

Fundamental Studies on Indoor Thermal Environment in an Apartment House Utilizing Cross Ventilation in Summer Season

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ABSTRACT: The summer season in Korea is very hot and humid, and cross ventilation has been used to cool the indoors. However, when it is insufficient to cool the indoors with only cross ventilation, it is hard to sleep in at night and outside is felt relatively cooler than inside. Apartment houses in Korea used to be built using reinforced concrete. It is regarded that the reinforced concrete, which is a weight material, raises the indoor temperature higher than the outside air temperature during the night. In this study, the indoor thermal environment in an apartment house was measured to understand thermal specificities under the conditions of cross ventilation, and to find the potentiality to improve indoor thermal environment during tropical nights. The results showed that indoor air temperature follows the change in outdoor air temperature. The difference between outdoor air temperature and indoor air temperature is less than 0.7 °C because air change rate is largely dependent on the condition of cross ventilation. There may be a possibility of improving indoor thermal environment in summer by utilizing the finishing material whose thermal conductivity is lower than the presently used material.

Keywords: Indoor Thermal Environment, Cross Ventilation, Tropical Night, Time-lag

1. INTRODUCTION

Summer season in Korea is characterized by high temperatures above 30°C and high humidity above 60%. Koreans traditionally utilized cross ventilation to keep cool in summer. However, in tropical nights (defined by days that the lowest temperature is at above 25°C), it is very hard to sleep in and outdoors is cooler than indoors. In tropical nights, it is usually not enough to cool indoors only with cross ventilation, and dwellers resort to turning on the air-conditioner.

Figure 1 shows the number of days experiencing tropical nights during the last 20 years. Though the number of days varies year by year, there is an increasing tendency

from 2003 to 2007. Seoul, Korea's capital, shows 10 tropical nights in average after 1994, and Cheju, Korea's southernmost city, shows 26 days in average.

The main material of the building structure of apartment houses in Korea is reinforced concrete. Concrete, which is a weight material with a large heat capacity, takes a long time to be heated or cooled, and it absorbs or emits large heat. Concrete structures that are heated by sun rays and by the high temperature of day time outdoor air, emit the heat to the indoor side of the wall during the night. This results in the indoor air temperature being higher than that of the outdoor air. The structures of the wall, the floor and the ceiling are composed of

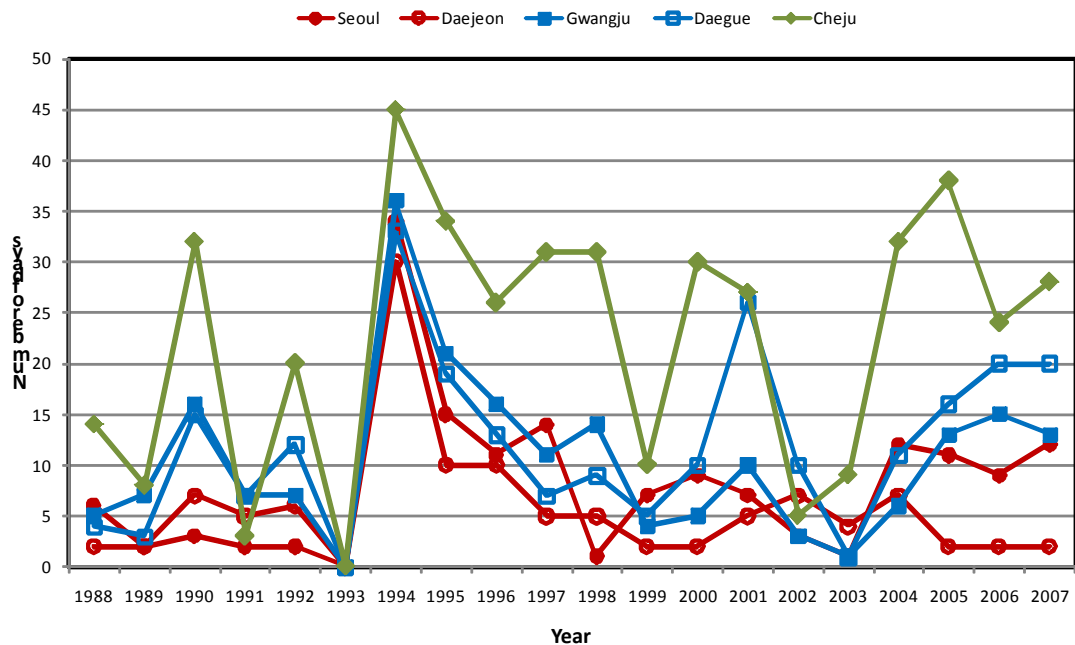


Figure 1: Number of days experiencing tropical nights during the last 20 years.

multiple layers. It would be great encouragement if we could improve the indoor thermal environment by changing the interior materials in a room. For this objective, the characteristics of thermal response of various wall, floor, and ceiling structures need to be understood. The purpose of this study is to investigate the possibility of improving indoor thermal environment by changing the material used for the structure of the room. Measurements of an apartment house observed in the summer are analyzed in this report.

2. ON-SITE MEASUREMENT

Figure 2 shows observations made in an apartment house in Eujeongbu City in the northern part of Seoul. There are 4 houses on the same floor, and the left and right walls are shared with the adjacent apartment houses. Each apartment house consists of a living room, a dining kitchen and 3 bedrooms, with a total floor area of 54m². Table 1 shows the composition of the floor, ceiling, and wall. The construction of the floor shows the Ondol-system which is a

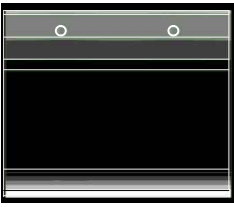
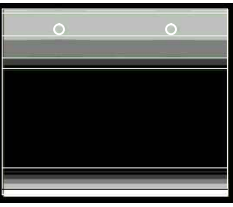
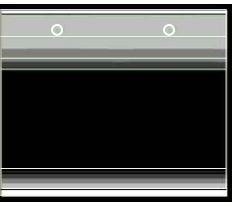
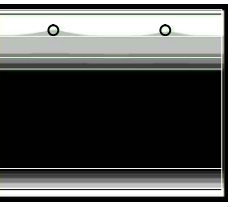
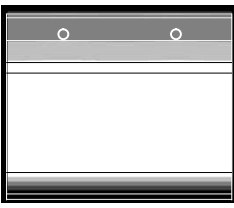
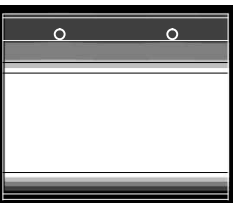
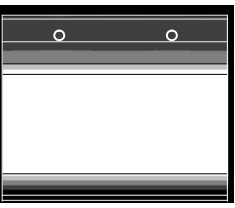
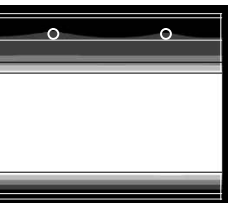


Figure 2: Measurements observed in an apartment house.

Table 1: Composition of the floor, ceiling, and wall.

Floor and ceiling	Wall

Table 2: Results of the numerical simulation.

Mode	3 hours later	6 hours later	9 hours later	12 hours later
Heating (24°C ↓ 29°C)				
Cooling (29°C ↓ 24°C)				

traditional Korean floor heating system. The indoor thermal environments of a Master's room were measured for 4 days from August 26 to August 29. To keep the measurement terms as usual, dwellers were asked to go about their normal activities at home. Measured items and points of measurement are shown in Figure 2. Outdoor air temperature, indoor air temperature, indoor globe temperature, and surface temperature of the floor, ceiling and wall are measured. All windows and doors except for the entrance door were opened to represent the utilization of cross ventilation.

3. HEAT ABSORPTION AND EMISSION IN THE STRUCTURE OF FLOOR AND CEILING

The structure of the floor and ceiling are composed of multiple layers such as concrete, insulation, air layer, and their thermal conductivity and heat capacity are different from each other. To investigate the characteristics of heat absorption and emission in the structure of the floor and ceiling, the characteristics of heat transfer according to the composition of layers needs to be understood. Numerical simulation

method was applied to examine the heat transfer through the structure of the floor and ceiling as shown in Table 1. Numerical simulation was conducted in an unsteady state. Heating mode is the case in which the temperature of the entire floor and ceiling structure is at 24 °C at the initial stage, and the indoor air temperature is at 29 °C. Cooling mode is the case in which the temperature of the floor and ceiling structure is at 29 °C at the initial stage, and indoor air temperature is at 24 °C.

Results of the numerical simulation are as shown in Table 2. In the heating mode, the temperature of the wood floor layer and mortar layer significantly increase, the mortar layer increasing above 28 °C. The insulation layer is effective in blocking heat transfer to the concrete slab so that the temperature of the slab is kept at below 25°C 12 hours later. The temperature of the gypsum board on the ceiling increases to near the indoor air temperature of 29 °C 3 hours later. Air layer is also an effective insulator and contributes to blocking heat transfer into the slab together with the

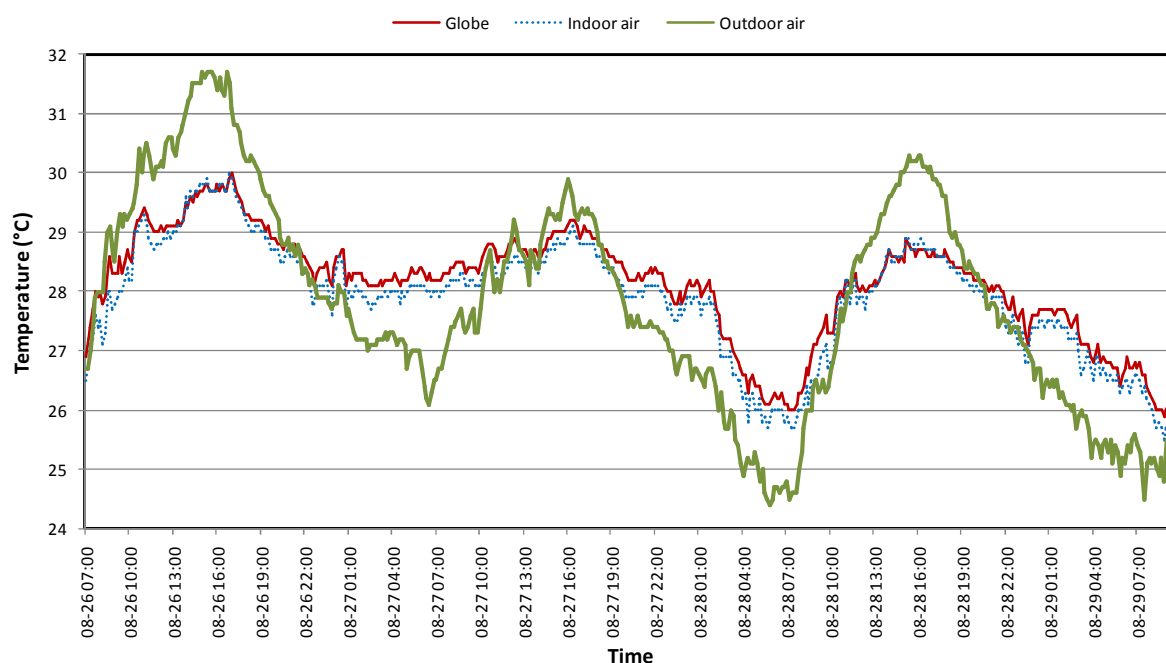


Figure 3: Globe temperature, indoor air temperature and outdoor air temperature

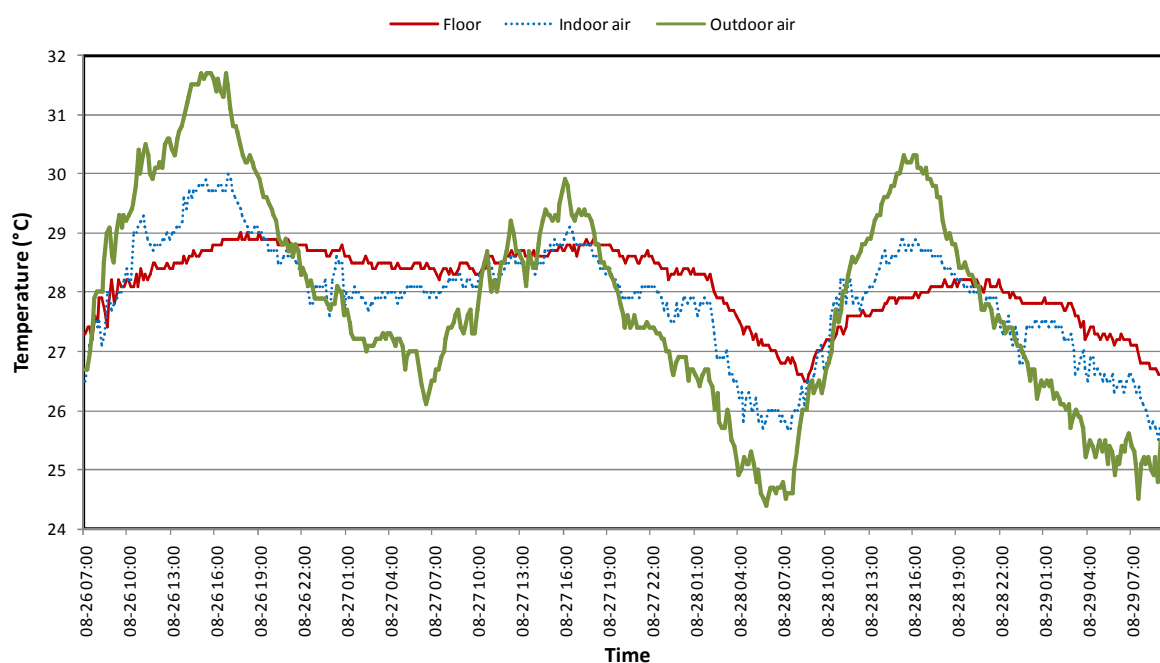


Figure 4: Floor surface temperature, indoor air temperature and outdoor air temperature

insulation layer of the floor structure. In the cooling mode, the relatively hot mortar layer inversely emits heat to the indoor side through the wood floor layer. The temperature of the gypsum board decreases to near the indoor air temperature of 24 °C 3 hours later. Insulation layer on the floor

structure and air layer on the ceiling structure conduct the role of insulation effectively, too. From the results of numerical simulation, it is observed that heat storage occurs mainly in the mortar layer.

4. RESULTS AND DISCUSSION

4.1 Outdoor Air Temperature, Indoor Air Temperature and Globe Temperature

Changes in outdoor air temperature, indoor air temperature and globe temperature in terms of measurement are as shown in Figure 3. Outdoor air temperature shows the maximum of 31 °C at about 16:00 and the minimum of 21 °C at about 06:00. Changes in indoor air temperature and globe temperature follow the change in outdoor air temperature. Time-lag between outdoor air temperature and indoor air temperature is shorter than 20 minutes except in the morning of August 27, which is thought that some disturbance by the dweller affected such a change..

Indoor air shows a temperature 0.8 ~ 1.7 °C lower than outdoor air temperature at the highest temperature of the day and 1.3 ~ 1.8 °C higher than outdoor air temperature at the lowest temperature of the day. Globe temperature rises higher than indoor air temperature except when the outdoor air temperature is maintained at the highest state which globe temperature is almost equal to indoor air temperature. Even though there were possibly some disturbances due to on-site measurement, the differences between globe temperature and indoor air temperature in general, becomes larger under the condition that outdoor air temperature is lower than indoor air temperature, and becomes smaller when outdoor air temperature is higher than indoor air temperature. Globe temperature is in average 0.2 °C higher than indoor air temperature and is highest at 0.7 °C increase. It is thought that the small difference between globe temperature and indoor air temperature is caused by large air change rate through cross ventilation. This can be interpreted as heat transfer by convection being larger than by radiation in a room.

4.2 Floor Surface Temperature

The floor surface temperature is as shown in Figure 4. The floor surface temperature shows small temperature change compared to indoor air temperature, and this is thought that it is because the mortar layer on the floor structure has a large heat capacity. Even though time-lag to outdoor air temperature is unstable because of various disturbances in on-site measurement, the average of it is 2 hours and 20 minutes.

The floor surface temperature is 1.0 °C lower than the indoor air temperature at its maximum temperature on August 26, and 0.7 °C lower on August 28. The floor surface temperature is 0.8 °C higher than the indoor air temperature at its minimum temperature on August 28.

4.3 Ceiling Surface Temperature

The ceiling surface temperature is as shown in Figure 5. Time-lag to outdoor air temperature is about 1 hour on average. The ceiling surface temperature is 0.6 °C lower than the indoor air temperature at its maximum temperature on August 26, and 0.2 °C lower on August 28. These correspond well with the results of the previous numerical simulation. However, the ceiling surface temperature is 1.3 °C higher than the indoor air temperature at its minimum temperature on August 28. This means that the ceiling surface temperature is 0.5 °C higher than the floor surface temperature, and it does not correspond with the results of the previous simulation. This inconsistency can be thought to be caused by airflows and other factors. However, this cannot be confirmed in this study.

4.4 Wall Surface Temperature

The wall surface temperature is as shown in Figure 6. Time-lag to outdoor air temperature is about one and a half hour. The wall surface temperature is 0.8 °C lower than the indoor air temperature at its maximum temperature on August 26, and 0.7 °C lower on August 28. The wall surface temperature is 1.0 °C higher than the indoor air

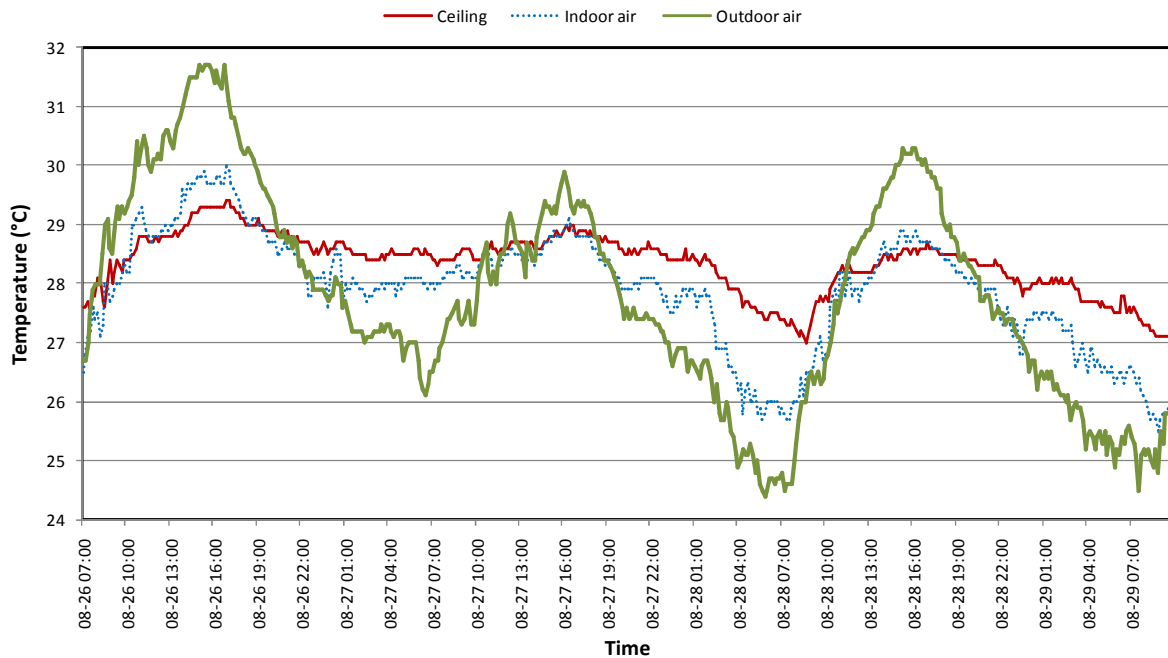


Figure 5: Ceiling surface temperature, indoor air temperature and outdoor air temperature

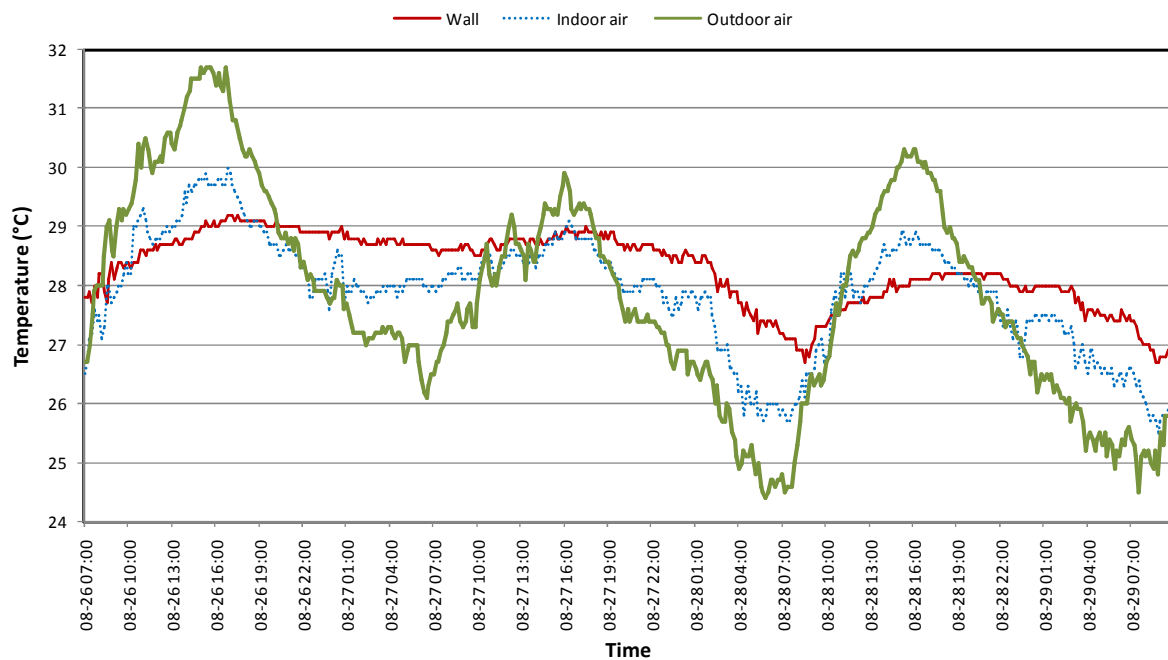


Figure 6: Wall surface temperature, indoor air temperature and outdoor air temperature

temperature at its minimum temperature on August 28. Meanwhile, the wall surface temperature is 0 ~ 0.2 °C higher than the floor surface temperature at its highest temperature and is 0.2 °C higher at its lowest temperature. Considering that the floor is finished by utilizing wood floor whose thermal conductivity is 0.11

W/m · K and thermal conductivity of concrete wall is 1.6 W/m · K, it can be thought that there may be a possibility of improving indoor thermal environment in the summer season by utilizing finishing materials whose thermal conductivity is lower than the ones currently being used.

5. CONCLUSION

From the results and discussions, a conclusions can be drawn as follows:

- 1) The indoor air temperature and the globe temperature follow the changes in outdoor air temperature, and the time-lag between outdoor air temperature and indoor air temperature is shorter than 20 minutes.
- 2) The indoor air temperature is 0.8 ~ 1.7 °C lower than the outdoor air temperature at the highest temperature of the day and 1.3 ~ 1.8 °C higher than the outdoor air temperature at the lowest temperature.
- 3) The difference between globe temperature and indoor air temperature is less than 0.7 °C because of the large air change rate due to cross ventilation.
- 4) There may be a possibility of improving the indoor thermal environment in the summer season by utilizing finishing materials whose thermal conductivity is lower than the ones currently being used.

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