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CALCULATIONS OF LONG-WAVE SPECTRAL ATMOSPHERIC EMISSIVITIES AND POTENTIAL OF SELECTIVE RADIATION COOLING FOR CHIANGMAI, THAILAND

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Abstract

Long-wave spectral emissivities for the climate of Chiang Mai, Thailand, were computed, with emphasis on emissivity in the 8-13 µm transparency window. Calculations were based on 1970 monthly-averaged upper-air data up to a height of 10 km, assuming clear skies. Outward radiation fluxes from several surfaces at ground level at Chiang Mai were also estimated. Results show that between 8-13 µm, atmospheric emissivity varies from 0.42 in January and February to 0.81 in June and July. At other wavelengths, the emissivity is essentially unity. Hemispherical total emissivity ranges from 0.77 in February to 0.87 in June and July. Outward radiation fluxes from an ideal cooling surface varies from 50 W/m² in January to 20 W/m² in July. Potential application of this outward radiation flux in a passive cooling system is discussed.

Introduction

The far-infrared spectral emissivity of the atmosphere, especially in the 8-13 µm transparency window, is of interest in calculations of the radiative cooling of a surface at ground level[1,2] The more common examples are radiative heat loss from a solar collector, and radiative cooling from nocturnal passive systems. This atmospheric emissivity is usually reported in terms of the total value integrated over all wave-lengths of interest. A study of this type for the climate of Thailand has been made by Exell[3], who calculated downward atmospheric radiation fluxes at Bangkok, Chiang Mai, Ubon and Songkhla, based on 1969 meteorological data.

The emissivity of the atmosphere depends mainly on water-vapor emission, with carbon dioxide making some contribution in the 13–17 μm wavelength range. In Fig. 1 is shown the emission spectrum of water vapor at 290 K and density-length product (m_w) of 1.0 g/cm^2. It can be seen that there is weak emission between the 8–13 μm range. Advantages can be taken of this weak radiation range, particularly for cooling purposes, by using surfaces which have high emissivity between 8–13 μm. To do this, however, one must have an estimate of the *spectral* emissivity of the atmosphere at the location of interest. Such an estimate for the Chiang Mai atmosphere has been made in this study. In addition, expected outward radiation fluxes from several types of surfaces at Chiang Mai have also been computed, and will be presented in this paper.

Calculation Method

The atmospheric emissivity calculations are based on monthly averaged upper air data for Chiang Mai in 1970. These data are usually taken at 7 a.m. (0000 GMT) daily. Each set of monthly upper air data up to a height of 10 km is divided into layers consisting of ground level, first significant level (which is usually the top of the thermal inversion, when present), 850, 700, 600, 500, 400 and 300 mbar. Each layer is divided further into several sublayers, and the density-length product (m_g) of water vapor in each sublayer is computed. Emissivity for each wavelength interval is then calculated from the approximate relation :

$$\varepsilon_\lambda = 1 - \exp(-K_{\triangle\lambda}\, m_g)$$

where ε_λ is the emissivity in the wavelength range $\triangle\lambda$, $K_{\triangle\lambda}$ is the absorption coefficient of water vapor, according to Kondratyev,[4] as shown in Table 1, and m_g is the density-length product of water vapor in the sublayer. Corrections are then made for the carbon dioxide emission band at 14.7 μm, although the emissivity of the Chiang Mai atmosphere is already almost unity in that wavelength region. The spectral emissivities are then corrected for pressure and temperature, based on averaged ground conditions. The calculation process is then repeated for all the months in 1970.

From the spectral atmospheric emissivities obtained, expected outward radiation fluxes are computed for each month and for several radiating surfaces. For cooling purposes, the surfaces used include an ideal selective radiator ($\varepsilon = 1.0$ for 8.5 - 12μm and 0 everywhere else), a black surface, a TEDLAR - coated aluminum sheet, and a plate of white-painted steel. Their spectral emissivities are shown in Fig. 2. Since radiative cooling rates depend on differences between the temperature of the ground and the radiator, several radiator temperatures were used, and the results extrapolated to theoretical equilibrium radiator temperatures (in the absence of conductive heat gain).

TABLE 1 LOGARITHMIC ABSORPTION COEFFICIENTS OF WATER VAPOR (AFTER KONDRATYEV^4)

$\triangle\lambda$ (μm)	$K\triangle\mu$ ($cm^{-2}g$)	$\triangle\lambda$ (μm)	$K\triangle\lambda$ ($cm^{-2}g$)
5.0–5.5	40	19–20	43
5.5–6.0	118	20–21	23
6.0–6.5	198	21–22	58
6.5–7.0	156	22–23	64
7.0–7.5	46	23–24	80
7.5–8.0	12.8	24–25	75
8.0–8.5	3.4	25–26	53
8.5–9.0	0.10	26–27	93
9.0–12.0	0.10	27–28	116
12–13	0.25	28–29	136
13–14	0.84	29–30	152
14–15	1.30	30–31	179
15–16	1.65	31–32	179
16–17	4.40	32–33	179
17–18	17.2	33–34	198
18–19	14.0	34–35	110

TABLE 2 CALCULATED SPECTRAL ATMOSPHERIC EMISSIVITY FOR CHIANG MAI

Month (1970)	Spectral Hemispherical Emissivity (μm)					Total Hemispherical Emissivity
	5–8.5	8.5–9.0	9.0–12.0	12.0–13.0	13.035.0	
January	1.0	0.42	0.42	0.98	1.0	0.78
February	1.0	0.42	0.42	0.97	1.0	0.77
March	1.0	0.43	0.43	1.0	1.0	0.78
April	1.0	0.61	0.61	1.0	1.0	0.82
May	1.0	0.75	0.75	1.0	1.0	0.85
June	1.0	0.81	0.81	1.0	1.0	0.87
July	1.0	0.81	0.81	1.0	1.0	0.87
August	1.0	0.78	0.78	1.0	1.0	0.86
September	1.0	0.75	0.75	1.0	1.0	0.85
October	1.0	0.70	0.70	1.0	1.0	0.84
November	1.0	0.60	0.60	1.0	1.0	0.82
December	1.0	0.49	0.49	1.0	1.0	0.79

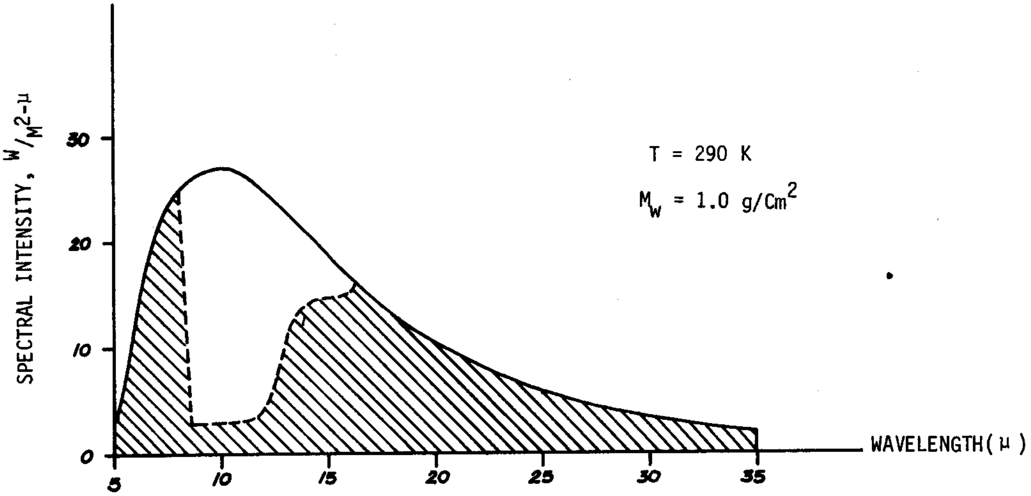

Fig. 1 Spectral Intensity of Water-Vapor Radiation (After Bliss[1])

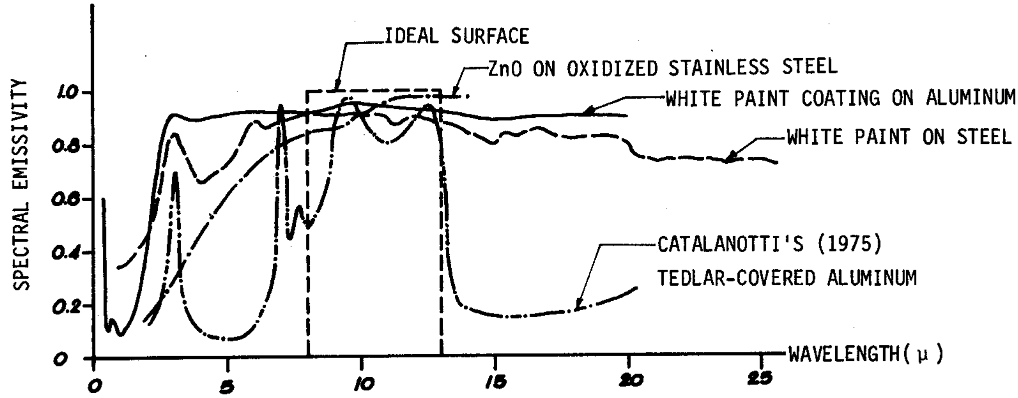

Fig. 2 Spectral Characteristics of Real Selective Surfaces.

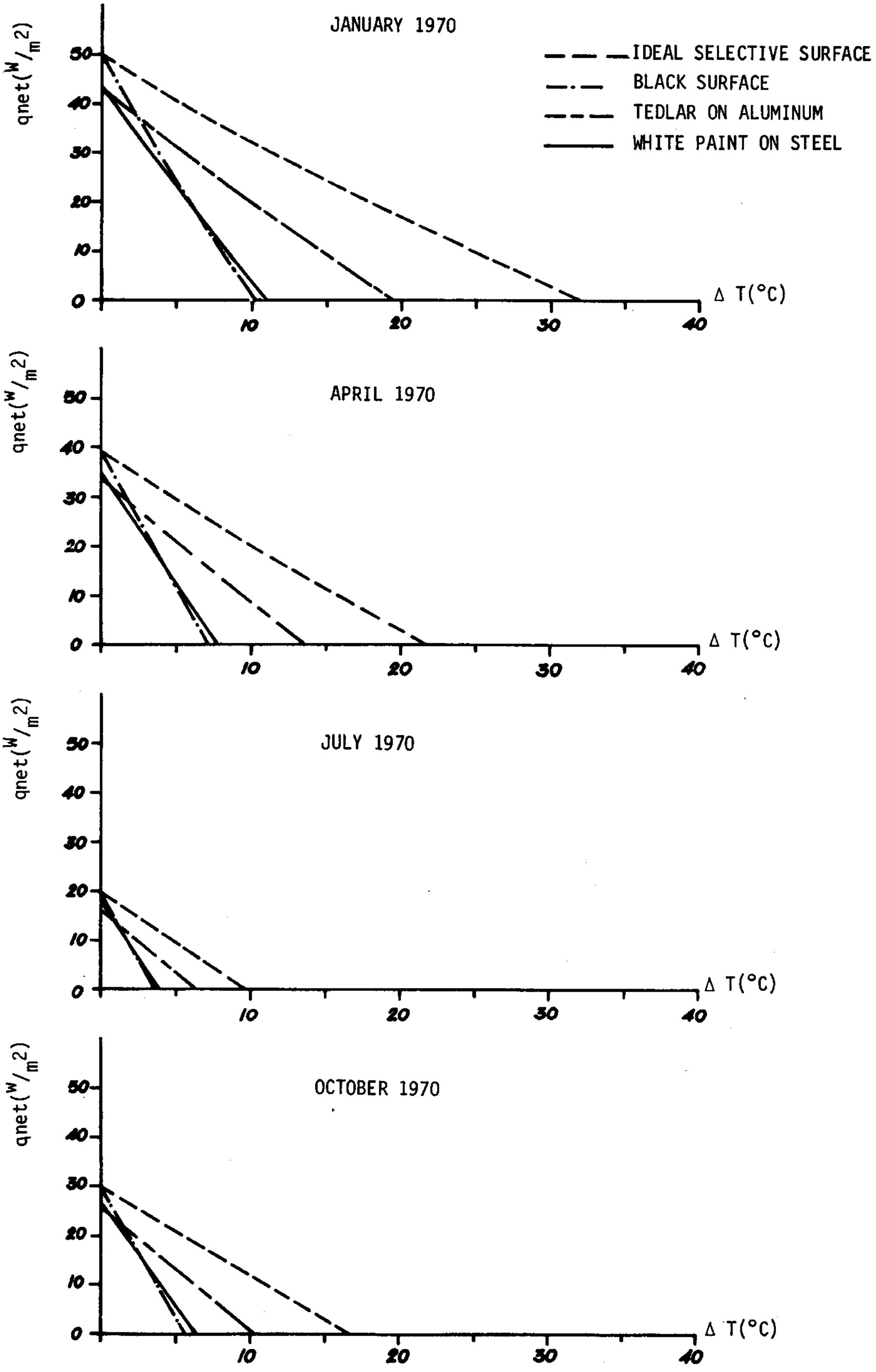

Fig. 3 Radiative Cooling Rate For Chiangmai Asa Function of Difference Between Ambient and Surface Temperatures (△T)

Results and Discussion

Results of spectral atmospheric emissivity calculations for Chiang Mai are summarized in Table 2. It is seen that only in the range 8.5 - 12 µm is the Chiang Mai spectral emissivity significantly less than unity. Spectral emissivities for the ranges 8.5-9.0 µm and 9.0-12.0 µm are equal for any month, since estimates for the coefficients $K_{\triangle\lambda}$ are the same for these two wavelength regions. Hemispherical total emissivity ranges from 0.77 in February to 0.87 in June and July.

For outward radiation fluxes calculations, spectral emissivities of the four surfaces previously mentioned are matched to each monthly atmospheric emissivity. The results are presented in Fig. 3. For an ideal cooling surface, a maximum cooling rate that can be expected is 50 W/m^2 in January, and 20 W/m^2 in July, both when the radiating surface temperature is the same as ambient temperature ($\triangle T = 0$). As temperatures of the radiating surfaces drop, radiation fluxes from the surfaces decrease. The rate of decrease varies, with the ideal cooling surface always showing the highest emitted radiation. The theoretical temperature difference between radiator and ambient ($\triangle T$ at zero emitted radiation, no thermal capacity and no conductive heat gain) for an ideal surface is seen to be 32°C in January and 9.5°C in July. With heat conduction into the surface, the equilibrium temperature will be higher, depending on the magnitude of conduction heat gain.

It must be emphasized that the calculations presented here are based on averaged meteorological data taken at 7 a.m., and an assumption of clear skies. Therefore, the results are strictly valid under those conditions only. However, it is believed that the results presented here could serve as an indication of radiative cooling behavior on an average night in Chiang Mai. For design purposes, results of these calculations are significant, for they show the monthly variations of radiative cooling rates that could be expected from several cooling surfaces.

Conclusion

Cooling by selective radiation in the 8-13 µm wavelength range has been shown to be significant, even in a tropical climate such as Chiang Mai. It is believed that radiative cooling of roughly the same magnitude should also be possible in the northeast. For example, Ubon, which is a northeast weather station for which upper-air data are available, should also be studied. Experimental verification of these calculations is also needed. In practical terms, this concept of passive radiation cooling could have significant applications as cool storage for agricultural products, especially in the north and northeastern highland areas of Thailand. A further study is therefore being undertaken to determine the feasibility of such a concept.

References

1. Bliss, Jr., R.W., (1961). Atmospheric Radiation Near the Surface of the Ground : A Summary for Engineers, *Solar Energy* 3, 103 - 120.

2. Catalanotti, S., Cuomo, V., Piro, G., Ruggi, D., Silvestrini, V. and Troise, G. (1975). The Radiative Cooling of Selective Surfaces, *Solar energy,* **17,** 83-89.

3. Exell, R.H.B. (1978) Atmospheric Radiation in a Tropical Climate, AIT Research Report No. 71, AIT, Bangkok, Thailand.

4. Kondratyev, K. Ya. (1969) *Radiation in the Atmosphere,* Academic Press, New York

บทคัดย่อ

บทความนี้ เสนอผลของการคำนวณหา spectral emissivity ในช่วงคลื่นยาวของบรรยากาศในบริเวณเมือง เชียงใหม่ โดยอาศัยข้อมูลการสำรวจอากาศชั้นบนของกรมอุตุนิยมวิทยาเมื่อปี 1970 จุดประสงค์เพื่อจะใช้ประกอบการศึกษาการทำความเย็นแบบ passive โดยวิธีเลือกแผ่รังสีในช่วง 8-13 μ ผลการคำนวณปรากฏว่าบรรยากาศในบริเวณเมือง เชียงใหม่มีค่า spectral emissivity ในช่วง 8-13 μ ตั้งแต่ 0.42 ในเดือนมกราคมและกุมภาพันธ์ ถึง 0.81 ในเดือนมิถุนายนและกรกฎาคม Total emissivity มีค่าตั้งแต่ 0.77 ในเดือนกุมภาพันธ์ ถึง 0.87 ในเดือนมิถุนายนและกรกฎาคม อัตราการแผ่รังสีจากผิวเลือกแผ่รังสีที่ perfect มีค่าตั้งแต่ 50 w/m^2 ในเดือนมกราคม ถึง 20 w/m^2 ในเดือนกรกฎาคม เมื่อท้องฟ้าแจ่มใส