Effect of the Evaporative Cooling Techniques by Spraying Mist Water on Reducing Urban Heat Flux and Saving Energy in Apartment House

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ABSTRACT

Verification tests and numerical simulations were conducted in order to investigate the effect of misting technologies on reducing urban heat flux and saving energy. An apartment house was used as the test building in an investigation of three types of evaporative cooling techniques: "Rooftop spraying", "Veranda spraying" and "Spraying to the outdoor unit of room air conditioner". We confirmed that misting technologies had the effect of reducing surface temperature, air-conditioning usage time, improving air-conditioning efficiency and reducing the cooling energy consumption through the verification tests. And also, through the numerical simulations, we confirmed that the introduction of misting technologies had the effect of saving energy consumption for cooling by over 80%. As for an urban heat flux, numerical simulations also confirmed the effect of reducing by over 60%.

Introduction

Evaporative cooling techniques using spraying mist water has been the recent focus of attention as a method of mitigating the thermal environment during the summer in Japan. Tsujimoto et al. (M. Tsujimoto et al. 2004) conducted the verification tests on a mist cooling technique that used water droplets micronized under high pressure. Takeda et al. (H. Takeda et al. 2006) conducted the verification tests on a system using photocatalyst technology to cool walls by forming a water film on their surfaces. Japan's Ministry of Environment (Ministry of the Environment 2006) also conducted the verification tests on a mist cooling technique intended to improve air conditioning efficiency by spraying water droplets to an outdoor unit of room air conditioner. This research focused on these technologies and conducted verification tests and numerical simulations to investigate reducing urban heat flux and saving energy in an apartment house equipped with the full array of mist spraying techniques.

Experimental Condition

a) Test building. An apartment house in Osaka City was used as the verification test building in an investigation of the energy consumption and urban heat flux 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. This building has 20 dwelling units and all units have the same floor plan. Figure 1 shows an outline and overall view of the building. Figure 2 shows a floor plan of a dwelling unit.

Rooftop spraying was carried out on the roof (Room No. 503), whereas veranda spraying and spraying to the outdoor unit of room air conditioner were carried out on the 4th floor (403). In order to provide comparison data for apartments where spraying was implemented, measurements were also made for adjacent apartments (502 and 402) not subjected to spraying.

Figure 1. Outline and Overall View of the Apartment House

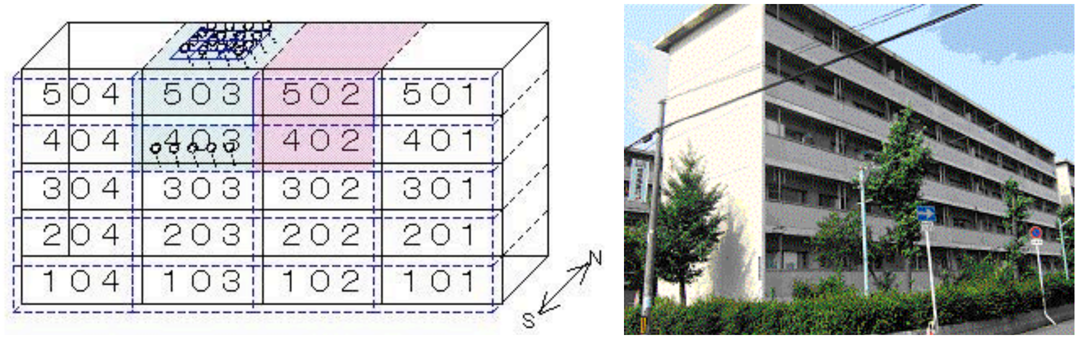
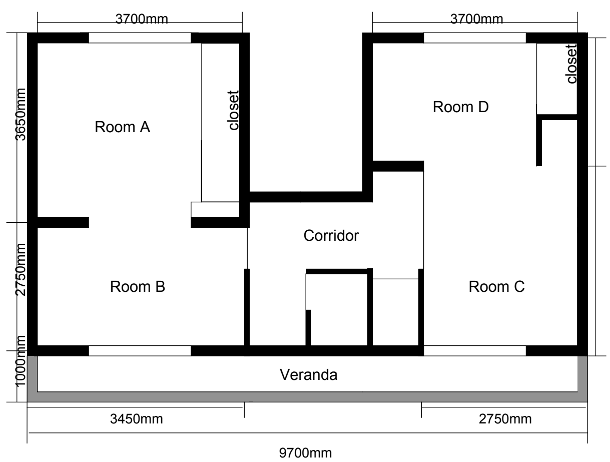


Figure 2. Floor Plan (One dwelling Unit)



b) 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.

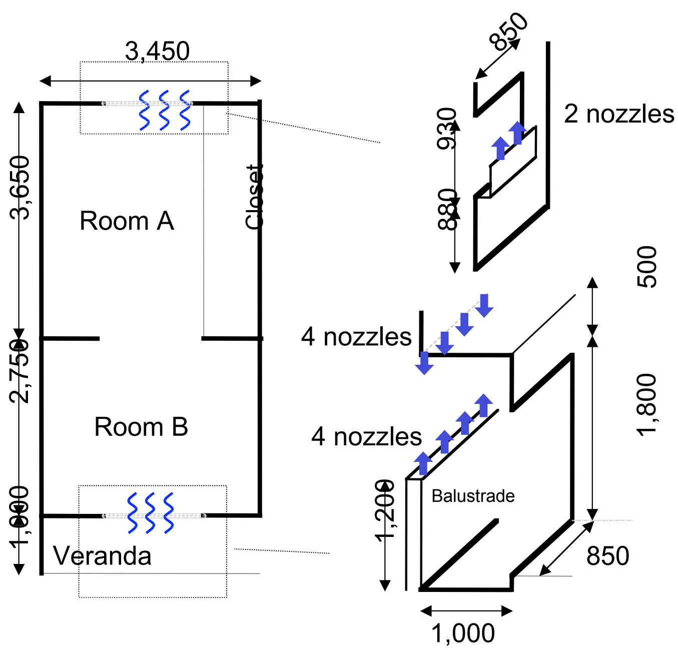
c) Spraying apparatus. Two types of single-flow nozzle were used for spraying water, each having different spray characteristics. Nozzle A sprayed relatively large water droplets (particle size approximately 300 μm) under mains water pressure, while nozzle B sprayed fine mist water droplets (particle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

d) 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 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 3 shows the view of the rooftop spraying.

Figure 3. View of the Rooftop Spraying (Left) and Veranda Spraying (Right)

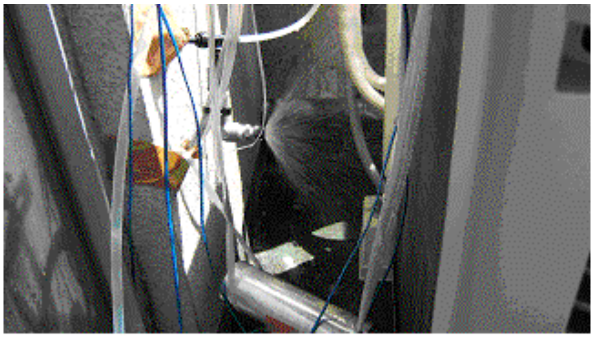
For veranda spraying, nozzle B was used to spray a fine mist type of water droplets from the veranda such that cooled outside air would enter the room using the natural draft. The spray system comprised eight nozzles installed on the south-facing veranda and 2 nozzles installed on the north-side window 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 3 shows the view of the veranda spraying test. Figure 4 shows the details of the nozzle setting for the veranda spraying.

Figure 4. 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 was conducted 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 5 shows the view of the spraying to the outdoor unit of room air conditioner.

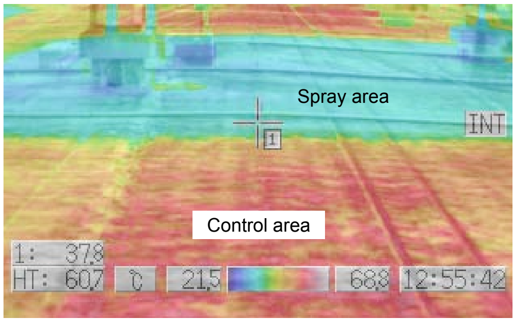
Figure 5. View of Spraying to the Outdoor Unit of Room Air Conditioner

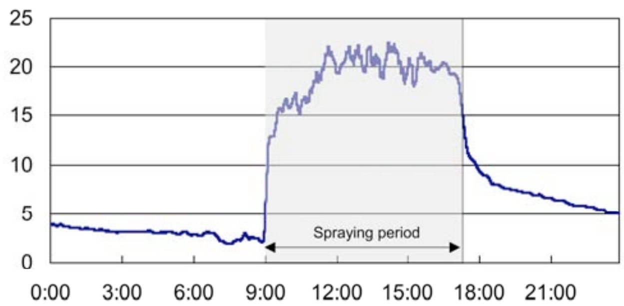


Verification Test Results

a) Rooftop spraying. Figure 6 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, 9.7% of reduction in energy consumption was confirmed where rooftop spraying was conducted.

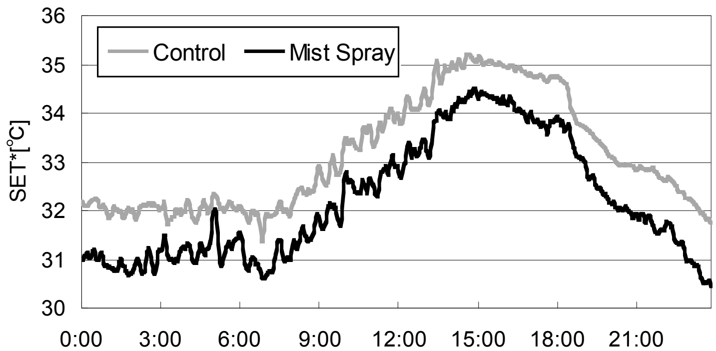
Figure 6. Thermal Image (Left) and Variation with Time (Right) of the Surface Temperature Reduction by Use of Rooftop Spraying (August 16)





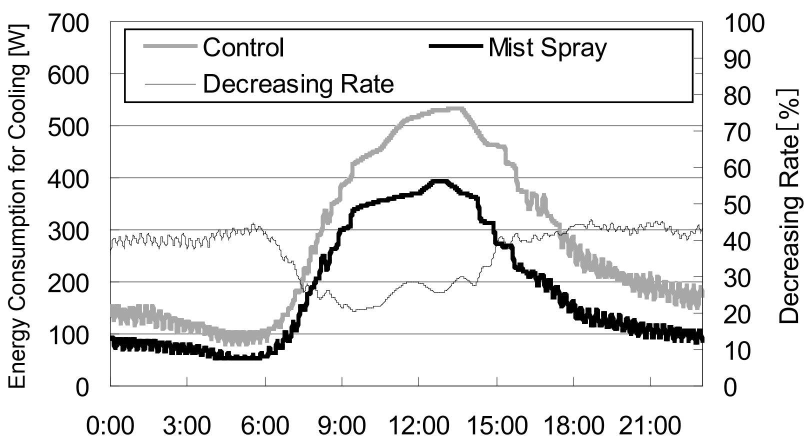
b) Veranda spraying. The results of measurements for veranda spraying showed a 1.9°C fall in the whole-day average indoor temperature at 120 cm above floor level on August 16. However, the whole-day average absolute humidity increased to 1.7 g/kg, and this rise in humidity could be expected to have a negative impact on thermal comfort. To investigate this point, the SET* index for evaluating overall thermal comfort was calculated. The result obtained for the SET* and presented in Figure 7 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 7. Comparison of Variation with Time of SET* by Use of Veranda Spraying (August 16)



c) 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 8, 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 the control room. The average reduction in energy consumption during the test period was 36%.

Figure 8. Variation with Time of the Electricity Consumption Reduction for Cooling by Use of Spraying to the Outdoor Unit of Room 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.

Effect on Saving Energy

For this investigation, the calculation program for houses SMASH (Simplified Analysis System for Housing Air Conditioning Energy) (IBEC 1999) was used, and the whole building (all 20 dwelling units) shown in Figure 1 was modeled.

For the energy evaluation, 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 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 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 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 summarizes the calculations for the effect of implementing all techniques simultaneously, giving values for each month separately. The reduction rate in cooling energy consumption 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 cooling energy consumption in September.

Table 3. Summary for the Effect of Implementing All Techniques Simultaneously

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

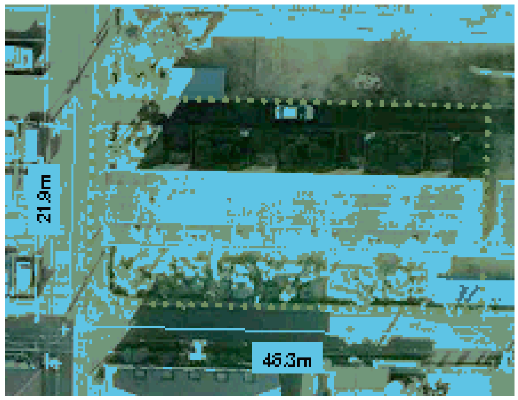
Analysis was then made of the water resources and energy consumption needed to implement each technique. The amount of water used by one person in daily life is given as 245 L/day (Osaka City Waterworks Bureau 2006). This increased by a factor of 1.3 when the all spraying techniques were implemented 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/m^3 for mains water generation (Osaka City Waterworks Bureau 2006) and pump operation during the veranda spraying period (30W or 60W). The reduction effect was found to be greatest in August.

Effect on Reducing Urban Heat Flux

There are two main categories of the thermal load on urban atmosphere (urban heat flux): surface emissions and anthropogenic emissions. In regards to the former, we calculate the three sources of emission from ground, rooftop and sidewall. For the latter, we calculate the emission from room air conditioner. Each of four sources of the thermal load was calculated in each time series. The countermeasures were directly related to reduce three sources of heat flux: “rooftop spraying”, “sidewall spraying” and “spraying to the outdoor unit of room air conditioner”. The conditions for each types of spraying are shown in Table 1. The results from a typical clear day in August were used.

As for the thermal load from ground and building surface, the computational domain was set as shown in Figure 9. We used the Assessment Tool for the Thermal Load on Urban Atmosphere (D. Narumi et al. 2009) to calculate the thermal load (urban heat flux) emitting from each area. The assessment tool performs a brief assessment of the thermal load on urban atmosphere by selecting information appropriate to the investigated area (considering building height and building-to-land ratio) from a pre-calculated database. In regards to the effect of reducing the thermal load on urban atmosphere caused by rooftop and sidewall spraying, the surface temperature is adjusted for evaporation efficiency to ensure it as close to the measured temperature as possible.

Figure 9. Computational Domain for the Evaluation Concerning the Thermal Load



As for the thermal load from room air conditioner, we used the results for investigating the effect of reducing energy consumption as mentioned above, the calculation was performed by summing the values for cooling load and electrical power consumption for room air conditioner. As for the effect of reducing the thermal load on urban atmosphere caused by spraying to the outdoor unit, it is assumed that all of the spraying mist will evaporate and the latent heat of evaporation would reduce the thermal load originating from the room air conditioner.

Figure 10. Variation with Time of Reduction in the Thermal Load on Urban Atmosphere Due to the Implementation of Each Spraying Measures

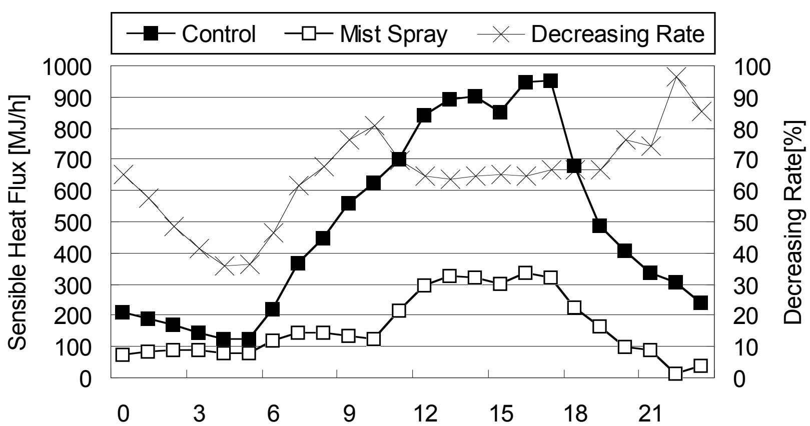


Figure 10 shows the results of the reduction in the thermal load on urban atmosphere due to the implementation of each spraying measures. Throughout the day, the averaged reduction rate for the overall thermal load was 64%. As for the each source, the thermal load from rooftop was reduced by 77% and the thermal load from sidewall was reduced by 61%. Regarding the spraying to the outdoor unit, on average there was an extremely large reduction rate of 189%. This is because the operation time of the air conditioner was long and the amount of evaporative latent heat from the spraying mist exceeded the amount of thermal exhaust heat.

Conclusion

Verification tests and numerical simulations were conducted in order to investigate the effect of misting technologies on reducing urban heat flux and saving energy. An apartment house was used as the test building in an investigation 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 misting technologies had the effect of reducing surface temperature, air-conditioning usage time, improving air-conditioning efficiency and reducing the cooling energy consumption through the verification tests. And also, through the numerical simulations, we confirmed that the introduction of misting technologies had the effect of saving energy consumption for cooling by over 80%. As for an urban heat flux, numerical simulations also confirmed the effect of reducing by over 60%.

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