Effect of Evaporative Cooling Techniques by Spraying Mist Waster on Energy Saving in Apartment House

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ABSTRACT: Verification tests and numerical simulations were conducted in order to investigate the effect of misting technology on energy saving in apartment housing. An apartment house was used as the verification test building in an investigation of the energy consumption reduction effect of three types of evaporative cooling techniques: "Rooftop spraying", "Veranda spraying" and "Spraying to the outdoor unit of room air conditioner". "Rooftop spraying" was intended to improve the thermal environment of the top floor by spraying water droplets onto the roof surface. "Veranda spraying" was spraying a fine mist of water droplets from the veranda such that cooled outside air would enter the room using the natural draft. "Spraying to the outdoor unit of room air conditioner" was spraying water droplets in the air inlet of an outdoor unit, thereby lowering the temperature of supply air and heat exchange fins and thus improving air-conditioning efficiency. We confirmed that mist cooling techniques had the effect of reducing air-conditioning usage time, improving air-conditioning efficiency and reducing the energy needed for air-cooling. Numerical simulations also confirmed that the introduction of these measures had the effect of cutting energy consumption for air-cooling by over 80%.

Keywords: energy saving, spraying mist water, evaporative cooling techniques, apartment house, air conditioner

INTRODUCTION

Evaporative cooling using mist water spray has been the recent focus of attention as a method of mitigating the effects of the thermal environment during the summer. Tsujimoto et al. [1] conducted verification tests on a mist spraying technique that used water droplets micronized under high pressure to cool the air. Takeda et al. [2] conducted verification tests on a system using photocatalyst technology to cool walls by forming a water film on their surfaces. Japan's Ministry of Environment [3] also conducted verification tests on a water misting system intended to improve air conditioning efficiency by spraying water droplets to an outdoor unit of air conditioning. The present research focused on these technologies and conducted verification tests and numerical simulations to investigate energy saving in apartment house equipped with the full array of misting technologies.

EXPERIMENTAL CONDITION

Test building An apartment house in Tsurumi Ward, Osaka City was used as the verification test building in an investigation of the energy consumption reduction effect of three types of evaporative cooling techniques: rooftop spraying, veranda spraying and outdoor air-conditioning spraying. The apartment building selected for the tests was a 5-story, 42-year-old building of reinforced concrete construction, provided as municipal housing. This building has 20 dwelling units and all units have the same floor plan. Figure 1 shows an outline of the targeted building and Figure 2 shows an overall view. Figure 3 shows a floor plan of a dwelling unit.

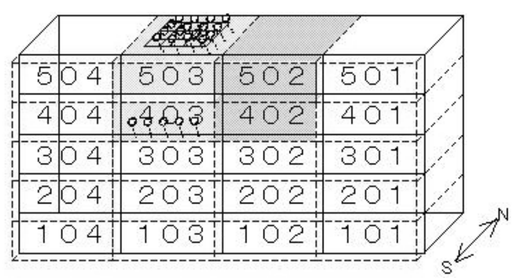

Figure 1: Outline of the Targeted Apartment House

Figure 2: Overall View of the Targeted Apartment House

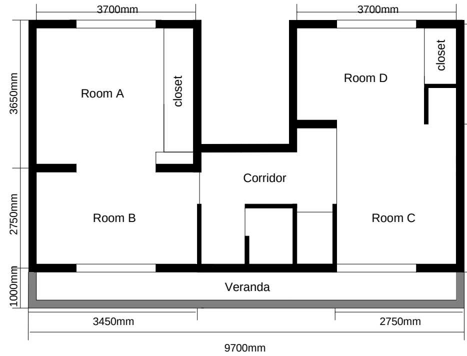

Figure 3: Floor Plan (One dwelling Unit)

Rooftop spraying was carried out on the roof, whereas veranda spraying and spraying to the outdoor unit of room air conditioner were carried out in apartments on the 4th floor. In order to provide comparison data for apartments where spraying was implemented, measurements were also made for adjacent apartments not subjected to spraying.

Test period The tests were carried out between August 10, 2007 and September 27, 2007. Because the test building was scheduled for demolition at the end of 2007, none of the apartments were inhabited throughout the test period, and therefore no energy or other resources were consumed.

Spraying apparatus Two types of single-flow nozzle were used for water spraying, each having different spray characteristics. Nozzle A sprayed relatively large water droplets (particle size approximately 300 μm) under mains water pressure, while nozzle B sprayed fine mist-like water droplets (particle size approximately 40 μm) under pump pressure of around 1.8 MPa.

Test conditions Rooftop spraying was intended to improve the thermal environment of the top floor by spraying water droplets onto the roof surface using nozzle A. The effect of water droplet spraying on the roof surface and inside apartments directly below (5th floor) was evaluated by comparing measured data for this area and the unsprayed area. The rooftop spraying method involved four rows of three nozzles arranged on the roof above apartment 503, and a spray cycle was followed whereby from 9 a.m. to 5 p.m. two pairs of rows each sprayed simultaneously for 15 seconds, then stopped for 7 minutes. Under this spraying condition the estimated volume of water sprayed was 261 L/day. Figure 4 shows the view of the rooftop spraying.

For veranda spraying, nozzle B was used to spray a fine mist of water droplets from the veranda such that cooled outside air would enter the room using the natural draft. The spray system comprised eight nozzles installed on the south-facing veranda and 2 nozzles installed on the north-side window railing of apartment 403, and spraying was continuous over 24 hours. Under this spraying condition the estimated volume of water sprayed was 322 L/day. Figure 5 shows the view of the veranda spraying test. Figure 6 shows the details of the nozzle setting for the veranda spraying.

For spraying to the outdoor unit of room air conditioner, nozzle A was used to spray water droplets in the air inlet of an outdoor unit, thereby lowering the temperature of supply air and heat exchange fins and thus improving air-conditioning efficiency. In this test, a single nozzle was installed in the air inlet of an outdoor unit, and spraying took place over 24 hours following a cycle of 1 second spraying followed by 29 seconds cessation. Under this spraying condition the estimated volume of water sprayed was 66 L/day. Figure 7 shows the view of the spraying to the outdoor unit of room air conditioner.

Figure 4: View of the Rooftop Spraying

Figure 5: View of the Veranda Spraying

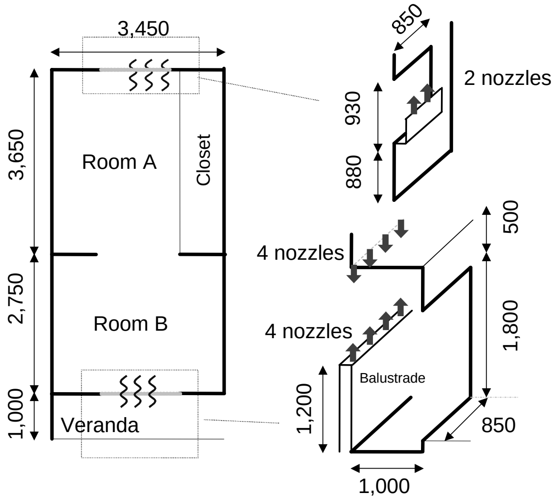

Figure 6: Details of the nozzle setting for the veranda spraying test

Figure 7: View of Spraying to the Outdoor Unit of Room Air Conditioner

VERIFICATION TEST RESULTS

Rooftop spraying

Figure 8 and 9 show a representative result for rooftop spraying, where a temperature reduction effect was observed for the roof surface on August 16. As the results in Figure 9, although the spraying period was 9 a.m. to 5 p.m., a lowering effect was obtained even after cessation of spraying, with the whole-day average falling by 16.4°C. The indoor environment showed a fall of 1.2°C at 120 cm above floor level, while a larger temperature lowering effect was obtained closer to the ceiling. With regard to air-conditioning usage time, a 9.7% reduction in energy consumption was confirmed in apartments where rooftop spraying was conducted.

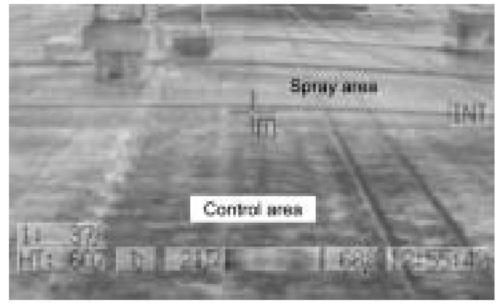

Figure 8: Thermal Image of the Surface Temp. Reduction by Use of the Mist Water Spray at Rooftop (August 16)

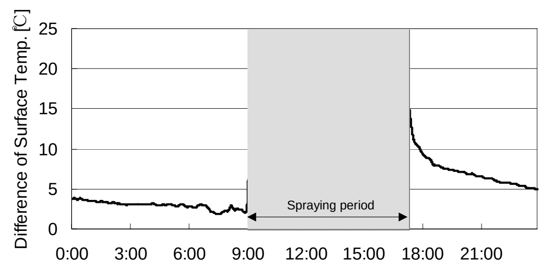

Figure 9: Variation with Time of Surface Temp. Reduction by Use of the Mist Water Spray at Rooftop (August 16)

Veranda spraying The results of measurements for veranda spraying showed a 1.9°C fall in the whole-day average indoor temperature at 120 cm above floor level on August 16. However, the whole-day average absolute humidity increased to 1.7 g/kg, and this rise in humidity could be expected to have a negative impact on thermal comfort. To investigate this point, the SET* index for evaluating overall thermal comfort, which incorporates air temperature and humidity, was calculated. The result obtained for the SET* and presented in Figure 10 indicate that thermal comfort is improved although humidity is increased, with a whole-day average temperature reduction of 0.9°C and a maximum reduction of 1.4°C.

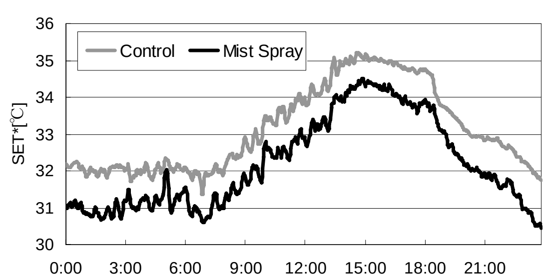

Figure 10: Comparison of Variation with Time of SET by Use of the Mist Water Spray at Balcony (August 16)*

Spraying to the outdoor unit of room air conditioner A representative result for spraying to the outdoor unit of room air conditioner is shown in Figure

11, which shows the effect on reduction of electricity consumption for air-cooling on September 22. On this day, energy consumption in the test apartment was 34.3% lower than in the control apartment. The average reduction in energy consumption during the test period was 36%.

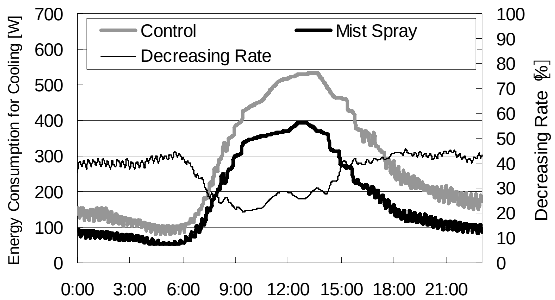

Figure 11: Comparison of Variation with Time of the Electricity Consumption Reduction for Cooling by Use of Mist Water Spray to the Outdoor Unit of Air Conditioner (September 22)

EVALUATION OF NUMERICAL SIMULATION

The verification tests confirmed the effectiveness of various cooling techniques used in a part of the building. This section describes the numerical simulation used to determine the effect gained by applying these evaporative cooling techniques to the entire building. For this research, the thermal load calculation program for houses SMASH (Simplified Analysis System for Housing Air Conditioning Energy) [4] was used, and the whole building (all 20 dwelling units) shown in Figure 1 was modelled.

For the energy evaluation calculations, each of the 20 dwelling units in the apartment building was assumed to be occupied by a family of four, and a schedule for occupancy and energy consumption in each room was set on this basis. In addition, to represent the evaporative cooling techniques, calculation was carried out for the five conditions shown in Table 1. Sidewall spraying was not performed in the verification tests describe above, but was treated in the same way as rooftop spraying for simulation.

Table 2 shows the average energy consumption reduction rates on each floor as a result of applying each technique. For rooftop spraying, no effect was observed below the 3rd floor, while veranda spraying showed the largest effect when each technique was applied independently.

Table 1: Experimental Cases of the Simulation

Case	Calculation Method
Rooftop	Using effective solar absorption for evaporation at rooftop (Control case:93%, Spray:30%)
Veranda	Decreasing -2K of the air temp. from control case
Outdoor Unit	Reducing 36% of energy consumption for cooling from control case
Sidewall	Using effective solar absorption for evaporation at rooftop (Control case:93%, Spray:30%)
All	All spraying method mentioned above
Control	No spraying method

Table 2: Average Energy Consumption Reduction Rates on Each Floor

Case	Energy Consumption Reduction Rates [%]				
	1F	2F	3F	4F	5F
Rooftop	0	0	0	1	22
Veranda	65	65	65	65	51
Outdoor Unit	36	36	36	36	36
Sidewall	5	5	5	4	4
All	79	79	79	79	80

Table 3: Summary for the Effect of Implementing All Techniques Simultaneously (Monthly Average)

Evaluation Items		Jul.	Aug.	Sep.
Energy Saving for Cooling [%]		85	74	89
Reducing Using Time of Room Air Conditioner [%]		85	68	90
Whole Energy Saving of each dwelling units [%]		13	14	13
Monthly Total Electricity Saving [kWh]		544	1111	435
Monthly Total Electricity Necessary for Mist Spraying [kWh]	Pump:60W	280	477	267
	Pump:30W	178	290	169
Monthly Total Water Necessary for Mist Spraying [m^3/month]		166	227	158

Table 3 summarizes the calculations for the effect of implementing all techniques simultaneously, giving values for each month separately. The reduction in energy consumed for air-cooling was greater in July and September than in August. This is because August was the hottest month, with fewer hours that can be tolerated using only evaporative cooling techniques. However, when considering the rate of reduction of energy consumption over the entire building, the reduction rate was smallest in September. The reason for this is the smaller proportion of energy consumed for air-cooling in September.

Analysis was then made of the water resources and energy consumption needed to implement each technique. The amount of water used by one person in daily life is given as 245 L/day [5]. This increased by a factor of 1.3 when the various cooling techniques were implemented across the 20 apartments each having four household members. Reduction in energy consumption was calculated taking into account the electric power consumption rate of 0.454 kWh/m3 for mains water generation [5] and pump operation during the veranda spraying period (30W or 60W). The reduction effect was found to be greatest in August.

CONCLUSION

Verification tests and numerical simulations were conducted in this study in order to investigate the effect of misting technology on energy saving in apartment housing. Verification tests confirmed that mist cooling techniques employed in apartment housing had the effect of reducing air-conditioning usage time, improving air-conditioning efficiency and reducing the energy needed for air-cooling. Numerical simulations also confirmed that the introduction of these measures had the effect of cutting energy consumption for air-cooling by over 80%. In the future, we would test the other negative or positive effects of mist spraying such as effect on the building materials, risk for mould and so on.

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