Application of Comfort Range Control logic for thermal comfort and energy saving in VRF system

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Abstract. In Korea, in order to reduce building energy, the policy applying insulation standard of passive house level to new buildings from 2017 was established. However, the concept of passive house applied in the Central and Western Europe area is feared to increase the cooling load in hot and humid areas in summer like Korea. Therefore, we propose a control logic for reducing the cooling energy in summer while maintaining occupants’ thermal comfort that can apply to VRF system installed in passive buildings. In this paper, Comfort Range Control logic based on ASHRAE Comfort Chart for occupants’ thermal comfort and energy saving was applied to VRF system in the actual office space of passive building in Korea. The indoor environment and energy consumption according to the conventional control method, Set-Point Control, and Comfort Range Control proposed in this study were analyzed by field measurement.

1. Introduction

Building sector accounts for a 20~40% of the total final energy consumption. Among building services, HVAC systems for heating, cooling and ventilation energy use account for 50% of building consumption [1]. In Korea, in order to reduce building energy, the policy that aims to reduce heating and cooling energy consumption by 60% through applying insulation standard of passive house level to new buildings from 2017 and requires new buildings to achieve zero energy house standard from 2025 was established [2]. Therefore, passive houses are expected to increase in Korea due to the building energy saving policy. However, the concept of passive house built in Germany since 1992 was adopted in Central and Western Europe and this might not be the case for passive buildings located in other geographical areas where cooling is occasionally necessary [3]. Especially, in non-residential buildings such as offices and schools, the level of internal gain due to occupants, lighting and office automation equipment is higher than that of residential buildings [4]. Therefore, it is concerned that the application of passive technology to non-residential buildings with high internal gain level will increase energy consumption during the summer due to increased cooling loads.

Small-medium-sized buildings, such as offices and schools, are mainly using a VRF(Variable Refrigeration Flow) system for cooling or heating. The VRF system is a multi-heat pump that connects a number of indoor units to a single outdoor unit and controls the flow rate of refrigerant supplied to the indoor units using the EEV(Electronic Expansion Valve). The use of VRF systems in small-medium-sized buildings has increased due to the advantages that are ease of responding partial loads, control of each zone, etc.

Therefore, in this study, we propose a control logic for reducing the cooling energy in summer while maintaining occupants’ thermal comfort that can apply to VRF system installed in passive buildings. In the past, there have been many researches on the control method by the thermal comfort index for
comfort and energy saving to control the indoor environment such as using PMV (Predicted Mean Vote) suggested by P.O. Fanger [5, 6], or using comfort zone based on psychrometric chart to maintain indoor temperature and humidity within ASHRAE Comfort Chart [7, 8]. However, in these literature reviews, the control methods have been mainly verified by simulation tool or experiment in testbed. Therefore, in this study, control logic for thermal comfort and energy saving was applied to VRF systems installed in the office space of the actual passive building to verify the validity of the control logic through field measurement for about three weeks. The control logic for thermal comfort and energy saving proposed in this study is Comfort Range Control that is based on the comfort zone proposed by ASHRAE [9]. It is easy to apply to actual VRF system because it does not need a lot of data and simply controls according to the state of the indoor environment. IoT (Internet of Things) enables the application of the Comfort Range control logic to the VRF system and the remote control of the indoor environment from outside the building. In other words, through remote management system, field measurement was conducted by changing the Set-Point Control, which is the conventional VRF system control method, and the logic of Comfort Range Control proposed in this study. The indoor temperature, humidity and power of the target space are monitored in real time to analyze the energy saving effect of Comfort Range Control logic.

2. Comfort Range Control logic

2.1. Control variable: operative temperature

When applying the summer comfort range of ASHRAE Comfort Chart (operative temperature 24-27°C, absolute humidity 0.012 kg/kg’ below) [9] to the actual VRF system, it is difficult to reflect indoor humidity change in control. Therefore, in this study, only the operative temperature was considered as the control variable of the comfort range control algorithm. The operative temperature is an index that comprehensively considers the effects of dry bulb temperature, air velocity and radiant temperature. As the general VRF system only recognizes indoor dry bulb temperature as return air temperature, the calibration value +0.5°C for dry bulb temperature was derived through preliminary test.

2.2. Control range: 25-26.5°C

T. Hoyt et al. [10] referred that when the indoor environment is controlled in a narrow range, the occupants cannot show high satisfaction in terms of comfort. Therefore, in this study, unlike the Set-Point control method which controls the indoor environment based on a certain temperature, the control range is widened to accommodate the range of occupants’ comfort. Based on the summer comfort range of the ASHRAE comfort zone, the control range of 25-26.5°C was derived from the preliminary test by evaluating the results of occupants’ TSV (Thermal Sensation Vote), CSV (Comfort Sensation Vote) and calculating the PMV. In addition, when the occupants are satisfied with the comfort, the occupant can feel discomfort due to the cold form overcooling [11]. Accordingly, the blowing mode was applied according to the control range, when the indoor operative temperature reaches 25°C, only the indoor unit is operated without operating the outdoor unit, and when the indoor operative temperature reaches 26.5°C or more, the outdoor unit is operated again for cooling.

3. Field Measurement

3.1. Target space and System configuration

An outline of the target space and control system is shown in Table 1 and Figure 1, respectively. DDC (Direct Digital Control) controller is a device that connects with VRF system and various instruments based on wired/wireless communication. It sends control signals to VRF system through Modbus and receives indoor temperature and power data. The IoT server serves to store and analyze data collected through the DDC controller based on BACnet (Building Automation and Control NETWORKs) and enables to monitor the data of space in the GUI (Graphical User Interface) working environment through a single screen. In addition, monitoring and remote control are also possible in external environments by synchronizing with mobile devices such as Tablet PCs.
3.2. Measurement conditions

The measurement conditions are as shown in Table 2. In the case of Set-Point Control, which is a conventional control method, the setting value of the Set-Point Control was selected at 25°C to reflect the result of the preliminary test, which is not the cooling set temperature commonly used in Korea at 26°C.

| Case                  | Set-Point Control | Comfort Range Control |
|-----------------------|-------------------|-----------------------|
| Control variable      | Dry-bulb temperature | Operative temperature |
| Control value/range   | 25°C              | 25-26.5°C             |
| Control mode          | Cooling           | Cooling, Blowing      |
| Air flowrate          | Fixed(Middle speed) | Fixed(Middle speed) |
| Operation schedule    | 08:00-18:00 4EA On; 18:00-20:00 2EA On |                      |
| Ventilation(ERV)      | Fixed(Middle speed) |                      |
| Door/Window           | Closed            |                      |
| Lighting              | On                |                      |

Table 1. Information of target space

| Target building     | Location                                                                 |
|---------------------|---------------------------------------------------------------------------|
|                     | Asan Central Library, 229, Nambu-ro, Asan-si, Chungcheongnam-do, Republic of Korea |
| Description         | Passive house design certification (Performance certification: 2.8L/m²a), Building Energy Efficiency Rating(1*) |

| Target space        | Location       |
|---------------------|----------------|
|                     | 4th Floor / Office |
| Size                | Area: 259.2m², Height: 2.7m |
| Occupant            | Male 5, Female 13 (Clothing insulation 0.5clo, Metabolic rate 1.1met) |
| Schedule            | 08:00 ~ 20:00 |
| VRF system          | Outdoor Unit 1EA, Indoor Unit 4EA |

Figure 1. System configuration
4. Results

4.1. Indoor environment

Figure 2 shows the change of the indoor air temperature and the EEV opening rate for each control method under the same weather conditions. In the case of indoor environment, indoor air temperature is maintained at 25°C ± 0.3°C in Set-Point Control but indoor air temperature is maintained at 25-26.5°C in Comfort Range Control. Comfort Range Control is controlled to be about 1.0-1.5°C wider than Set-Point Control. It can be seen that the EEV opening rate also changes with the indoor air temperature. In Comfort Range control, in order to lower the indoor air temperature from 26.5°C to 25°C, the EEV opening rate is larger than the Set-Point Control, but when the indoor air temperature reaches 25°C, the variation of EEV does not appear to be relatively significant because the outdoor unit is not operated.
4.2. Thermal comfort
Figure 3 and Figure 4 show the results of the TSV and CSV according to each control performed on the occupants working in the target space. The occupants did not know about the control information and evaluated the indoor environment. In the case of Set-Point control, the results of the preliminary test were also additionally shown for the set temperature of 26°C control. In the results of TSV, the percentage of respondents who answered 'neutral' to the Comfort Range control was 53%, which is higher than the set-point control. For Set-Point 25°C control, the ratio of 'cold' and 'cool' was 20% and 30%, respectively, and for Set-Point 26°C control, 'hot' was 27%. In the results of CSV, 91% of respondents answered 'Comfortable' to Comfort Range control and the comfort sensation was improved compared to Set-Point control. The reason for the improved comfort sensation in the Comfort Range control is due to the increase in the ratio of thermally neutral sensation. In the case of Set-Point Control, which is controlled based on a constant temperature (25°C or 26°C), the control range is narrow, so the rate of thermal 'neutral' is less than Comfort Range Control because the occupants feel 'cold' or 'hot' depending on the set temperature.

4.3. Energy consumption
Figure 5 shows the average energy consumption for each control. 26.67kWh/day for Set-Point Control and 17.72kWh/day for Comfort Range Control, it is shown that energy consumption can be reduced by about 34% in the Comfort Range Control. The reason why it was possible to save energy compared to the conventional Set-Point Control is that the ratio of operating the outdoor unit is reduced according to the control range.

5. Conclusions
In this study, the control logic for thermal comfort and energy saving is applied to the VRF system and the validity of the control logic is verified through the field measurement in actual passive building during summer. Based on the operative temperature by ASHRAE comfort zone, a comfort range was derived from preliminary test and applied to the VRF system installed in the office space based IoT. The conventional Set-Point Control and the Comfort Range Control proposed in this study were analysed in terms of indoor environment, thermal comfort and energy consumption. The results are as follow.

- In the Comfort Range control, the indoor air temperature is maintained in a wide range compared to the Set-Point Control.
- According to the results of surveying occupants, the percentage of respondents who answered 'Comfortable' to Comfort Range Control was 91% that is 18% and 38% higher than Set-Point 25°C and Set-Point 26°C, respectively. Since the indoor air temperature is controlled according
to the control range, the temperature range that the occupants can thermally accommodate has been widened, and the percentage of the occupants feeling thermally 'neutral' and 'comfort' has increased.

- As results of the average energy consumption, it has been found that energy consumption can be reduced by about 34% compared to Set-Point Control when applying Comfort Range Control. The reason for this is that the indoor units only operate according to the control range.
- Based on the above results, Comfort Range Control proposed in this study is expected to be a way to reduce cooling energy while maintaining thermal comfort when applied to the VRF system of passive buildings that is feared to increase cooling load during the summer.

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