Energy Requirements of a Multi-Sensor Based Demand Control Ventilation System In Residential Buildings

Nam Chul Seong[1], Sung Min Hong[1], Dong Won Yoon[1]

[1] 1Kyoungwon University, Seoul, Korea

Abstract

In Korea, in 2006, the building regulation was revised to apply 0.7 ACH (Air Change Rate) ventilation systems to improve indoor air quality in residential apartment housing. The purpose of this study is to evaluate energy requirement and indoor contaminant level characteristics for residential building applying with sensor-based DCV (Demand Control Ventilation) system. It has been simulated both in a setting of the constant volume of 0.7 ACH intakes as recommended by the Korean Indoor Air Act and in a sensor-based DCV system controlled with CO2 and chemical material such as TVOC (Total Volatile Organic Compound).

Our study demonstrates that the DCV system is energy efficient and maintains better indoor air quality because the indoor contamination level is reduced by controlling the outdoor air intakes. DCV system consists of a hardware module of sensor units and a control algorithm that implements several integrated ventilation strategies to meet the ventilation requirements.

In this study, the energy requirements have been evaluated with two ventilation control strategies; one for the conventional ventilation type and the other for a sensor-based DCV system. DCV is a real time, occupancy and contamination level based ventilation approach that can lead to significant energy saving over the traditional fixed OA (Outdoor Air) intake ventilation system. Our approach enables the incorporated system to maintain proper IAQ (Indoor Air Quality) at all times in a space where adequately ventilated to reduce the indoor pollutant level and thus improves the air quality in an indoor environment.

Keywords: Indoor Air Quality, DCV (Demand Control Ventilation), Sensor-Based Control, Residential Ventilation System, Energy Simulation.

Introduction

Recently, people spend 90% of their time indoors with the majority their life (Klepeis et al, 2001). The apartment house is a domestic residential trend in Korea from industrialization and rapid urbanization.

According to government (Ministry of Land, Transport and Maritime Affairs, MOLTMA) figures, in 2008 the percentage of apartment houses was increasing steadily, and reached 43.89% and that of new construction supply 85.8% during the last five years. For this reason of changing trend in residential buildings, highly air-tight envelopes and lack of operable windows make it difficult to meet the ventilation needs without using mechanical ventilation systems.

Due to the trend, in 2006, Building regulation has been revised to make it mandatory to keep ventilation rate at 0.7 ACH or above air changes during 24 hours to improve Indoor Air Quality in resident buildings. Thus, they have to install a mechanical or natural ventilation system. However, a survey in other research reveals that many mechanical ventilation systems are not often operated by residents because of following. First, it is found that occupants tend to avoid powering their ventilation system in order to save utility cost. Relying on occupants' decision in tuning on or off of their ventilation system may be a bigger problem in the effectiveness of operating current mechanical ventilation systems.

Actually, there has been a variety of research to identify emission characteristic and reduce emission rate of chemical source from building material and product. However, research on energy consumption is still under way to identify their impact. Also, it is insufficient to evaluate and validate the performance of ventilation systems against government regulations.

Purpose

With maintaining comfortable and healthy indoor environment, minimizing the energy consumption of ventilation systems is required. When the mechanical ventilation systems installed in residential buildings, the followings are suggested in this study to improve mechanical ventilation performance concerned energy efficiency and indoor air quality. The purpose of this study is to control appropriate ventilation and maintenance of indoor contaminant levels for reduction of energy consumption in residential building while improvement indoor air quality.

Methods

- Multi-Simulation using Coupled Tools

It has been simulated both of constant volume of 0.7 ACH intakes as guidelines on the Korean indoor air Act and sensor-based DCV system controlled with both of CO_2 and chemical sensor for operating mechanical ventilation system.

CO_2 and chemical contamination level simulation has been performed using CONTAM 2.4 and energy simulation has been performed using Energy Plus Ver. 3.1 with TMY2 (Typical Meteorological Year) format of weather data for Seoul, Korea. Fig 1 is shown the simulation processing in this study. Subject household is selected an apartment house of Korean standard model that has an area of 84 ㎡ and floor plan is as follow Fig 2.

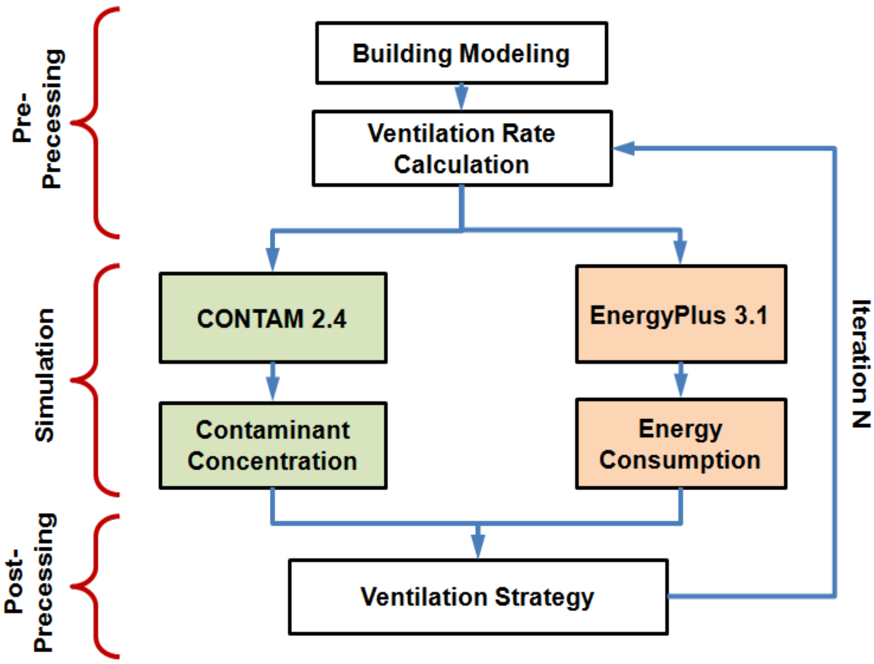


Fig. 1 Simulation Processing

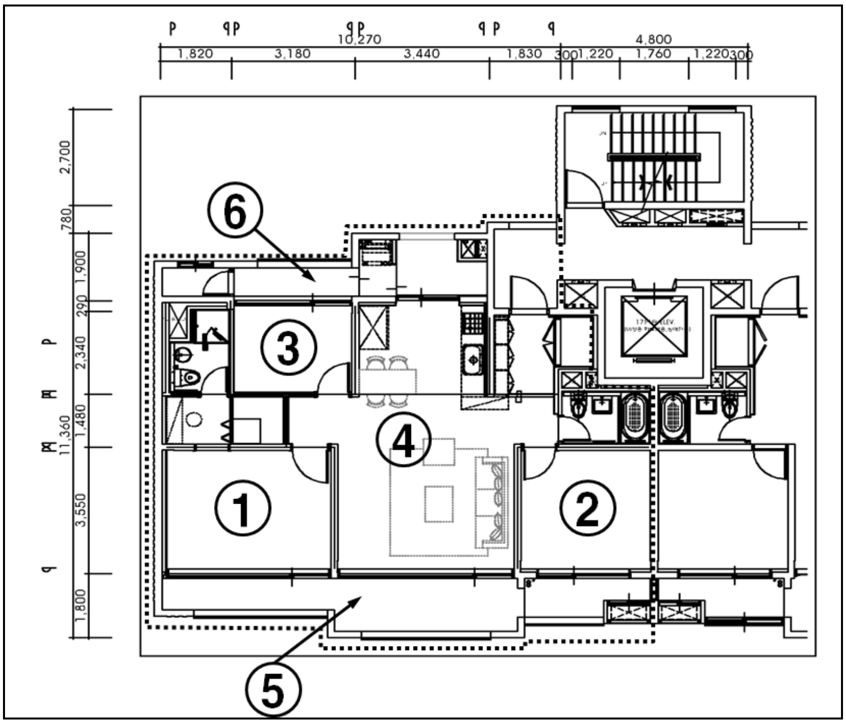


Fig. 2 Floor plan of Subject household (84 ㎡)

Simulation

1) Performance assessment for indoor contaminants control

The modeling to calculate contamination of each zone is as Fig3. for simulation using CONTAM 2.4. Exhaust air is balanced with the supply air. Multi-Zone has an air flow network through the open fraction and infiltration condition is 0.15 air change per hour each Zones. Infiltration condition of unconditioned Zone like balcony is 2.0 airchange per hour because considering to be adjacent outside air.

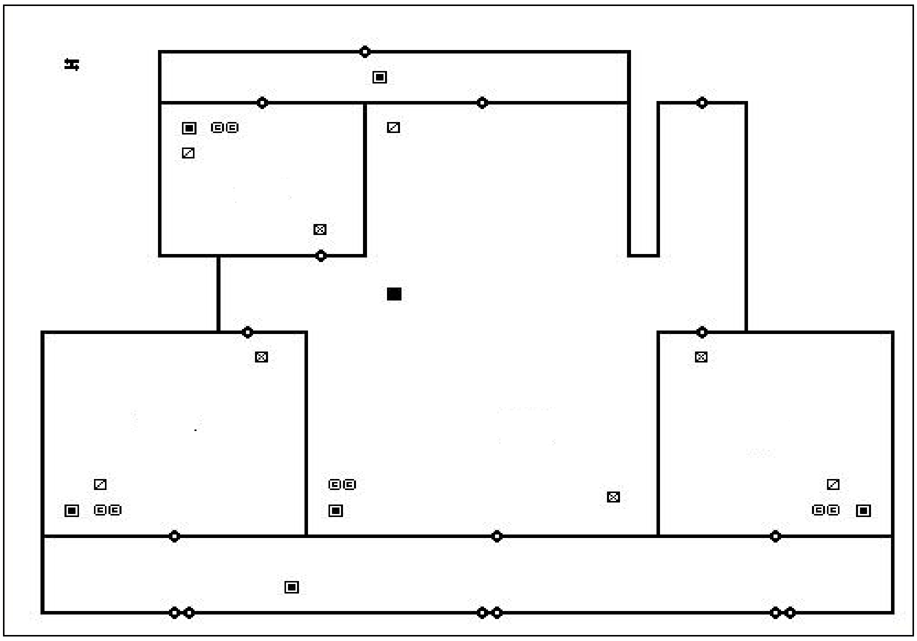


Fig. 3 Multi-zone modeling for subject household using CONTAM 2.4

The initial CO_2 concentration is set to 400ppm. The CO_2 generation rate per person is set to 17liter per hour(ℓ/h) for adult with common indoor activity (ASHRAE Handbook Fundamentals, 2005).

TVOC generation rate is calculated based on data had been already measured in the government case studies.(Study of emitting pollutants from appliance and furniture, Ministry of Environment,2006) It is assumed that TVOC emission rate from finishing material is based on certificated first class material in Korea. The initial

TVOC concentration is set to 1000[$\mu g/m^3$]. Calculation basis of VOCs Emission rate are described in Table 1 and Table 2

Table 1 Calculation basis of VOCs Emission Rate

	Area of wall, ceiling [m^2]	**Area of floor [m^2]**	**First Class Emission rate per hour [$mg/m^2 \cdot h$]**	**Finishing material [mg/h]**	**Product [mg/h]**	**Total Calculated Emission rate per hour [mg/h]**
Bedroom	54.94	18.95	0.1	7.389	2.42	9.809
Room 1	44.89	13.97	0.1	5.886	3.57	9.456
Room 2	32.12	9.024	0.1	4.1144	2.87	6.9844
Living Room	86.24	37.29	0.1	12.353	10.625	22.978

Table 2 Calculation basis of VOCs Emission Rate from Product and Appliance

Bedroom [mg/unit·h]	**Furniture**	**Bed mattress**	**Chest of drawers**		
	1.77	0.65	1.77		
Room 1 [mg/unit·h]	**Bed mattress**	**Desk**	**Personal Computer**	**Chest of drawers**	**Chair**
	0.65	1.1	0.58	1.77	0.12
Room 2 [mg/unit·h]	**Bed mattress**	**Desk**	**Chest of drawers**		
	0.65	1.1	1.77		
Living Room [mg/unit·h]	**Kitchen unit**	**Shoe rack**	**TV**		
	7.16	2.875	7.75		

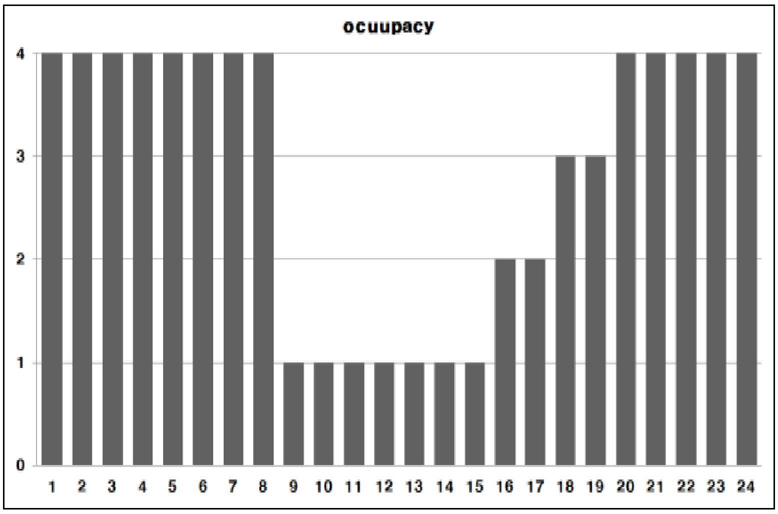
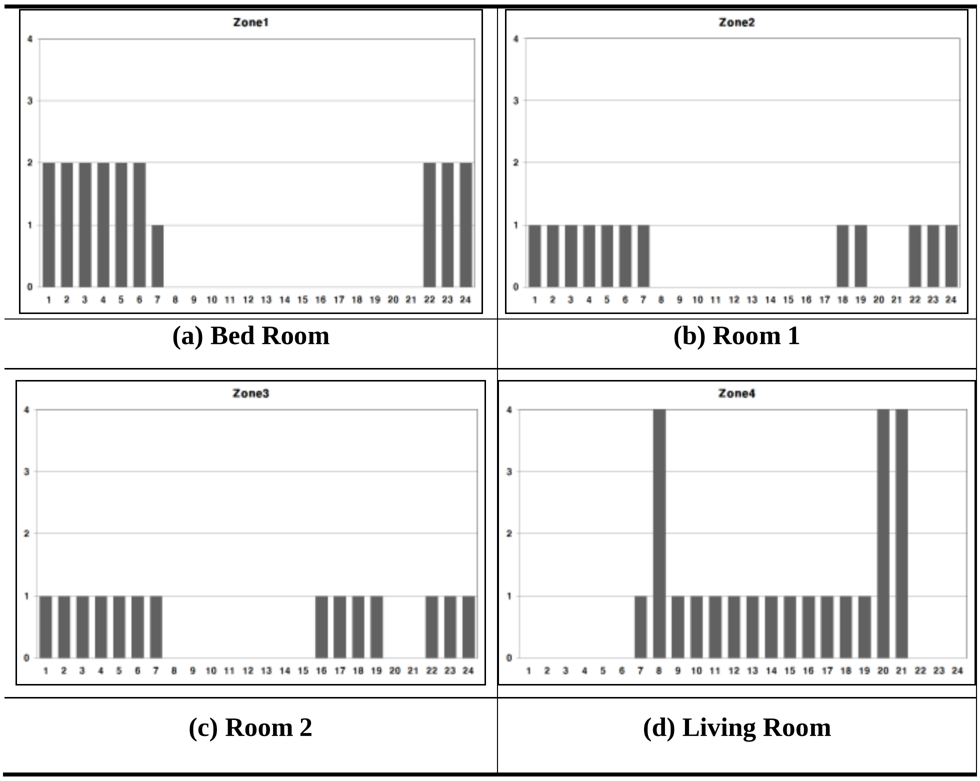


Fig. 4 Occupancy Schedule



(a) Bed Room **(b) Room 1**

(c) Room 2 **(d) Living Room**

Fig. 5 Occupancy Schedule of each Zone

Occupants in the house are assumed a family of four and occupancy schedule is shown in Fig4 and Fig5.

2) Analysis of Energy Consumption

A thermal dynamic energy simulation has been performed using Energy Plus Ver. 3.1 with TMY2 format of weather data for Seoul, Korea. Energy requirements have been evaluated with both of ventilation control strategies for conventional type and sensor based DCV system. Outputs of energy consumption for heating in winter have been compared with ventilation requirements and also the fractions of energy consumptions on the two different control strategies. Table 3 shows basic conditions for simulation in Energy Plus.

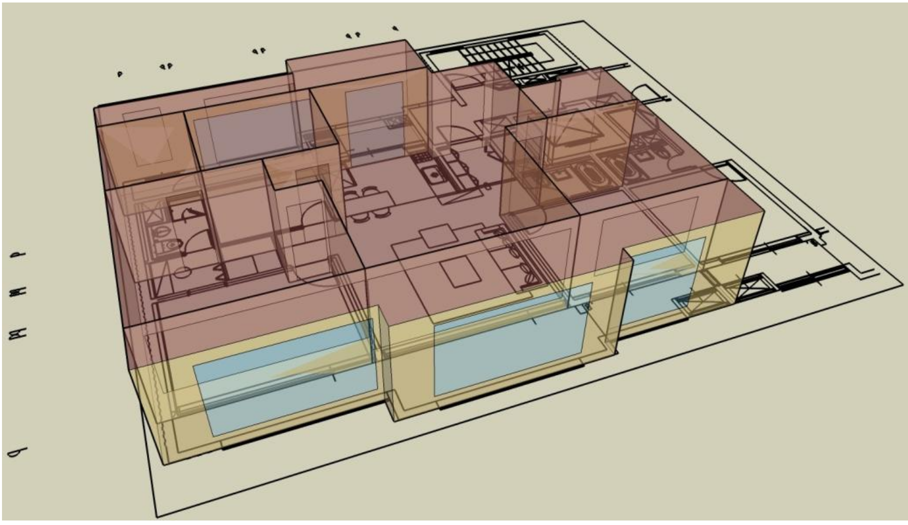


Fig. 6 Modeling and Rendering for subject household using Openstudio

Table 3 Basic Conditions of Simulation in Energy Plus

	Version Identifier	**3.1**
Site	North Axis	0
	Terrain	City
	Heat Balance Algorithm	Conduction Transfer Function
Time Step	Number of Time steps	1 Hour
Site Location	Name	Seoul Design_Conditions
Run Period	Begin Month	11
	Begin Day of Month	1
	End Month	3
	End Day of Month	31

Fig7 shows an overview of the heating modeling schematics. Heating-coil is modeled with coil length per flow, hot water circulation pump flow and head referred to measurement case studies in order to calculate the exact energy consumption. Supply hot water temperature of floor heating system is set to 60 Celsius degree. Also, Fig8 shows an overview of the mechanical ventilation system including heat recovery modeling schematics. Specifications of ventilation system (fan efficiency, pressure-rise) is referred to commercialized products.

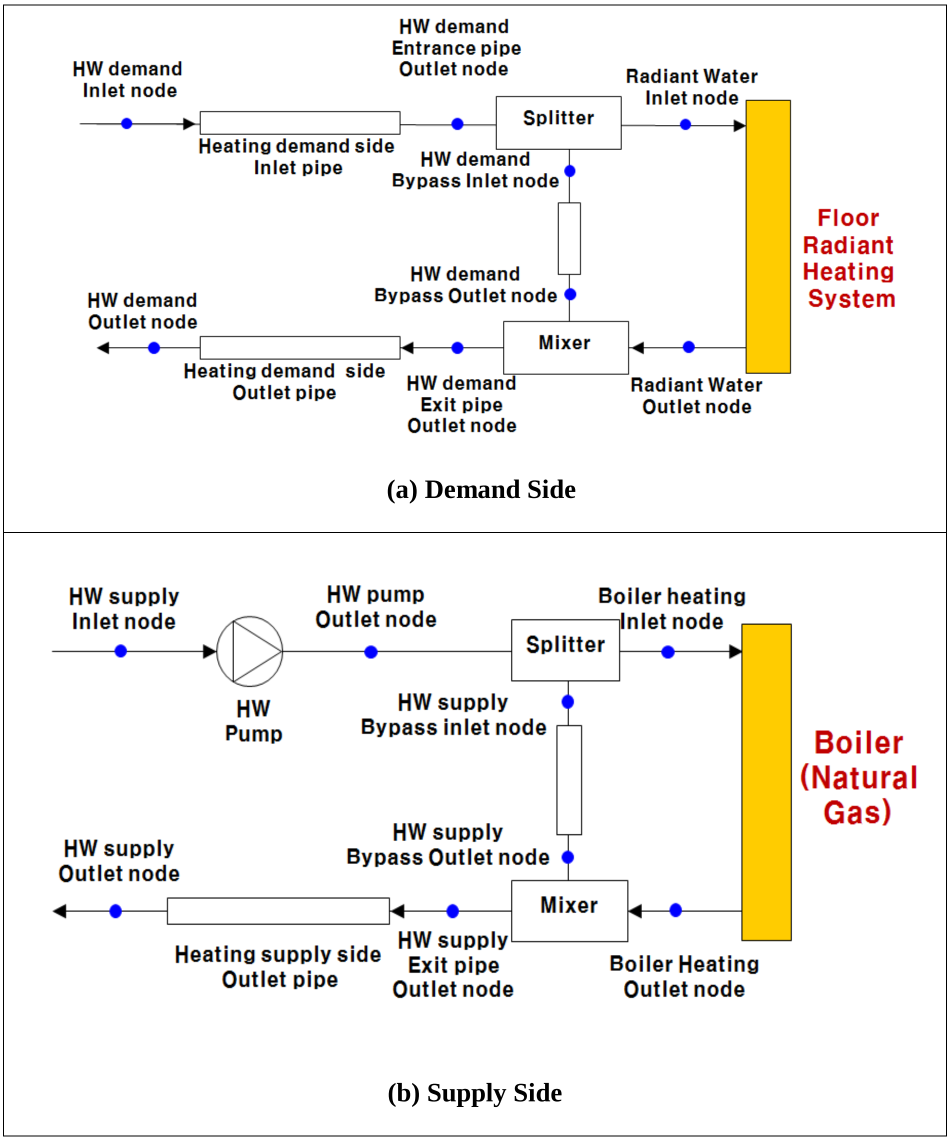
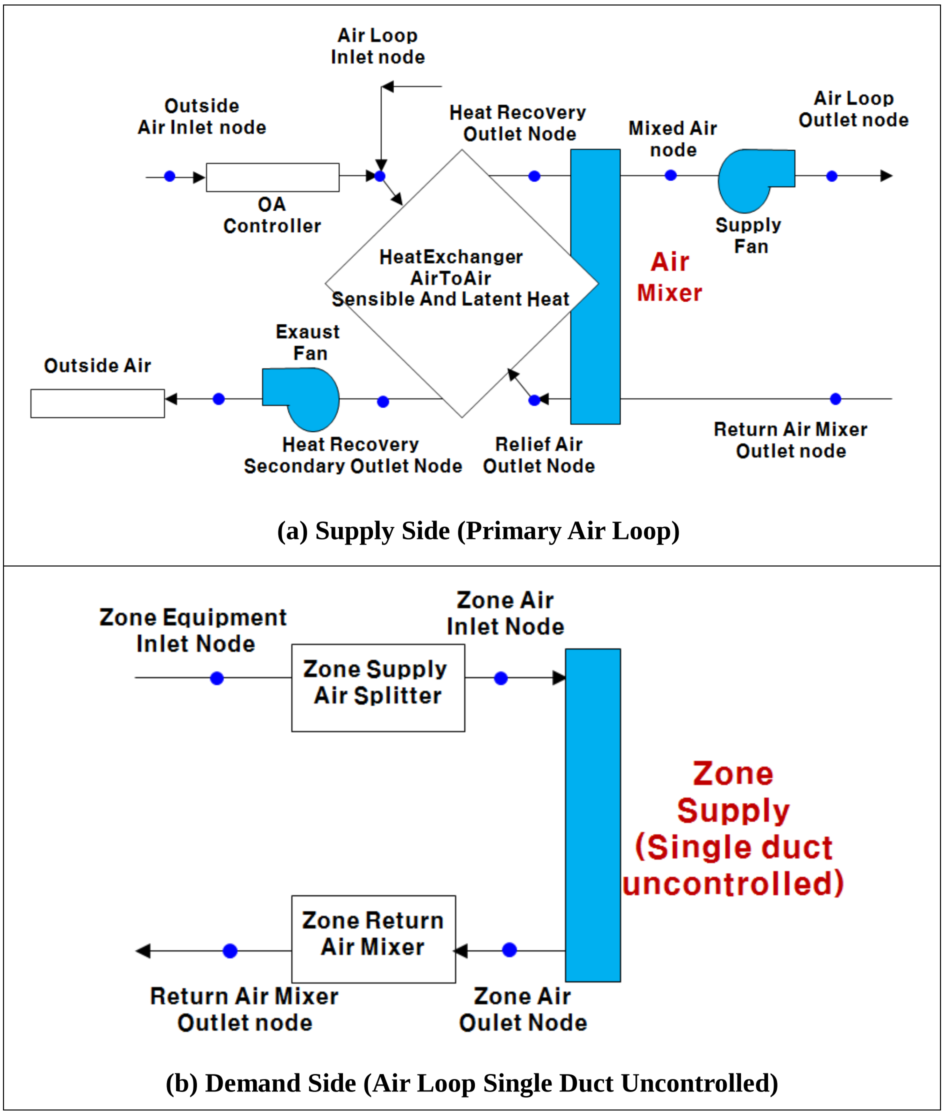


Fig. 7 Schematic of Hot Water Plant (Boiler) and Radiant Floor Heating System



(a) Supply Side (Primary Air Loop)

(b) Demand Side (Air Loop Single Duct Uncontrolled)

Fig. 8 Schematic of the Air Loop for ventilation included the heat recovery

Table 4 Ventilation Rate of Korean standard for simulation

Zone Name	Volume [㎥]	Ventilation Rate [㎥/h]
		Korea Standard (0.7ACH)
Bedroom	45.48	31.836
Room1	33.52	23.464
Room2	21.66	15.162
Living Room	89.50	62.650

Results

1) Ventilation Rate with Korean standard (0.7ACH)

Fig 9 shows the result of simulation for the current Korean ventilation standard and change of CO_2 concentration. When the ventilation system is not operating concentration of CO_2 is reached about 5000[ppm] in the each room during sleeping time of occupancies but ventilation rate is 0.7[ACH] concentration of CO_2 is maintained below 1600[ppm].

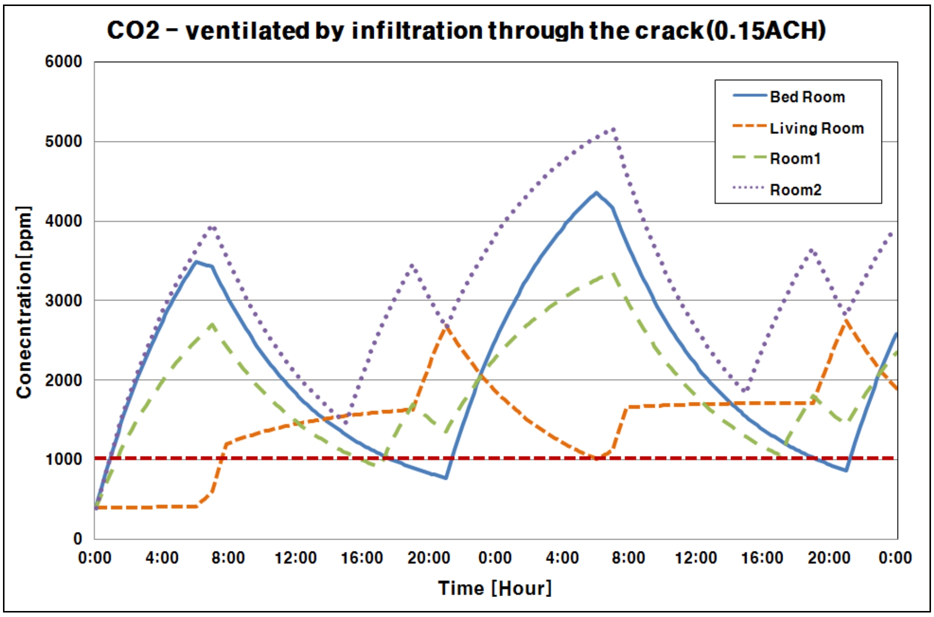


Fig. 9 Change of CO_2 concentration (Non-ventilation)

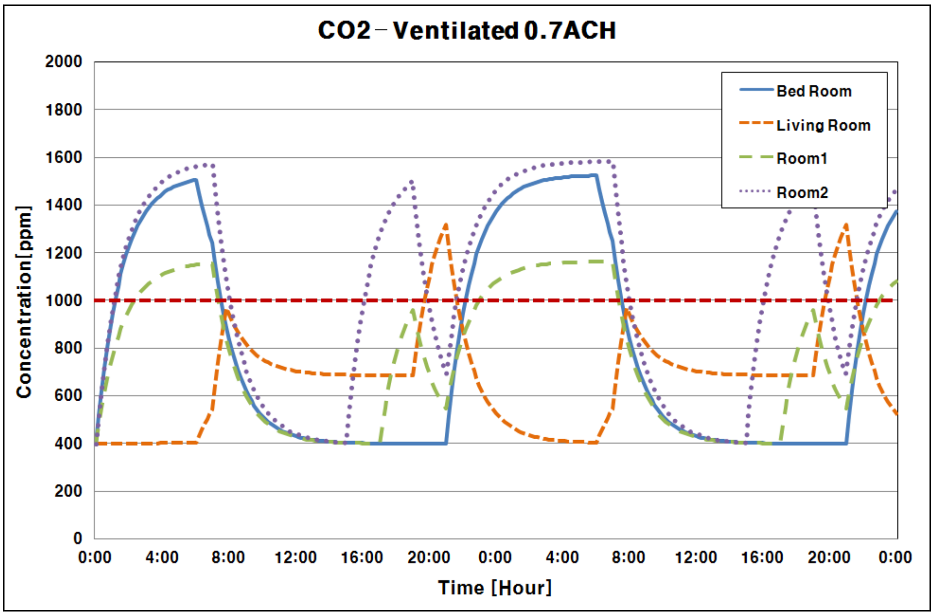


Fig. 10 Change of CO_2 concentration (0.7ACH)

Fig 11 and Fig 12 are results of simulation by comtam2.4 program. It is assumed that infiltration air volume is 0.15[ACH] and the initial concentration of TVOC is 1000[㎍/㎥]. Without ventilation, TVOC concentration level is risen to about 4000[㎍/㎥], and when ventilated by Korean standard, is maintained 600[㎍/㎥]. Table5 is the result of gas consumption simulated using Energyplus each case in winter of Korea.

Table 5 Comparison Boiler gas consumption with each case applied Korean ventilation standard

Boiler Gas Consumption [MJ]		
Month	**No vent-0.15[ACH])**	**(Vent 0.7ACH)**
NOV	676.29	1236.30
DEC	1362.11	2624.25
JAN	1590.46	3209.31
FEB	1354.20	2552.46
MAR	757.36	1584.424
TOT	5740.32	11206.77

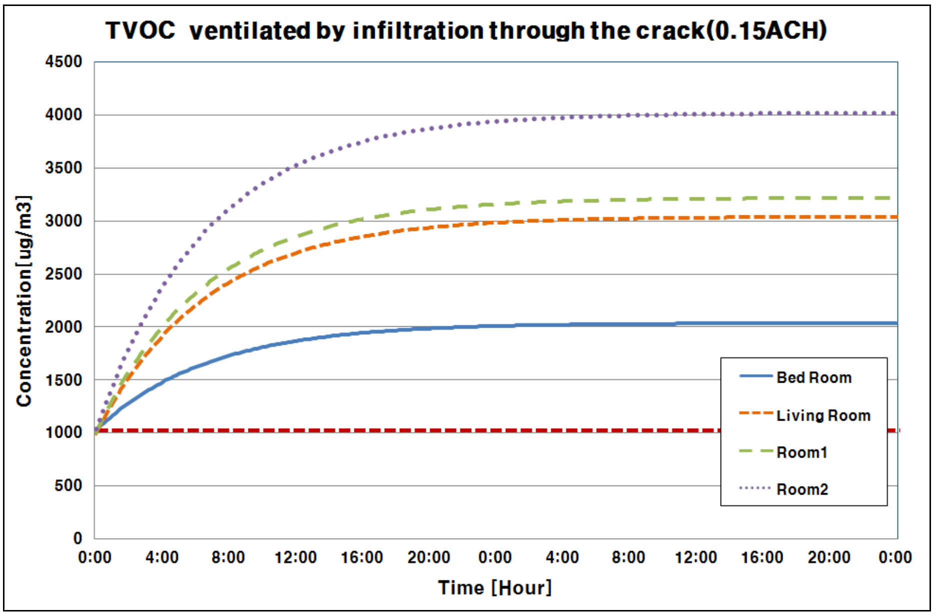


Fig. 11 Change of TVOC concentration (Non-ventilation)

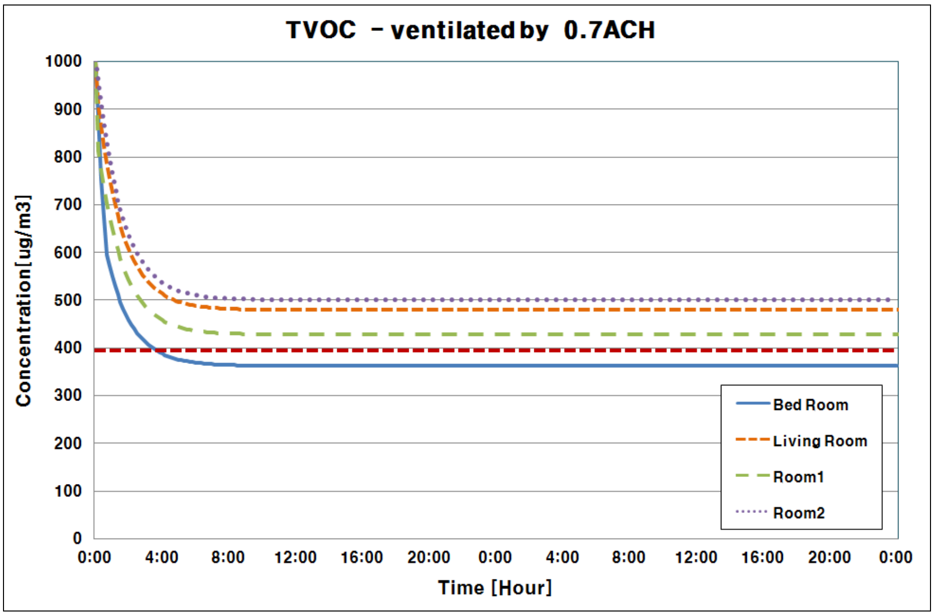


Fig. 12 Change of TVOC concentration (0.7ACH)

2) Ventilation with CO_2 sensor-DCV Type

Fig13 and Fig14 shows CO_2 and TVOC level which are the results of CO_2-DCV to maintain below Korean standard (1000[ppm]) in the commercial building. The air volume is 1.5[ACH] calculated mass balancing equation. When the vent turn off, TVOC concentration rise rapidly.

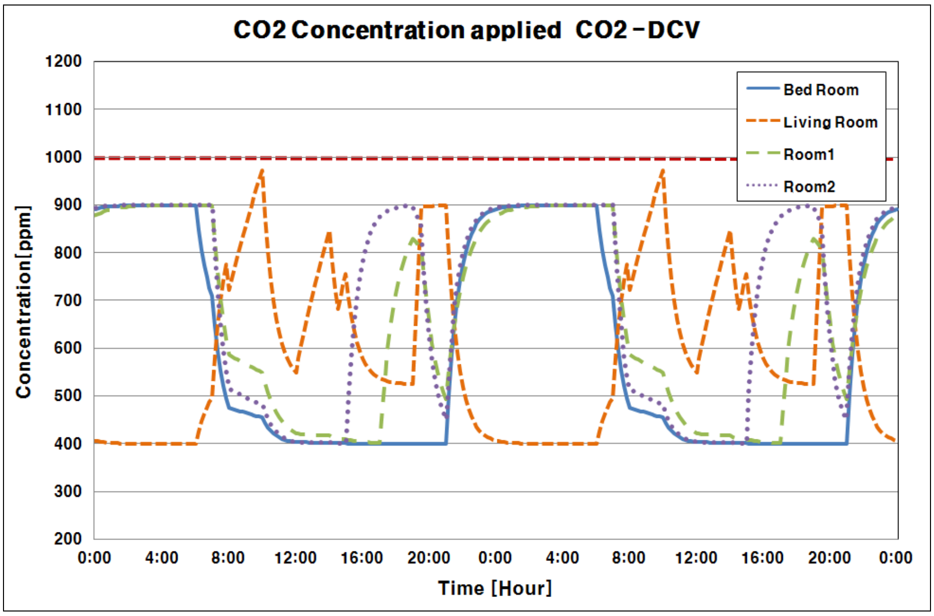


Fig. 13 CO_2 concentration with CO_2-DCV

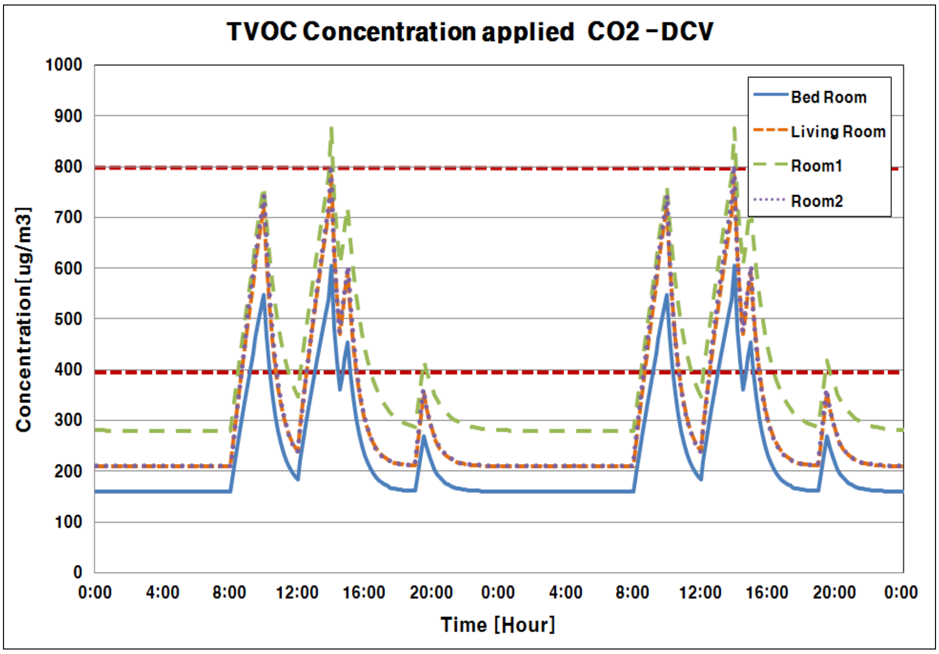


Fig. 14 TVOC concentration with CO_2-DCV

3) Ventilation with TVOC sensor-DCV Type

Fig15 and Fig16 shows the result of TVOC-DCV to maintain TVOC-800[㎍/㎥] each room, the ventilation is operating with regular interval of 0.7[ACH]. CO_2 is maintained irregularly below 2000[ppm] according to the occupant's schedule.

Table 6 is shown energy consumption with the simulation results. When the ventilation is controlled by TVOC-DCV (0.7ACH, On/Off control), the energy consumption has reduced at 26% compared with 24 hour continuous ventilation. In the CO_2-DCV for maintaining 1000ppm as standard concentration, the energy consumption is increased at 17% compared with those of 0.7[ACH], because of increasing of ventilation air volume.

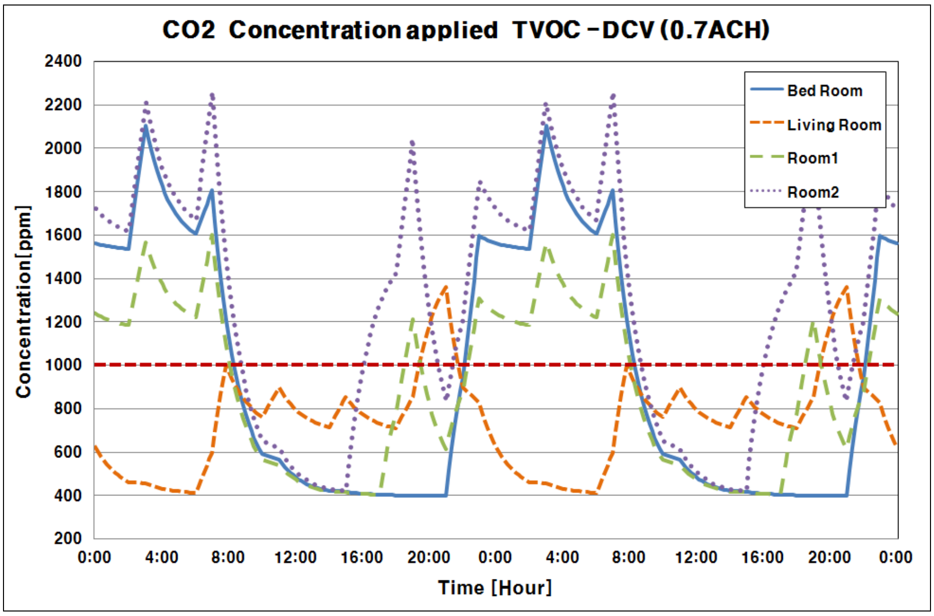


Fig. 15 CO_2 concentration with TVOC-DCV

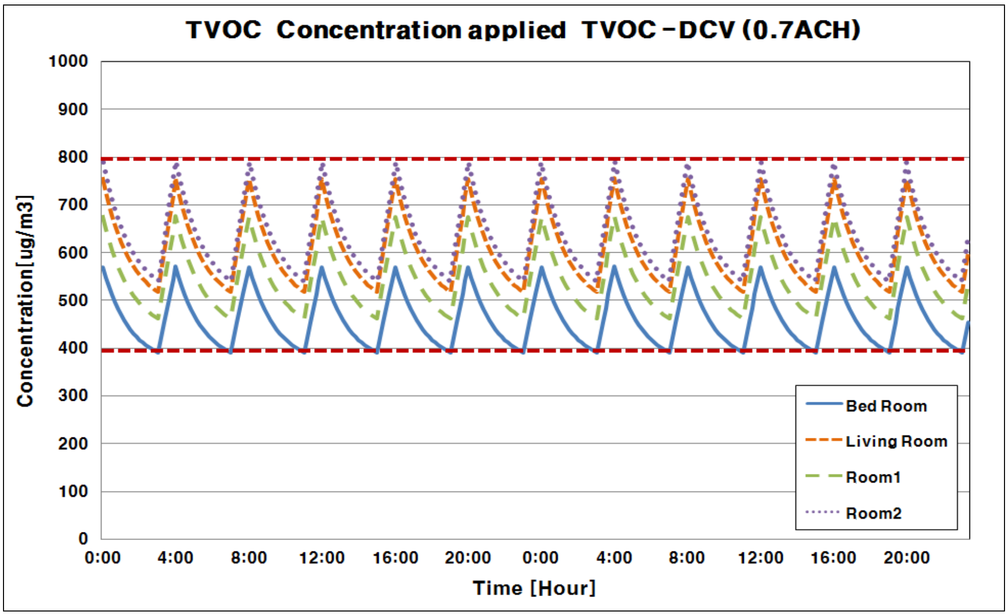


Fig. 16 TVOC concentration with TVOC-DCV

Table 6 Comparison with Energy Consumptions

Boiler Gas Consumption [MJ]			
Month	**0.7ACH**	**TVOC DCV (0.7 ACH)**	**CO_2 DCV (1.5 ACH)**
NOV	1236.31	718.43	1482.65
DEC	2624.26	1949.60	3109.84
JAN	3209.32	2499.72	3695.23
FEB	2552.47	1947.43	2925.38
MAR	1584.42	1220.55	1977.74
TOT	11206.78	8335.72	13190.84

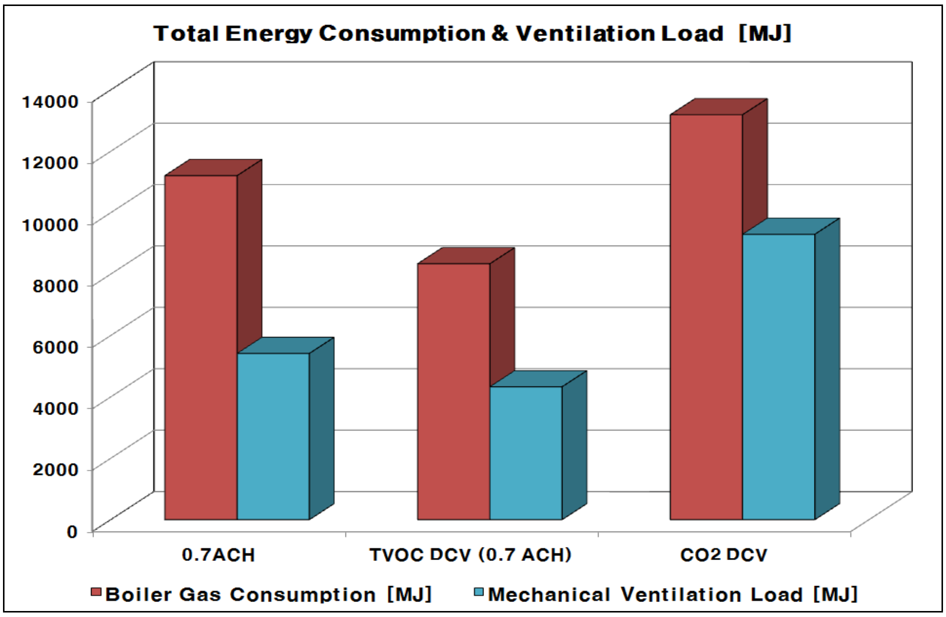


Fig. 17 Comparison with Energy Consumptions and OA Loads

Conclusions

As a Korean Ventilation Regulation, it is an essential to install the mechanical ventilation system or natural ventilation devices with 0.7 ACH rate in every residential apartment house. But there are lack of explanation how to operating ventilation system as confirm the perceived IAQ. Without any sufficient ventilation control strategies, it is difficult to improve IAQ by an occupant ON-OFF control.

If the ventilation unit is operating for 24 hour, the energy consumption would be dramatically increased. Therefore, the sensor based DCV control is very efficient control strategies in the residential building for comfort and energy saving.

From the result of simulations, the Korean Ventilation Regulation in the residential building is dissatisfied to keep the CO_2 levels properly at 1000 [ppm]. In the individual room with door closed, the CO_2 concentration is rapidly increased during sleeping period as over range of 1000 ppm. Additional air volume is necessary to reduce the CO_2 concentration.

When the TVOC is maintained from 600[㎍/㎥] to 400[㎍/㎥] in the room, it is enough to reduce the chemicals with ventilation rate of 0.7[ACH]. As a result of analysis, CO_2 is not sufficient to use as a surrogate factor in the residential building. The CO_2 concentration is varied with schedule of occupancy in individual room. TVOC concentration is emitted steadily from the finishing materials, CO_2-DCV type can't control the chemical concentration efficiently than TVOC-DCV type.

The current Korean Ventilation Regulation with 0.7[ACH] of ventilation rate is not sufficient to control the CO_2 concentration, but it is enough to reduce TVOC concentration properly. For energy conservation of ventilation system, the sensor-based DCV is very efficient in the residential building, and TVOC is the proper target than CO_2 concentration to control the perceived IAQ for occupant's healthy and comfortable environment.

Acknowledgments

Acknowledgements can be published at the end of the text before references.

References

1. DOE, Energy Plus Input Output Reference. ver 3.1, 2009.
2. NIST, George N. Walton W. Stuart Dols, CONTAM 2.4 User Guide and Program Documentation. , 2008
3. ASHRAE Standard 62.1-2007 Ventilation for Acceptable Indoor Air Quality