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Performance Analysis of Night Sky Radiant Cooling System (Nocturnal Radiator)

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ABSTRACT

This paper deals with the Numerical investigation effect of wind Velocity, Relative humidity, cloudiness and Radiator plateemissivity on Cooling capacity of Nocturnal radiator (NR). The present investigation concludes that as the increases in wind velocity, cooling capacity of NR decreases due to convection heat losses.As increase of Relative Humidity Cooling Capacity of NR decreases, and that Clear Sky have Maximum Cooling Capacity as Compare to Cloudy Sky.The nocturnal radiators have the potential for reducing space temperatures by between3 -4^{o}C and can yield 16-40% savings in the energy demand of a building.

KEYWORDS: Nocturnal Radiator (NR), Passive Cooling, Dew point Temperature, Wind speed, Dew point temperature, Relative Humidity.

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INTRODUCTION

Radiative cooling is based on the heat loss by long-wave radiation emission from a body towards another body of lower temperature, which plays the role of a heat sink. In the case of buildings the cooled body is the building and the heat sink is the sky, since the sky temperature is lower than the temperatures of most of the objects upon the earth [2].

There are two methods of radiative cooling are known for buildings. The first one is called direct or passive radiative cooling where the building envelope radiates towards the sky and gets cooler. The second method is called hybrid radiative cooling. In this case, a metal sheet is the Radiator, which can be the roof of the building itself. In the cooling process, air or water is circulated under or in the radiator before it enters the building once again to cool it down with slab or ceiling cooling.

The working Principle of Nocturnal Radiator is opposite to the Solar air Heater, and it is operated in Night. Nocturnal Radiator is used for Space cooling, building cooling and used hybrid Cooling System.the nocturnal radiators have the potential for reducing space temperatures by 3^0C to 4^0C, it Consist of a high emissive radiator Plate , a rectangular passage which insulated from side and bottom. And a pump required circulating the air. When air passes through duct air get cooled by means of radiation and convection heat loss. the temperature gap between the radiative plate of the sky radiator and ambient temperature in the clear sky condition was bigger than that in the cloudy sky condition[3].

There are various parameters that affect the performance of Nocturnal RadiatorDew point Temperature, Relative Humidity, Wind speed,View FactorEmissivity and Spectral Characteristics,.

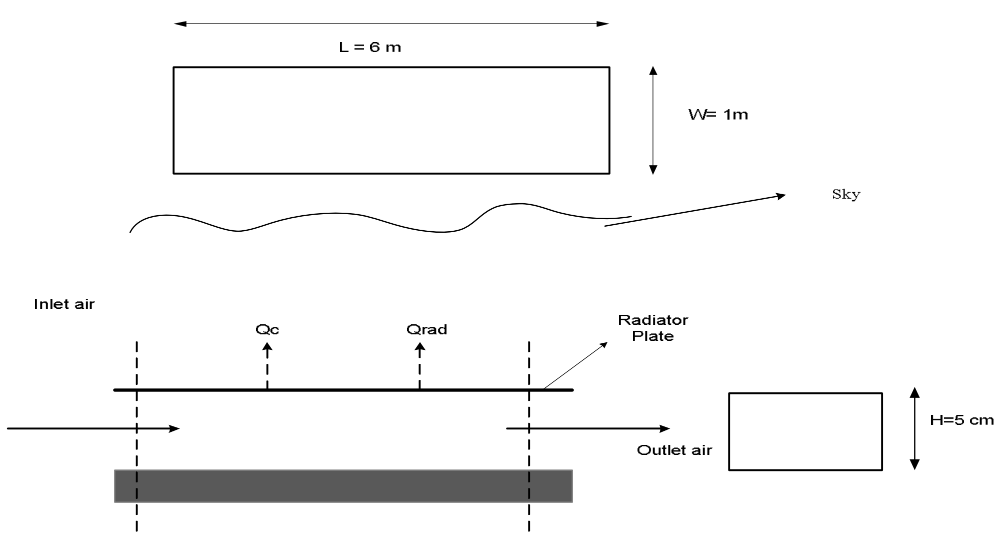

Figure 1.1 Construction details of night sky radiant Cooling System

METHODOLOGY

2.1 *Nocturnal radiator cooling*

The sky temperature is usually lower than the temperature of the most objects on the earth, so, any ordinary surface that ''sees'' the sky has a net long wave radiant loss [10]. The heat transfer between the Nocturnal Radiator and ambient environment at night mainly includes convection heat transfer and heat radiation transfer.

The overall energy balance of the nocturnal radiator is given by

$Q_c = Q_{rad} + Q_{con}$

Where,

Q_{con} = Convective Heat transfer

Q_{rad} = Radiative heat transfer

2.2 Convective Heat Transfer

The convective heat exchange between the radiator and the ambient air, which can express the cooling energy delivered to the building, can be written as:

$Q_{conv} = h_w(T_r - T_a)$ .... (i)

where,

h_w = the convective heat transfer coefficient which is a function of wind velocity.

T_a = Ambient Temperature

T_r = Radiator plate temperature

The convective heat transfer coefficients, used in the present study are calculated using the following expressions[2].

For a radiator without wind-screen

$h_w = 5.7 + 3.8V$ For $V < 4$ m/s

$h_w = 7.3V^{0.8}$ For $V > 4$ m/s

For a radiator covered by a single Polyethylene layer windscreen

$$h = 0.5 + 1.2V^{0.5}$$

Where h_w is the convective heat transfer coefficient between the wind screened covered radiator and the ambient air

2.3RadiativeHeat Transfer

The cooling power by long-wave radiation is given by

$Q_{rad} = \epsilon_{rad}\sigma[T_r^{\,4} - T_{sky}^{\,4}]$ .... (ii)

$$T_r = \frac{T_{in} + T_{out}}{2}$$

Where,

σ = Stephan Boltzman constant = 5.67×10^{-8} w/m^{2}K^4

ϵ_{rad} = emissivity of radiator plate

T_r= Radiator plate temperature

T_{sky}= Sky Temperature

2.4 Sky Temperature

Ambient temperature and sky equivalent temperature are two effective measures of the surrounding conditions. These two measures affect the cooling performance and outlet temperature of the collector exposed to the night sky. The difference between ambient temperature and sky equivalent temperature demonstrates the potential of the nocturnal cooling.

$$T_{sky} = T_a(\epsilon_{sky})^{.25} \qquad \text{........................ (iii)}$$

Where, ϵ_{sky} =Sky Emissivity

The mathematical formulation expressing the emissivity of clear sky, as a function of the ambient dew point temperature, many correlations are reported in the literature for calculating the sky emissivity. In this paper, the Berdahl and Martin relation are:

$$\epsilon_{cs} = .711 + .56\left(\frac{T_{dp}}{100}\right) + .73\left(\frac{T_{dp}}{100}\right)^2$$

Where T_{dp} = dew point temperature in ^{0}C

2.5Dew point temperature

Dew point temperature is Function of Relative Humidity of air and calculated by following Correlation:

$$T_{dp} = \frac{C_3 \times \{\ln(RH) + C_1\}}{C_3 - \{\ln(RH) + C_1\}} \qquad \text{................................ (iv)}$$

C_1 to C_3 can be calculated as the following

$C_1 = \frac{C_2 \times T_a}{C_3 + T_a}$ $\qquad C_2 = 17.0808$

$C_3 = 234.175$

Where,

RH = Relative Humidity

T_a =Ambient Temperature

2.6 Cloudiness

Cloudiness has an effect on the atmospheric radiation which can be expressed by the factor

$$CF = 1 + 0.0224n - 0.0035n^2 + 0.00028n^3 \qquad \text{.............................. (v)}$$

Where n is the total opaque cloud amount (0 for clear sky and 1 for overcast sky).

Therefore, the sky emissivity is given by

$\epsilon_{sky} = CF \times \epsilon_{cs}$

CF = Cloudiness factor

2.7 Stagnation temperature

The stagnation temperature of a metallic radiator is the minimum temperature that the radiator can attain and can be calculated as a function of the air and sky temperatures,cloudiness and wind velocity.

Thus, it can be expressed as follows:

$$T_{st} = T_a - \frac{q_0}{h_e} \qquad \text{................. (vi)}$$

Where,

T_{st} = stagnation temperature

q_0 = The net radiative power of a blackbody at the ambient temperature

The net radiative power of a blackbody at the ambient temperature is given by

$$q_0 = \sigma T_a^{\ 4}(1 - \epsilon_{sky})$$

2.8 Overall heat transfer coefficient

Overall heat transfer coefficient calculated by the following expression:

$$\frac{1}{U} = \frac{1}{h_e} + \frac{1}{h_f} + \frac{d}{k} \qquad \text{........................... (vii)}$$

Where, d is the thickness of the radiator

k = the thermal conductivity of the radiator

h_f= heat transfer coefficient between the radiator and the air circulating in the duct,

And h_e= the effective heat transfer coefficient

Effective heat transfer coefficient defined by the following expression:

$$h_e = h_w + h_r$$

Radiative heat transfer coefficient h_r, which is derived from eqn.

$$h_r = 4\sigma\epsilon_r\ T^3{}_a$$

Hence

$$h_e = h_w + 4\sigma\epsilon_r\ T^3{}_a$$

Peavy (1979) recommends the following relationship for turbulent flow over smooth surfaces at low air velocities (V < 3 m/s):

$$h_f = 7.176 v^{.8} L^{-.2}$$

L =Length of the Radiator

V= Velocity of air inside the duct

2.9 Temperature Distribution

The temperature distribution in the flow direction is a key parameter in the design of a cooling radiator. The exit air temperature of the heat transfer fluid flowing through a one-dimensional path in a radiator is presented by the following expression:

$$\frac{T_{out} - T_{st}}{T_{in} - T_{st}} = e^{\frac{-UA}{m_a C_p}}$$

Where A is the surface area of the radiator

C_p= Specific Heat KJ/kg K

m_a= mass flow rate of air in kg/sec

T_{in} = Inlet temperature of Air

T_{out} = Outlet temperature of Air and

U = the overall heat transfer coefficient between the air circulating under the radiator and the ambient air,

CALCUALTION

In this analysis the nocturnal radiator model of dimension 6 m length 1m width of radiator plate of steel is used in the analysis of cooling Capacity of nocturnal radiator. Assume ambient temperature 27^0C and other Parameter as shown in table 1.1

Table No. 1.1 value of design parameter of nocturnal Radiator

Parameter	Value
Radiator plate	Steel
Length (L)	6 m
Width (W)	1m
Thickness of Radiator plate (t)	2 mm
Height of duct Under plate (Z)	5cm
Emissivity of the metal Plate Radiator (ε)	0.9
Thermal conductivity of Plate (steel)	16 w/m^2
Air Velocity inside the radiator	2.765 m/s
Cloudiness	Clear Sky

RESULTS AND CONCLUSIONS

4.1 Effect of Relative Humidity

Generally, the clear sky emissivity varies with the dew point temperature declining as dew point temperatures fall. This obviously varies with climate. one commonly described index to radiative cooling potential is the "sky temperature depression" which is merely the average difference between the air and sky temperature. dry locations have the greatest sky temperature depression and thus the greatest potential to take advantage of radiative coolingfrom the fig 4.1 it is seen that Cooling Capacity of Nocturnal radiator is decreases as relative Humidity of air Increases, and we know that dew point temperature is function of Relative Humidity. Due to increase in dew point temperature Cooling Capacity of Nocturnal radiator is decreases.

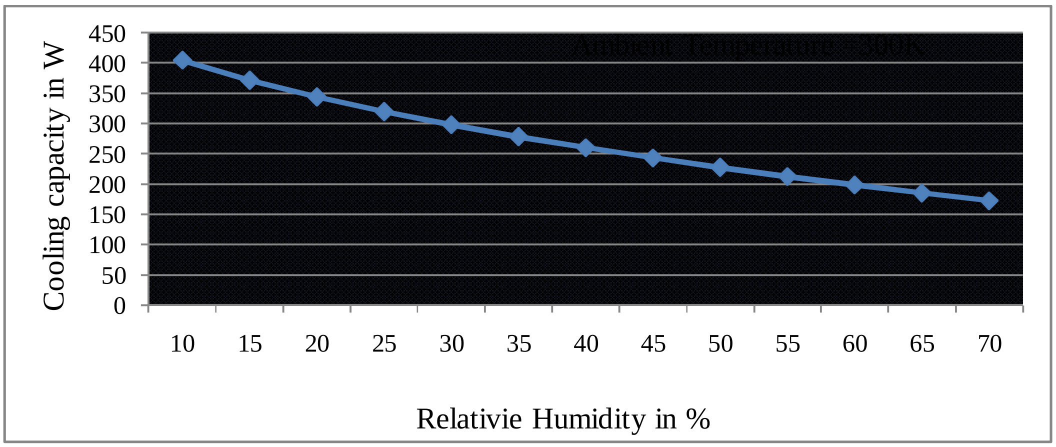

Fig No. 4.1 Effect of Relative Humidity on Cooling Capacity

4.2 Effect of Wind Velocity

Night sky cooling can be strongly affected by winds. As Radiator surfaces fall below the ambient air temperature, they begin to gain heat by air convection. Still air and windless conditions produces the least heat added to the exposed surface. Thus anything that reduces wind speeds around the radiating surfaces (without blocking the sky view) will help increase nocturnal radiation. From fig 4.2 it is seen that Cooling Capacity of Nocturnal radiator is Decreases as Wind Velocity of air Increases, because high wind increase the Convection Heat transfer but decrease the radiation heat transfer, hence net heat transfer is decreases. Total heat transfer decreases due to increase in radiator Surface Temperature.

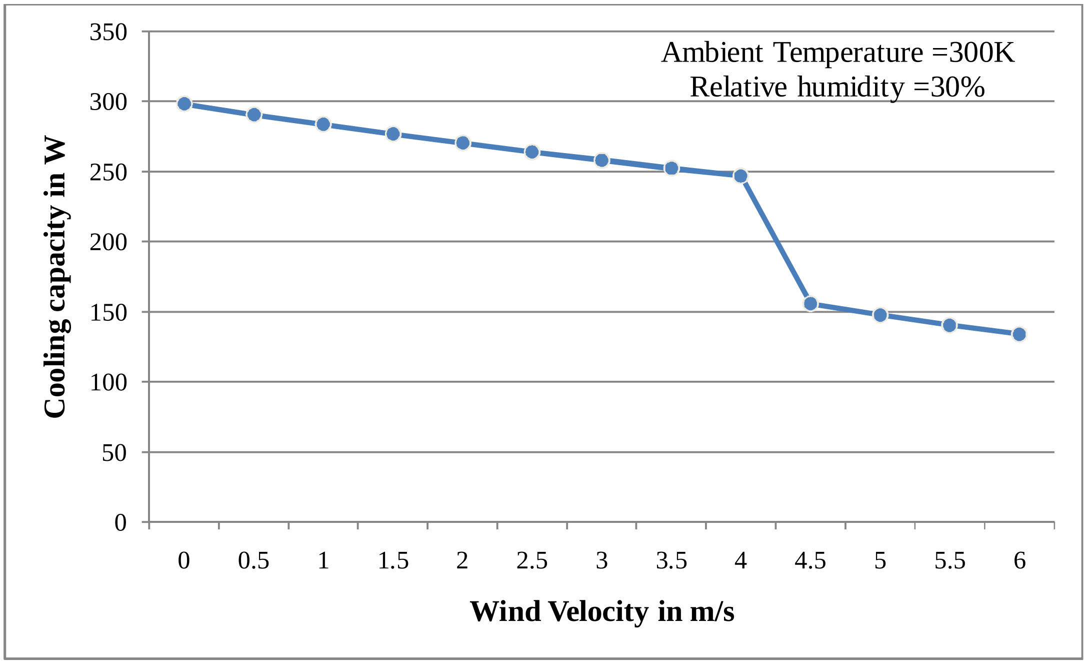

Fig No. 4.2 Effect of Wind Velocity onCooling Capacity

4.3 Effect of Cloudiness

A cloudy sky during night-time hours is a known factor in reducing the potential for nocturnal cooling. clear sky conditions allow night sky radiation to reach its maximum potential. From the fig 4.3 it is seen that Cooling Capacity of Nocturnal radiator is decreases as Cloudiness Factor is increases due to cloud amount increase. Sky temperature depend upon the Cloudiness factor, Cloudy sky increases the Sky Temperature hence Cooling Capacity of Nocturnal radiator decreases.

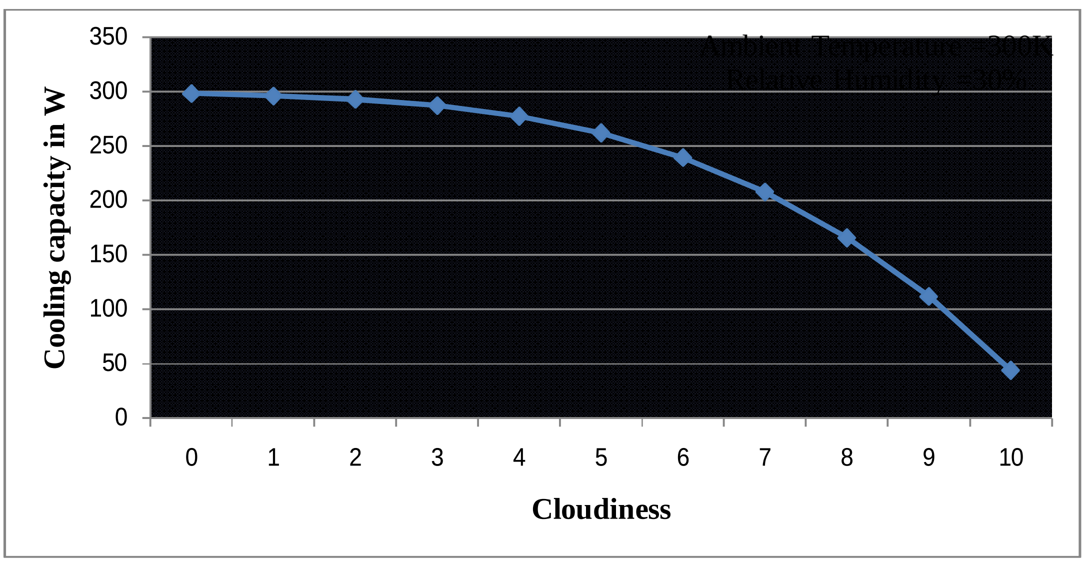

Fig No. 4.3 Effect of Cloudiness on Cooling Capacity

4.4 Effect of Emissivity of radiator Plate

Building surfaces radiate to the night sky primarily in the so-called “sky window” between 8 and 13 nanometres. Thus surfaces which have their highest emittance in this range will perform best. From the fig 4.4 it is seen that Cooling Capacity of Nocturnal radiator is Increases as emmisivity of Radiator Plate Increases

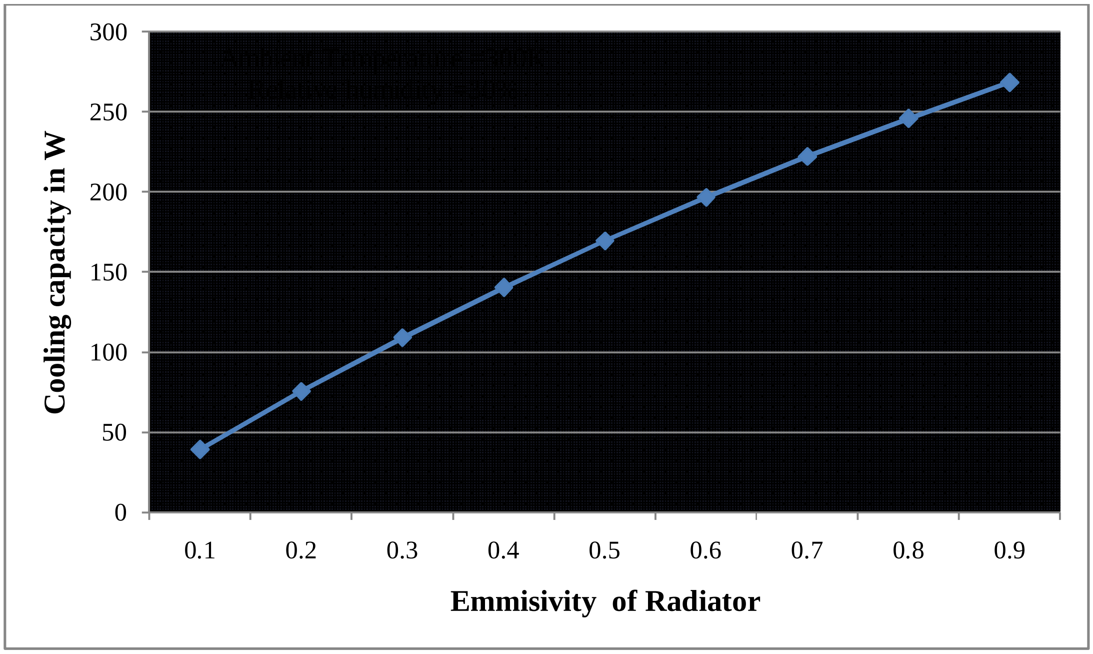

Fig No. 4.4 Effect of Emissivityof radiator on Cooling Capacity

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