temperatures

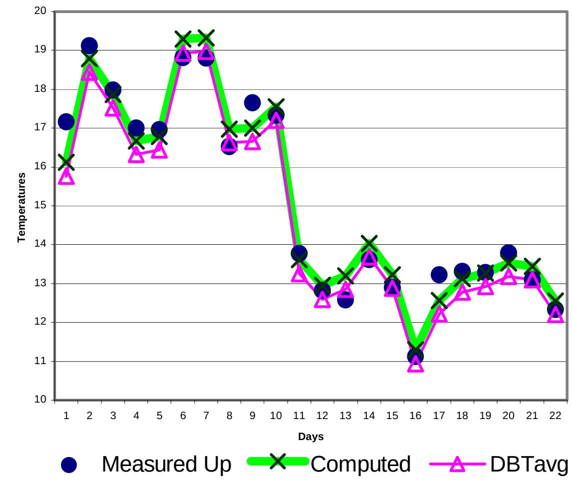

Figure 6: DBT average and the measured and computed indoor maximum temperatures.

Fourth Series: Ua = 13 W/sqm K

In the fourth series (November 14-December 5) part of the insulation from the south wall was also removed, increasing the UA value of the cell to 13 W/sqm.K..

Figure 7 shows the daily climate data and the measured indoor maximum during the fourth series.

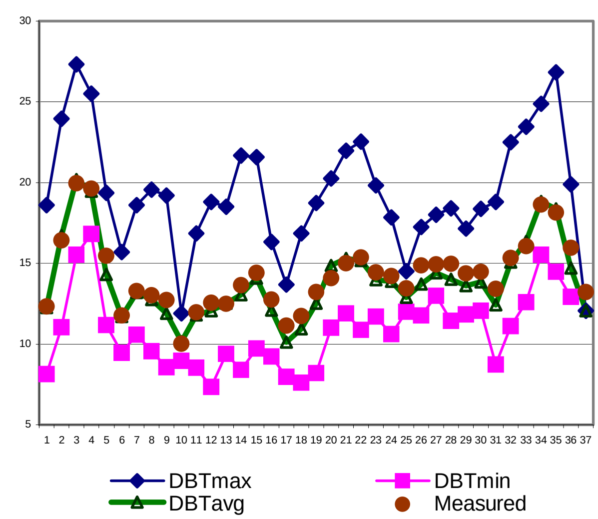

Figure 7: Daily outdoor temperatures and the indoor maximums in the third series.

Again, the indoor maximum followed very closely the outdoor average, with an elevation of about 0.4 oK. But close inspection of the relationship between the indoor maximum and the outdoor average has shown that it is slightly affected by the daily diurnal swing. As the diurnal swing was higher the indoor maximum elevation was smaller.

The formula expressing these observations is:

T(in)max=Tavg+0.8-0.05*(Tmax-Tmin)

Figure 8 shows the DBT average and the measured and computed indoor maximum in the forth series.

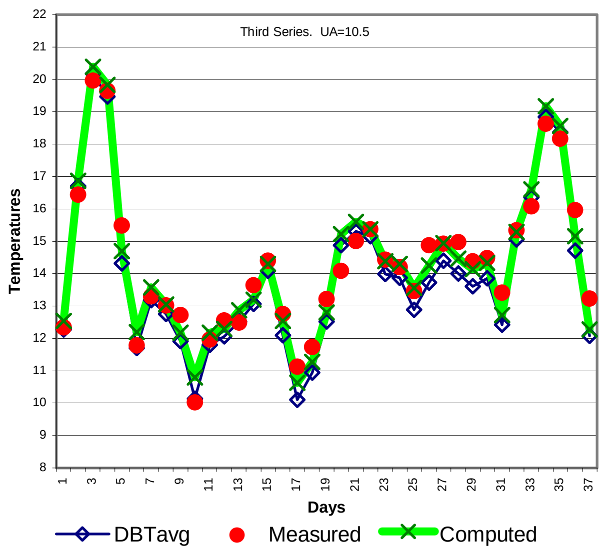

Figure 8: Daily DBT average and the measured and computed indoor maximums in the third series

Fifth Serie: Ua = 15.4

In the fifth series (July 28 – September 7, 2001) also part of the insulation of the west wall was removed, increasing the UA value to 15.4 W/sqm.K.

Figure 9 shows the daily climate data and the measured indoor maximum during the fourth series.

The indoor maximums have followed the outdoor daily average with an average elevation of 4.4 oK.
Larger diurnal swings have increased slightly this elevation.

The resulting formula for the indoor maximum is:

T(in)max=Tavg+4.4 +0.16(Tmax-Tmin)-1.9

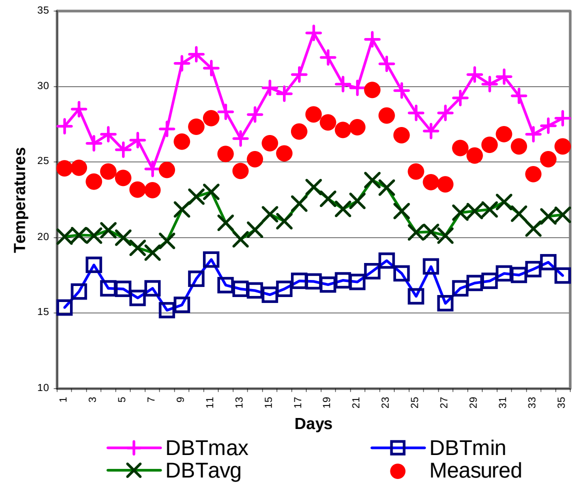

Figure 9: Daily climate data and the measured indoor maximum during the fourth series.

Figure 10 shows the measured and the predicted indoor maximums and the outdoor average temperatures.

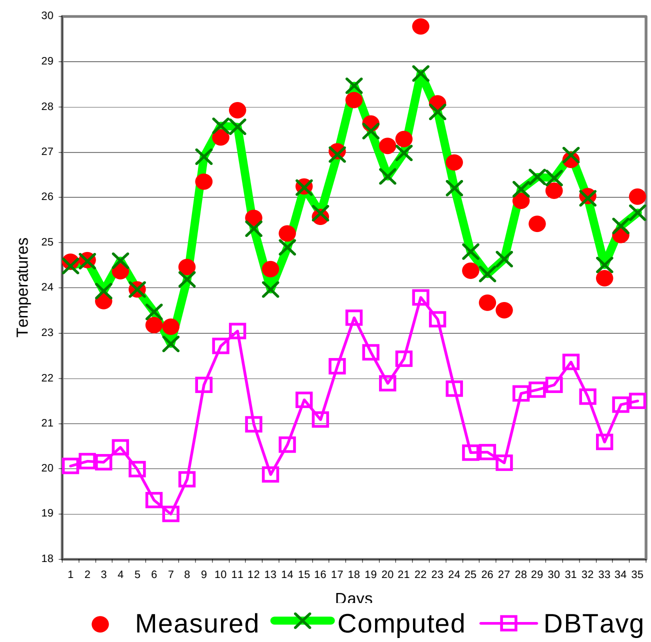

Figure 10: Daily measured and the predicted indoor maximums and the outdoor average temperatures.

DISCUSSION

The main variable in the various series was the UA value of the test cell. However, as the testing of the various series took place in different seasons, the average solar radiation was also different in each series.

A higher UA value of the test cell and a higher average solar radiation during a given series have increased the average elevations of the daily indoor maximum above the outdoor average. Analysis of the data in the various series resulted in the following formula:

Max Elevation = 0.324* UA+0.0115*solar-4.4

The following table shows the measured and the computed elevations of the maxima in the various series.

Table 1. Measured and computed values

Series Number	Ua	Solar	Measured	Computed
1	4.6	160	-0.7	-1.1
2	8.1	356	2.0	2.3
3	10.5	107	0.4	0.2
4	13	95	0.4	0.9
5	15.4	314	4.4	4.1

Figure 11 shows the measured and the computed elevations of the indoor maximums in the various series graphically.

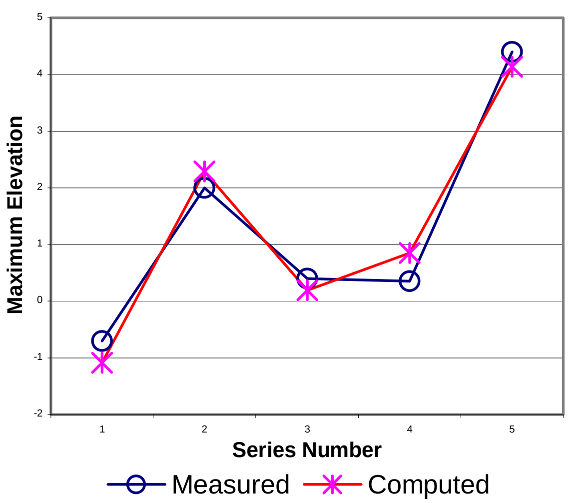

Figure 11: Measured and computed elevations of the indoor maximums in the various series.

REFERENCES

P. La Roche and B. Givoni (2002) : Effect of Heat Gain on the Performance of a Radiant Cooling System. PLEA'2002.