Energy and Buildings 41 (2009) 579–586

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

# Performance prediction of a hybrid ventilation system in an apartment house

Moo-Hyun Kim *, Ji-Hyeon Hwang

*School of Mechanical and Automotive Engineering, University of Ulsan, Ulsan 680-749, Republic of Korea*

ARTICLE INFO

*Article history:*
Received 29 May 2008
Received in revised form 2 December 2008
Accepted 7 December 2008

*Keywords:*
Hybrid ventilation system
Ventilating flow rate
Thermal comfort
CFD technique
Acceptable criteria

ABSTRACT

The performance of a hybrid ventilation system, composed of a natural supply inlet and mechanical exhaust, was predicted numerically for a South Korean apartment. Analysis was performed using Computational Fluid Dynamics (CFD) for three ventilating flow rates: 30, 60, and 120 $m^3$/h. The heating period chosen in this study reflects how residents are usually exposed to poorer indoor environments in winter. An effort was made to create acceptable residential comforts regarding air current, temperature and $CO_2$ concentration distributions. The results show that ventilating flow rates are identified as an important parameter, not only in residential comfort, but also in energy savings. An ACH of 0.7 or greater seems to be a reasonable value for the permissible minimum ventilation flow rate in occupied zones. The results also show that for a ventilating flow rate of 60 $m^3$/h, some acceptable criteria are satisfied and residents achieve comfort. In the 30 and 120 $m^3$/h cases, however, residents no longer feel as comfortable with regard to thermal conditions and air currents. Lastly, when a whole apartment has a flow rate of 180 $m^3$/h, and the living room-kitchen region has a flow rate of 120 $m^3$/h, energy losses occur.



## 1. Introduction

Recent regulations on indoor air quality (IAQ) for residential buildings have increased in severity. Since 2005, an ACH (air change per hour) of 0.7 or greater is required for new construction and/or remodeled residential buildings in Korea [1,2]. It is well known that natural ventilation is the most effective and energy efficient method used in residential homes. However, the small size of openable windows during the summer presents a problem for ventilation; while increasing energy consumption because of open windows presents another problem during winter. In addition, recent high-rise and high-tech modern buildings need high insulation and airtightness to decrease energy consumption and improve noise prevention. Windows are usually not openable in these energy-efficient buildings, and ventilation through window cracks and/or gaps is not available.

Hybrid ventilation is a relatively new technology, providing increased ventilation efficiency as well as thermal comfort. However, these systems are more structurally complex and difficult to build compared to natural ventilation systems. Throughout the indoor space, diverse flow patterns can exist depending upon the different types of hybrid systems. In recent years, research on ventilation problems in modern kitchen spaces has been actively conducted [3–7]. This topic is particularly of great interest in northeast Asian countries such as Korea and China, because adequate ventilation systems are needed to efficiently remove smoke, grease particles and volatile organic compounds produced during the cooking process. However, their efforts were focused on a confined kitchen space. A number of field and indoor experimental procedures were performed in three typical apartment buildings located in two street canyons by Niachou et al. [8]. In the presence of cross ventilation and with sufficient ambient wind speeds, natural ventilation is shown to be more effective with regard to ACH, in comparison with hybrid systems. However, when only single sided ventilation is possible or under calm conditions, hybrid ventilation has a slight advantage over natural ventilation systems. Brohus et al. [9] investigated the measurements of hybrid ventilation performance in an office building. Results showed an office environment with an acceptable thermal comfort level and a high level of indoor air quality, but with relatively high energy use for heating. Yoshino et al. [10] conducted an experimental study on the performance evaluation of ventilation systems. This study was performed in a full-scale test house over a heating period.

Prior to real application or construction, it is important to predict the various performances of any hybrid ventilation system using the CFD technique. In this paper, a numerical study is presented on a hybrid ventilation system with a natural supply and mechanical exhaust. Analysis is performed on three ventilating flow rates over a heating period. Results show residential comfort levels and verify the acceptable criteria with regard to indoor air velocity, temperature and $CO_2$ concentration.

* Corresponding author. Tel.: +82 52 259 2128; fax: +82 52 259 1680.
*E-mail address:* mhkim@ulsan.ac.kr (M.-H. Kim).

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doi:10.1016/j.enbuild.2008.12.003

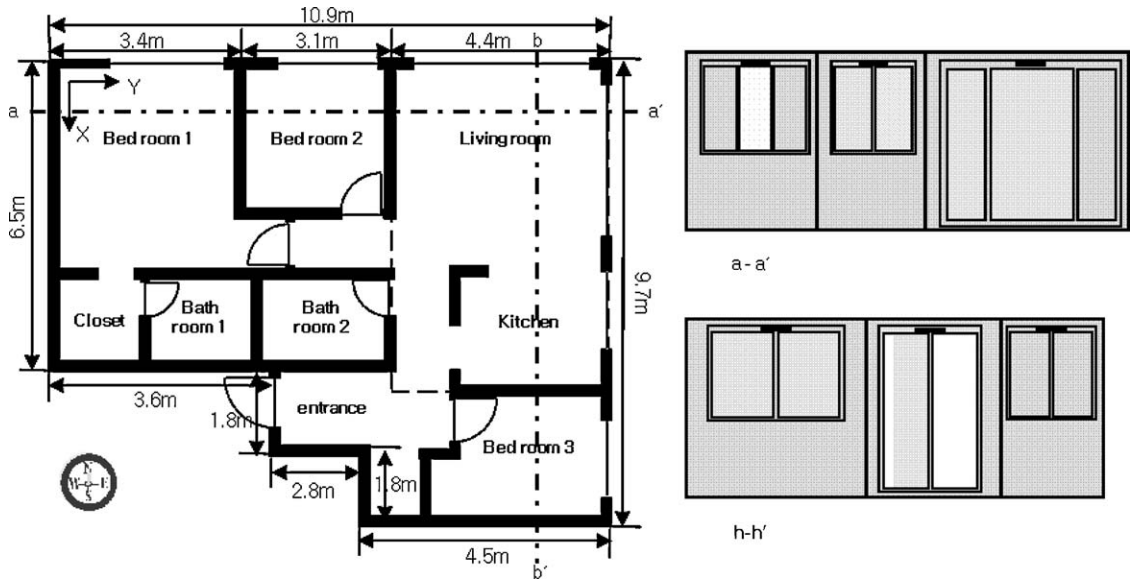


**Fig. 1.** Plan of the model apartment, in meters.

## 2. Analytic model

The model apartment plan is illustrated in Fig. 1. The apartment building is a reconstruction of a building located in a residential area of Seoul, Korea. The horizontal section of the apartment building has four similar apartment houses. Each apartment house has an area of 100.28 $m^2$, which includes adjoining areas such as an elevator and stairway. It consists of a living room, three bedrooms, two bathrooms and a kitchen. In this floor plan, the living room is connected to the kitchen, and can be coupled into one space. The Cartesian coordinate with the corresponding components (*X, Y*) for the whole apartment is indicated at the top left corner of bedroom 1. Shown in the figure, north and east walls are facing outdoors. Each of the outer walls has three windows, while the other two sides (south and west) have no windows. Thus, natural cross ventilation is impossible and hybrid ventilation with a mechanical fan is inevitable with calm conditions outside or from cooking. The living room and kitchen areas are generally regarded as the central zone of family life in a modern apartment lifestyle. Hence, the present study was carried out in two regions: (1) the living room-kitchen region and (2) the whole apartment.

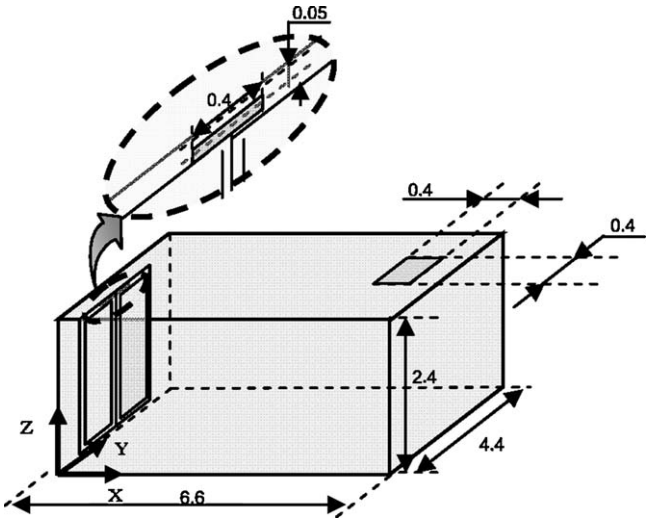


**Fig. 2.** Schematic diagram of the living room-kitchen region, in meters.

Fig. 2 shows the simplified schematic diagram of the living room-kitchen region, which has a volume of 6.6 m × 4.4 m × 2.4 m. The Cartesian coordinate with the corresponding components (*X, Y*) is indicated at the upper left corner of the living room. A dividing door is usually constructed between the living room and the entrance space. A natural supply air inlet with dimensions of 0.4 m × 0.05 m is located at the center of the top window of the north wall, while a 0.4 m × 0.4 m mechanical exhaust air outlet is in the ceiling of the kitchen area to effectively remove produced emissions. The air supply unit for window mounting is referenced in "Fresh ventilation" [11].

Fig. 3 illustrates the main activity region for the residents, assuming that the main activity region is 1.8 m or less in height and 0.6 m away from the vertical walls. This assumption is based on the fact that the average height of a person is less than 1.8 m and furniture often occupies the vicinity of vertical walls. Shown in Table 3, residents feel comfortable in the activity region when air movement is under 0.15 m/s during a heating period and under 0.25 m/s during a cooling period. In addition, both vertical and horizontal temperature gradients should be small in the main activity region to ensure thermal comfort.

## 3. Numerical analysis and boundary conditions

### 3.1. Calculation procedures

The flow was assumed to be in unsteady state, incompressible and turbulent. This study treats the problems of mixed convection induced by a combination of the buoyancy effect (floor heating) and the forced outlet flows by the fan. The governing equations were composed of continuity, momentum, energy, concentration, turbulent kinetic energy and dissipation rate equations. Another assumption was that the behavior of $CO_2$ follows that of air

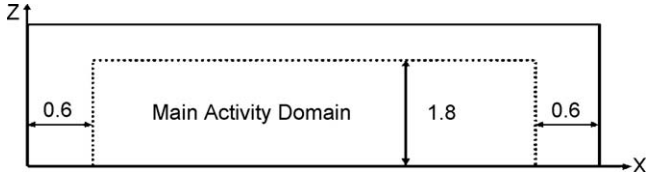


**Fig. 3.** Main activity region for residents, in meters.