INTERNATIONAL ENERGY AGENCY
Energy conservation in buildings and
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Technical Note AIVC 64

Ventilation in Korea

Air Infiltration and Ventilation Centre
Operating Agent and Management
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Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-four IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use in buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods as well as air quality and studies of occupancy.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial.

To date the following have been initiated by the Executive Committee (completed projects are identified by *):

1 Load Energy Determination of Buildings *
2 Ekistics and Advanced Community Energy Systems *
3 Energy Conservation in Residential Buildings *
4 Glasgow Commercial Building Monitoring *
5 Air Infiltration and Ventilation Centre
6 Energy Systems and Design of Communities *
7 Local Government Energy Planning *
8 Inhabitant Behaviour with Regard to Ventilation *
9 Minimum Ventilation Rates *
10 Building HVAC Systems Simulation *
11 Energy Auditing *
12 Windows and Fenestration *
13 Energy Management in Hospitals*
14 Condensation *
15 Energy Efficiency in Schools *
16 BEMS – 1: Energy Management Procedures *
17 BEMS – 2: Evaluation and Emulation Techniques *
18 Demand Controlled Ventilation Systems *
19 Low Slope Roof Systems *
20 Air Flow Patterns within Buildings *
21 Thermal Modelling *
22 Energy Efficient communities *
23 Multizone Air Flow Modelling (COMIS)*
24 Heat Air and Moisture Transfer in Envelopes *
25 Real Time HEVAC Simulation *
26 Energy Efficient Ventilation of Large Enclosures *
27 Evaluation and Demonstration of Residential Ventilation Systems *
28 Low Energy Cooling Systems *

29	Daylight in Buildings *
30	Bringing Simulation to Application *
31	Energy Related Environmental Impact of Buildings *
32	Integral Building Envelope Performance Assessment *
33	Advanced Local Energy Planning *
34	Computer-aided Evaluation of HVAC Systems Performance *
35	Design of Energy Hybrid Ventilation (HYBVENT) *
36	Retrofitting of Educational Buildings *
36 WG	Annex 36 Working Group Extension 'The Energy Concept Adviser' *
37	Low Exergy Systems for Heating and Cooling of Buildings *
38	Solar Sustainable Housing *
39	High Performance Insulation systems (HiPTI) *
40	Commissioning Building HVAC Systems for Improved Energy Performance *
41	Whole Building Heat, Air and Moisture Response (MOIST-EN)
42	The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (COGEN-SIM)
43	Testing and Validation of Building Energy Simulation Tools
44	Integrating Environmentally Responsive Elements in Buildings
45	Energy-Efficient Future Electric Lighting for Buildings
46	Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)
47	Cost Effective Commissioning of Existing and Low Energy Buildings
48	Heat Pumping and Reversible Air Conditioning
49	Low Exergy Systems for High Performance Buildings and Communities
50	Prefabricated Systems for Low Energy Renovation of Residential Buildings

Annex V: Air Infiltration and Ventilation Centre

The Air Infiltration and Ventilation Centre was established by the Executive Committee following unanimous agreement that more needed to be understood about the impact of air change on energy use and indoor air quality. The purpose of the Centre is to promote an understanding of the complex behaviour of air flow in buildings and to advance the effective application of associated energy saving measures in both the design of new buildings and the improvement of the existing building stock.

The Participants in this task are Belgium, Czech Republic, Denmark, France, Greece, Japan, Republic of Korea, Netherlands, Norway and United States of America.

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1 Country data

1.1 General data

South Korea is located in East Asia, on the southern half of the Korean Peninsula, protruding from the far east of the Asian mainland. The Korean peninsula, including all of its associated islands, lies between latitudes 33º06'40" N and 43º00'39" N and longitudes 124º11'00" E and 131º52'08" E. The latitude of Korea is similar to that of the Iberian Peninsula and to that of Greece. The total area is about 99,000 km², and in 2007 the total population was estimated at approximately 49 million.

Seoul is the capital city and the country's largest city and chief industrial center. In 2006, Seoul had 10.3 million inhabitants, making it one of the most populated single cities in the world. Other major cities include Busan (3.65 million), Incheon (2.63 million), Daegu (2.53 million), Daejeon (1.46 million), Gwangju (1.41 million) and Ulsan (1.10 million). The map of the Republic of Korea is shown in Figure 1.

Figure 1: Map of the Republic of Korea (source: http://www.korea.net)

1.2 Climate

As part of the East Asian monsoon region, Korea has a temperate climate with four distinct seasons. Geographically, it is located in the middle latitudes of the Northern Hemisphere, on the east coast of the Eurasian Continent and is adjacent to the Western Pacific. Korea experiences a wide temperature difference between summer and winter and a high precipitation in comparison to that of the European Continent. It is also subjected to a distinct monsoon wind, a rainy period in the East-Asian Monsoon (known locally as "Changma"), typhoons, as well as often heavy snowfalls in the winter. Korea belongs to a relatively wet region due to its significantly higher precipitation compared to the world average.

The annual mean temperature ranges from 10°C to 16°C for all regions excluding the high mountainous areas. The warmest month is August, while the coldest month is January. The monthly mean temperature ranges from 23°C to 27°C in August and from -6°C to 7°C in January. The annual precipitation ranges from 1,000 mm to 1,800 mm in the southern part of Korea and from 1,100 mm to 1,400 mm in the central part. The prevailing wind systems are southwesterly in summer and northwesterly in winter. Humidity is highest in July, reaching 80~90% nationwide, and lowest in January and April, reaching 30~50%.

Changma, which occurs during the summer Asian Monsoon system, begins in the southern part of Korea in late June and gradually proceeds northward. It typically continues for 30 days, bringing frequent heavy rains and flash floods. There are approximately 28 typhoons generated annually in the Northwest Pacific, and two or three influence the Korean Peninsula from June to October. Table 1 shows the selected climate data for four major cities in Korea.

Table 1: Long-term climate data for the period of 1971-2000
(Source: Korea Meteorological Administration, http://www.kma.go.kr)
(a) Mean air temperature (°C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
Seoul	-2.5	-0.3	5.2	12.1	17.4	21.9	24.9	25.4	20.8	14.4	6.9	0.2	12.2
Daejeon	-1.9	0.2	5.4	12.4	17.6	22.0	25.3	25.5	20.3	13.8	6.8	0.7	12.3
Daegu	0.2	2.1	7.1	13.8	18.7	22.5	25.7	26.1	21.3	15.4	8.6	2.5	13.7
Busan	3.0	4.3	8.3	13.4	17.4	20.5	24.2	25.7	22.1	17.3	11.3	5.6	14.4

(b) Solar radiation (MJ/m2)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
Seoul	7.04	9.58	12.37	15.19	16.49	15.53	12.11	12.43	12.16	10.33	7.08	5.88	11.35
Daejeon	7.83	10.93	13.56	17.24	17.64	16.08	14.71	15.25	13.40	11.98	8.39	7.13	12.85
Daegu	8.32	10.63	13.07	16.39	17.87	16.36	14.59	14.32	12.75	11.50	8.45	7.53	12.65
Busan	8.90	10.85	12.84	16.03	17.51	15.81	14.96	15.67	12.76	12.02	9.21	8.21	12.90

(c) Wind velocity (m/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
Seoul	2.5	2.7	2.9	2.9	2.6	2.3	2.3	2.1	1.9	2.0	2.3	2.3	2.4
Daejeon	1.4	1.7	2.0	2.2	2.1	1.9	1.9	1.8	1.5	1.3	1.3	1.3	1.7
Daegu	3.1	3.2	3.2	3.2	3.1	3.0	2.9	2.9	2.5	2.4	2.6	2.9	2.9
Busan	4.1	4.2	4.3	4.4	3.9	3.6	4.2	4.1	3.8	3.6	3.8	3.9	4.0

(d) Precipitation (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot.
Seoul	21.6	23.6	45.8	77.0	102.2	133.3	327.9	348.0	137.6	49.3	53.0	24.9	1344.3
Daejeon	29.5	36.4	60.5	87.2	97.0	174.3	292.2	296.5	141.5	56.9	51.7	30.1	1353.8
Daegu	21.6	27.1	51.6	75.2	75.3	140.7	206.7	205.8	129.6	42.0	37.1	15.2	1027.7
Busan	37.8	44.9	85.7	136.3	154.1	222.5	258.8	238.1	167.0	62.0	60.1	24.3	1491.5

2 Building stock

2.1 General building stock

At the end of 2006, there was a recorded 6,290,263 buildings in Korea. General data on the types of building stock is shown in Figure 2.

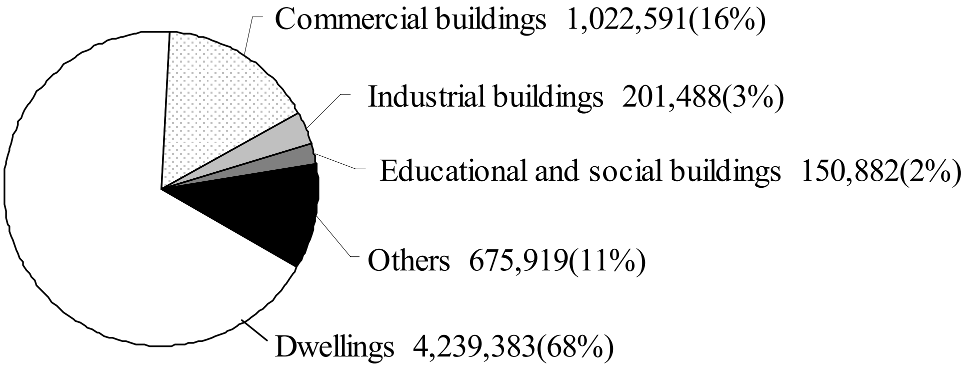


Figure 2: Portion of building types in 2007

2.2 Dwellings

Due to the rapid urbanisation and modernisation of Korea, the demand for housing has increased considerably more than in other countries. Most of the efforts that have been made to meet this demand have been directed toward resolving the quantitative shortage of housing. According to the population and housing survey executed every five years by the Ministry of Land, Transport and Maritime Affairs, the average size of a house increased 1.22 times from 68.4m^2 in 1980 to 83.5 m^2 in 2005, and the floor area per person doubled from 10.1 m^2 in 1980 to 22.8 m^2 in 2005, as shown in Table 2.

Today, the demand for an improvement in the qualitative aspects of housing is growing considerably due to the increase in the housing supply rate. The focus of construction activities has gradually been shifting from the quantity to the quality of housing. The quality of existing inferior standard houses has improved as a result of redevelopment, reconstruction and many other residential environmental improvement projects.

As shown in Table 3, the apartment building has become the prevalent housing type in many cities and suburbs in Korea. By 2005, there were over 12 million housing units, while the portion of dwelling units in apartment buildings had risen to about 53%. In the case of cosmopolitan cities such as Seoul, Busan, and Daegu, the number of units in multi-family residential buildings is almost twice that of detached houses.

Table 2: Trends in the quantitative levels of housing stocks
(Source: Ministry of Land, Transport and Maritime Affairs, http://www.mltm.go.kr)

Classification \ year		1980	1985	1990	1995	2000	2005
Number of houses per 100 persons		14.2	15.1	17.9	20.7	24.9	28.0
Floor area (m^2)	per house	68.4	72.6	80.8	80.6	81.6	83.5
	per household	45.8	46.4	51.0	58.6	63.1	67.3
	per capita	10.1	11.3	13.8	17.2	20.2	22.8
Number of rooms	per house	3.3	3.5	4.0	4.6	4.8	4.8
	per household	2.2	2.2	2.5	3.1	3.4	3.6
	per capita	0.47	0.51	0.71	0.9	1.1	1.2

Of the 435,901 new housing units constructed in 2006, there were 409,745 units in multi-family residential buildings, including apartment buildings and row houses.

In Korea, apartment buildings are usually constructed of reinforced-concrete on a massive scale, in hundreds or in thousands of housing units by numerous construction companies. Figure 4 shows the number of dwelling units recorded at the end of 2001, classified according to the number of stories. The construction of high-rise residential buildings over 20 stories has increased considerably in the last decade.

Table 3: Trends in dwelling stocks

	Total	2000 ~2005	1990 ~1999	1980 ~1989	1970 ~1979	1960 ~1969	Before 1960
Total	12,494,827	2,756,034	5,709,033	2,445,064	871,561	302,363	410,772
Detached houses	3,984,954	436,020	1,187,080	990,730	674,120	290,477	406,527
Apartments	6,626,957	1,769,598	3,687,142	1,029,924	135,132	5,144	17
Row houses	1,684,563	515,361	756,318	370,555	41,171	976	182
Others	198,353	35,055	78,493	53,855	21,138	5,766	4,046

(a) Apartments

(b) Row houses

Figure 3: Features of multi-family residential buildings in Korea

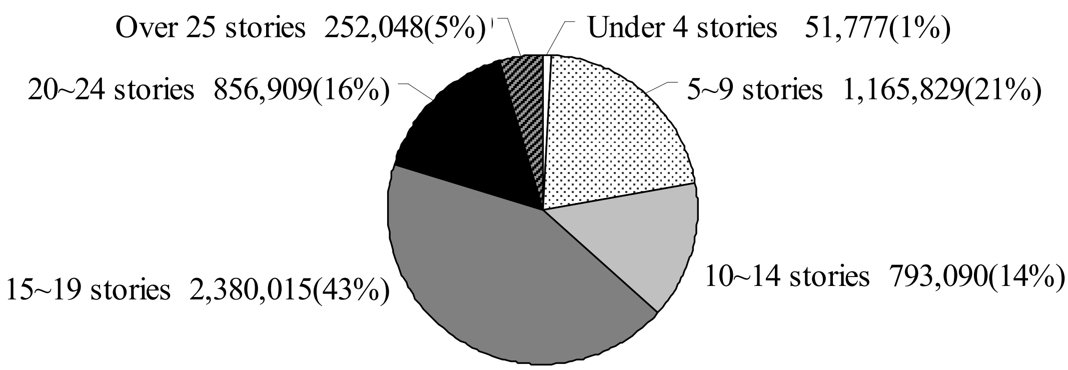


Figure 4: Number of stories in apartment buildings in 2001

Figure 5 shows two typical plans of apartment units in Korea. Usually, more than two sides of the unit are exposed to the outside, enabling cross ventilation by opening windows. Most of the apartment units have three or more bedrooms, with the exception of the studio type apartment.

(a) 107.66 m^2 (b) 155.36 m^2

Figure 5: Typical plan of apartment units in Korea

3 Drivers and issues for ventilation

As mentioned above, apartment buildings have become the most prevalent housing type due to the need to meet the quantitative demands for housing resulting from Korea's rapid urbanisation and high population density. Because residents are now interested in improving their 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 the poor indoor air quality and consequent health complaints of new housing residents.

In order to suggest the recommended guidelines for indoor air quality of new housing, the Korea Institute of Construction Technology, sponsored by the Ministry of Environment, investigated the indoor air quality of new apartment houses during the period of 2004 to 2005. The intention of this survey was to assess the effects of harmful chemical substances on the health of the human body and to take into consideration 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, the storey of the unit, and the types of built-in furniture and interior building materials.

The investigation results are shown in Table 4. The detection frequency of formaldehyde, benzene, toluene, ethylbenzene, xylene, styrene, and acetaldehyde exceeded 99% of the total dwellings. The detection frequency of 1,3,5-trimethybenzene, 1,2,4-trimethylbenzene, trichloroethane, acetone, propionaldehyde, butylaldehyde, benzaldehyde and acrorein ranged between 50-80%.

The emission of VOCs from building materials and household products possibly contributes to the problem of indoor air pollution in new houses. Ventilation deficiency from an airtight building envelope also contributes to high concentration levels of VOCs. While the survey results show that natural ventilation was the most commonly used method for providing fresh air exchange in Korean apartment buildings, residents tend to close the windows in order to maintain thermal comfort, energy saving, and security. In the online survey of 2,213 occupants provided by the Ministry of Environment, ventilation deficiency was considered to be the major contributor to indoor air pollution, as shown in Figure 6.

Table 4: Measured concentrations of pollutants in survey 2005 (μg/m³)

		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

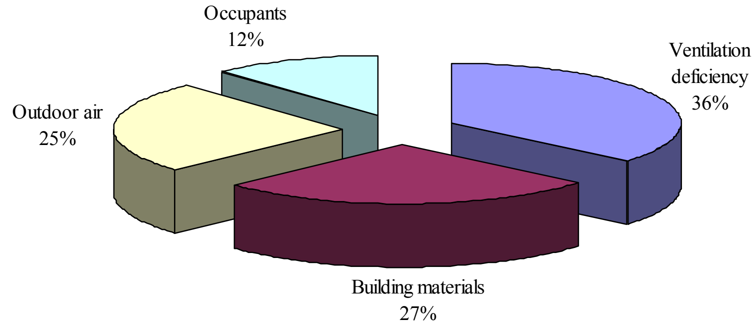


Figure 6: Survey results on the cause of indoor air pollution (December 2003)

Realising the significance of the indoor air quality problem of newly constructed apartment buildings, the Ministry of Land, Transport and Maritime Affairs and the Korea Institute of Construction Technology have conducted research for the establishment of a ventilation standard. Based on this effort, the new regulation for 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.

4 Standards, regulations and certifications

4.1 Trends in IAQ and ventilation requirements

Since 1989, when the recommended standards for underground spaces were enacted by the Ministry of Environment, standards and regulations on indoor air quality have been legislated and continuously revised. 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. Table 5 shows the recommended guidelines for pollutant concentration levels of newly built apartment buildings in Korea, based on the survey results in 2005, a human health risk assessment results, and other international guidelines.

In February 2006, the Ministry of Land, Transport and Maritime Affairs established the regulation of ventilation for newly built apartment buildings & multi-purpose facilities. This regulation specified mandatory installation of ventilation systems in apartment buildings and multi-purpose facilities, and recommended the ventilation standard suitable for a particular type of building design. Figure 7 shows the major policies for healthy indoor environment in Korea and Table 6 shows the recent revisions of regulations for different types of facilities.

Table 5: Recommended guidelines for IAQ of newly built apartment buildings in Korea

Substances	Survey 2005 (Mean value) (μg/m³)	Other international Guidelines (μg/m³)	Recommended guidelines in Korea (μg/m³)
Formaldehyde	210	30~120	210
Benzene	4	16~110	30
Toluene	773	260~1,092	1,000
Ethylbenzene	62	1,447~3,800	360
Xylene	138	870~1,447	700
Styrene	42	30~300	300

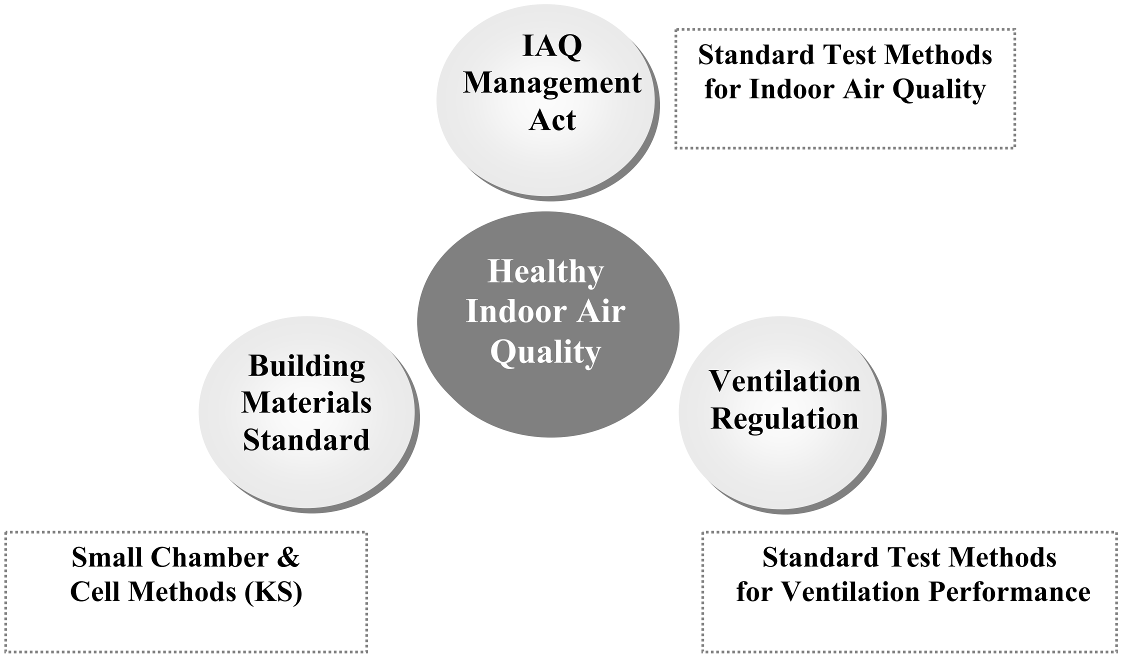


Figure 7: Major policies for healthy indoor environment in Korea

Table 6: Recent revision of IAQ and ventilation regulations

Authority	Regulation & Standard (as of May 2008)
Ministry of Environment	- Revision of indoor air quality management act in multi-purpose facilities & new apartment buildings (2005) - Enactment of standards and investigation of indoor air qualities in public transportation (2007) - In progress of revising the indoor air quality measuring methods by MOE (scheduled for 2008) - Revision an accepted amount of indoor air pollutants emitted from building materials (scheduled for 2008) - Enactment of evaluation standards for pollutants emitted from Furniture & electronic devices (scheduled for 2009)
Ministry of Land, Transport and Maritime Affairs	- Enactment of legislation on "Regulation of ventilation in newly built apartment buildings & multi-purpose facilities (2006) - Enactment of performance rating system in residential buildings (2006) - Enactment of adhesive and paint usage guidelines to mitigate the Sick House Syndrome (2006) - Official notification of guidelines for major building materials to reduce the amount of pollutants emitted(scheduled for 2008)
Ministry of Knowledge Economy	- Enactment of legislation on the test method (KS) for pollutant emitting rates of environment-friendly building materials(scheduled for 2008) - Enactment of emission testing method for furniture using large chambers (scheduled for 2008) - Enactment of indoor air quality testing method for automobile (scheduled for 2008)
Ministry of Education, Science and Technology	- Revision of School Health & Hygiene Law (ventilation & IAQ standard included) (2005) - Enactment of simple testing method for assessing indoor air quality in school (scheduled for 2008)
Ministry of Labor	- Guideline for indoor air quality control in offices (2007)

4.1.1 Dwellings

According to the 'Indoor air quality management act', when a construction company constructs new apartment building complexes that have over 100 residential units, the concentration levels of six toxic substances must be measured before the residents move in. The construction company is also enforced to give public notification by submitting the results of these measurements to the heads of local governments and by posting the information on bulletin boards for 60 days in convenient locations for residents.

The new ventilation requirement for newly built or remodeled apartment is established as a minimum of 0.7 ACH. The definition of natural and mechanical ventilation systems as mentioned in this regulation is as follows:

- *Mechanical ventilation system*: a forced ventilation system operated by a motorized fan. The Korean Industrial Standard (KS) provides a thorough description with additional details of the general requirements for the installation of a mechanical ventilation system.
- *Natural ventilation system*: a ventilation system designed to allow the passage of air through the building envelope driven by wind and buoyancy, with the exception of conventional openings such as windows and doors. The system must be checked by the regional construction committee to determine that the required ventilation rate is satisfied

The major checkpoints for the application of a mechanical ventilation system are as follows:

- Confirm that each room is supplied with equal amounts of outdoor air
- Confirm that the system has at least 3 steps for the regular airflow control unit
- Verify that appropriate consideration is given to the pressure loss that occurs in the duct during the normal operating conditions of the ventilation system (this can be determined from the performance report and specification of the ventilation system)
- Verify the official document of the public authority to determine if the noise level based on the Korean Standard is below 40dB
- Confirm the particle distribution rate measuring method and results for the mechanical ventilation system in order to evaluate the structure and performance of the air filter (verify the official report to determine if the particle collection efficiency, obtained through either the light-scattering or the absorptimetry method based on the Korean Standard is above 60%)
- Confirm that the air inlet and the air outlet are located 1.5m apart in order to avoid the short circuit of exhaust air and to verify that the directions of the inlet and outlet are over an angle of 90˚
- When a heat-recovery ventilation system is installed, confirm the ventilation performance data report evaluated by the Korean Standard test method(heat-exchanging devices are not mandatory).

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

- Confirm that each room is supplied with sufficient amounts of outdoor air
- Thoroughly examine the submitted specifications of the target natural ventilation system to determine whether or not mechanical fans are necessary
- Verify whether or not pre-filtering devices that can filter the pollutants flowing in from the outside are installed within the ventilation systems (scheduled for Dec. 2007 because the performances of pre-filters have not yet been provisioned)
- Confirm that there is an official test result that determines if the noise coming from the natural ventilation system is below 40dB in typical conditions
- Confirm that the system doesn't allow the indoor warm (or cool) air to be directly lost to the outside
- Confirm that the system provides 24 hours of constant ventilation
- Determine if the performance evaluating conditions of the in-situ experiments, mock-up test or computer simulation (CFD or network model) are the same as those specified in the manual and determine whether or not the simulation results are objective

4.1.2 Multi-purpose facilities

The mandatory ventilation standard for multi-purpose facilities, which had previously regulated the ventilation rates for four building types, was largely reclassified into seven different types of facilities, each following the 'mechanical ventilation installation and ventilation standard procedures' according to the ventilation characteristics of the building. Table 7 shows the ventilation standard for multi-purpose facilities.

Table 7: Ventilation standards for multi-purpose facilities

Classification of multi-purposed facility		Required ventilation rate (m^3/person.hour)	Note
Underground facilities	Subway station	25 or more	-
	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

4.1.3 Schools

The indoor air quality standard and ventilation requirement in schools is specified in the "School health & hygiene law", which was revised on December, 2005 by the Ministry of Education, Science and Technology. Figure 8 shows the indoor air quality standard for schools. School buildings should be ventilated at the air flow rate of more than 21.6m^3/person.hour by opening windows or operating mechanical ventilation systems. This law also specifies the standard for the structure and installation method of mechanical ventilation systems in order to ensure that sufficient capacity and balanced fresh air distribution are provided. The Ministry of Education, Science and Technology distributed the environmental control manual for school buildings in 2006, and has developed a plan to revise the detailed guidelines and specifications for ventilation systems.

Table 8: IAQ standard in "School Health & Hygiene Law" (December 2005)

Substances	Guideline values	Zone
PM10	100 μg/m^3	classroom
CO_2	1,000 ppm	
Formaldehyde	100 μg/m^3	
Microbes	800 CFU/m^3	
Bacteria	10 CFU/room	infirmary, cafeteria
CO	10 ppm	Classroom (facing road)
NO_2	0.05 ppm	
Radon	4.0 pCi/L	underground classroom
TVOC	400 μg/m^3	newly built school (within 3 years)
Asbestos	0.01 unit/cc	classroom, staff room
Ozone	0.06 ppm	staff room
House dust mites	100 unit/m^2	infirmary

4.1.4 Offices

In Korea, recently developed office buildings have usually been designed to be operated as open-plan workspaces. However, the traditional enclosed workspace can still be found in a number of small office buildings. While the older and small-sized office buildings are usually ventilated by natural forces, most modern office buildings are equipped with HVAC systems. The guideline for the minimum ventilation of a workplace is $0.57m^3$/person.min or 0.4 ACH, as specified in the “Guideline for IAQ Control in Offices” of the Ministry of Labor, January 2007. Table 9 shows the IAQ guidelines for offices.

Table 9: IAQ standard in ‘Guideline for IAQ Control in Offices’ (January 2007)

Substances	Guideline values
PM10	150 $\mu g/m^3$
CO_2	1,000 ppm
CO	10 ppm
Formaldehyde	120 $\mu g/m^3$
TVOC	500 $\mu g/m^3$
Total microbes	800 CFU/m^3
NO_2	0.05 ppm
Ozone	0.06 ppm
Asbestos	0.01 unit/cc

4.2 Trends in energy requirements

Since Korea has four distinct seasons, there is a wide variation in the range of outdoor temperatures throughout the year. In Korea, the traditional radiant floor heating system, Ondol, which uses hot water in embedded tubes, is widely used in most residential buildings. For cooling, the demand for, and the installation 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 insulation standard for building envelopes, specified in the ‘Equipment Standards for Buildings’ section of the building regulations, was recently reinforced by more than 20%. Since June 2001, eight types of high-energy consuming buildings, including offices and hospitals, have been mandated to apply a separate ‘Design Standard for Energy Efficiency’. In order for these buildings to meet the requirements specified in this standard, efforts must be made to increase the use of high efficiency energy products such as high efficiency gas boilers and refrigerators. Besides these mandatory regulations, government authorities are operating various types of voluntary certification and labeling programs.

Table 10: The proportion of energy consumption in Korea (2003)

Year	1999	2000	2001	2002	2003
Industry	56.1%	56.0%	55.7%	55.6%	55.4%
Transportation	19.8%	20.6%	20.9%	21.0%	21.1%
Building	24.1%	23.3%	23.5%	23.4%	23.5%

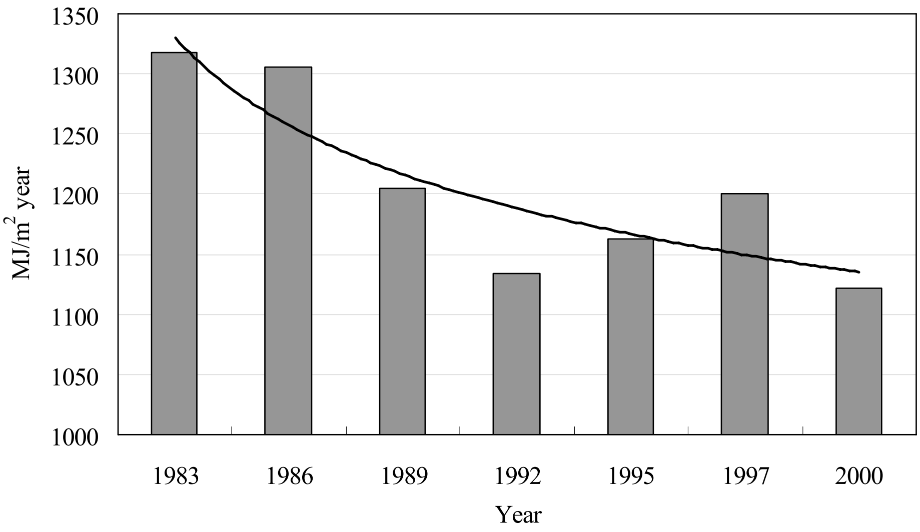


Figure 8: Trend of energy intensity of residential buildings in Korea

4.2.1 Energy Efficiency Labeling Program for Buildings

In order to increase energy efficiency in the building sector, building energy efficiency labeling programs have been issued for newly built and remodeled multi-family residential buildings with more than 18 households. Buildings can be classified into grades 1~3 according to the use of energy-conserving facilities and equipment. Considering the possibility of ventilation deficiency in air-tight buildings, additional credit is available for certified buildings that satisfy the following indoor air quality criteria:

Table 11: IAQ criteria in Energy Efficiency Labeling Program for Buildings

Substances	CO_2	CO	Formaldehyde	Radon
Value	1000ppm (1h)	10ppm (1h)	0.08ppm (30min)	150Bq/m^3 (1h)

Where it can be demonstrated that a building meets the required performance standard, the owner /developer will be issued with a Certificate of Building Energy Efficiency and a construction loan at a lower interest rate. From 2004~2010, the Korean government will annually expand the energy efficiency labeling program by targeting detached houses and business buildings.

4.2.2 Green Building Certification Program

The Green Building Certification Program provides an evaluation of the degree of sustainability of a building throughout the life cycle of the construction process. This is carried out in order to improve the environmental performance of buildings and to reduce greenhouse gas emissions. Various versions 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. For multi-family residential buildings, ventilation performance can be evaluated from the following criteria:

Table 12: Ventilation criteria in Green Building Certification Program

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

For school buildings, ventilation performance can be evaluated from the area ratio of operable windows that allow cross-ventilation in the classroom. Additional credit can be obtained for schools where science laboratories are equipped with mechanical supply and exhaust systems.

4.2.3 Housing Performance Grading Indication System

To provide a more comfortable housing environment and to develop housing construction technology, the Ministry of Land, Transport and Maritime Affairs issued the mandatory application of the Housing Performance Grading Indication System to newly built apartment building complexes that have more than 1000 households. In the Housing Performance Grading Indication System, housing performance can be evaluated by using 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 13: Ventilation criteria in Housing Performance Grading Indication System

Level	Criteria
Level 1	- Equipped with mechanical or natural ventilation systems with more than 0.7ACH - Equipped with both high performance air filter and heat recovery
Level 2	- Equipped with mechanical or natural ventilation systems with more than 0.7ACH - Equipped with high performance air filter or heat recovery
Level 3	- Equipped with mechanical or natural ventilation systems with more than 0.7ACH

4.3 Trends in building air-tightness

As previously discussed, high-rise apartment buildings in Korea account for approximately 50 percent of the residential buildings and over 90 percent of these have a reinforced concrete structure. An air flow path related to air-tightness performance in apartment buildings can be seen in Figure 9. In general the air flow rate through such air flow paths depends on the following three factors:

- Size and position of air flow paths;
- Flow characteristics in air flow paths;
- Pressure differences between indoor and outdoor.

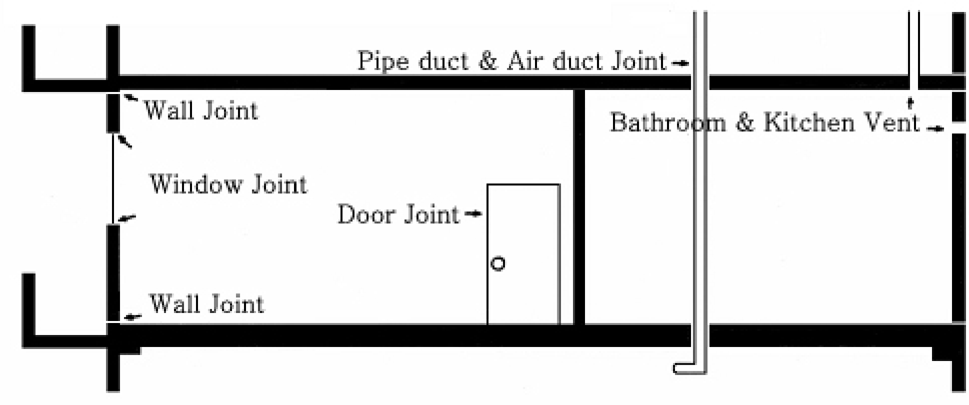


Figure 9: Typical air flow path in apartment buildings

Due to the structural characteristics of apartment buildings, the basic air-tightness performance is considered to be satisfactory. Therefore, air-tightness performance and its basis have not yet 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. In addition, KS has an alternative test method that uses the ISO Standard (KS L ISO 9972-2006).

The reason for this is that most residential buildings are apartment buildings with a reinforced concrete structure, where air-tightness performance can easily be secured. Conversely, in European countries, the air-tightness performance of residential buildings can be represented by the air-tightness performance of windows and doors. When the air-tightness performance through an apartment building structure is measured by a blower door test, the air-tightness must be secured with an error tolerance level. In Korea, the requirements for air-tightness performance for office and school buildings are seemingly on a similar level with that of European countries and the U.S.

Research has been carried out on the actual condition enforced according to ASTM E779 for the case where there is a 4Pa pressure difference between indoor and outdoor ventilation. Results show that the equivalent air leakage area (ELA) for each unit of floor area, which is an air-tightness performance index for the building envelope, is about $1.5cm^2/m^2$~$3.2cm^2/m^2$. However, when considering that most countries show a tendency to reinforce the air-tightness performance of residential buildings to up to $1.0cm^2/m^2$, we also have to make efforts to increase building air-tightness at the design and construction stage.

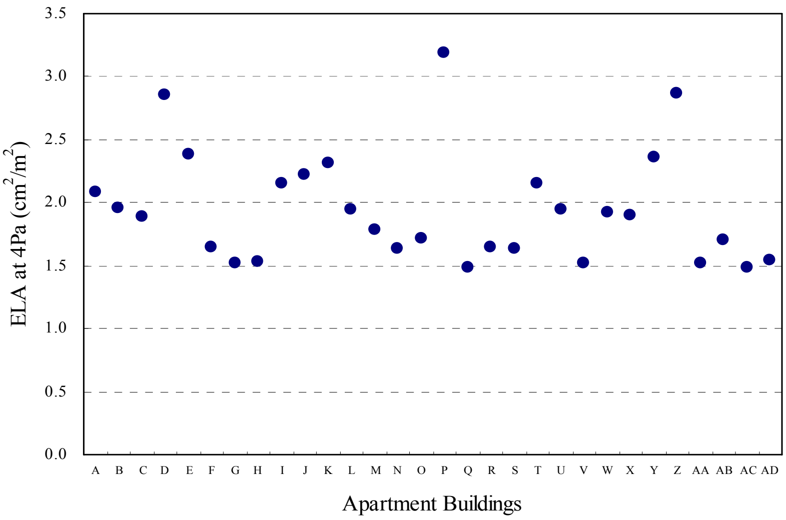


Figure 10: Measured air-tightness data of apartment buildings in Korea

5 Market of ventilation systems

With the exception of mechanical exhaust fans in bathrooms and kitchens, in the past, most residential buildings were not designed to be equipped with ventilation systems. 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 have been supplied in order to meet the mandatory ventilation requirements.

Since April 2007, heat recovery ventilation systems have had a predominant share in the market of ventilation systems. More than 10 companies are manufacturing and supplying mechanical ventilation systems, while duct-type systems and exterior-wall-attached ductless systems are the most common types of mechanical ventilation systems. Figure 11 shows the market size of the mechanical ventilation systems. In terms of natural ventilation systems, natural ventilation devices have also been developed and supplied that can be installed on window glazing.

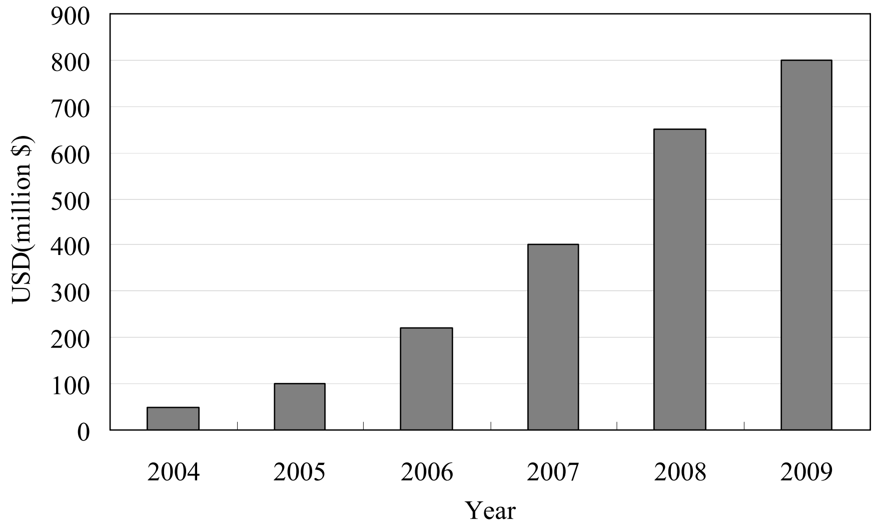


Figure 11: Market size of the mechanical ventilation systems (with heat recovery)

5.1 Mechanical ventilation system

A mechanical ventilation system can lower the indoor concentration of contaminants by exchanging polluted indoor air with 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 has enforced mandatory installation of 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. Most common ventilation systems draw in air through a duct either to or from the outside of the building. However, ductless ventilation systems have also been developed and supplied for the market of housing units that have a lower ceiling height. While the most prevalent type is the duct-type heat recovery ventilation system, other systems are also being continually developed. Figure 12 shows the typical types of ventilation systems and figure 13 shows the examples of mechanical ventilators developed in Korea.

(1) Heat recovery ventilation system

- Built-in heat exchanger in the ventilation system
- Heats or cools incoming fresh air by transferring the heat energy from the conditioned exhaust air

(2) Ventilation system with underfloor embedded duct

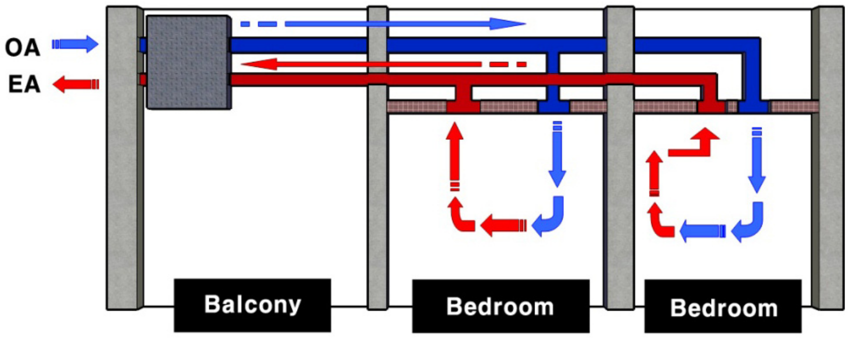
- A ventilation system with an embedded duct in the floor heating system
- Heats incoming fresh air by floor heating system
- Exhaust indoor air supplied through diffusers or grills on the ceiling
- Additional heat source for heating incoming air is not necessary

(3) Heat recovery kitchen exhaust system

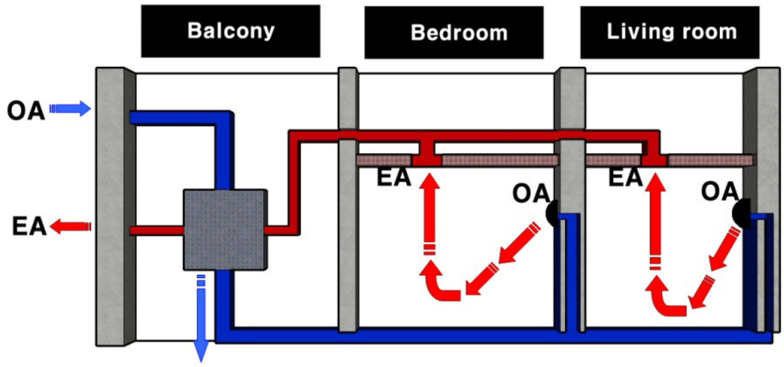
- Built-in heat exchanger in the kitchen exhaust system
- Heats or cools incoming fresh air by transferring the heat energy from the conditioned exhaust air
- When operating the kitchen hood for local exhaust, a by-pass mode is available to avoid mixing supply and exhaust air

(4) Ductless ventilation system

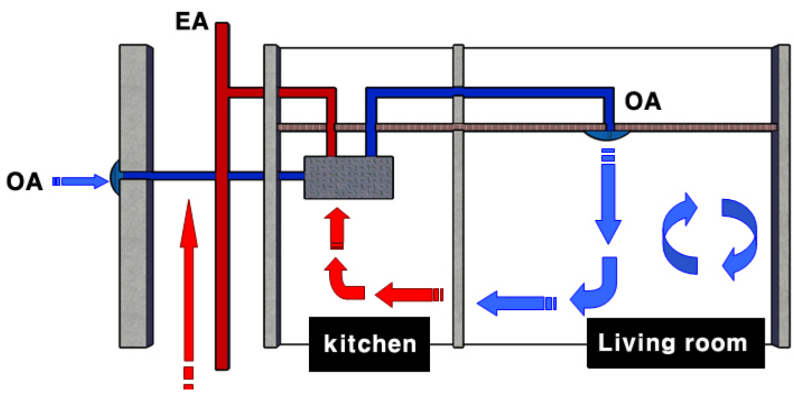
- Supplies required fresh air volume directly through the ventilation system, which is installed on the balcony adjacent to the outside.
- Beneficial when a housing unit does not have sufficient ceiling height to install ducts



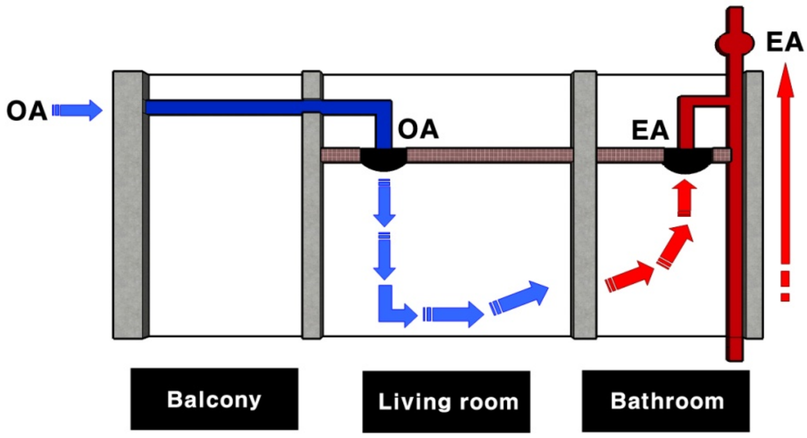
(a) Heat recovery ventilation system



(b) Ventilation system with underfloor embedded duct

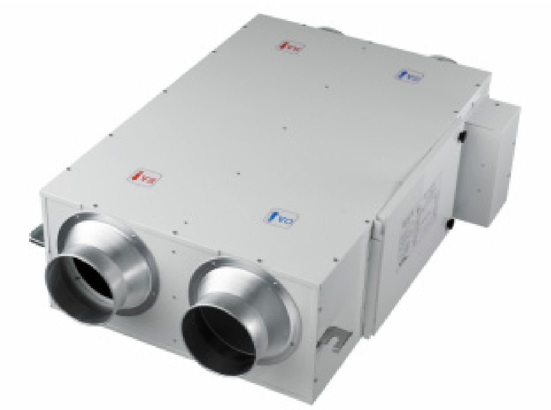


(c) Heat recovery kitchen exhaust system



(d) Ductless ventilation system

Figure 12: Typical types of mechanical ventilation systems in Korea



a) Duct type *b) Ductless type*

Figure 13: Examples of mechanical ventilation systems

5.2 Natural ventilation system

Korea has rigid insulation standards for reducing the unnecessary loss of energy. The main purpose for using natural ventilators in Korean apartment buildings has been to solve condensation problems in balconies during winter. Since the application of ventilation systems was legislated, the purpose has shifted to meet the required ventilation rates. The performance criteria and installation standards for natural ventilators have not been definitely described yet. Therefore, various products have been developed in order to meet the basic performance and requirements for windows. In order to improve the performance of natural ventilators, it is necessary to establish the performance criteria and test methods.

Natural ventilators can be mounted through openings in the window glazing unit, window frame, or building structure. Products with filters have been developed to meet the needs of consumers who are sensitive to outdoor air pollution. Automatic controllable ventilators have also been introduced to the market. While the market share of natural ventilation systems was estimated to be less than 5% in 2007, the application of natural ventilation systems is expected to increase gradually.

Figure 14: Example of natural ventilation system

5.3 Hybrid ventilation system

Recently, various research projects on hybrid ventilation have been widely conducted, while the development of hybrid ventilation is accelerating through technical cooperation between ventilation manufacturers. The objective of this research and development is to meet the ventilation requirements and to pursue further energy saving and sustainability by utilising the advantages of both mechanical ventilation and natural ventilation systems. It is expected that highly effective hybrid ventilation systems will be launched in the near future in order to reduce both the initial construction and maintenance costs.

6 Looking ahead

Ventilation regulations are enforced in Korea in an attempt to resolve the problem of sick building syndrome. It is important that a continuous ventilation rate is secured and that issues related to condensation and filters are resolved. For the ventilation rates for newly built apartment buildings, the focus has been on formaldehyde concentration as the target pollutant. The maximum concentration permitted was targeted in order to satisfy the WHO standard of 100µg/m^3.

In Korea, more than 90% of the mechanical ventilation systems installed in apartment buildings have a heat-exchanger. This is because during winter the temperature difference between indoors and outdoors rises to over 30K. Furthermore, because apartment buildings have wide facades, ductless mechanical ventilation systems can provide legitimate ventilation efficiency.

While most natural ventilation systems are in the form of window frame installations, the disadvantages of this type of installation is that it not able to filter yellow dust and other pollutants from the outdoors and that it creates a cold draft in winter. In Korea, the most common type of natural ventilation system is horizontally installed on glazing, while the most common form of mechanical ventilation system is installed in the ceiling of each room.

In order to improve natural ventilation systems, a new test method is currently being researched to evaluate the performance of natural ventilation systems based on the air flow rates at a specific pressure difference (2Pa). Highly effective hybrid ventilation products are also being developed. While still in the initial stages, researchers are actively concentrating on such investigations. Considering the current technology and supply levels, it is expected that the hybrid ventilation systems will become more widely distributed in the near future.

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