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Trends in the Korean building ventilation market and drivers for change

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1 Introduction

Apartment buildings are the most common type of residence in Korea, but since the 1970s it was difficult to supply fresh air due to airtight exterior walls that were constructed with energy conservation in mind. In addition to this problem, Sick House Syndrome and Multi Chemical Sensitivity issues arose from having used petrochemical building materials and furniture that often emit volatile organic compounds and formaldehyde with high possibilities.

In order to solve the Sick House Syndrome, the Korean Ministry of Environment recently passed a law on ventilation standards and likewise on February 13. 2006 the Ministry of Construction and Transportation made it mandatory to install ventilation systems in apartment houses and multi-purpose facilities, as well as propagate the ventilation standard suitable for a particular type of building design.

The ventilation standard requires a 0.7 ACH for newly built or remodelling apartment buildings and apartment & stores complexes containing over 100 apartment houses.
Lately, researchon ventilation systems has become more widespread , and developments are being accelerated through technical cooperation between ventilation manufactures. The objective of this research and development is to meet the ventilation requirements as well as to pursue energy saving and sustainability by utilising mechanical and natural ventilation systems.

This paper briefly explains indoor air quality conditions of apartment buildings, the newly enacted regulation of ventilation and various ventilation systems available on the market in Korea.

2 National Issues for Ventilation

Apartment buildings have become the most prevalent housing type to meet the quantitative demands for housing with rapid urbanization and high population density in Korea. With the increase of residents' interest in improving the quality of life, the focus of construction activities has gradually shifted to improving the quality of housing. In particular, there has been a growing public concern over poor indoor air quality of new housing and residents' health complaints.

In order to suggest the recommended guidelines for indoor air quality of new housing, the Korea Institute of Construction Technology investigated the indoor air quality of new apartment houses in the period of 2004 to 2005, sponsored by the Ministry of the Environment. This survey was intended to assess the health effects of harmful chemical substances on the human body and to take into consideration the technical, cultural, and economic aspects when establishing the indoor air quality standards for newly built apartment buildings. The concentrations of formaldehyde and selected volatile organic compounds were measured and analyzed for 1,067 houses from 90 apartment complexes throughout the country. The overall environmental conditions were also investigated including climate conditions, history of the unit, type of built-in furniture, and interior building materials.

The investigation results are shown in Table 1. The detection frequency of formaldehyde, benzene, toluene, xylene, ethylbenzene, styrene, and acetaldehyde exceeded 99% of total dwellings. The detection frequency of 1,3,5-trimethy-benzene, 1,2,4-trimethylbenzene, trichloro-ethane, acetone, propionaldehyde, butyl-aldehyde, benzaldehyde and acrorein ranged between 50-80%. VOCs emission from building materials and household products might be attributed to the indoor air pollution in new houses.

Ventilation deficiency from the airtight building envelope was also responsible for high concentration levels of VOCs. Natural ventilation was the most common mode for fresh air exchange in Korean apartment buildings, but people are apt to close the windows for the reason of thermal comfort, energy saving, and security. In the Ministry of Environment's survey of 2,213 occupants, ventilation deficiency was thought to be the major contributor to the indoor air pollution, as shown in Figure 1.

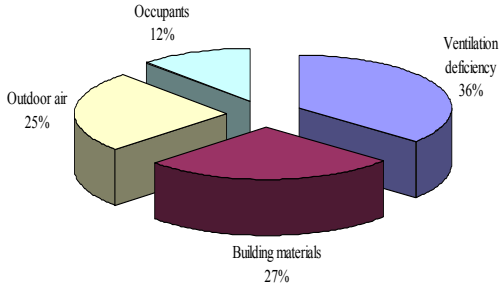


Figure 1: Survey results on the cause of indoor air pollution (2003. 12. 1)

Realizing the significance of the indoor air quality problem of new built apartment buildings, the Ministry of Construction and Transportation and the KICT conducted research on the establishment of a ventilation standard. Based on this effort, the new regulation of ventilation was outlined in the Korean Building Regulation in February 2006, and the technical specification for the proposed ventilation standard was distributed in June 2006.

Table 1: Measured concentrations of pollutants in survey 2005 (μg/m^3)

		Formaldehyde	Benzene	Toluene	Ethylbenzene	Xylene	Styrene	TVOC
Total Samples	n	1,067	1,067	1,067	1,067	1,067	1,067	1,067
Detection Frequency	N	1,067	1,065	1,063	1,067	1,067	1,067	1,067
	%	100.0	99.9	99.6	100.0	100.0	100.0	100.0
Average		293.1	5.1	1003.0	120.0	286.9	63.2	2646.2
S.D.		238.3	5.4	746.3	129.9	362.2	71.3	1992.4

3 Trends in IAQ and ventilation requirements

Since the recommended standards for underground spaces were enacted in 1989 by the Ministry of Environment, standards and regulations on indoor air quality have been legislated and revised continuously. In 2005, the 'Indoor air quality management act' was revised to restrict the use of pollutant-emitting building materials and to set indoor air quality standards for multi-purpose facilities and newly built apartment buildings. The Ministry of the Environment has also introduced a set of recommended or obligatory guidelines for pollutant concentration levels in new apartment units.

On February, 2006, the Ministry of Construction and Transportation set the regulation of ventilation for newly built apartment buildings & multi-purpose facilities. This regulation made it mandatory to install ventilation systems in apartment buildings and multi-purpose facilities, as well as to propagate the ventilation standard suitable for a particular type of building design. Table 5 shows the recent revisions of regulations for different types of facilities.

3.1 Dwellings

According to the 'Indoor air quality management act', construction companies constructing new apartment building complexes with over 100 residential units are required to measure the concentration levels of six toxic substances before the residents move in. They are also enforced to give public notification by submitting those results to the heads of local governments as well as posting the information on bulletin boards for 60 days in convenient locations for residents.

Table 2: Recent revision of IAQ and ventilation regulations

Authority	Regulation & Standard (as of May 2007)
Ministry of Environment	• Revision of indoor air quality management act in multi-purpose facilities & new apartment buildings (2005) • In progress of revising the IAQ measuring methods by MOE (scheduled for late 2007) • Revision of the accepted amount of indoor air pollutants emitted from building materials (scheduled for December 2007) • Setting of evaluation stand- ards for pollutants emitted from Furniture & electronic devices (scheduled for July 2009) • Setting of standards and in-vestigation of IAQ in public transportation
Ministry of Construction & Transportation	• Legislation of "Regulation of ventilation in newly built apartment buildings & multi-purpose facilities (February 13th, 2006) • Official notification of guidelines for major building materials to reduce the amount of pollutants emitted (scheduled for 2008) • Enforcement of performan-ce rating system in residen-tial buildings (January 9th, 2006) • Enactment of adhesive and paint usage guidelines to mitigate the Sick House Syndrome (2006)
Ministry of Commerce, Industry, & Energy	• Legislation of the test me-thod (KS) for pollutant emitting rates of environment friendly building materials (scheduled for October 2007) • Enact of emission testing method for furniture using large chambers (scheduled for 2008) • Enact of indoor air quality testing method for auto mobile (scheduled for 2008)
Ministry of Education	• Revision of School Health & Hygiene Law (ventilation & IAQ standard included) (2005) • Enactment of simple testing method for assessing IAQ in school (scheduled for 2008)
Ministry of Labor	• Guideline for IAQ controls in offices (January 5th, 2007)

The new ventilation requirement is set to be more than 0.7 ACH for apartment houses that are newly built or remodeled. The definition of natural and mechanical ventilation systems mentioned in this regulation is as follow:

- *Natural ventilation system* : a system that allows constant ventilation due to the pressure differences between indoor and outdoor air, except for conventional openings such as windows and door. It must be checked by the regional construction committee whether the required ventilation rate is satisfied
- *Mechanical ventilation system* : a forced ventilation system that employs a motorised fan. The general requirements for the installation of mechanical ventilation system are thoroughly described, with additional details, by the Korean Industrial Standard (KS).

The general checkpoints for the application of mechanical ventilation systems are as follows:

- *Natural ventilation system* : a system that allows constant ventilation due to the pressure differences between indoor and outdoor air, except for conventional openings such as windows and door. It must be checked by the regional construction committee whether the required ventilation rate is satisfied
- Determine if each room is supplied with equal amounts of outdoor air
- Determine if the system has at least 3 steps of regular airflow control unit
- Verify that the pressure loss that occurs in the duct during the normal operating conditions of the ventilation system is appropriately considered (can be determined from the performance report and specification of the ventilation system)
- Verify the official document of the public authority that allows determining if the noise level based on KS B 6361 is below 40dB
- Confirm the particle distribution rate measuring method and results of mechanical ventilation systems in order to evaluate the structure and performance of the air filter (check with the official report that allows one to determine if the particle collection efficiency obtained through light-scattering or the absorptimetry method based on Korean Standard is above 60%)
- Confirm that air inlets and outlets are located 1.5m apart from each other so that intersecting of pollution doesn't occur and also verify that the direction of the inlets and outlets is over 90˚
- When a heat recovery ventilation system is installed, check with the report that allows determining if the effective ventilation rates have been examined based on the Korean Standard. (Heat-exchanging devices are not mandatory)

The general checkpoints for the application of the natural ventilation system are as follows:

- Determine if each room is supplied with equal amounts of outdoor air
- *Natural* Thoroughly examine the submitted specifications of the target natural ventilation system to determine whether or not mechanical fans are used
- *Natural* Verify whether or not pre-filtering devices that can filter the pollutants flowing in from the outside are installed within ventilation systems (scheduled for Dec. 2007 because the performances of pre-filters have not yet been provisioned)
- *Natural* Confirm that there is an official test result that allows one to determine if the noise coming from natural ventilation system is below 40dB in typical conditions
- *Natural* Determine whether or not the system allows the indoor warm (or cool) air to be directly lost to the outside
- *Natural* Confirm that the system features a 24 hour constant ventilation
- *Natural* Determine if the performance evaluating conditions of in-situ experiments, mock-up test or computer simulation (CFD or network model) are identical to that in the manual and also determine whether or not the simulation results are objective

3.2 Multi-purpose facilities

The mandatory ventilation standard for multi-purpose facilities, which had previously regulated ventilation rates and the amount of ventilation per occupant of the existing 4 building types, was largely reclassified into 7 types that follow the mechanical ventilation installation and ventilation standard procedures according to the ventilation characteristics of the building.

3.3 School and office buildings

The ventilation requirement in schools is specified in the "School health & hygiene law," which was revised on December, 2005 by the Ministry of Education in Korea. School buildings should be ventilated at the air flow rate of more than 21.6m^3/h·p by opening windows or operating mechanical ventilation systems. This law also specifies the standard for the structure and the installation method of mechanical ventilation systems in order to ensure enough capacity and balanced fresh air distribution. The Ministry of Education distributed the environmental control manual for school buildings in 2006, and has a plan to revise the detailed guidelines and specifications for ventilation systems.

Recent office buildings are usually designed and operated as an open-plan workspace in Korea. The enclosed workspace can be found in some small office buildings. Old and small office buildings are usually ventilated by natural forces, but most of modern office buildings are equipped with HVAC systems. The ventilation guideline for workplace is 0.57m^3/min.person or 0.4 ACH, and it was specified in the "Guideline for IAQ Control in Offices" of the Ministry of Labor on January, 2007.

4 Trends in Energy requirements

Since Korea has four distinct seasons, there is a wide range of outdoor temperature variation throughout the year. The Korean traditional radiant floor heating system (Ondol) is widely used in most residential buildings in Korea, which use hot water in embedded tubes.

For cooling, demands and installations of packaged air-conditioning systems have increased considerably in residential buildings. Mechanical heating and cooling systems are very common in various types of buildings including commercial, industrial, and other multi-purpose facilities.

The building regulations on 'Equipment Standards for Buildings' specifies the insulation standard for the building envelopes, which was recently reinforced by more than 20%. 8 types of high-energy consuming buildings, including offices and hospitals, have been mandated to apply a separate 'Design Standard for Energy Efficiency' since June 2001. For the approval of these buildings, efforts must be made to expand the use of high efficiency energy products such as high efficiency gas boilers and refrigerators. Besides these mandatory regulations, various kinds of voluntary certification and labeling programs are operated by government authorities.

Table 3: Ventilation standards for multi-purpose facilities

Classification of multi-purposed facility		Required minimum ventilation rate (m^3/person.hour)	Note
Underground facilities	underground subway station	25 or more	-
	Underground arcade	36 or more	gross area of shop : 2000m^2 or more
Culture and assembly facilities		29 or more	gross area : 3000m^2 or more
Sale and business facilities		29 or more	gross area : 2000m^2 or more
Medical facilities		36 or more	gross area : 2000m^2 or more
Research and welfare facilities		36 or more	gross area : 1000m^2 or more
Car facilities (indoor parking lot)		27 or more	gross area : 2000m^2 or more
Other facilities		25 or more	gross area : 500m^2 or more

4.1 Energy Efficiency Labeling Program for Buildings

To increase energy efficiency in the building sector, building energy efficiency labeling programs were issued to newly built or remodeling multi-family residential buildings with more than 18 households. Buildings can be classified into grades 1~3 depending on the use of energy-conserving facilities and equipment. Considering the possibility of ventilation deficiency in the air-tight buildings, additional credit is available for the certified buildings which satisfy the following indoor air quality criteria.

Buildings with a certain performance standard will be given the Certificate of Building Energy Efficiency and a loan for the construction at a lower interest rate. The Korean government will annually expand the energy efficiency labeling program by targeting detached houses and business buildings in 2004~2010.

4.2 Green Building Certification Program

The Green Building Certification Program evaluates a building's degree of sustainability throughout the life cycle of the construction process in order to improve the environmental performance of the buildings and reduce greenhouse gas emissions. Various version of certification criteria have been established in phases for multi-family residential buildings, housing and commercial complexes, commercial buildings, accommodation facilities, and schools. Additional criteria will be added for various types of facilities in the near future. As for multi-family residential buildings, ventilation performance can be evaluated by the following criteria.

Ventilation performance of schools can be evaluated by the area ratio of operable windows, which allow cross-ventilation in the classroom. Additional credit can be added for science laboratories equipped with mechanical supply and exhaust systems in schools.

Table 4. IAQ criteria in Energy Efficiency Labeling Program for Buildings

Pollutant	CO_2	CO	HCHO	Radon
Criteria	1000ppm (1h)	10ppm (1h)	0.08ppm (30min)	150Bq/m^3 (1h)

Table 5: Ventilation criteria in Green Building Certification Program

Level	Criteria	Weight
1	More than 15% of operable window area to floor area Controllable air in-let devices with heat exchanger in living room or kitchen	1.0
2	More than 15% of operable window area to floor area Controllable air inlet devices in living room or kitchen	0.7
3	More than 15% of operable window area to floor area	0.4

4.3 Housing Performance Grading Indication System

To provide more comfortable housing environment and to promote the housing construction technology, the Ministry of Construction and Transportation issued the mandatory Housing Performance Grading Indication System to newly built apartment building complex with more than 1000 households. Housing performance can be evaluated by various indicators and criteria including sound insulation, structural safety, indoor and outdoor environmental quality, flexibility and durability, and fire safety. Ventilation performance can be evaluated by the following criteria.

***Table 6**. Ventilation criteria in Housing Performance Grading Indication System*

Level	Criteria
1	Equipped with mechanical or natural ventilation systems with more than 0.7ACH Equipped with both high per-formance air filter and heat exchanger
2	Equipped with mechanical or natural ventilation systems with more than 0.7ACH Equipped with high perfor-mance air filter or heat exchanger
3	Equipped with mechanical or natural ventilation systems with more than 0.7ACH

5 Trends in Building Air-tightness

As seen earlier, high-rise apartment buildings account for some 50 percent of the residential buildings and over 90 percent of them have a reinforced concrete structure in Korea. An air flow path related to air-tightness performance in apartment buildings can be seen in Figure 2. In general the air flow rate through such air flow paths depends on the following three factors:

1. Size and position of air flow paths
2. Flow characteristics in air flow paths
3. Pressure differences of indoor and outdoor

Due to the structural characteristics, the basic air-tightness performance of apartment buildings is judged to be satisfactory and no air-tightness performance and its basis have been stipulated on a national level. Only the test methods (KS F 2292-2003) and performance grades for air-tightness of windows and doors are presented. Also KS has another test method using the ISO Standard (KS L ISO 9972-2006).

This is basically because most of the residential buildings are apartment buildings with reinforced concrete, which can easily secure air-tightness performance unlike the European countries and the air-tightness performance of windows and doors can represent the air-tightness performance of the residential buildings. When the air-tightness performance through an apartment building structure is measured by blower door test, it is seen to have secured the air-tightness performance with an error tolerance level of theblower door test.

Office buildings and school buildings are seen to be on similar levels of European countries and the U.S.

According to the results on research on the actual condition enforced in line with ASTM E779 for the case of 4Pa pressure difference of indoor and outdoor, the equivalent air leakage area(ELA) for each unit of floor area, an air-tightness performance index for building envelope, is about $1.5cm^2/m^2$~$3.2cm^2/m^2$. However, when considering that most of the countries are showing a tendency to reinforce the air-tightness performance of residential buildings up to $1.0cm^2/m^2$, more effort for designing apartment buildings and improving construction technology should be put in as soon as possible.

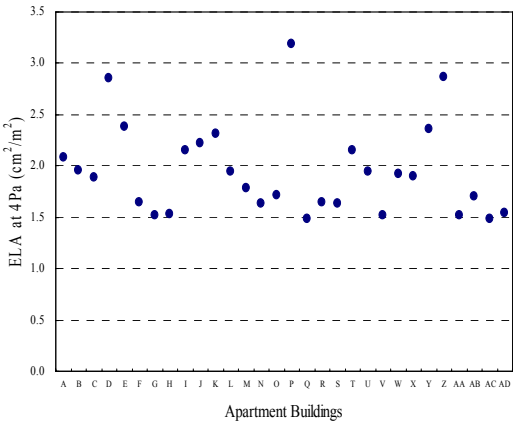


Figure 3: Results of air-tightness performance of apartment buildings

encourage , Researche of evaluation methods and establishing its basis for air-tightness performance of apartment buildings as the national standard are currently underway and is scheduled to be presented by the end of 2008.

6 Trends in Building Ventilation Systems

Most of the old residential buildings were not intentionally equipped with ventilation systems except for mechanical exhaust fans in bathrooms and kitchens. Building ventilation was usually achieved by opening windows and doors. Since the Korean Ministry of Environment enacted the 'Indoor air quality management act' for newly built apartment buildings and multi-purpose facilities in 2004, a variety of types of ventilation systems are supplied to meet the mandatory ventilation requirements.

As of April 2007, the heat recovery ventilation system has a predominant share in the market of ventilation systems. More than 10 companies are manufacturing and supplying mechanical ventilation systems, and duct-type systems and exterior-wall-attached ductless systems are the most common types of mechanical ventilation systems. As for the natural ventilation systems, natural ventilation devices are also developed and supplied, which can be installed on window glasses.

6.1 Mechanical ventilation system

Mechanical ventilation system can lower indoor concentration of contaminants by exchanging polluted indoor air and fresh outdoor air. The control and reliability offered by mechanical ventilation systems is a significant advantage when compared to natural ventilation systems. Since the government made it mandatory to install ventilation systems in apartment buildings, mechanical ventilation systems have been widely and rapidly applied to newly designed and constructed buildings.

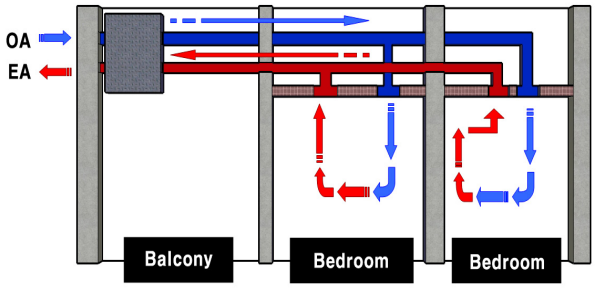
Mechanical ventilation systems can be classified into three basic types, a balanced system, a supply-only system, and an exhaust-only system. Although the most common ventilation system take air through a duct to or from the outside of building, ductless ventilation systems are also developed and supplied in the market for housing units with lower ceiling height. The most prevalent type is the duct-type heat recovery ventilation system, and other systems are also being developed consistently. Typical types of ventilation systems are shown in Figure 4.

(1) Heat recovery ventilation system
- Built-in heat exchanger in the ventilation system
- Heat or cool incoming fresh air by transferring the heat energy from the conditioned exhaust air

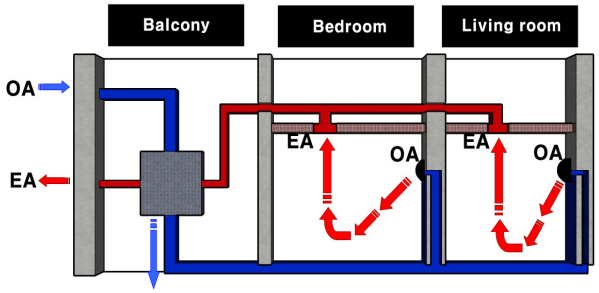
(2) Ventilation system with underfloor embedded duct
- Built-in heat exchanger in the ventilation system
- A ventilation system with embedded duct in the floor heating system
- Heat incoming fresh air by floor heating system
- Exhaust indoor air through diffusers or grills on the ceiling
- Additional heat source for heating in-coming air is not necessary.

(3) Heat recovery kitchen exhaust system
- Built-in heat exchanger in the kitchen exhaust system
- Heat or cool incoming fresh air by transferring the heat energy from the conditioned exhaust air
- When operating the kitchen hood for local exhaust, a by-pass mode will be available to avoid mixing supply and exhaust air

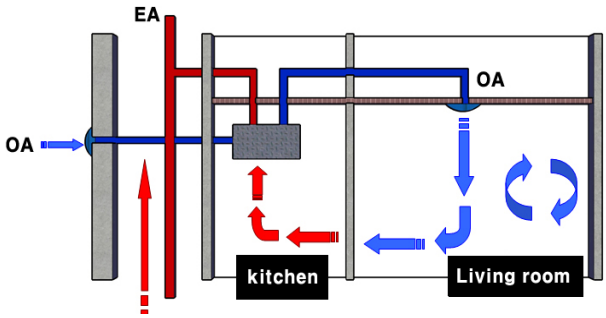
(4) Ductless ventilation system
- Supply required fresh air volume directly through the ventilation system which is installed on the balcony adjacent to the outside
- (Useful to the housing unit that does not have enough ceiling height to install)



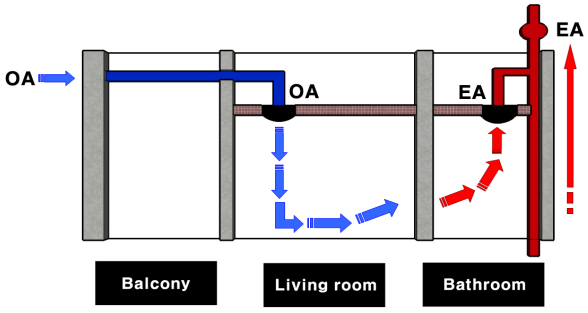
(a) Heat recovery ventilation system



(b) Ventilation system with underfloor embedded duct



(c) Heat recovery kitchen exhaust system



(d) Ductless ventilation system

Figures 4: Typical types of mechanical ventilation systems in Korea

a) Duct type b) Ductless type

Figures 5: Examples of mechanical ventilation system

6.2 Natural ventilation system

Korea is one of the countries with rigid insulation standards to prevent unnecessary energy loss. The performance criteria or installation standards for natural ventilation systems are not definitely described yet. Therefore, various products have been developed to meet the basic performance and requirements of windows. Products with filter system were developed to meet the needs of consumers who are sensitive to Yellow dust from china and outdoor air pollution. Automatic controllable natural ventilators were also introduced to the market.

There are three typical types of natural ventilation systems. The structure installation type is inserted and installed at the wall punching section. In this case, there is aweakness in that it is difficult to make equal ventialtion in the whole room room in Korean style apartments due to lack of walls adjacent to outdoors. The window frame insertion type is inserted and installed after grooving the window, frequently shown in European countries such as UK. However, it is difficult be introduce in Korea as reinforcement materials are in the inside of PVC windows so punching is hard and an issue is made because of deteriorating the original capability of the window in punching. The window insertion type is easy to install and does not give an impact to window capability.

The main purpose of natural ventilation systems in apartment buildings was to solve the condensation problems on the balcony in winter. Since the application of natural ventilation systems was legislated, the purpose has been shifted to meet the ventilation criteria. The Market share of natural ventilation systems was estimated at less than 5% in 2007, but the application of natural

ventilation system is expected to be expanded after 2008.

6.3 Hybrid ventilation system

Lately various research projects on hybrid ventilation have been carried out , and developments are being accelerated through technical cooperation between the ventilation manufactures. The objective of this research and development is to meet the ventilation requirements as well as to pursue energy saving and sustainability by utilising mechanical and natural ventilation systems. Figure 7 shows a hybrid ventilation system adopted by a construction company. Electric heat recovery ventilation system and natural ventilation system were installed together. It is expected that highly effective hybrid ventilation systems will be launched in the near future to reduce the initial construction and maintenance costs as well.

7 Conclusion

The ventilation regulations in Korea are enforced to resolve the sick building syndrome. It is important that a continuous ventilation rate is secured as well as resolving condensation and filter issues. The ventilation rates for newly built apartment buildings focused on formaldehyde concentration as the target pollutant. The maximum allowed concentration was targeted to satisfy the WHO standard of 100μg/m^3.

In Korea, more than 90% of the mechanical ventilation systems installed in apartment buildings have heat exchangers, because the temperature difference between indoors and outdoors rises over 30□ in winter. Also since apartment buildings have wide facades, ductless mechanical ventilation systems can provide legitimate ventilation efficiency.

Natural ventilation systems come most commonly in the form of window frame installations but one of its disadvantages is dealing with the filtering of yellow dust and other pollutants from the outdoor and the effect of cold drafts in winter. In Korea, natural ventilation systems comes in the form of horizontal installations on window glass whereas a ceiling installation in each room is the most common form of mechanical ventilation system.

Figure 6 : Example of natural ventilation system

Figure 7: Example of hybrid ventilation system

For an improvement of natural ventilation systems, we are researching a new test method to evaluate the performance based on the air flow rates at specific pressure differences (2Pa) and developing highly effective hybrid ventilation products. Still in the initial stages, research is being concentrated in this area. Considering the current technology and supply levels, the hybrid ventilation systems are expected to become more widely distributed in the near future.

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The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim is to promote the understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in the design of new buildings and the improvement of the existing building stock.