THERMAL AND VENTILATION CHARACTERISTICS IN A ROOM WITH UNDERFLOOR AIR-CONDITIONING SYSTEM

Hwataik Han[1], Kwang-Seop Chung[2] and Kyung-Jin Jang[3]

[1]Kookmin University, Seoul, Korea
[2]Seoul National University of Technology, Seoul, Korea
[3]Kookmin University Graduate School, Seoul, Korea

ABSTRACT

It is the objective of the present paper to investigate indoor environmental characteristics of an office building with an underfloor air conditioning system. Thermal conditions in the room were monitored including horizontal and vertical temperature distributions, supply and exhaust air temperatures, and globe temperature. Indoor air quality was investigated by measuring carbon monoxide, carbon dioxide and airborne particulates. Velocity distributions around a floor air terminal, and thermal comfort around a supply air terminal were also investigated. Room ventilation characteristics were obtained by a pulsed tracer gas technique. It shows that the underfloor air conditioning system provides good ventilation characteristics in cooling modes, while airborne particulate levels are comparable with those found in conventional ceiling supply systems. The detailed temperature and velocity information can be used to design the floor layout to improve the performance of the UFAC systems.

INTRODUCTION

Various air-conditioning systems have been developed and utilized to provide comfortable indoor environments while minimizing energy consumption. Underfloor air conditioning (UFAC) systems have been recently received attention, since they can provide flexible plane layout in an office space and can be used as a personal air-conditioning system.[1,2] Research related to this subject has been abundant worldwide during the last decade. However, in Korea, there are a limited number of buildings with UFAC systems, and little research have been done on this subject.[3,4]

The purpose of the present paper is to evaluate the thermal and ventilation performance of the system in one of the few buildings with a UFAC system. The experimental results on indoor air quality, airflow, and temperature distributions can be used to develop and improve the performance of the UFAC system and to increase its popularity in Korea.

EXPERIMENTAL METHODS AND PROCEDURES

The 8 story building is located in the south-western part of downtown Seoul. It has a central air-conditioning unit with a conventional ceiling supply-exhaust system except on the 6th floor. Experiments were carried out in a conference room located on the 6th floor where the whole floor has been raised to implement a floor supply-exhaust system. The layout of the room is shown in Fig. 1.

The air-conditioning system consists of a CAM (Conditioned Air Module) and an FTU (Floor Terminal Unit). The space underneath the floor is partitioned to be used for both supply and exhaust air paths, which is indicated with a dashed line in Fig. 1. The height of plenum is

0.3m. A CAM is designed to supply cool air to the plenum underneath the floor at 5-10°C lower than the setting temperature, and an FTU operates its own fan to discharge the conditioned air into the room.

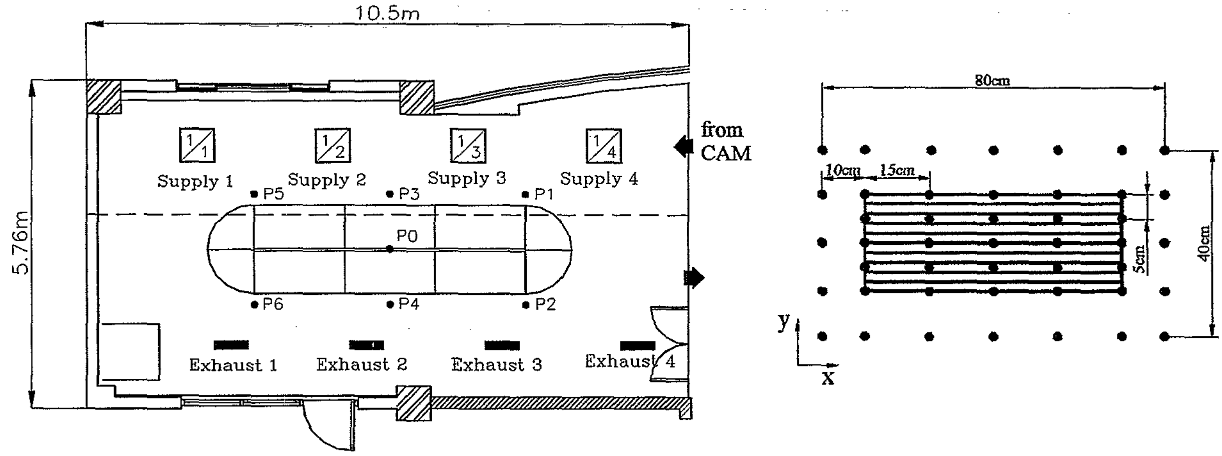


Fig. 1 Layout of the room and velocity measuring points around a supply air terminal

Experiments were carried out during the summer of 1998. The system started operating approximately one hour before office hours (9:00-18:00) began, and shut off at 18:00. The room set temperature was 25°C, and the height of the room is 2.5m. Vertical temperature distributions in the room were measured at the center of the room (P0). The heights of the thermocouple locations are 0, 0.1, 0.6, 1.1, 1.7, and 2.5m from the floor. A globe temperature was measured at P0, and supply and exhaust air temperatures were also measured. Temperature data from thermocouples were recorded using a data acquisition system every 5 minutes. Horizontal temperature distributions in the room were measured manually using a portable thermometer at the height of 1.1m every 2 hours.

Air quality in the room was investigated by measuring carbon dioxide, carbon monoxide, and air-borne particulate concentrations in the room. The measuring points are P1 to P6 shown in Fig. 1 at the height of 1.1m from the floor.

The ventilation performance of the room was investigated using SF_6 tracer gas. A known amount of tracer was injected as a pulse near a supply air terminal, and the concentration variation was monitored at 10 sec intervals. The SF_6 detector is a colorimetric type using a membrane galvanic cell, whose response time is 30sec. The measured concentration response is used to calculate local mean age and room mean age. [5,6] Airflow characteristics around supply and exhaust terminals are very important to indoor air movement and thermal comfort. Air velocity magnitudes in the vicinity of the terminals were measured in detail using an omni-directional velocity probe by traversing in the x, y, and z directions. Both of the face areas of the supply and the exhaust grilles are 0.6 x 0.2m. Measurements were made at the horizontal locations shown in Fig. 1 at every 0.10m in the z-direction.

RESULTS AND DISCUSSION

Temperature distribution

Figure 2 shows hourly variations of indoor air, outdoor air, and globe temperatures. While the air-conditioning system is on, indoor air temperature is maintained between 23.6-26.4°C.

When the system turns off at 18:00 the temperature increases because of the remaining cooling load from the outside. As outdoor air temperature decreases in the evening, the cooling load also decreases. The indoor temperature begins to exceed the outdoor temperature at around 20:00. This temperature reversal persists until the next morning. The globe temperature is on the average 0.4°C higher than the indoor air temperature. It indicates wall surfaces are warmer than the indoor air. There would be no thermal discomfort associated with the radiation heat flux.

The air temperature at each supply grille is shown in also shown in Fig. 2. It shows oscillatory behavior during operating hours because of the temperature control of the system. The air temperature at supply #4 shows the lowest value, and it is located closest to the air-conditioning system. As air travels along the underfloor path, it gains heat from the surroundings. The average temperatures at supply #1 and supply #4 are 22.3 and 20.9°C, respectively. Those at supply #2 and at supply #3 fall between. The maximum difference between supply air temperatures is slightly greater than the design value of 0.11°C /m.

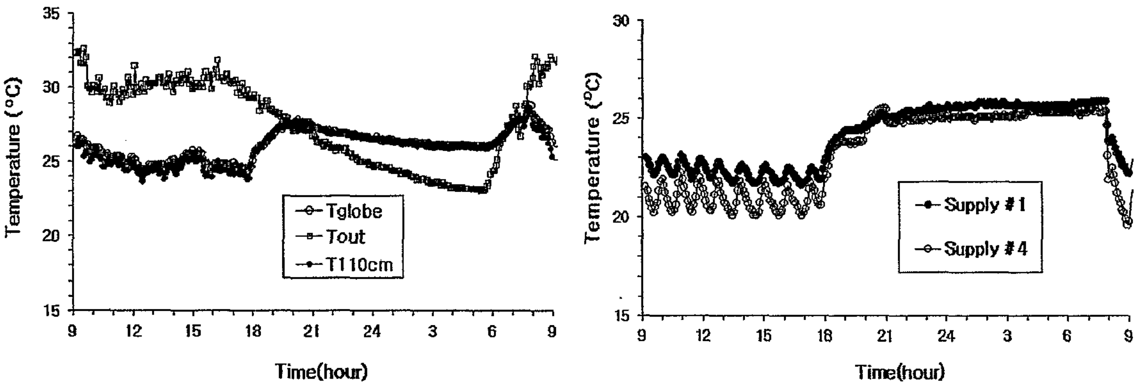


Fig. 2 Outdoor, indoor, globe temperatures and air temperatures at supply grilles

The plan views of the temperature contours in the room are shown in Fig. 3a) and 3b), which show distributions at 11:00 and 17:00, respectively. Both figures show the air temperature in the room is uniformly distributed horizontally. It is slightly cooler near the supply side compared to the exhaust side of the room. Vertical temperature distributions in the room are shown in Fig. 4. Non-uniform temperature profiles can be seen during an initial period of operation, i.e. 9:00 in the figure. The non-uniformity disappears and the distributions are quite steady during operating hours. The vertical temperature gradients in the room have been found no greater than those observed in conventional ceiling supply systems.

Indoor air quality

Concentration of carbon dioxide varies depending on the number of occupants in the room. The measured concentration ranges from 640ppm to 740ppm, lower than the CO_2 criteria of 1000ppm. The concentration of carbon monoxide was also measured, but it was below a detectable range (1ppm) for the instrument used. It is of general concern that underfloor air conditioning systems may cause higher particulate concentrations compared to conventional ceiling supply systems, because of possible dust rising from floors. The concentration of air-borne particulate ranges 0.006 to 0.023mg/m^3, which is within the same range of concentrations detected in a room with a ceiling supply system measured in the same building. It is considerably lower than the indoor criterion of 0.15mg/m^3.

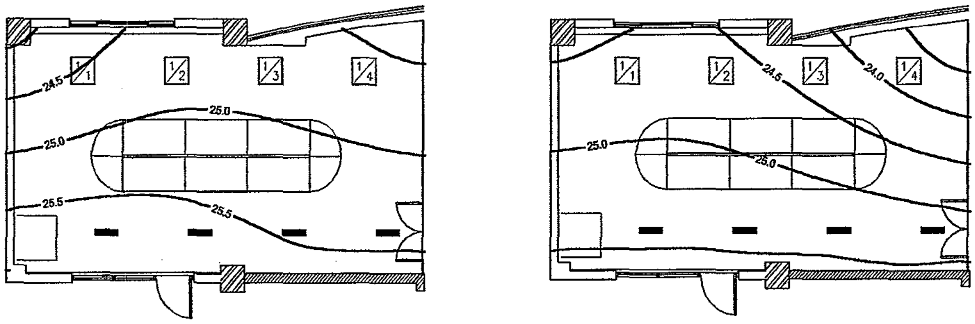


Fig. 3 Horizontal temperature distributions at 11:00 and 17:00

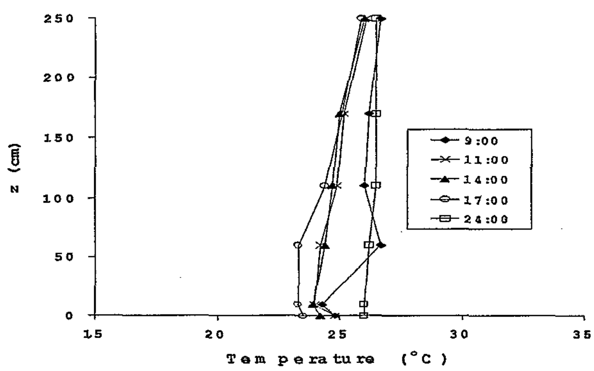


Fig. 4 Vertical temperature distributions at the center of the room

Ventilation effectiveness

Concentration responses of tracer gas at exhaust #2 are shown in Fig. 5 after pulse injections given at supply #2 and #4. The concentration graphs can be subdivided into three periods, i.e. an initial delay period, a peak period, and an exponential decay period. During the initial delay period, it takes time for the first part of the tracer gas to reach the exhaust. During the peak period, most significant diffusing and mixing mechanisms take place in the room. After a sufficient mixing of the room air, the concentration decays exponentially regardless of the location. The area under the curve indicates the amount of tracer gas passing through the exhaust, and the first moment indicates the mean age at the exhaust. The maximum concentration depends on the amount of tracer gas, but it does not affect the mean age calculations. The mean age from the supply #2 to the exhaust is calculated to be 750sec and that from the supply #4 to the exhaust 780sec. The overall ventilation effectiveness in the room is calculated to be 0.77.

Air velocity distribution

Airflow velocity distribution around a supply air terminal is shown in Fig. 6. The velocity distribution on the zero height indicates airflow magnitude discharged from the supply. It appears to be nearly symmetric, but is not quite uniform over the entire surface. The integrated airflow rate over the surface is measured to be 17.6L/s. It can be observed that the jet becomes asymmetrical and is inclined to one side of the diffuser, as it goes up. Air velocity over 1.0m/s persists up to 0.5m.

Figure 7 shows velocity contours in the center plane above an exhaust. The magnitude decreases quite rapidly as the height increases. The contour plot is similar to those obtained by a potential flow calculation, but it tends to lean to one side of the terminal.

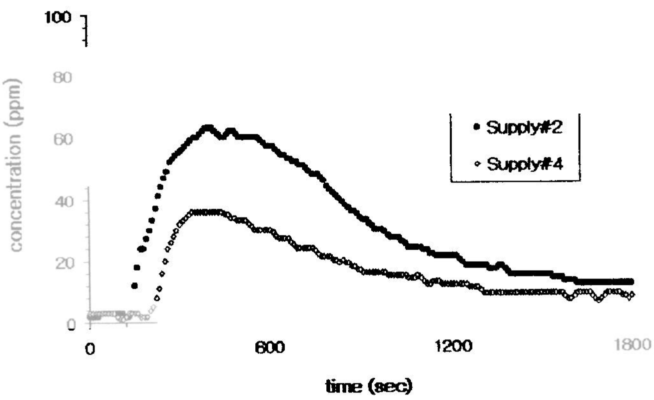


Fig. 5 Concentration responses at exhaust #2 after a pulse injection at supply#2 and #4

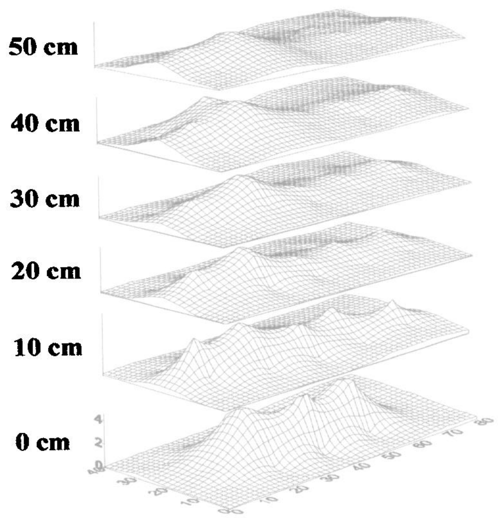


Fig. 6 Airflow distribution around a supply air terminal

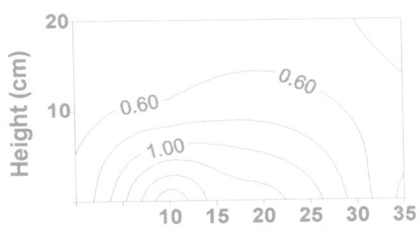
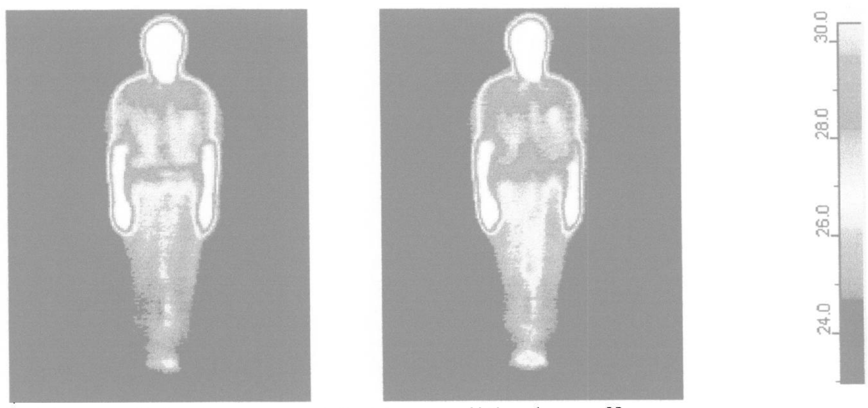


Fig. 7 Velocity contours in the vertical center plane above an exhaust terminal (m/sec)

Thermal comfort

Infra-red camera images are shown in Fig. 8, which show temperature distributions of a person standing above a supply grille with the air-conditioning system on and off. Temperature differences can be detected between the figures especially near the feet, even though color images are printed in black and white. The measured ankle temperatures are 26.6°C, 27.2°C when the system is on and off, respectively for a standing posture. Infra-red camera images for a sitting posture, which are not included in the paper, indicate 26.8°C and 27.5°C for the system is on and off, respectively. Based on the measurement, it is believed a person may feel discomfort because of a local draft especially on their feet, when he is standing or sitting around a supply terminal location.



(a) Air-conditioning on (b) Air-conditioning off

Fig. 8 Infra-red camera images of a person standing on a supply air terminal

CONCLUSIONS

Following conclusions were drawn from the experimental observations in a room with an underfloor air conditioning system.

1. The underfloor air conditioning system provides quite uniform temperature distributions in the room vertically and horizontally. However, effort needs to be focused reducing the supply air temperature variations along the air path depending on the distance from the air-conditioning module.
2. The air-borne particulate concentration level is significantly lower than the indoor criterion, and it is in the same range with those found in conventional ceiling supply systems. The carbon oxide levels are also satisfactory.
3. Air jets from a supply air terminal can reach the occupied level, and can cause discomfort because of cold air drafts. However, air velocity decreases so rapidly in the vicinity of an exhaust terminal, that there is not concern about discomfort around the exhaust.
4. Overall ventilation effectiveness of the room is found to be 0.77, which is approximately 20% less than complete mixing.

REFERENCES

1. Heinemeier, K E, Schiller, G E, and Benton, C C. 1990. Task Conditioning For the Workspace: Issues and Challenges. ASHRAE Transactions, Vol. 96 (2), pp 678-689.
2. Shute, R W. 1992. Integrated access floor HVAC. ASHRAE Trans, Vol. 98 (1), pp 696-698.
3. Lee, E T. 1997. POE of UFAC System. Technical Seminar on Underfloor Air Conditioning System, Samsung Research Institute of Construction, pp. 113-121.
4. Shin-Sung E&G. *Underfloor Air Conditioning System Engineering Guide.*
5. Sangberg, M. and Sjoberg, M. 1983. The Use of Moments for Assessing Air Quality in Ventilated Rooms. Building and Environment, Vol. 18 (4), pp 181-197.
6. Han, H. 1999. Local Mean Age Measurements for Heating, Cooling and Isothermal Supply Air Conditions. ASHRAE Transactions, Vol. 105.