**Purdue University**
**Purdue e-Pubs**

International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

2008

# The Effect of the Ventilation and the Control Mode on the Performance of a VRV System in Cooling and Heating Modes

Tolga N. Aynur
*University of Maryland*

Yunho Hwang
*University of Maryland*

Reinhard Radermacher
*University of Maryland*

Follow this and additional works at: http://docs.lib.purdue.edu/iracc

Aynur, Tolga N.; Hwang, Yunho; and Radermacher, Reinhard, "The Effect of the Ventilation and the Control Mode on the Performance of a VRV System in Cooling and Heating Modes" (2008). *International Refrigeration and Air Conditioning Conference.* Paper 1002.
http://docs.lib.purdue.edu/iracc/1002

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.
Complete proceedings may be acquired in print and on CD-ROM directly from the Ray W. Herrick Laboratories at https://engineering.purdue.edu/Herrick/Events/orderlit.html

# The Effect of the Ventilation and the Control Mode on the Performance of a VRV System in Cooling and Heating Modes

Tolga N. AYNUR, Yunho HWANG*, Reinhard RADERMACHER

Center for Environmental Energy Engineering, Department of Mechanical Engineering,
University of Maryland, 3163 Glenn Martin Hall Bldg., College Park, MD 20742, USA
*Corresponding Author: 301 405-5247, yhhwang@umd.edu

## ABSTRACT

The effects of the ventilation and the control mode on the performance of the variable refrigerant volume (VRV) system integrated with a heat recovery ventilation (HRV) were field-tested in both cooling and heating seasons in an office suite. It was found that, for both cooling and heating seasons, the VRV system in the individual control mode provided better thermal comfort than the VRV system in the master control mode. It was also observed that the HRV system increased the indoor humidity ratio in the cooling season by introducing the high humidity outdoor air to the indoors, resulting in a humid indoor environment. On the other hand, it decreased the indoor humidity ratio in the heating season by introducing the low humidity outdoor air to the indoors, resulting in a dry indoor environment. Due to the additional ventilation load, the ventilation assisted VRV system consumed higher energy than the non-ventilated VRV system.

## 1. INTRODUCTION

Air conditioning and ventilation for residential and commercial buildings are highly demanded due to concerns on thermal comfort and healthy environment of the living space in modern society. Since multi-split air conditioning system features variable refrigerant volume technology and consists of one outdoor unit with several indoor units, it is called multi-split VRV system. It is finding its way in residential and commercial buildings, since it provides precise capacity control with an inverter driven compressor and individual electronic expansion valves (EEV) for each indoor unit. A schematic drawing of a VRV system with four indoor units is provided in Figure 1. The first VRV system was installed almost 25 years ago (Goetzler, 2007). Due to the long history, the multi-split technology has been widely investigated both experimentally (Choi and Kim, 2003), (Xia *et al.*, 2002), (Hu and Yang, 2005) and numerically (Wu *et al.*, 2005), (Shi *et al.*, 2003). On the other hand, the main drawback of these systems is the ventilation problem (Goetzler, 2007). Basically, they cannot provide any fresh air to the indoors during the conditioning. That's why additional ventilation system needs to be installed, like the heat recovery ventilation (HRV) system, which provides fresh air while recovering heat from the exhaust air stream in order to reduce the ventilation loads (Quazia *et al.*, 2006). A schematic drawing of a typical HRV unit is provided in Figure 2.

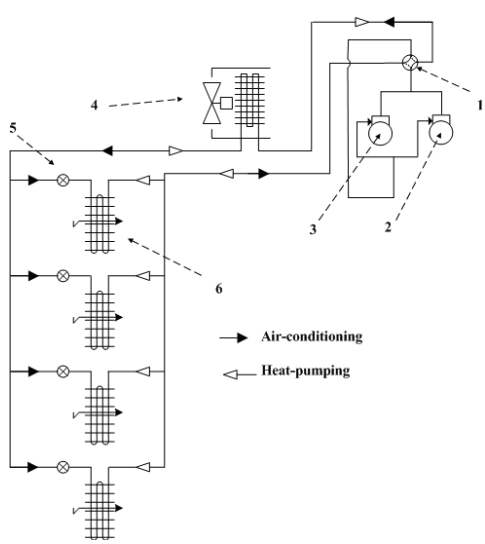


Figure 1: Schematic drawing of a VRV system, (1-four-way valve, 2-fixed speed compressor, 3-variable speed compressor, 4-outdoor unit heat exchanger, 5-EEV, 6-indoor unit heat exchanger)

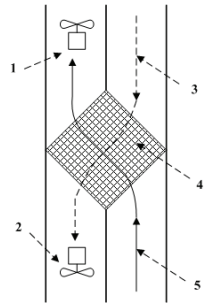


Figure 2: Schematic drawing of an HRV unit,
(1-supply fan, 2-exhaust fan, 3-exhaust air stream, 4-paper based heat exchanger, 5-outdoor air stream)

In this study, the effects of the ventilation and the control mode on the energy consumption and thermal comfort of the VRV system were investigated in both cooling and heating seasons in an office suite.

## 2. EXPERIMENTAL SYSTEMS

Two VRV outdoor units with same capacities, eight indoor units and four HRV units were installed in an office suite. Layouts of the VRV systems with the thermostat locations and the HRV units can be seen from Figure 3. As seen from Figure 3a, the VRV outdoor unit1 was connected to four indoor units located in Rooms A, B, C and D and the VRV outdoor unit2 was connected to the rest of the four indoor units located in Elevator, Receptionist, Aisle and Room E. The first and second VRV systems were referred as System1 and System2, respectively. Two different control modes, individual control mode (ICM) and master control mode (MCM) were applied to the VRV systems for the indoor temperature control. In ICM, all the indoor units were controlled by their own individual thermostats located in each room, shown in Figure 3a. In MCM, all the indoor units were controlled by only one thermostat located in the center of the office suite in order to simulate the operational characteristics of the central control mode typically used in the USA. Burd and Burd (2000, 2002) indicated that 65.8 out of 101.5 million residential houses in the USA are controlled by a central thermostat located in the living room which is responsible for the indoor temperature of the entire house.

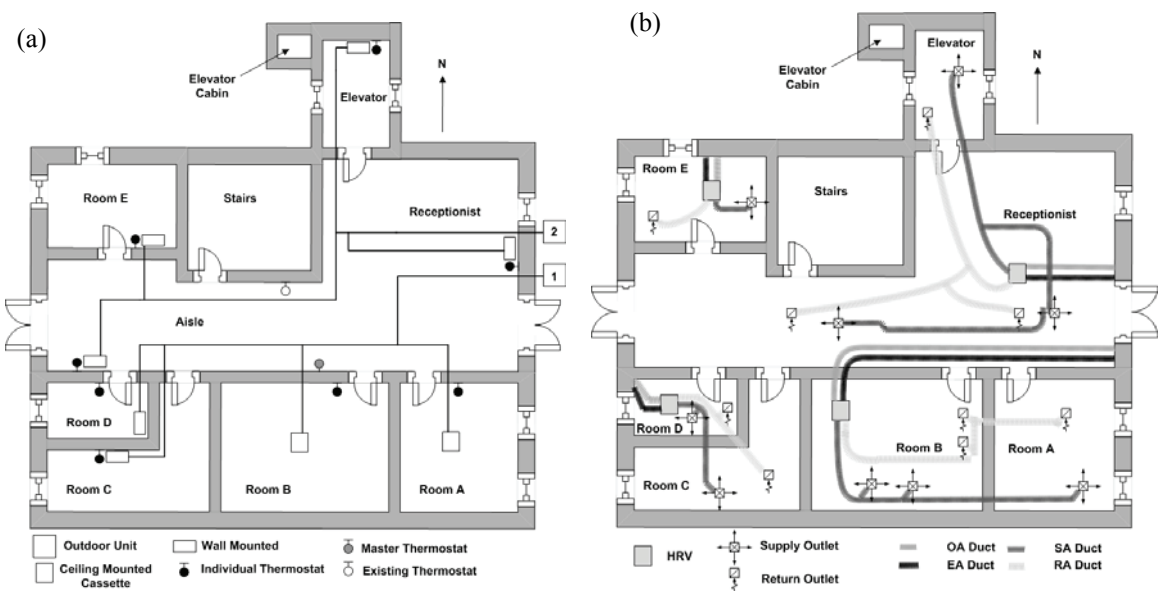


Figure 3: Layout of the VRV systems and the HRV units in the office suite, (a) VRV systems, (b) HRV units

### 2.1 Measurement System

Indoor and outdoor conditions were recorded by T-type thermocouples and relative humidity sensors with accuracies of ± 0.5°C and ± 3%, respectively. Indoor conditions were recorded next to each thermostat, and the outdoor measurement location was shielded against the radiation and the rain. Power consumptions of the outdoor

units were measured by separate watt meters with accuracies of ± 0.5% of full scale. Another watt meter was used for the measurement of the total power consumption of the indoor units and the HRV units with an accuracy of ± 0.2% of full scale.

### 2.2 Weekly Operation Schedule

In order to evaluate the effects of the ventilation and the control mode on the VRV system, a field performance evaluation was carried out based on the following weekly operation schedule for both cooling and heating seasons of 2006 and 2007. Each test was performed from 7 am to midnight.

Table 1: Weekly operation schedule for cooling and heating seasons of 2006 and 2007

| | System Configuration for Cooling Mode | | | System Configuration for Heating Mode | | |
|---|---|---|---|---|---|---|
| Day, Year | Control Mode | Set Temperature (°C/°F) | Ventilation | Control Mode | Set Temperature (°C/°F) | Ventilation |
| Monday, 2006 | Individual | 25 / 77 | w/ | Individual | 23.3 / 74 | w/ |
| Tuesday, 2006 | Individual | 25 / 77 | w/o | Individual | 23.3 / 74 | w/o |
| Thursday, 2006 | Master | 25 / 77 | w/ | Master | 23.3 / 74 | w/ |
| Saturday, 2006 | Master | 25 / 77 | w/ | Master | 23.3 / 74 | w/ |
| Sunday, 2006 | Individual | 25 / 77 | w/ | Individual | 23.3 / 74 | w/ |
| Monday, 2007 | Individual | 25 / 77 | w/ | Individual | 23.3 / 74 | w/ |
| Tuesday, 2007 | Individual | 25 / 77 | w/o | Individual | 23.3 / 74 | w/o |
| Thursday, 2007 | Master | 25 / 77 | w/ | Master | 23.3 / 74 | w/ |
| Friday, 2007 | Individual | 25 / 77 | w/ | Individual | 23.3 / 74 | w/ |

### 2.3 Evaluation Methodology

Comparisons were performed in seasonal basis based on the similar outdoor profiles. Psychrometric charts were used for the thermal comfort comparison, and the ASHRAE summer and winter comfort zones were superimposed on the psychrometric charts (ASHRAE, 2005), since the measured indoor dry bulb temperature could be assumed to be equal to the operative temperature (Newsham *et al.*, 1997; Amai *et al.*, 2007).

## 3. RESULTS AND DISCUSSION

### 3.1 The Effect of the Control Mode in the Cooling Mode

Figures 4a and 4b depict the variation of the number of data points with the outdoor temperature and the comparison of the outdoor conditions for the ICM and the MCM tests performed in the cooling seasons of 2006 and 2007, respectively. As seen, the seasonal outdoor profiles of the ICM and the MCM tests are similar. Figures 5a and 5b show the seasonal comparison of the System1 indoor conditions provided by the ICM and the MCM with 10-minute averaged data, respectively. As seen, for a set temperature of 25°C, the VRV system in the ICM controls the indoor temperature much better than the VRV system in the MCM and maintains it throughout the cooling seasons. The indoor temperatures higher than 27°C, shown in Figure 5, correspond to the initial zone temperatures. It is found that 68% and 48.7% of all System1 indoor condition data provided by the ICM and the MCM fall in the ASHRAE summer comfort zone, respectively. Besides, it is observed that the MCM provides much colder indoor environment than the ICM. 46.5% of all System1 indoor condition data provided by the MCM is found in the cold region (left side of the comfort zone), while there is no data found in the same region for the ICM. Similar trends are observed for the System2 zones. It is observed that 87.1% and 68.5% of all System2 indoor condition data provided by the ICM and the MCM fall in the ASHRAE summer comfort zone, respectively. 10.2% and only 1.7% of all System2 indoor condition data provided by the MCM and the ICM are found in the cold region, respectively.

On the other hand, it is found that the daily averaged energy consumption of the total VRV systems (VRV System1+VRV System2) in the MCM is 16.9% higher than that of the total VRV systems in the ICM. This is because the VRV in the MCM provides more cooling and results in both colder indoor environment and higher energy consumption than the VRV in the ICM, as shown in Figure 5.

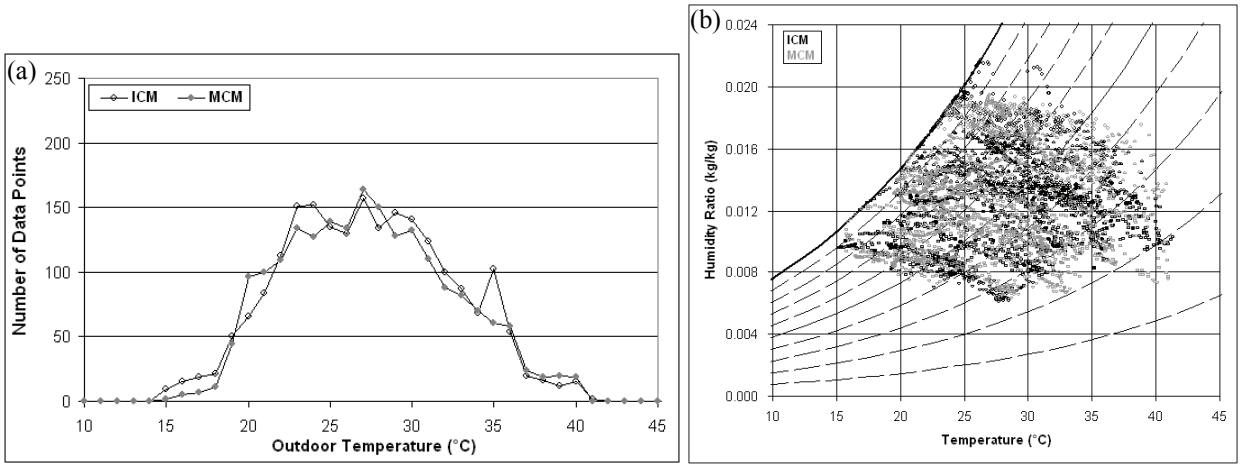


Figure 4: Comparison of the outdoor conditions for ICM and MCM tests for the cooling seasons of 2006 and 2007, (a) number of data points, (b) comparison of outdoor conditions

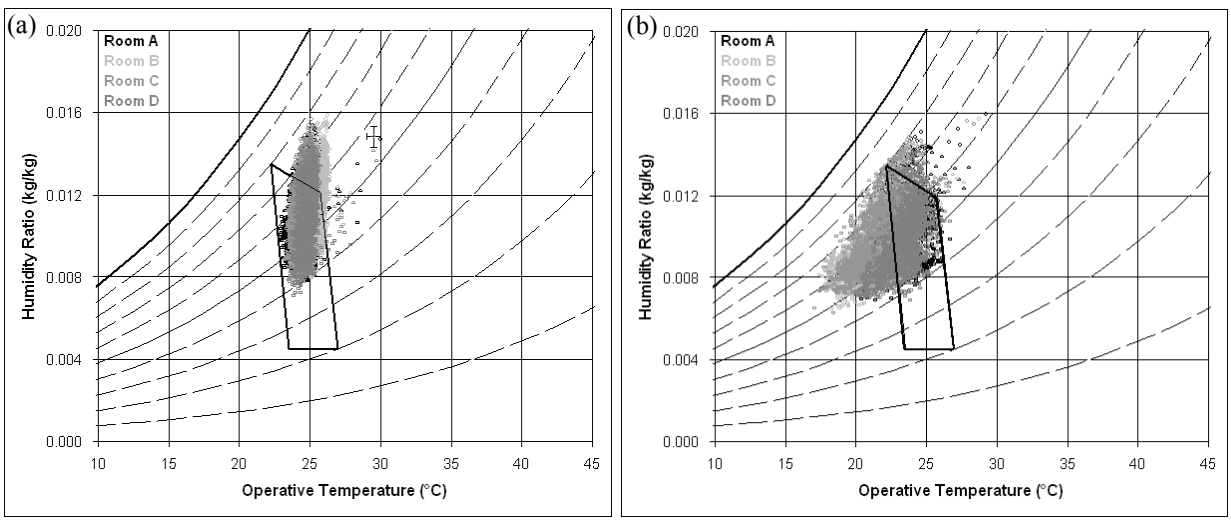


Figure 5: Seasonal comparison of System1 indoor conditions provided by ICM and MCM, (a) ICM, (b) MCM

### 3.2 The Effect of the Ventilation in the Cooling Mode

Figures 6a and 6b depict the variation of the number of data points with the outdoor temperature and the comparison of the outdoor conditions for the ventilation assisted (VA) and non-ventilated (NV) VRV system tests performed in the cooling seasons of 2006 and 2007, respectively. As seen, both seasonal outdoor profiles are similar. Figures 7a and 7b show the seasonal comparison of the System1 indoor conditions provided by the VA and the NV tests with 10-minute averaged data, respectively. As seen from Figure 7, the ventilation does not have any effect on the indoor temperature control of the VRV system. Both VA and NV systems control and maintain the set temperature of 25°C. On the other hand, it is found that 64.5% and 86.2% of all System1 indoor condition data provided by the VA system and the NV system fall in the ASHRAE summer comfort zone, respectively. The difference is due to the effect of the ventilation on the indoor humidity ratio. 33.7% and 12.3% of all System1 indoor condition data provided by the VA and the NV systems are found in the humid region (above the comfort zone). The difference is due to the ventilation effect. Since the HRV unit has a very low dehumidification capacity, within 0.5-2 g/kg, (Aynur, 2008), the VA system introduces the humid outdoor air to the indoors, and thus, increases the indoor humidity ratio resulting in a less percentage of data in the ASHRAE summer comfort zone than the NV system. Similar trends are also found for the System2 zones.

On the other hand, as expected, it is found that the daily averaged energy consumption of the VA total systems is 18% higher than that of the NV total systems due to the additional ventilation load.

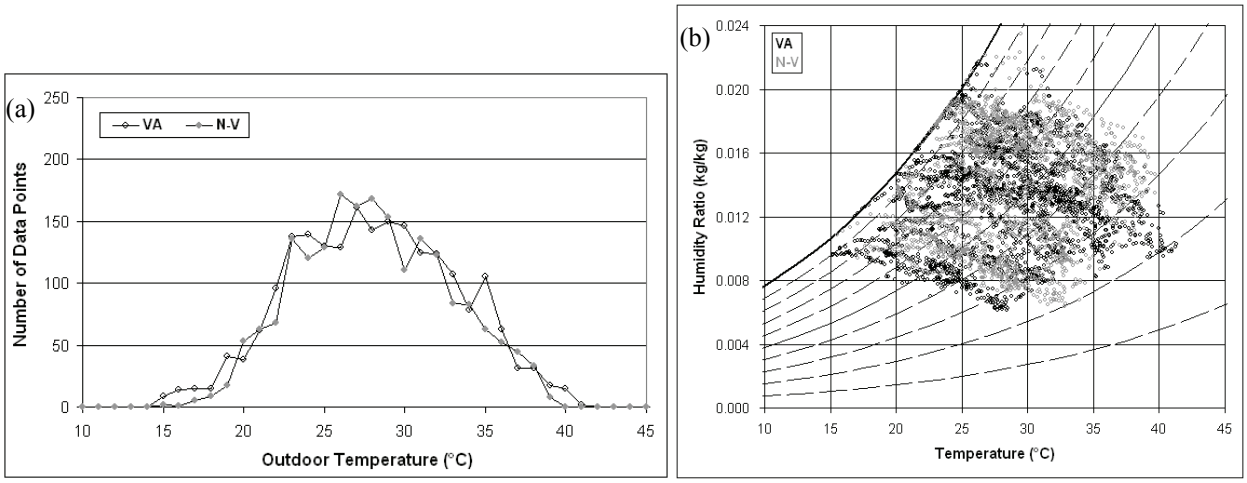


Figure 6: Comparison of the outdoor conditions for VA and NV tests for the cooling seasons of 2006 and 2007, (a) number of data points, (b) comparison of the outdoor conditions

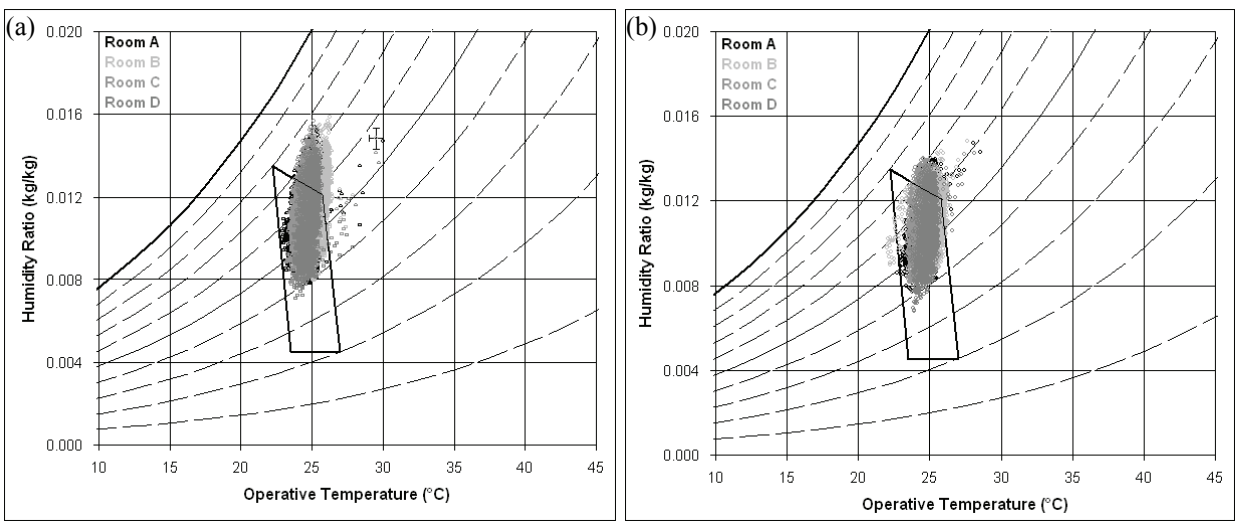


Figure 7: Seasonal comparison of System1 indoor conditions provided by VA and NV, (a) VA, (b) NV

### 3.3 The Effect of the Control Mode in the Heating Mode

Figures 8a and 8b show the variation of the number of data points with the outdoor temperature and the comparison of the outdoor conditions for the ICM and MCM tests performed in the heating seasons of 2006 and 2007, respectively. As can be seen, the seasonal outdoor profiles are similar. Figures 9a and 9b show the seasonal comparison of the System1 indoor condition data provided by the ICM and the MCM with 10-minute averaged data, respectively. As seen, the VRV system in the ICM controls the indoor temperature much better than the VRV system in the MCM and maintains it throughout the heating seasons. As can be seen from Figure 9b, especially for Room A, which has the highest heating load due to the windows as shown in Figure 3a, the indoor temperature cannot be maintained at the set temperature of 23.3°C by the VRV system in the MCM, however, the VRV system in the ICM can maintain the same zone's temperature at the set temperature.

It is found that 30.8% and 20.8% of all System1 indoor condition data provided by the ICM and MCM fall in the ASHRAE winter comfort zone. It is also found that 7.9% of all System1 indoor condition data provided by the MCM is found in the cold region (left side of the comfort zone), while only 1.6% of all System1 indoor condition data provided by the ICM is found in the same region. It is also observed that 64.3% and 66.1% of all System1 indoor condition data provided by the ICM and MCM are found in the dry region (bottom of the comfort zone).

Similar trends are found for the System2 zones. Figures 10a and 10b depict the seasonal comparison of the System2 indoor condition data provided by the ICM and MCM with 10-minute averaged data, respectively. As seen, similar to the results of the System1 zones, the VRV system in the ICM controls the indoor temperature much better than the VRV system in the MCM. It is found that 30.7% and 20.6% of all System2 indoor condition data provided by the ICM and MCM fall into the ASHRAE winter comfort zone, respectively. On the other hand, 12.3% of all System2 indoor condition data provided by the MCM is found in the cold region, however, only 1% of all System2 indoor condition data provided by the ICM is found in the same region.

On the other hand, it is found that the daily averaged energy consumption of the VRV total systems in the ICM is 29.9% higher than that of the total system in the MCM. This is because the VRV in the ICM keeps the indoor temperature at the set temperature. However, the MCM cannot maintain the set temperature, as shown in Figures 9b and 10b. That's why the VRV in the ICM consumes higher energy than the VRV in the MCM for the heating season.

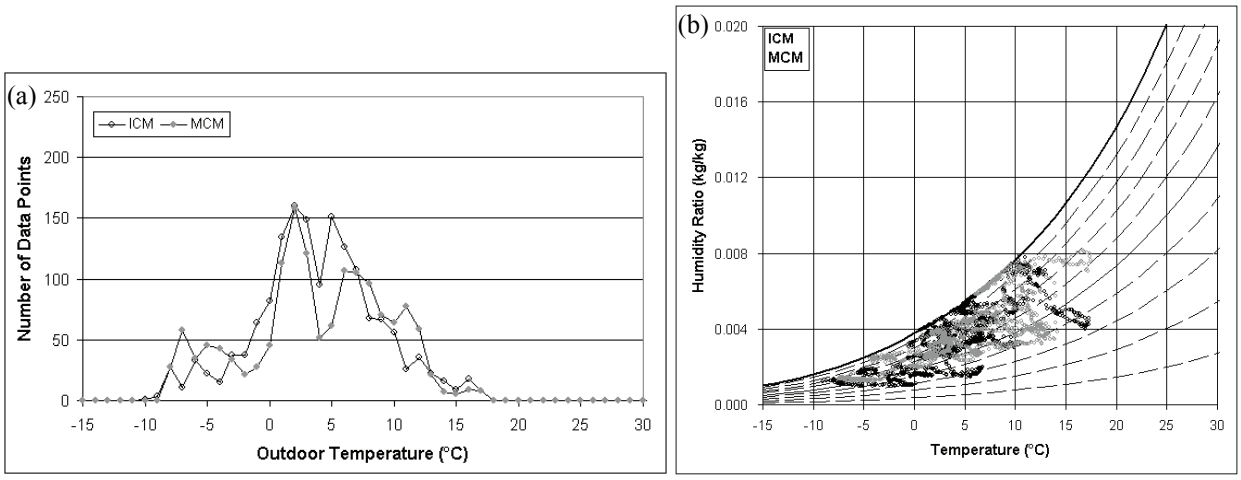


Figure 8: Comparison of the outdoor conditions for ICM and MCM tests for the heating seasons of 2006 and 2007, (a) number of data points, (b) comparison of the outdoor conditions

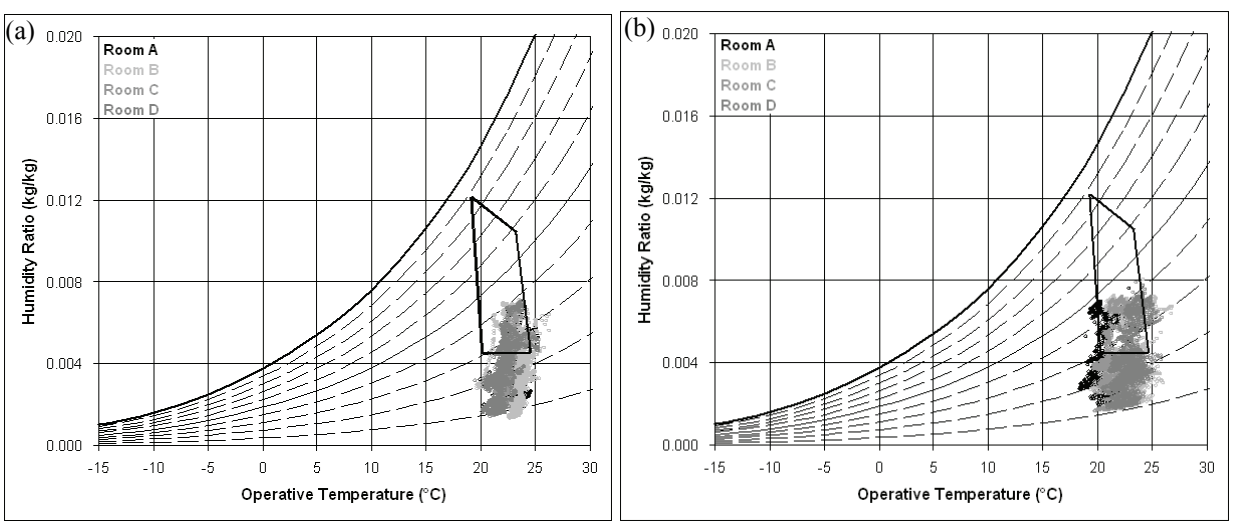


Figure 9: Seasonal comparison of System1 indoor conditions provided by ICM and MCM, (a) ICM, (b) MCM

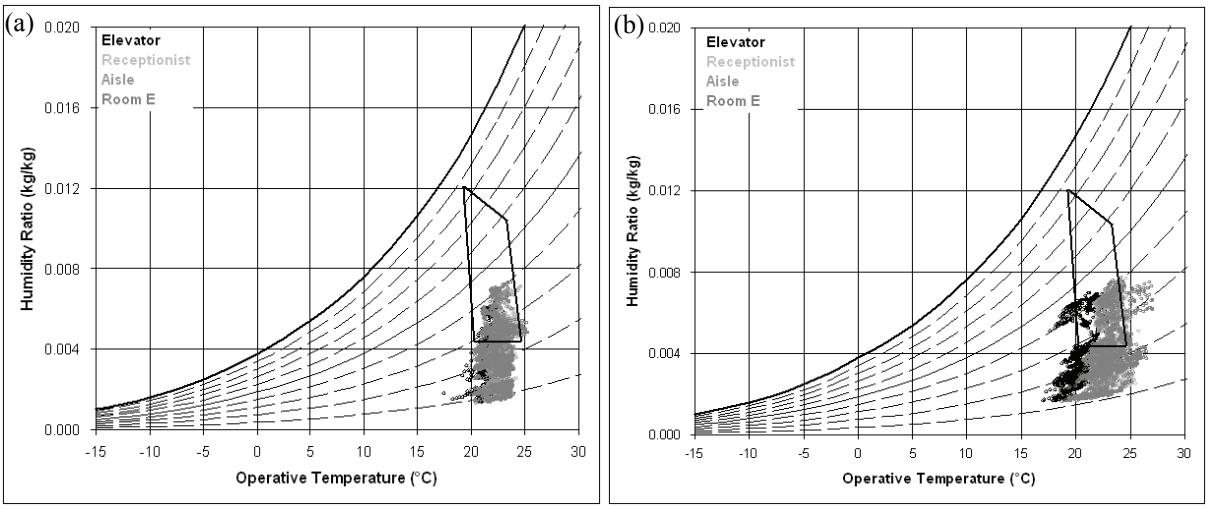


Figure 10: Seasonal comparison of System2 indoor conditions provided by ICM and MCM, (a) ICM, (b) MCM

### 3.2 The Effect of the Ventilation in the Heating Mode

Figures 11a and 11b depict the seasonal comparison of the System1 indoor conditions provided by the VA and NV systems with 10-minute averaged data, respectively, based on the similar seasonal outdoor profiles. It is observed that both systems provide similar thermal comfort. 40.4% and 39.1% of all System1 indoor condition data provided by the VA and NV systems fall in the ASHRAE winter comfort zone, respectively. On the other hand, similar to the cooling season evaluation, it is found that the main difference comes from the indoor humidity ratio due to the ventilation effect. It is found that 21.2% and 7.1% of all System1 indoor condition data provided by the VA and NV systems are found to be less than 3 g/kg indoor humidity ratio, respectively. Since the HRV units introduce the low outdoor humidity ratio to the indoors for the VA system, the indoor humidity ratio decreases, however, since there is no ventilation in the NV system, the indoor humidity generation due to the occupants increases the indoor humidity ratio. Similar trends are found for the System2 zones. It is found that 22.3% and 13.6% of all System2 indoor condition data provided by the VA and NV systems are found to be less than 3 g/kg indoor humidity ratio, respectively. Since the occupancy density is low for the System2 zones compared to the System1 zones due to the non-occupant zones such as aisle and elevator, as shown in Figure 3, the difference between the percentages of the System2 zones decreases as compared to the System1 zones.

On the other hand, as expected, due to the additional ventilation loads, it is found that the daily averaged energy consumption of the VA total systems is 35.2% higher than that of the NV total systems.

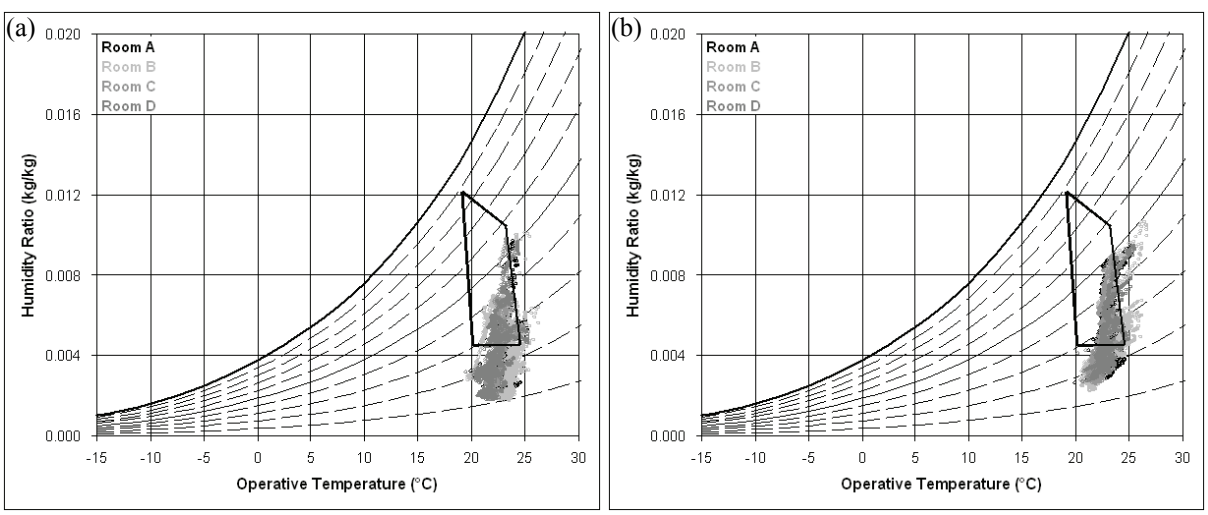


Figure 11: Seasonal comparison of System1 indoor conditions provided by VA and NV, (a) VA, (b) NV

## 4. CONCLUSIONS

The effects of the ventilation and the control mode on the energy consumption and thermal comfort of the VRV system were investigated in a field test for both cooling and heating seasons. From the experiments, the following conclusions are deduced.

- The VRV system in the individual control mode provides better thermal comfort than the VRV system in the master control mode in both cooling and heating seasons.
- The HRV system increases the indoor humidity ratio in the cooling season by introducing the high humid outdoor air to the indoors, resulting in a humid indoor environment. On the other hand, it decreases the indoor humidity ratio in the heating season by introducing the low humid outdoor air to the indoors, resulting in a dry indoor environment.
- As expected, due to the additional ventilation loads, the ventilation assisted VRV system consumes higher energy than the non-ventilated one.
- The VRV system integrated with a desiccant system for the cooling season and integrated with a humidification system for the heating season has the potential to provide better thermal comfort by reducing the indoor humidity ratio for the cooling season, and increasing the indoor humidity ratio for the heating season.

## NOMENCLATURE

| | | | |
|---|---|---|---|
| EEV | electronic expansion valve | NV | non-ventilated |
| HRV | heat recovery ventilation | OU | outdoor unit |
| ICM | individual control mode | VA | ventilation assisted |
| IU | indoor unit | VRV | variable refrigerant volume |
| MCM | master control mode | | |

## REFERENCES


Amai, H., Tanabe, S., Akimoto, T., Genma, T., 2007, Thermal sensation and comfort with different task conditioning systems, *Building and Environment*, 42, 12: pp. 3955-3964.

ASHRAE, 2005, *ASHRAE handbook of fundamentals,* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA, USA.

Aynur, T.N., 2008, Evaluation of a multi-split type air conditioning system under steady-state and transient conditions, Ph.D. thesis, ITU, Turkey.

Burd, A.L., burd, G.S., 2000, Mobile thermostat for climate control in residential buildings, *Proceedings of CIBSE/ASHRAE Joint Conference*, Dublin, Ireland, H-1562: pp. 1-22.

Burd, A.L., Burd, G.S., 2002, Application of mobile wireless thermostat and energy conservation and comfort in residential houses, *ASHRAE Transactions*, 108, 2: pp. 202-211.

Choi, J.M., Kim, Y.C., 2003, Capacity modulation of an inverter-driven multi-air conditioner using electronic expansion valves, *Energy*, 28, 2: pp. 141-155.

Goetzler, W., 2007, Variable refrigerant flow systems, *ASHRAE Journal*, 49, 4: pp. 24-31.

Hu, S.C., Yang, R.H., 2005, Development and testing of a multi-type air conditioner without using AC inverters, *Energy Conversion and Management*, 46, 3: pp. 373-383.

Newsham, G.R., Tiller, D.K., Phil, D., 1997, A field study of office thermal comfort using questionnaire software, *ASHRAE Transactions*, 103, 2: pp. 3-16.

Quazia, B.K., Julien, M., Swinton, M.C., Manning, M., 2007, Assessment of the enthalpy performance of houses using energy recovery technology, *ASHRAE Transactions*, 112, 2: pp. 1-11.

Shi, W., Shao, S., Li, Xi., Peng, X., Yang, X., 2003, A network model to simulate performance of variable refrigerant volume refrigerant systems, *ASHRAE Transactions*, 109, 2: pp. 61-68.

Wu, C., Xingxi, Z., Shiming, D., 2005, Development of control method and dynamic model for multi-evaporator air conditioner (MEAC), *Energy and Conversion*, 46, 3: pp. 451-465.

Xia, J., Winandy, E., Georges, B., Lebrun, J., 2002, Testing methodology for VRF systems, *9th International Refrigeration and Air Conditioning Conference at Purdue*, West Lafayette, IN, USA, R4-2, pp. 1-8.


## ACKNOWLEDGEMENT

The support of this research through Daikin Industry Ltd. and the Alternative Cooling Technologies and Applications Consortium of the Center for Environmental Energy Engineering at the University of Maryland is gratefully acknowledged.