# VALIDATION OF THE THERMAL EFFECT OF ROOF-SPRAYING AND GREEN PLANTS IN AN INSULATED BUILDING

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## ABSTRACT

In recent years, roof-spraying and rooftop lawns have proven effective on roofs with poor thermal insulation. However, the roofs of most buildings have insulating material to provide thermal insulation during the winter. The effects of insulation has not previously been quantified.

In this study, the authors collected measurements of an insulated building to quantify the thermal effects of roof-spraying and rooftop lawns. Roof-spraying did not significantly reduce cooling loads and required significant amounts of water. The conclusion is that roof spraying is not suitable for buildings with well-insulated roofs. Rooftop lawns, however, significantly stabilized the indoor temperature while additionally helping to mitigate the heat island phenomenon.

## INTRODUCTION

In recent years, environmental problems have become serious, and consequently various passive methods have been adopted in architectural design. Rooftop lawns have many merits such as: reduction in building air conditioning load and mitigation of the heat island phenomenon. Roof spraying systems are effective fon poorly insulated roofs, reducing heat load in summer.

In earlier research on rooftop spraying system, Hasegawa(HASEGAWA Tomohisa et al. 2001) carried out an analysis of the thermal effect of a slant roof spraying system. Tanabe (TANABE toshihiko et al. 2000)( SAITO hidenori et al.2000) conducted a field study of a rooftop spraying system.

However, at present to adopt roof spraying system in such general buildings, most buildings have insulating material in their roofs for winter season thermal insulation. There has been a trend to adopt roof spraying in such general buildings, but it is unclear how much actual effect it has.

Ishihara(Osamu ISHIHARA et al.1996) conducted an experimental study on thermal characteristics and water performance of rooftop lawns, and Hoyano (HOYANO Akira et al 2000) clarified the indoor thermal control effect of rooftop lawn planting with a thin soil layer on a wooden building. However, here are few studies on the thermal environment in reinforced concrete(RC) buildings.

In this study, the authors measured building with a rooftop spraying system and a roof lawn. The studied building is an office building at the Advanced Research Institute of Science and Engineering, Waseda University, which is located in the Kitakyushu Science and Research Park, Japan.

## OUTLINE OF THE MEASUREMENT

### Description of the Studied Building

To demonstrate green architecture, the studied building has adopted various methods, such as a rooftop lawn and roof spraying. Figure1 shows its layout, which is typical for an office building. Enclosing a courtyard, it is composed of the 3 wings and 3-stories, each with a one side corridor plan (Figure 2).

The building is used as an experimental and research laboratory for Waseda University. The wing facing south (the Environment Department) has adopted a rooftop lawn. The other 2 wings on the east and west are for the Science Department; these have an automatic rooftop spraying device. The wall and roof structure is shown in Figure 3. The building is iron frame construction, with exposed insulation is used in the roof. Rigid urethane insulation is used right under the alsphalt water proof layer. The roof with rooftop lawn was covered with another 250 mm soil layer. For the wall, ISOWAND 35mm is used as exterior thermal insulation.

### Measurement Periods and Place

From August 15th to 17th, 2001, the authors made measurements from the 3rd floor of the studied building. Figure 4,5 shows the 3rd floor plan and measurement points. Measurement of roof spraying was conducted on the west facing [west wing].

Though there were 4 rooms on the 3rd floor, in order to remove the influence of outside air, the two middle rooms S302 and S303 were chosen for roof spraying. Measurement of the rooftop lawn was done in room E305 of Environment Department [South wing].

The window material of each room is glass in the top 2/3 and aluminum in the bottom 1/3. There are two doors in each corner of the wall on the corridor side. There are windows of full glass in the corridor as well. To isolate the effect of the rooftop lawn and the roof spraying, all other elements are controlled. All windows and doors were closed in the 3 rooms, and all the windows of the corridor were closed too. All rooms were empty of occupants.

### Measurement Method and Arrangement

An automatic water device sprinkler is installed on the roof of the west wing, but because the volume of water was small, manual water spraying was added. We sprayed continuously with a hose to keep it in a condition with the surface of the roof always wet. Equally, the quantity of water used was confirmed and recorded every hour. Table 1 shows the amount of sprayed water from 9:15 until 16:15, on the 15th, by the same point, sprayed water during 12:00 - 17:00 on 16th, and during 10:00 - 17:00 on 17th.

Measurements were taken on all four sides of each room and in the center. The point of the window side, the center, the corridor side was made as point 1, 4, 5, in order to measure the indoor temperature. To specify the effects of the sprinkling and roof lawn, surface temperatures of 1m, 2m heights for each wall (made as point 2,3,5) and the ceiling were also measured, which were shown in the Table 2 and Figure 4 and 5.

Indoor air temperature was measured in two places (center and corridor side). Humidity and globe temperature were measured in the center of the rooms. Ceiling surface temperatures were measured in five places (the center and the four corners of the ceiling). Wall surface temperatures were measured in six places (1m and 2m from floor on all walls except window side). The surface temperature of the floor and air velocity at the center of the room were also measured.

Finally, the air temperature, velocity and surface temperature outside were also measured.

Room S302 had water spraying and room S303 did not.

In order to observe the effect of water spraying more clearly, and comparing the difference between two rooms, all doors and windows were closed to keep conditions similar in both rooms. The effect of air velocity is not discussed in this paper.

Table 2 lists the data collected. Data logs were kept automatically at 10 minutes intervals.

This paper concentrates on the data for the 17th because the effect appears most clearly here.

## DISCUSSION AND RESULT ANALYSIS

### Solar Radiation

As shown in Figure 6, the quantity of solar radiation from August 15th to 17th was greatest from 12:00 to 13:00, and the quantity on 15th exceeds 1MJ/m$^2$, exceeds 0.96 MJ/m$^2$on 16th, exceeds 0.88 MJ/m$^2$on 17th. All days were almost clear throughout the survey period.

### Exterior Temperatures and Relative Humidity.

Figure 7 shows the air temperature and the relative humidity. It was a typical summer day in Kitakyushu.

On the 15th, the outdoor air temperature peaked at 17:00, and the temperature was 36.8°C. On the 16th, the lowest temperature was 26.5°C at 6:00, the highest temperature was 35.3°C at 12:00, and the daily temperature range was 8.8°C. On the 17th, the lowest temperature was 25.2°C at 6:00, the highest temperature was 34.2°C at 14:00 and the daily range was 9°C.

On the other hand, the lowest relative humidity was 43.6% at around 17:00 on 15th, the highest relative humidity on 16th was 81.6% at around 6:00, when the lowest relative humidity occurring at 12:00 at about 39.8%. The highest relative humidity on 17th was 89.2% at around 6:00, with the lowest relative humidity occurring at 13:30 at about 46.8%. The daily range was 41.8% on 16th, 42.4% on 17th.

Basically, the sprinkler/green lawn is used to reduce summer season heat load, in another words, to reduce the solar radiation heat passing through the roof. Atmospheric conditions would not affect the results significantly.

### Temperatures and Relative Humidity of Indoor

The analysis of temperature and relative humidity of the indoors was collected from the center of the room. Figure 8 shows each room's temperature, Figure 10 shows the temperature of the corridor. Table 3 shows the comparison of the daily temperature range, lowest temperature and the highest temperature on 17th.

Figure 9 shows the relative humidity. Regarding the relative humidity of rooms with a rooftop lawn (E305) on the 17th, it was kept at 57% from 0:00 to 7:00, and became lower from 7:00, the lowest reading was 46% from 13:00 to 14:00. The daily range was about 11%. The room without Roof Spraying was kept at 57% from 0:00 to 6:00 and became lower from 7:00, the lowest reading was 38% at 17:40. The daily range was from 15% to 19%. The relative humidity of the room with roof spraying above kept at 59% from 0:00 to 6:00 and became lower from 7:00, the lowest value was 41% at 17:40. The daily range was 16% to 18%.

As shown as Figure 8, compared with the other two rooms, the temperature of the room with the rooftop lawn was relatively stable. Also, it continued low during the afternoon, although the temperature is higher than the other two rooms in the morning. The highest temperature appears early, but it became constant and fluctuation became gradual during daylight. On the other hand, in the room without a rooftop lawn the temperature goes up sharply during the afternoon, the highest temperature was 3-4°C higher than the room with a rooftop lawn. The peak temperature is delayed as long as 4 hours in the room with the rooftop lawn until it reaches the highest temperature, and it was observed that the temperature went up sharply under the influence of the afternoon sun.
There was little temperature difference between the room with the spraying and the room without the spraying, i.e. spraying water did not affect room temperature. This result from RC building seems to be dependent on the room's ceiling insulation material.

The outdoor air temperature change was extreme, while the indoor temperature remained stable by comparison. The humidity level of the room with rooftop lawn was also lower than that of the outdoors. Therefore, it can be said that the rooftop lawn can mitigate the maximum air temperature and as a result, provide a good thermal environment.

### Indoor Surface Temperature

- The Ceiling

To observe the effect of the roof spraying and the rooftop lawn, we studied the ceiling surface temperature. The study used the mean value of 5 measurement points. The fluctuation of ceiling surface temperature resembles room temperature.

Figure11 and Table 4 shows the results for the three rooms.

The surface temperature of the ceiling of the room with the rooftop lawn remained stable compared with the other two rooms, and its maximum temperature was 3.5°C less than in the other two rooms.

On the other hand, in the case of the two rooms without a rooftop lawn covering (temperature, as shown as the Figure12), the average ceiling surface temperature of the sprayed roof room was 0.3°C less than the non-sprayed roof room.

And also, the difference increases gradually on the third day of spraying. This resulted from the heat capacity effect of the roof, suggesting that the effect of the spraying increased little by little.

The fluctuation of the ceiling surface temperature resembles the indoor air temperature; the room with rooftop lawn remains stable compared with the other two rooms. In the case of the two rooms without rooftop lawns, west wing temperature fluctuated sharply.

- The Wall and the Floor

Wall surface temperatures were measured one meter and two meters above the floor. The results appear in the Figures 13,14. The temperature of the wall of the corridor side was highest in each room, and the sidewall temperature was almost the same. The surface temperature was higher in accordance with the height for the same wall, and the difference was about 0.2°C . From Figures 13 and 14, it is seen the temperature increases from floor, wall, to ceiling.

There was no difference between rooms 302 and 303 of the west wing, but the wall temperature of the room with a rooftop lawn was 1°C -1.5°C lower.

As shown in Figure 15, the temperature of the floor with the rooftop lawn lowered gradually, and on the 17th, it was even lower than the room without the rooftop lawn. Furthermore, the room with the rooftop lawn had a carpeted floor while the rooms on the west wing did not.

### Surface Temperature of Roof

Figure16 contains information on the surface temperature of the roof. The roof temperature without water spraying reached its minimum at 4:00, when it was 21.6°C, and the highest temperature was around 60.8°C at 13:00. On the other hand, the roof with water spraying reached its lowest temperature of 22.8°C at 4:10. Before spraying it reached 48.3°C, but when began water spraying at 10:00, it was kept at 37.5°C, and became highest at 0:20 without exceeding 39°C.

Regarding the roof of south wing, the authors took measurements at two points, one was the concrete surface along the corridor, and the other was the lawn on the room. The temperature of the concrete was fluctuating from 27°C to 48°C during the three days, and the lawn was fluctuating from 25°C to 37°C, but remaining relatively stable.

The rooftop temperatures varied in accordance with their composition: The west wing, with its spread prevention sheet, was 13°C lower in temperature than the other roofs which were concrete.

### The Effect of Spraying on Surface Temperature of Roof and Ceiling

Figure17 shows the temperature difference of roof and ceiling between rooms with and without roof spraying water. The ceiling temperature difference between two rooms is shown in the second column because it’s so small.

Before the application of roof spraying water, the roof surface temperature of the two rooms is the same. When spray begins, the ceiling surface temperature of the room that was sprayed fell siginificantly. The temperature difference became biggest from 11:00 to 15:00, when the temperature was 20°C～25°C. From 15:00, the difference was reduced and they almost became the same again after the water spraying stopped.

On the other hand, the ceiling surface temperature difference was not siginificantly for a while. Even after spraying started, in the room with spraying, ceiling surface temperature was much higher at the beginning.

After spraying water, temperature fell gradually. The difference between two rooms increased even after spraying stopped. It became biggest at 20:00, three hours after spraying stopped, the temperature diffrence was 0.5°C. The peak time appears delayed for seven or eight hours from the peak time of roof surface temperature difference. And after spraying stopped, the difference was retained all night until 8:00 of the next morning.

The effect of spraying appears very late, but stays in effect for a long time. It may be a function of the insulation efficiency of the RC building.

### Wind Velocity of Indoor and Outdoor

The outside wind velocity, ranged from 0.1 m/s to 5.5 m/s with an average of 1.4 m/s, while there was almost no wind velocity indoors. Figure 18 shows the results.

## CONCLUSIONS

In this research, the authors through their analysis, have clarified the effect of rooftop lawn and roof spraying in a building with RC construction and high thermal insulation. Although this is a case of limited water, the effect of the roof spraying is seen to some extent, but it is difficult to say that it contributed to the reduction of the heat load because the good roof insulation. Considering how much water had to be sprayed, it is hard to say water spraying can save energy. The results might change with different types of insulation. Roof spraying systems are clearly more effective for low heat insulation low performance roofs. Our conclusion is that roof spraying is not suitable for an RC building with a high degree of insulation in the roof. On the other hand, the rooftop lawn had good characteristics in stabilizing the indoor environment where the lowest temperature obtained at nighttime. It mitigated and restrained the maximum air temperature of the daylight, and also helped in mitigating the heat island phenomenon. The rooftop lawn is an effective passive method and is also adaptable to many buildings.

## ACKNOWLEDGMENT

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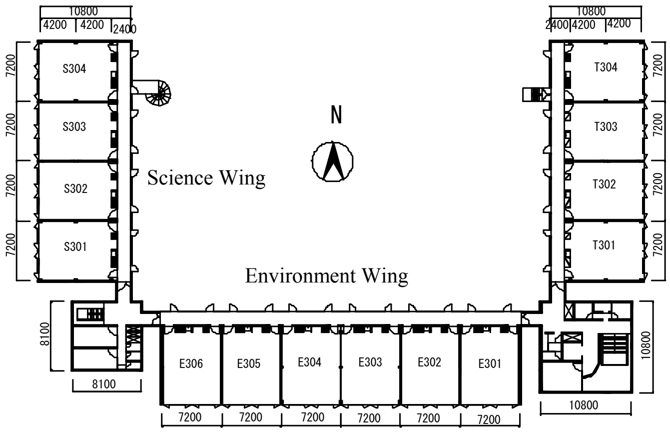



*Figure 1 The Plan of measurement floor*

*Figure 2 Building appearance*

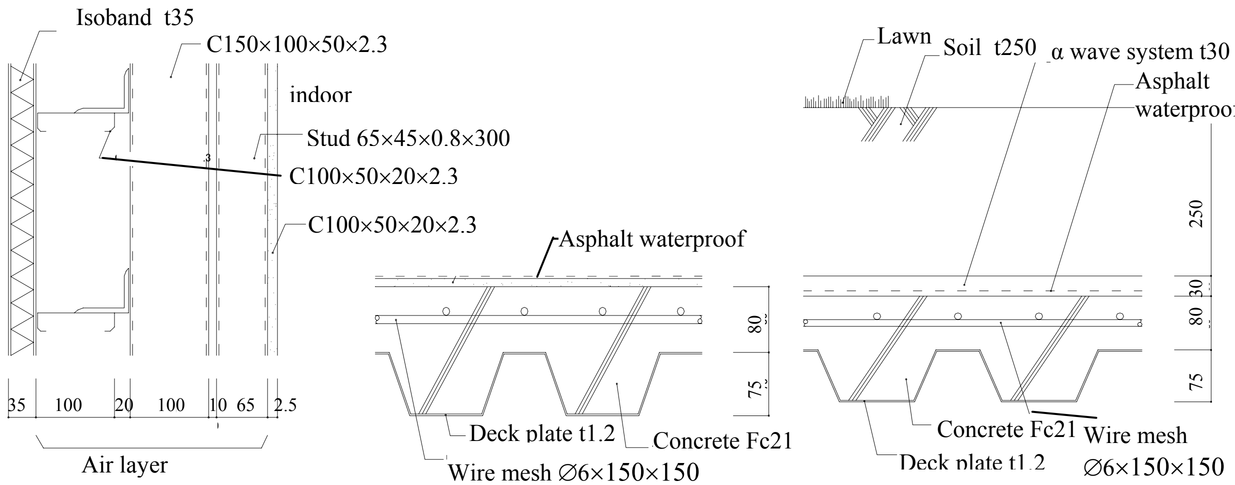



*Figure 3 The Structure of the wall and roof*

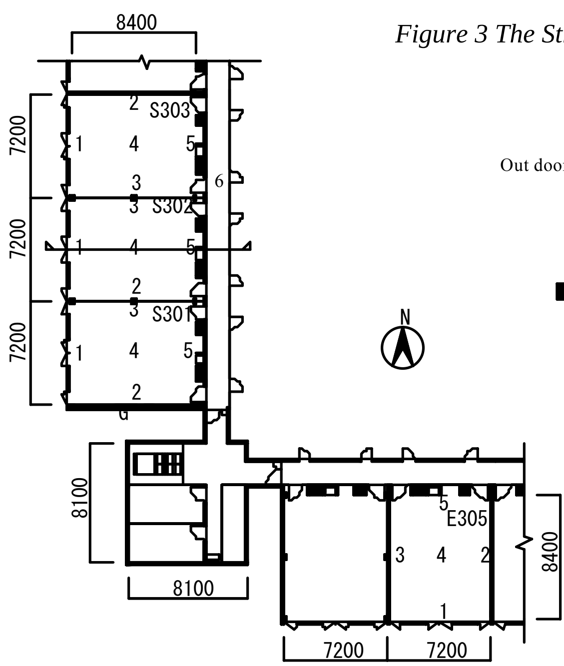



*Figure 4 The Measurement point in plan*

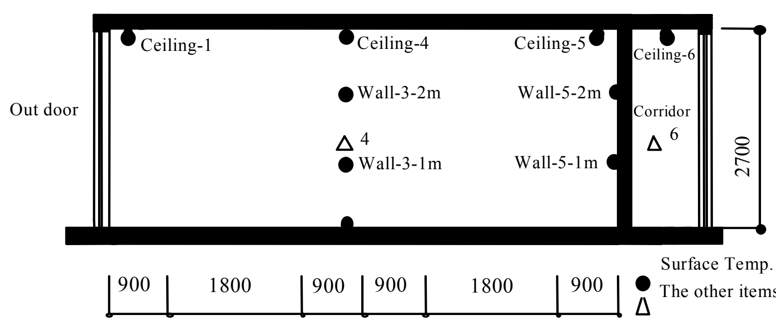



*Figure 5 The Measurement Point in Section*

*Table 1 Quantity of spraying*

| Time | Quantity of spraying | Averrage spraying amount(ml/sm$^2$) |
|---|---|---|
| 09:15–10:15 | 229 | 1.05 |
| 10:15–11:15 | 182 | 0.84 |
| 11:15–12:15 | 313 | 1.44 |
| 12:15–13:15 | 319 | 1.46 |
| 13:15–14:15 | 158 | 0.73 |
| 14:15–15:15 | 154 | 0.71 |
| 15:15–16:15 | 154 | 0.71 |

*Table 2 Measurement items and method*

| Items | Points | | Used devices | Detail |
|---|---|---|---|---|
| Room temperature | center of each room and corridor | 4,6 | Thermo Recorder RH Cooper Constant | ①Thermo Recorder RH（T&D．TR-72）②Cooper Constant (T-type 0.3mm) |
| | side of each room | 5 | | Cooper Constant 0.3mm |
| Room humidity | center of each room | 4 | | Thermo Recorder RH（T&D．TR-72） |
| Surface temperatur | 5 points of ceiling, 1 point for corridor | 1,2,3, 4,5,6 | Cooper Constant | T-type 0.1mm |
| | floor | 4 | | |
| | wall | 2,3,5 | | T-type 0.3mm |
| Air velocity | center of each room and corridor | 4,6 | Anemo-Thermo meter | Anemo-Thermo Meter（AM－05） |
| Glove | center of each room and corridor | 4,6 | Glove Cooper Constant | |
| Outdoor temperature and humidity | outdoor | | Thermo Recorder RH Cooper Constant | ①Thermo Recorder RH（T&D．TR-72）②Cooper Constant (T-type 0.3mm) |
| Wind velocity | outdoor | | | RION ANEMOMETER（AM－09T） |
| Surface temperature of roof | 2 points of each wing | | Cooper Constant | T-type 0.1mm |
| Recorder device | west wing | | Dataloga | ①Tokyosokki DATALOGA（TDS－601） |
| | south wing | | | ② Automatil Swiching Box（ASW-SOC) |

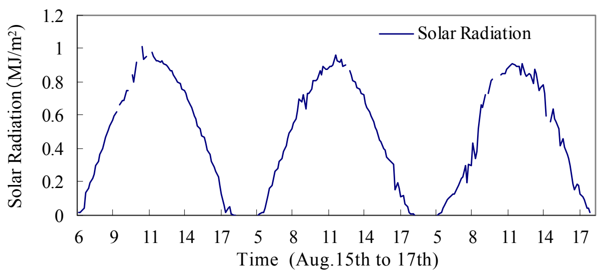



*Figure 6 Solar radiation during the survey period*

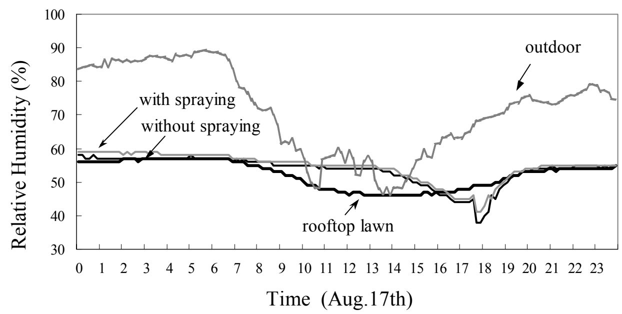



*Figure 9 Indoor relative humidity*

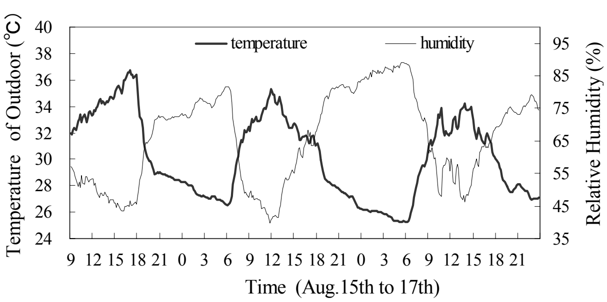



*Figure 7 Outdoor temperature and relative humidity*

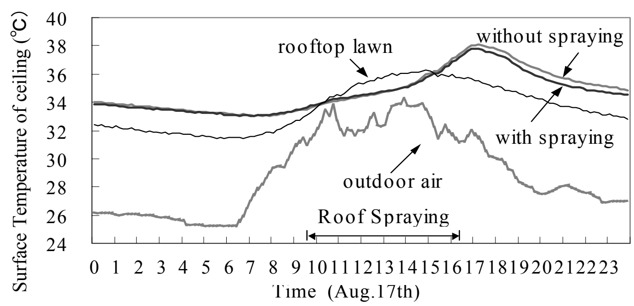



*Figure 11 Ceiling surface temperatures*

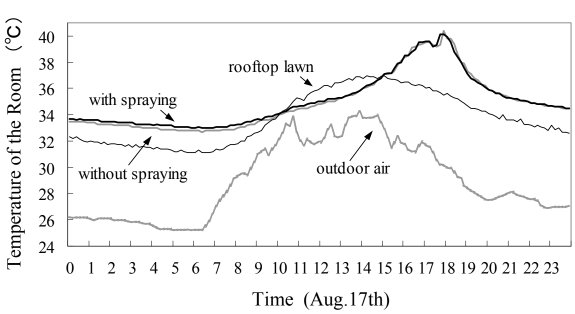



*Figure 8 The indoor air temperature*

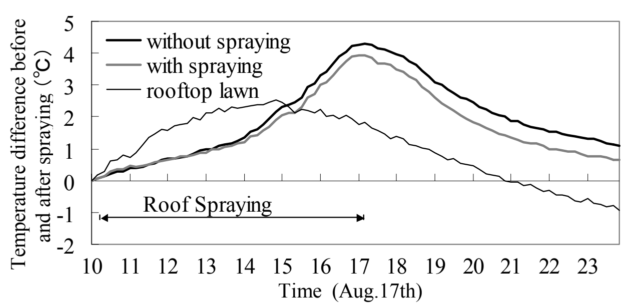
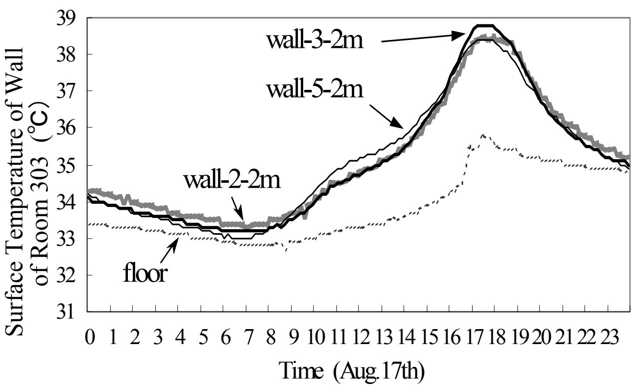
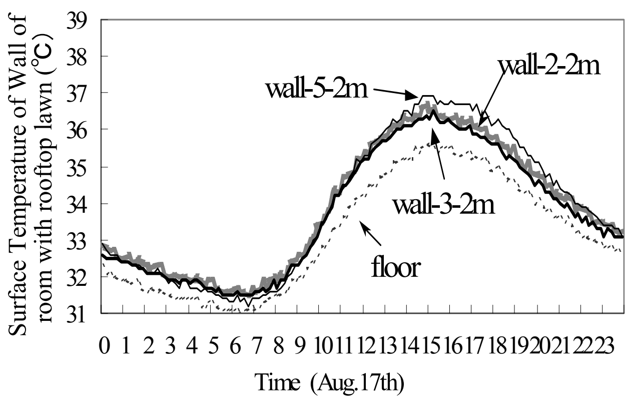
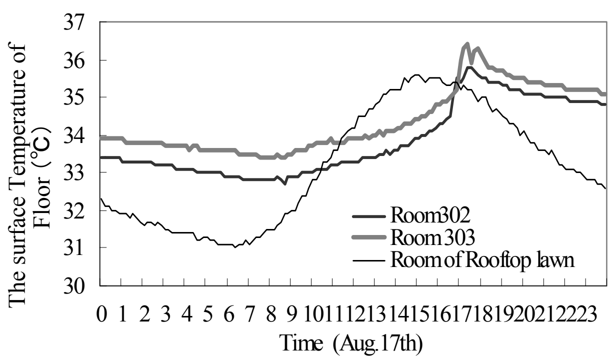
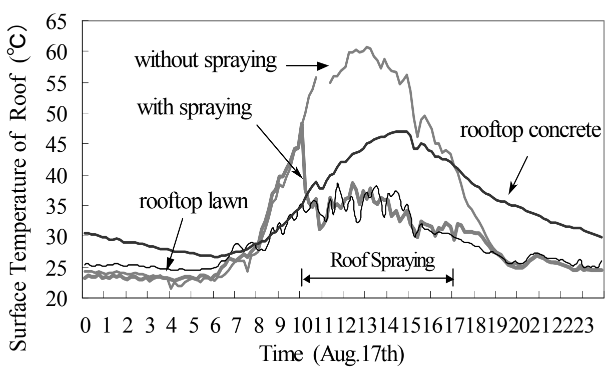



*Figure 12 Difference between before and after spraying*



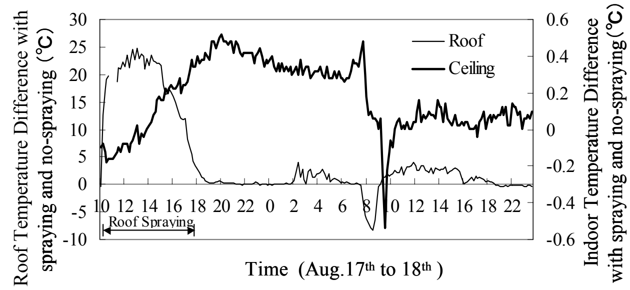




*Figure 17 Temperature differences of roof and ceiling*

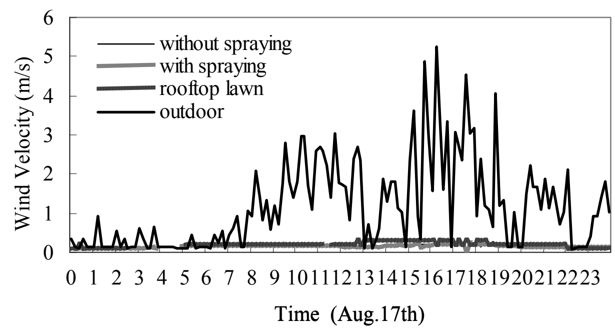



*Figure 18 Indoor and outdoor wind velocity*

*Table 3 Indoor temperatures of each room*

| | **THE DAILY TEMPERATURE RANGE** | **THE LOWEST TEMPERATURE AND THE TIME** | **THE HIGHEST TEMPERATURE AND THE TIME** |
|---|---|---|---|
| Rooms with Rooftop Lawn | 5.3 to 5.8°C | 31.2°C (6:00 to 7:00) | 36.5°C--37 °C (13:00 to 15:00) |
| Rooms without roof spraying | 7.7°C | 32.7°C (6:00) | 40.4°C (17:50) |
| Rooms with roof spraying | 7.1°C | 33°C (6:00) | 40.1°C (17:50) |
| Corridor of the south ridge | 8.8°C | 29.9°C (5:30) | 38.7°C (17:20) |
| Corridor of the west ridge | 9°C to 14.6°C | 31.6°C (5:30) | 41.1°C (10:40) |

*Table 4 Indoor surface temperatures of each room*

| | **THE LOWEST TEMPERATURE AND THE TIME** | **THE HIGHEST TEMPERATURE AND THE TIME** |
|---|---|---|
| Rooms with Rooftop Lawn | 31.4°C (6:00 to 7:00 ) | 36.2°C (15:00) |
| Rooms without roof spraying | 33.1°C (6:00 to 8:00 ) | 38.1°C (17:10) |
| Rooms with roof spraying | 33°C (6:00 to 8:00 ) | 37.8°C (17:00) |