Topic B3: Control of indoor environment

High-Temperature Cooling & Low-Temperature Heating AC System (Part 2) Evaluation of thermal comfort with All Air Supplied Induction Radiant and Laminar Flow AC

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Keywords: All Air Supplied Induction Radiant and Laminar Flow AC, thermal comfort

SUMMARY

While air conditioning systems are widely incorporated in many buildings to pursue comfort, Convection Flow has been the mainstream for these air conditioning systems. However, people may feel discomfort or stress about air stream when the cold/hot air hit their bodies directly after staying there for a long period. There are also problems of noise generation from the air outlet and temperature irregularity. Therefore, All Air Supplied Induction Radiant and Laminar Flow AC System was developed and introduced in order to address reduction in energy consumption for air conditioning and improve the comfort.

INTRODUCTION

In All Air Supplied Induction Radiant and Laminar Flow AC, the indoor air is induced and mixed by utilizing the air supply pressure from the air conditioner to cool/heat the radiation plate with the air to radiate heat from the panel and blow with laminar flow. Since condensation is prevented by the induction mixing function, it is possible to perform Low Temp. of Air-blow temperature of 13°C with reduced air volume from the air conditioning system and thus address reduction in blowing power.
In this study, we took measurements on indoor temperature environment addressed by various air conditioning methods in laboratories with installation of an All Air Supplied Induction Radiant and Laminar Flow AC System or a conventional air conditioning system and verified their psychological effects.
The periods of the experiments are as shown below.
1. The heating experiment was conducted from January to March 2012.
2. The cooling experiment was conducted from July to September 2012.

METHODOLOGIES

1. Summary of all air supplied induction radiant and laminar flow air conditioning

An example structural diagram of the all air supplied radiant and laminar flow unit (hereinafter called “Induction air beam”) is shown in Illustration 1-1. An induced and mixed air supply cools or heats the heat storage radiation plate and the radiant and laminar flow panel. And then from the panel opening, heat is radiated and a laminar flow is blown. The

radiation directly acts on objects. The laminar flow has a speed of 0.2 to 0.8 m/s. Therefore no wind is felt in the living area. This reduces any indoor temperature irregularity and draft for a uniform indoor environment, so that comfort can be improved. A conceptual image is shown in Illustration 1-2. Also the reference value of the mixing ratio is 60% air supply and 40% indoor air. However please note that the ratio slightly varies depending on the temperature, air volume and model used.
In addition, since the radiant and laminar flow unit is an air outlet, it can be used in all air conditioners. In this study, FCU, which allows the air supply temperature to be easily adjusted, and the induction air beam were combined.

Illustration 1-1. Cross section of induction air beam

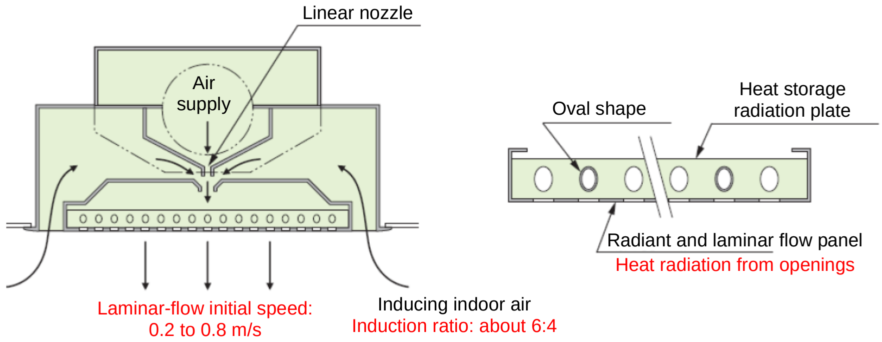
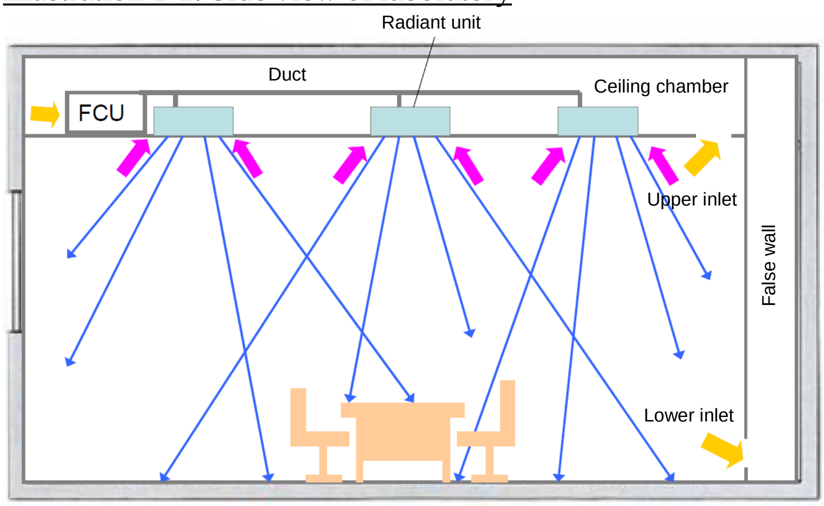


Illustration 1-2. Side view of laboratory



2. Experimental apparatus

The dimensions of the laboratory are 7.5 m (d) × 3.75 m (w) × 2.6 m (h), and it has a window on the north side. Three all air supplied induction radiant AC units and four linear LED lights are placed side by side on the ceiling. Depending on the radiation temperature of the living area, the flow rate of hot water from a hot-water boiler is controlled, and for this control a radiation temperature sensor is placed on the center of the ceiling.
Hot water supplied from the hot-water boiler is sent to a ceiling embedded/suspended fan-coil unit (FCU). The FCU heats return air from the room inside and supplies it to the induction air beam. In addition, the ceiling suspended indoor unit of another package-type air conditioner (hereinafter called “air-con”) is installed on the window side of the laboratory separately from the radiant unit, which allows comparison with a conventional air-conditioning system. Table 2-1 and Table 2-2 show the specifications of the induction air beam and FCU, respectively.

Table 2-1. Specifications of induction air beam

SLM-200S	
Standard air volume/range	200 m^3/h (180 to 240 m^3/h)
Induction mixing air volume	330 m^3/h
Air supply temp.	Cooling: 13 to 16°C, Heating: 40 to 42°C
Induction mixing temp.	Cooling: +6 to +5°C, Heating: -4 to -6°C
Standard capacity	Cooling: 1.3 kW, Heating: 1.2 kW

Table 2-2. Specifications of FCU

HSR4-400Z105W	
Standard air volume	720 m^3/h
Cold water temp. difference	10.0°C
Hot water temp. difference	10.0°C
Cold water volume	7.6 l/min
Hot water volume	6.9 l/min

The method of measurement was one where the vertical temperatures of the room inside were measured at 48 points located on four poles placed in the laboratory. Also it was decided to check the horizontal temperature distribution from 18 measurement points 1.1 m above the floor. There were three points for measuring the wall temperature on each wall, and they were at a height of 0.5 m, 1.3 m and 2.1 m. Furthermore, there was temperature measurement point for each of the upper/lower inlets and three points for the inside of the ceiling. For each radiant unit, measurement was made at 15 temperature points and five humidity points. The detail is shown in Illustration 2-1. In addition, the measurement conditions of the laboratory and the induction air beam are shown in Illustration 2-2 and Illustration 2-3.

Illustration 2-1. Measurement points in laboratory floor plan

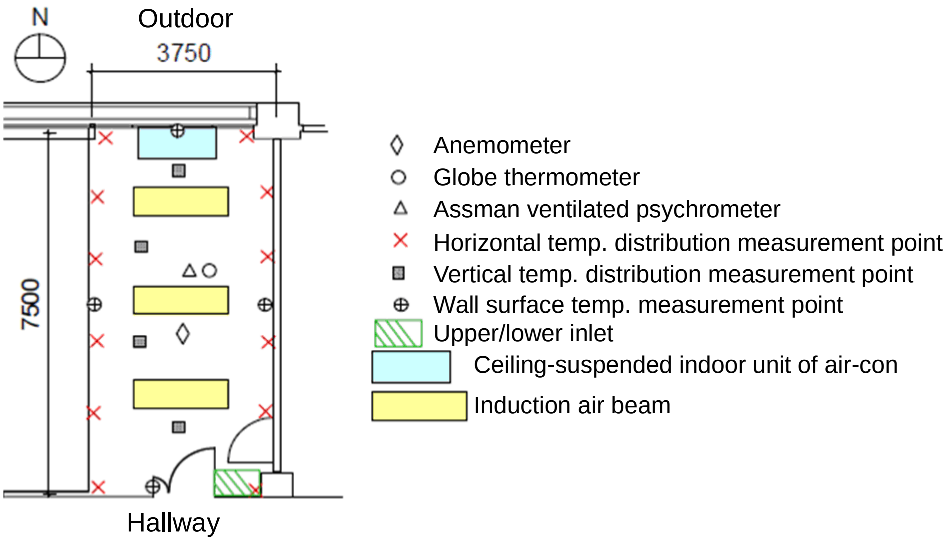


Illustration 2-2. Full view of laboratory

Illustration 2-3. Measurement of induction air beam

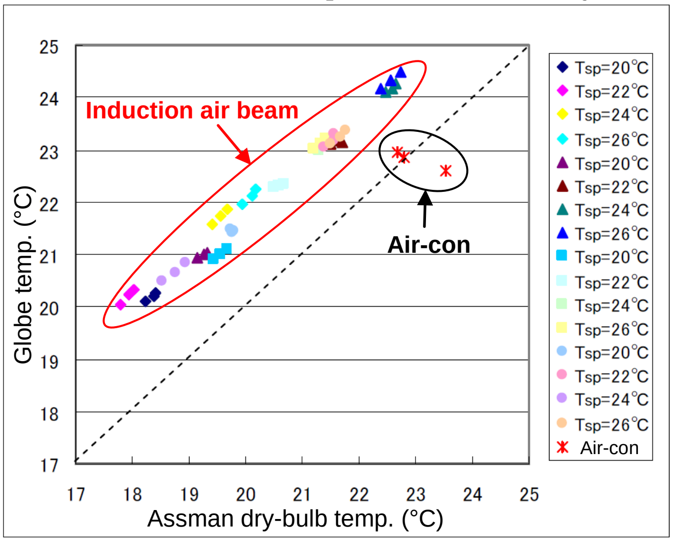
3. Experimental result of heating

3-1, Assman dry-bulb temperature and globe temperature in heating

The relationship between the Assman dry-bulb temperature and the globe temperature is shown in Illustration 3-1. When the three radiant units are running and the room temperature is stable, a temperature difference of about 1.5°C exists between the Assman dry-bulb temperature and the globe temperature. This is considered to be caused by the radiation effect because of the warmed wall/floor surface.

Meanwhile, when the air-con is operated at a level similar to the outdoor air temperature and temperature setting, the Assman dry-bulb temperature and the globe temperature are almost the same. Therefore it can be said that the induction air beam can provide an indoor environment with a warmer feeling at the same level as the dry-bulb temperature.

Illustration 3-1. Relationship between Assman dry-bulb temperature and globe temperature in heating



3-2, Vertical temperature distribution in heating

Illustration 3-2 shows each vertical temperature distribution at the room center when the induction air beam or the air-con is operated at a 20°C temperature setting and at an outdoor air temperature of about 8°C. When the operating units of the induction air beam are changed from three units to two units (the center and the window side) and one unit (the window side), the ceiling surface temperature gradually becomes lower but the floor surface temperature is almost constant, so that the vertical temperature difference becomes small. In the case of the air-con, the ceiling surface temperature is not so different but the floor surface temperature becomes slightly higher at the corresponding points of time. The floor surface temperature, however, becomes lower overall than the case of the induction air beam, and a change in temperature becomes larger in the range from the floor surface to a height of 0.3 m, so that it is considered that a person in the room is likely to feel cold around the feet.

Illustration 3-3 shows the effect of the inlet position (the upper or the lower) located on the door side on the vertical temperature distribution of the room inside under the conditions of 22°C temperature setting, an outdoor air temperature of 10°C and 12°C, respectively. A change in temperature becomes mild at a height of 2 m or less for the upper inlet and at a height of 1.7 m or less for the lower inlet. In addition, the lower inlet has a relatively wider change in the vertical temperature difference at a height of 2 m or less according to the control of the number of the induction air beam units. The case of the lower inlet has a slightly larger temperature difference between 0.1 m and 1.1 m above the floor. This leads to the possibility that a temperature difference of 3°C or less, recommended by ISO, cannot be met.

Illustration 3-2. Vertical temperature distribution for induction air beam and air-con in heating

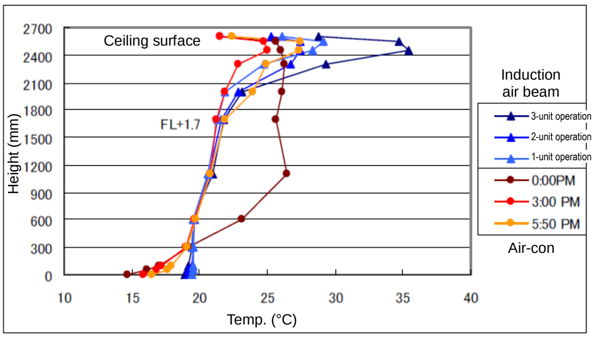
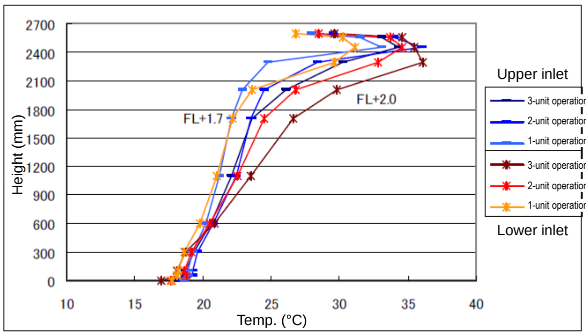


Illustration 3-3. Comparison between upper and lower inlets in heating by induction air beam



3-3, Horizontal temperature distribution in heating

Illustration 3-4 shows the horizontal temperature distribution of the room inside drawn from the values of 18 points at 1.1 m above the floor by using the 30-minute average values when the room temperature is stable. The temperatures around the wall surfaces on the east and west side of the laboratory are relatively high. On the other hand, the lowest-temperature area is near the window. In addition, there is a place with a slightly lower temperature on the west side of the door. When the operating units of the induction air beam are changed from three units to two units (the center and the window side) and one unit (the window side), it is shown that the temperature becomes 0.5 to 1°C lower step by step. Meanwhile the case of the air-con is shown in Illustration 3-5. Though in this case the lowest-temperature area is similarly located near the window, the temperature becomes gradually lower from the center to the circumference, and the temperature gradient is larger than the case of the radiant unit. From the above, it can be expected that heating by the induction air beam has the effect of radiation from the induction air beam and the whole ceiling surface, which makes the surrounding wall surfaces warmer to form the uniform horizontal temperature distribution of the room inside.

Illustration 3-4. Horizontal temperature distribution with the number of induction air beam units controlled in heating

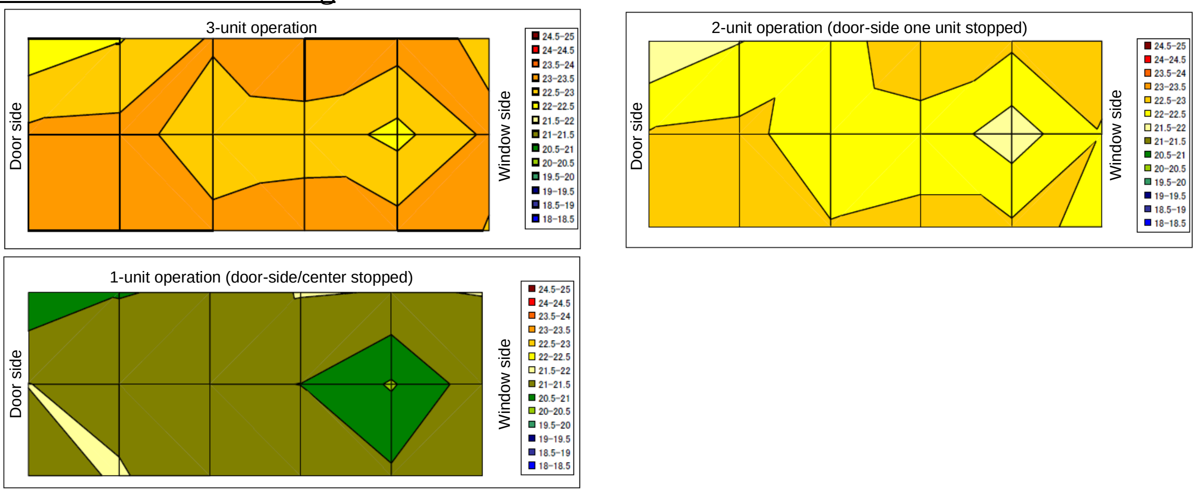
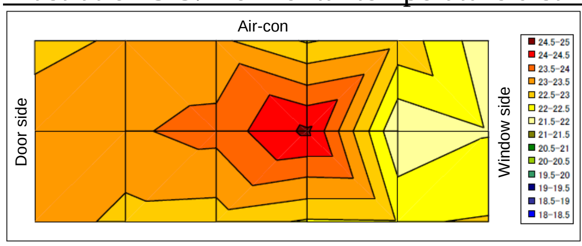


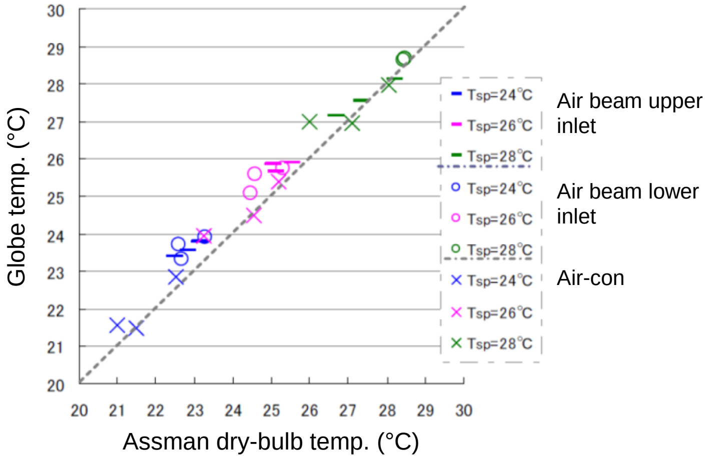
Illustration 3-5. Horizontal temperature distribution for air-con in heating



4. Experimental result of cooling

4-1, Assman dry-bulb temperature and globe temperature in cooling
The Assman dry-bulb temperature and the globe temperature when the room temperature in cooling is stable under the experimental conditions of different AC systems and temperature settings are shown in Illustration 4-1. Since the air-con generates higher wind speed, the effect of the air current causes the globe temperature to easily get close to the Assman dry-bulb temperature.
On the other hand, since the radiant unit has a much lower wind speed, the globe temperature becomes slightly higher than the Assman dry-bulb temperature. In addition, a tendency is observed in which the higher the temperature setting becomes, the smaller is the temperature difference between both. Also in the case of cooling the Assman dry-bulb temperature becomes closer to the temperature setting than the case of heating. On the other hand, even if the temperature setting is the same, the air-con is likely to form a larger temperature range.

Illustration 4-1. Assman dry-bulb temperature and globe temperature in cooling



4-2, Vertical temperature distribution in cooling

Illustration 4-2 shows the vertical temperature distribution at the room center when the temperature setting is 26°C, and the outdoor air temperature is about 30°C for the radiant unit and about 32°C for the air-con. The temperature difference between 0.1 m and 1.1 m above the floor in cooling becomes almost zero. This shows that the vertical temperature difference becomes much smaller than heating. The blowing temperature of the radiant unit, which induces and mixes indoor air, is slightly higher. On the other hand, the air-con has a lower air supply temperature, so that the temperature at 0.6 m above the floor drops to 24°C. Even if the operating units of the radiant units are changed from three units to two units and one unit, the vertical temperatures are almost constant.
Illustration 4-3 shows the effect of the inlet position on the vertical temperature distribution at a temperature setting of 26°C. The outdoor air temperature was about 30°C for the upper inlet and about 33°C for the lower inlet. This illustration shows that the vertical temperatures for the upper inlet become milder. For the lower inlet, the temperatures at 1.1 m or less above the floor become slightly lower, and the change in temperature becomes slightly larger. In addition, the positions of the inlets did not make a big difference in the ceiling surface temperature and the floor surface temperature as with the case of heating.

Illustration 4-2. Vertical temperature distribution for induction air beam and air-con in cooling

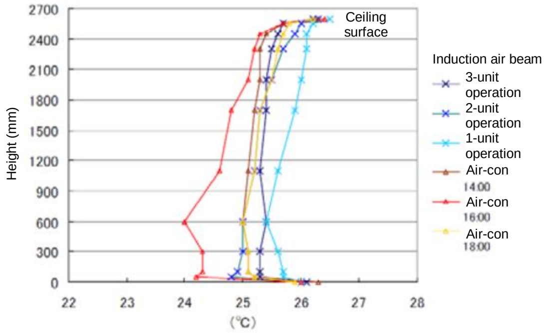
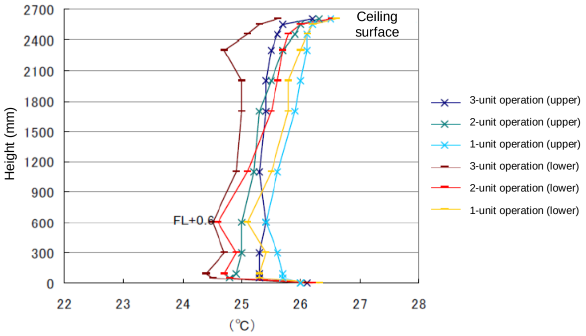


Illustration 4-3. Comparison between upper and lower inlets in cooling by induction air beam



4-3, Horizontal temperature distribution in cooling

Illustration 4-4 and Illustration 4-5 show the horizontal temperature distribution of the room inside based on the 30-minute average values when the room temperature is stable by using the measured values of 18 points at 1.1 m above the floor. The radiant unit makes the room center temperature lowest and the door-side/window-side temperatures become about 1°C higher. If the operating units of the radiant units are changed from three units to two units (the center and the window side), the room center temperature becomes slightly lower, but if the operating units are changed from two units (the center and the window side) to one unit (only the window side), the temperature becomes 0.5 to 1°C higher.
In the case of the air-con, one-unit operation is kept, so that the horizontal temperature distribution of the room inside does not vary much as the operating time passes, but a tendency is observed in which the temperature on the door side becomes slightly higher. Then the area with the lowest temperature caused by the direction of a blown air current is the room center in the same way. However, since the air current does not reach well to the area between the window side and the room center, there is a temperature difference of about 3°C. From the above, it can be expected that the radiant unit can form the uniform horizontal temperature distribution of the room inside.

Illustration 4-4. Horizontal temperature distribution with the number of induction air beam units controlled in cooling

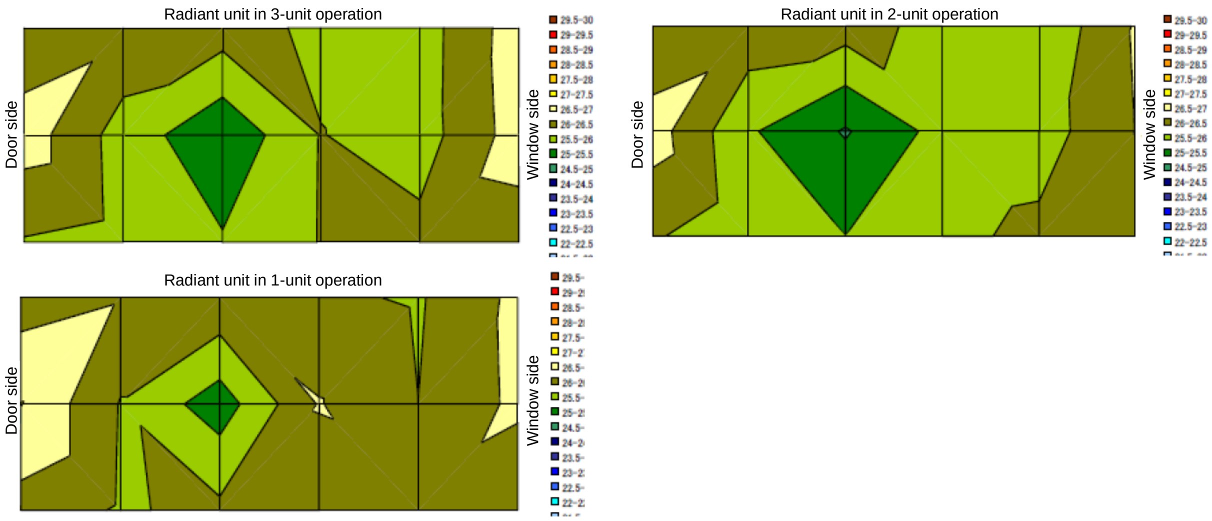
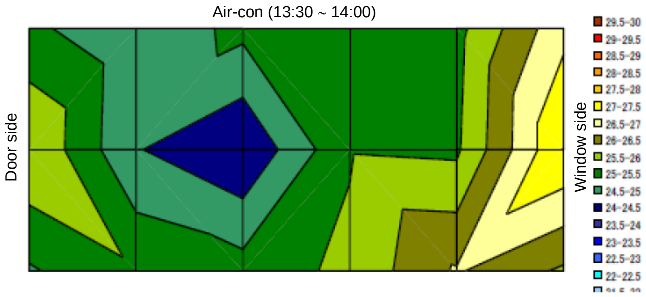


Illustration 4-5. Horizontal temperature distribution for air-con in cooling



RESULTS AND DISCUSSION

The All Air Supplied Induction Radiant and Laminar Flow AC System caused, in the indoor residential space, vertical and horizontal differences in temperature less than 1°C when cooled. When heated, both of the differences were less than 2°C. Meanwhile, the conventional air conditioner resulted into the difference of temperature of 3°C when cooling and 4°C when heating. According to responses to questionnaires, the All Air Supplied Induction Radiant and Laminar Flow AC system produced almost no sensible airflow.

CONCLUSION

As a result, All Air Supplied Induction Radiant and Laminar Flow AC System formed more uniform indoor temperature distribution than the conventional air conditioning system. We have also confirmed that it improved the thermal comfort while eliminating the uncomfortable air stream.
From the above, it is considered that simultaneous use of the high-temperature cooling & low-temperature heating AC System and the all air supplied induction radiant and laminar flow air conditioner can provide both great energy saving and comfort.

ACKNOWLEDGEMENT

This study had considerable cooperation for the experiments and the summarization of the study results from Ms.Yan Hanyue, who graduated from the Graduate School of Environmental Studies at Nagoya University in 2013. We would express to show our gratitude to her for this.

REFERENCES

1) Zen Kuuki Shiki Yuuin Housha Kuuchou Houshiki No Danbou Seinou Hyouka Houkokusho (Heating performance evaluation report of all air supplied induction radiant and laminar flow system)
Kuno Laboratory, Graduate School of Environmental Studies, Nagoya University, June 2012

2) Zen Kuuki Shiki Yuuin Housha Kuuchou Houshiki No Reibou Seinou Hyouka Houkokusho (Cooling performance evaluation report of all air supplied induction radiant and laminar flow system)
Kuno Laboratory, Graduate School of Environmental Studies, Nagoya University, March 2013