MEASUREMENT OF NIGHT SKY EMISSIVITY IN DETERMINING RADIANT COOLING FROM COOL STORAGE ROOFS AND ROOF PONDS

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ABSTRACT

Members of the Passive Solar Research Group have undertaken a project to measure the radiant cooling component of a cool storage roof at the Solar Energy Research Test Facility located at Allwine Prairie near Bennington, Nebraska. There are over fourteen hundred data points taken in a year's period of time that measure sky and surface water temperatures, night sky radiation, ambient temperature and dew point temperature. The purpose of this study is to develop a relationship between night sky emissivity values and dew point temperatures in order to develop an algorithm to predict radiant cooling.

The equation developed at the University of Nebraska is:

$$e_{sky} = 0.736 + 0.00577 \times T_{dp}$$

where:

e_{sky} is the sky emissivity ($0 < e_{sky} < 1.0$)
T_{dp}: dewpoint temperature in degrees Celcius

INTRODUCTION

Earlier work done by Berdahl and Fromberg at the University of California at Berkeley (1) and by Clark and Allen at Trinity University in San Antonio (2)(3) obtained different results. Berdahl and Fromberg obtained:

$$e_{sky} = 0.741 + 0.0062 \times T_{dp}$$

Clark and Allen of Trinity University, San Antonio, Texas, obtained,

$$e_{sky} = 0.787 + 0.0028 \times T_{dp}$$

Preliminary work performed by the Passive Solar Research Group (Chen, B. et al) at Nebraska (4) and published in 1991 with 149 data points, produced a value for the sky emissivity of:

$e_{sky} = 0.732 + 0.00635 \times T_{dp}$

CALCULATIONS

The sky emissivity values are obtained from an Eppley pyrgeometer that measures night sky radiation in watts/meter^2 which can then be divided by Boltzman's constant and the ambient temperature raised to the fourth power.

Hemispherical radiation is given by:

$S = e_o \sigma T^4$

where

S : radiation in watts/meter^2
e_o : emissivity (dimensionless)
σ : Stefan-Boltzman constant 5.6697×10^{-8} watts/meter^2 - ^oK
T : temperature of body ^oK

Sky emissivity is a dimensionless quantity which is a measure of the atmosphere's ability to transfer heat by radiation and is dependent on temperature (atmospheric and radiator) and water vapor content (cloud cover and humidity).

$$e_{sky} = \frac{S}{\sigma T_a^4}$$

where:

e_{sky} : clear night sky emissivity
T_a : ambient air temperature ^oK

The value of e_{sky} is then plotted against the dewpoint temperature and a least squares fit straight line equation is generated. The dew point sensor is a General Eastern Instruments Hygro M1 and Hygro E1 Optical Dew Point Monitor (Model 1211 H).

RESULTS

The graph of sky emissivity versus dew point temperature (in ^oC) is shown in Figure 1. Over 1400 individual points were used as data to develop a least squares fit linear equation. Maple 3.0 was the mathematics package employed in the regression analysis.

The linear equation is given by:

$$e_{sky} = 0.736 + 0.00577\ T_{dp}$$

For all 1446 data points, the standard deviation is 0.0350.

In addition to the straight line fit, a quadratic curve fit was also developed with a standard deviation of 0.035.

$$e_{sky} = 0.736 + 0.00571\ T_{dp} + 0.3318 \times 10^{-5}\ T_{dp}^2$$

The value of the coefficient related to the quadratic temperature term is quite small relative to the first order term (0.000003318 versus 0.00571) by an order of magnitude of over one thousand.

Over the expected temperature range of interest ($0 < T_{dp} < 30^oC$), the difference for the sky emissivity value is < 0.001 so the linear equation can be adopted.

ALGORITHMS TO MEASURE THE RADIATIVE ROOF POND COOLING COMPONENT

Once the clear night sky emissivity is known as a function of dew point temperature, the net radiative cooling from a roof pond, R, can be found from:

$$R = e_r\ (\sigma T_{pond}^4 - S)$$

where:

R : net radiative roof pond cooling W/m^2
S : global thermal sky radiance W/m^2
e_r : roof pond surface emissivity $0.93 < e_r < 1.0$
T_{pond} : roof pond temperature ^oC

The value of S can be measured with an Eppley pyrgeometer and the pond temperature is also known. The net radiative cooling component can be directly computed from the measurements for S and T_{pond}.

Replacing S in the above equation we can obtain an alternate solution involving pond and ambient temperatures (T_{amb}). Now, R is given by:

$$R = e_r (\sigma T_{pond}^4 - e_{sky} \sigma T_{amb}^4)$$

An upwards facing infrared thermometer from Everest Interscience (with a 165^o sky aperture) provides sky temperature readings. The value for S as a function of sky temperature rather than ambient temperature can be written as:

$$S = \sigma T_{sky}^4$$

As a result, given the night sky temperature we can rewrite the equation for net radiative cooling R as:

$$R = e_r \ (\sigma T_{pond}^4 \ - \sigma T_{sky}^4) \ W/m^2$$

CONCLUSIONS

As a conclusion it appears that the Nebraska results correlate well with the Berkeley results by Berdahl and Fromberg (within 2%) and to a lesser extent with Trinity University results by Clark and Allen (within 7%). Thus, for any dewpoint temperature, a sky emissivity can be computed. If the pond and ambient temperatures are known and given the pond surface's emissivity value, the net radiation to the sky can be computed. Alternatively, one can also utilize the pond temperature and the global thermal sky radiance S or the sky temperature T_{sky} to calculate the net radiative cooling component R.

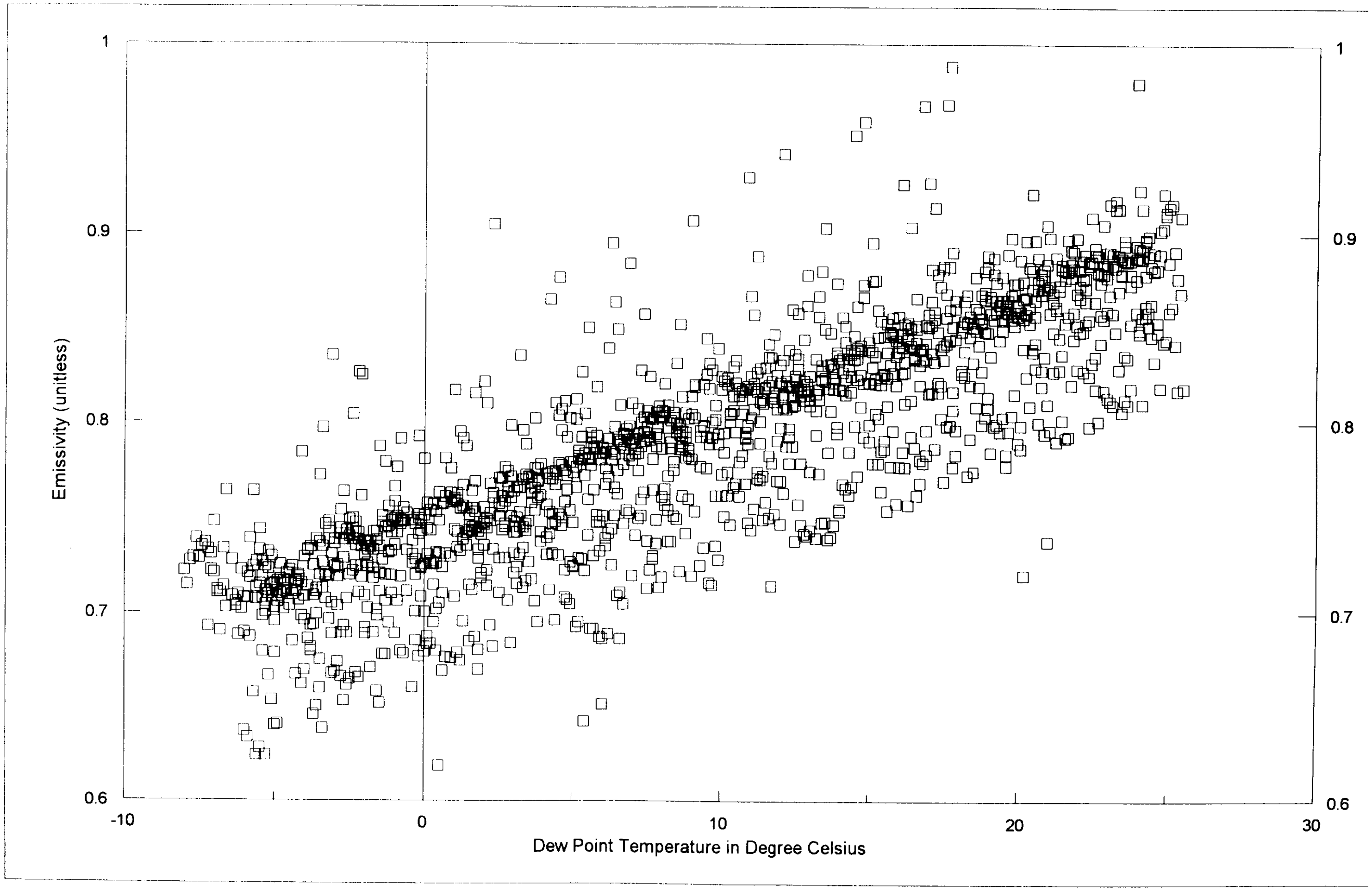

Fig. 1 Clear Night Sky Emissivity vs. Dew Point Temperature

REFERENCES

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