RENEWABLE ENERGY 2010 Proceedings
27 June - 2 July, 2010
Pacifico Yokohama, Yokohama, Japan

P-At-22

STUDY ON COOLING SYSTEM WITH USING WATER MIST - CONTROL STRATEGY FOR WATER MIST SYSTEM -

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This study aims to promote usage of cooling system with water mist. To achieve subject of this study, it is necessary to make clear for the proper operation and establish control scheme. The cooling system with water mist is controlled on/off by water pump; operation of turn on / turn off. Also, there are two control methods, manual and automatic. The automatically control will be needed when the getting wet resident face and cloth not permitted or water-drop must be prevented. In this paper, the control scheme for water mist system was evaluated and proposed proper control method based on empirical control scheme. 28.5 - 29 degree C of Dry-bulb and 70% of relative humidity are considered proper range to spray mist.

Keywords: Evaporative cooling system, Water mist, CFD, Control strategy, Urban hot climate

INTRODUCTION

In recent, urban hot climate in summer advance and the danger of healthy damage to the citizen and the economic loss increased more and more. This urban hot climate due to artificial exhaust heat from building, factory and cars, also sky factor decrease by building, improve absorption for solar radiation, reduction of cooling effect by green decrease, road pavement and air pollution. As a measure against urban hot climate, the increase of evaporation cooling effect by increasing green such as plant and lawn. However increasing green takes time and cost, this measure should be promoted by a point of view of the long term. From a short-term point of view, the cooling system by using water mist is nominated for proper measures. Water mist cooling system is a simple system, composed of water pump, nozzles and pipe. And, this system is inexpensive one compared with measure of increasing green. Also, this system can be obtained evaporative cooling effect exactly. From these reason, we can say that water mist cooling system is to be immediate effect measure against urban hot climate.

The installation examples of the Water mist system increase, and a performance evaluation result is provided by actual field experiment. According to these results, air temperature fall down of 3-4 degree C could be obtained by using Water mist system [1]. In addition, it is proved that water mist system have influenced to thermal comfortable [2]. As mentioned above, the effectiveness of the Water mist system has been evaluated. On the occasion of spread of this systems promotion, it is necessary a design procedure can be enabling to proper design and use. However, water mist system is designed and operated by empirical data, and it has not proved yet the empirical data is valid or not.

In this paper, the control scheme for water mist cooling system is discussed based on conventional control scheme, and the proper control parameter will be proposed.

ANALYSIS METHOD

As for the control parameter of the Water mist system, air temperature, humidity, the wind velocity, the rain fall are considered. In this paper, air temperature and humidity are discussed only because other parameter will not be determined by cooling effect of water mist. CFD analysis adapted the disperse phase model that the validity was proved [1] was used for this analysis.

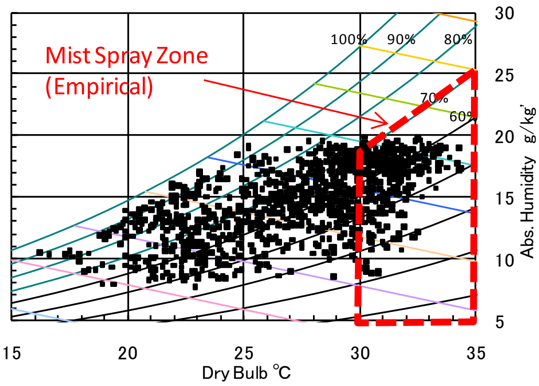

Figure 1. Water mist spray condition

Table 1. Empirical Control Strategy for Spray

	To be start (If all conditions shown below are satisfied)	To be stopped (If any conditions shown below are satisfied)
Outdoor air temp.	31 Degree C. above	30 Degree C. under
Outdoor air Humidity	60% Rh under	70% Rh above
Air velocity	When mean velocity during 10 minutes is under 3.0 m/s	3.0 m/s above
Rain fall	No rain	Rain

In figure 1 Tokyo weather data are shown on psychometric chart. The dots in figure 1 are data for outdoor air during cooling season; 1st June to 30th September only from 9 am to 5 pm. A red broken line shown in figure 1 indicates a zone determined by experience as a proper condition for outdoor air to spray mist. The zone is prescribed by Dry-bulb temperature and relative humidity; Dry-bulb temperature is 30 degrees Celsius over, relative humidity is 70% below. The number of hours to spay according to this zone will be 184 hours during the cooling season.

For the outdoor air conditions to spray mist shown in Figure 1. the simulation is conducted for verification and proposal of the proper control strategy, assuming semi-open outdoor area installed water mist system.

As shown in Figure 2, the calculation domain is to be a 50-m long, 15-m deep, and 4-m high semi-outdoor space for analysis. The three sprayers are positioned at a height of GL 1.5 m. We then applied the boundary conditions shown in Table 1.

The parameters of simulation are outdoor air temperature and air humidity. Outdoor air temperature is given as 29C, 30C, 32C and 34C. And, Air humidity is given as 60%, 70%, 75% and 80%. In order to investigate the cooling effect of the mist at different outside air temperatures and humidity levels, we fixed the value for the external air inflow at 0.1 m/s, and solar radiation is consumed to 363 W/m^2 which is an average rate for the assumption period. The two boundaries of the rooftop surface and the ground were given a surface temperature and a coefficient of heat convection.

We used the common numerical fluid analysis software Fluent 6.3 for numerical analysis. The Discrete Phase Model was used and we considered the interaction between the mist particles and gas (air), including heat transfer, phase changes, and the momentum conservation law. Also, we adopted the pressure-swirl atomizer model to analyze the nozzle spray conditions shown in Table 2.

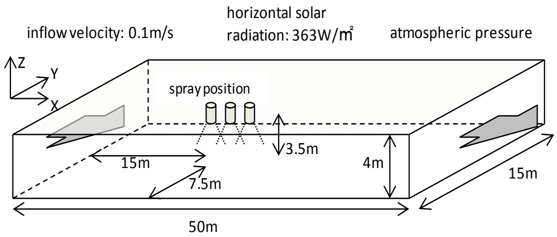

Figure 2. Calculation domain

Table 1. Boundary conditions

Boundary	Conditions
Roof top surface (z=4m) PVC-coated glass-fiber plain-weave	Thermal conductivity : 0.11 W/m·K
	Solar absorptance :10.8 %
	Solar transmittance : 13.7%
	Heat transfer coefficient : 23 W/m^2·K
Ground surface (z=0m) Concrete paved	Thermal conductivity : 1.4W/m·K
	Solar absorptance : 60 %
	Heat transfer coefficient : 23 W/m^2·K
Upwind / Downwind flow boundary	Upwind : air velocity, 0.1 m/s
	Downwind : atmospheric pressure
Side surface (y=0, y=15)	Free-slip
	Adiabatic boundary

Table 2. Spraying conditions

Mass flow rate	0.83 g/s
Water temperature	28.0 ℃
Spray cone angle	50 °
Injection pressure	6 MPa

RESULTS

(1) Investigating the Cooling Effects

Figures 3, 4 and 5 show differences in the flat surface temperature contour diagrams with different outdoor air conditions respectively. In order to compare the cooling effects of the mist, each contour diagram is shown with the temperature difference of the inflowing air. Figure 6 plots the temperature on the line segment Y=7.5, Z=1.5 where the nozzle directly below, and on a line segment directly below the nozzle 1meter away on a parallel(Y=8.5m, Z=1.5 m).

Comparing the air temperature reduction due to the different outdoor humidity of 80% (Fig. 3) and 60% (Fig. 4). In the case with 80% humidity, we can see a relatively uniform temperature difference by observing the nozzle height from the ground surface in the cross-sectional contour diagram. However, the temperature decrease at the planar surface at a height of 1.5 m was focused on the area near the position of the sprayer. In the temperature distribution of the line segment in Figure 6, a temperature decrease of around 2.0°C can also be seen directly below the nozzle. However, at the parallel line segment 1 m away, a temperature decrease of only 0.5°C was observed.

In the case 60% humidity, a large temperature decrease was observed in a narrow area in the vicinity of the nozzle on the downwind side as shown in the cross-sectional contour diagram. And, the temperature decrease in the vicinity of the ground surface upwind was negligible. Also, in the planar surface contour diagram, the range in which a small temperature decrease could be seen was distributed to a relatively wider area. Regarding the temperature distribution on the line segment, the temperature decrease below the nozzle upwind was

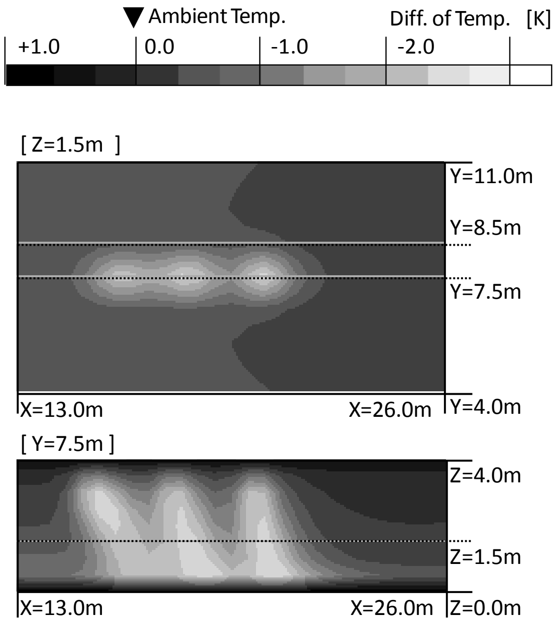

Figure 3 Cooling effect at 30C/80%rh

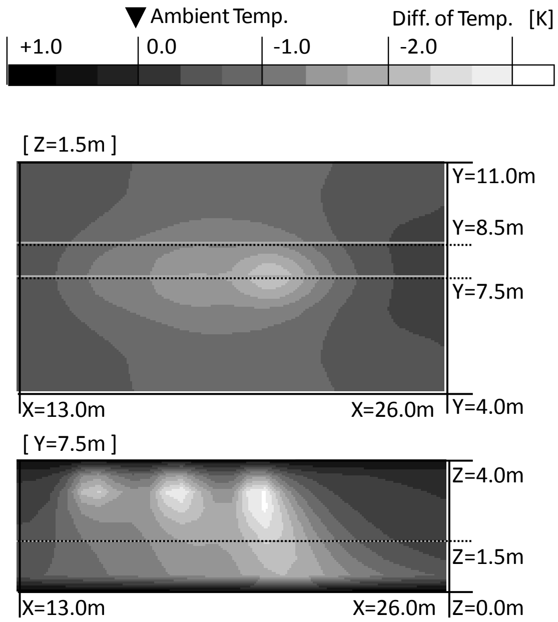

Figure 5 Cooling effect at 34C/60%rh

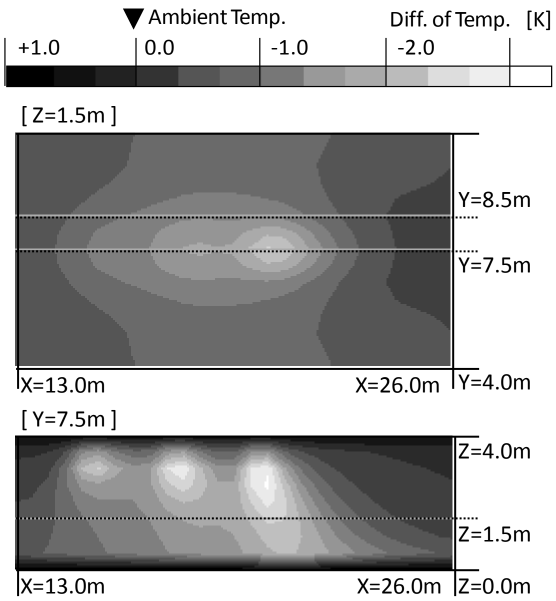

Figure 4 Cooling effect at 30C/60%rh

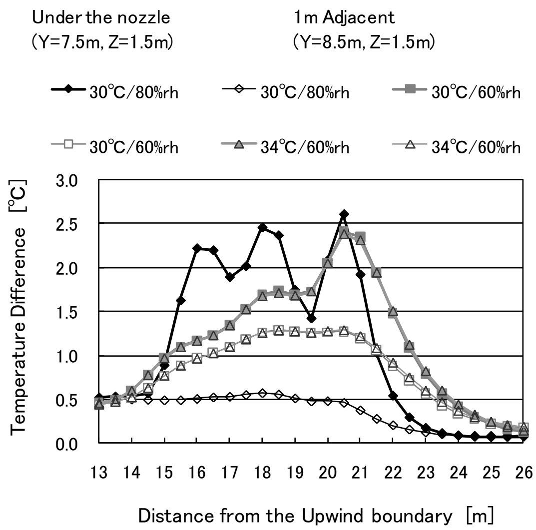

Figure 6 Temperature reductions at each outside temperature condition

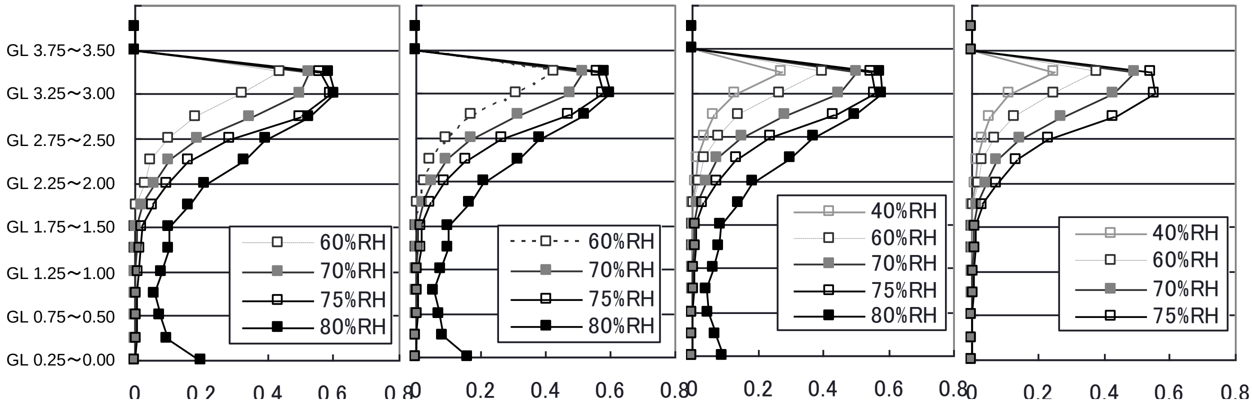

Figure 7. The mass fraction of water mist in each height

about 1°C, while downwind a maximum temperature decrease of 2.5°C was observed. Also, at the parallel segment line 1 m away, a temperature decrease of approximately 1°C was observed.

We consider the difference in the cross-sectional temperature distribution when the humidity was 80% (Fig. 3) and when the humidity was 60% (Fig. 4) can be explained as follows. In the case of 80% humidity, the particles that descended near the ground evaporated, creating a large temperature decrease in the space. However, in the case of 60% humidity, the particles vaporized rapidly, and the particles evaporate at higher level than the case of 80% humidity.

Also, when comparing the case where the outdoor air humidity was 60% and the outdoor air temperature was 30°C (Fig. 4) with that where outdoor air humidity was also 60% but the outdoor air temperature was higher at 34°C (Fig. 5), the distribution was almost identical. Thus, if the relative humidity was the same, even if the outdoor air temperature was different, the distribution of the temperature decrease showed the almost same tendencies.

(2) Investigation of the Height of the Remaining Particle mass distribution

Figure 7 shows the total mass of all the water particles remaining within the computational domain for each temperature and humidity condition. Regardless of the temperature condition of the case investigated, as the relative humidity of the outside air increased, the mass of the remaining mist particles in the computational domain also increased. Thus, in any outside air temperature condition, when the relative humidity is 80 % at a height of GL 0 to 0.25 m the mist will remain without completely evaporating.

We can expect that this will cause the ground surface to become wet, thus indicating that the environment is unsuitable for spraying. Also, if the design conditions are such that they require it to be in a residence and at a height of GL 1.5 m without the existence of mist, then a suitable condition for spraying is when the relative humidity is less than 70% at any of the temperatures modeled.

It is found out that the evaporative cooling effect of the water mist did not depend on air temperature. Also, it depends on relative humidity greatly, and control value for relative humidity of 70% was valid that it is a proper value in a system of nozzle 3.5m in height.

DISCUSSION

The control value of air humidity can be determined by the restrict condition that it must be get wet floor or residence face and cloth. If the air humidity is 70% below, the water mist generated from nozzle will be vaporized completely within 2m below from the nozzle high. So, it is proper that the control strategy for air humidity is 70% rh.

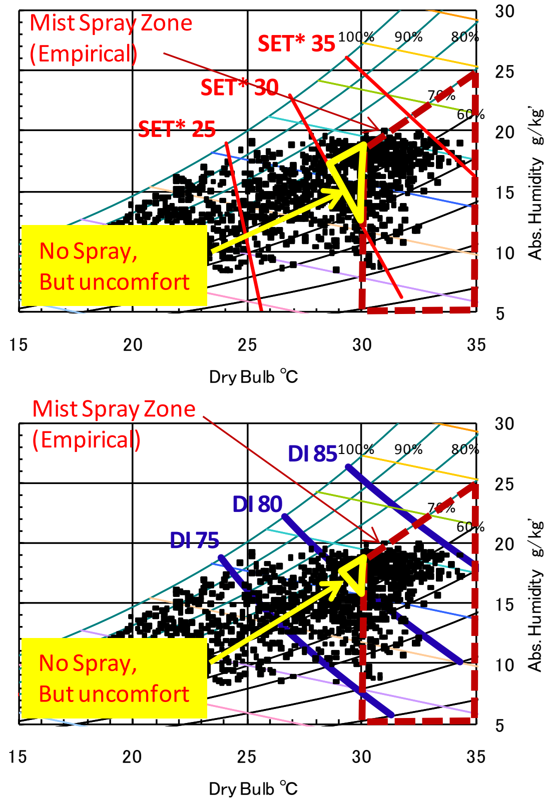

Figure 8. Outdoor air conditions and comfortable index

Next, the control value of air temperature can be determined by thermal comfort index and others. Figure 8 shows again outdoor air conditions as Figure 1 including lines of SET* and DI (Discomfort Index). If we assumed that it is desired to spray mist under the conditions which SET* 30 above or ID 80 above, it is found out that there are hours no spray but it is uncomfortable as shown in yellow area in figure 8. To spray on this hours, it is needed to widen the spray zone; 30 degree C. to 28.5 degree C. (In case of DI, it should be 29 degree C.)

CONCLUSIONS

It is considerable that the proper control strategy for water mist; outdoor air temperature is 28.5 degree C. or 29 degree C. and for air humidity is 70 % rh

References

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