NATURAL, MECHANICAL AND HYBRID VENTILATIONS

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Contents

Summary

The aim of this section is to give an overview of natural, mechanical and hybrid ventilation applications intended for residential buildings. It begins with the basics of ventilation: *why ventilate* and *what produces airflow*. It discusses the relationship between ventilation and airtightness. The concept of the ventilation design is also presented. Three main approaches to ventilating residential buildings are explained in detail. Finally, it presents the airflow modeling.

1. Introduction

Ventilation is the process of supplying or removing air to or from any space. Historically, ventilation of residential buildings has served two purposes: to remove or dilute contaminants, odors and/or moisture to ensure proper indoor air quality (IAQ), and to provide a thermally-comfortable indoor environment. Both objectives contribute to the fundamental purpose of housing: to sustain a healthy and comfortable environment for its occupants.

In warm or temperate climates, larger airflows in dwellings generally improve both IAQ and comfort. However, in regions characterized by climatic extremes, such as hot/arid, hot/humid or extreme cold, an increase in ventilation rates would usually cause an increase in energy consumption due to the necessary air-conditioning processes. In such instances, a balance is often sought between energy and environmental conservation on one hand whilst the health and well-being of occupants on the other. In fact, this duality has remained the focus of much research and development in the building sciences and industry since the sharp rise in oil prices in the 1970's.

2. Mechanisms of airflow

Airflow occurs when a pressure difference exists on either side of an opening or airflow path. A distinction is made between *natural* and *mechanical* forces. Airflow caused by wind pressures, or *wind force ventilation*, and by differences in indoor and outdoor temperature, or *buoyant force ventilatio*n, is considered natural, while airflow produced by fans is referred to as *mechanical ventilation*.

For a more detailed presentation of the physics behind natural and mechanical ventilation, one should consult ASHRAE Handbook of Fundamentals (1997), Aynsley, Melbourne and Vickery (1977), Etheridge and Sandberg (1996), as well as Allard (1998).

2.1 Natural ventilation

There are three main mechanisms that act together to produce natural airflow through an envelope: differences in static pressure, in kinetic energy, also referred to as dynamic pressure, as well as in temperature**.** Their relationship in a steady, incompressible and non-viscous flow is given by Bernoulli's equation:

$$P_{stat} + \frac{1}{2}\rho v^2 + \rho g z = \text{CONSTANT},$$

where:
- P_{stat} = static pressure
- ρ = air density
- v = wind speed
- g = gravitational force
- z = reference height

2.1.1 Ventilation due to wind effect

The interactions between wind and urban as well as natural environment produce energy exchanges between the static and dynamic components of the Bernoulli equation. The magnitude of the pressure differences is affected by several factors such as wind speed, wind direction, local topography and building shape. Openings in a building's envelope tend to act as short-circuits, relieving pressure differences between air masses near the building façades, (Figure 1-a). The energy available near a building's windward façade is the sum of the static and dynamic pressure. The energy near the leeward façade is the static pressure, while the kinetic energy in the jet of air exiting at the leeward opening represents an energy loss, which is dissipated downstream. This is the basic mechanism behind cross-ventilation. Similarly, leeward-facing wind stacks are often designed as exhausts, harnessing the induction effect of the wind caused solely by the differences in static pressure (see section 6.2).

2.1.2 Ventilation due to buoyant effect

Temperature differences between two air masses produce differences in air density, which in turn produces differences in pressure. When an indoor space is heated, the outside pressure near the lower part of the building is generally greater than the indoor pressure, whereas the outside pressure near the upper part of the building is generally lower. This difference in pressure causes airflow spanning across the building envelope, a phenomenon often referred to as the stack effect (Figure 1-b). The level where the pressure difference is zero is called the neutral zone. Below the neutral zone, the outdoor air enters the space, while above the neural zone the indoor air exits the space. The airflow increases as the temperature differences become larger (see section 6.1).

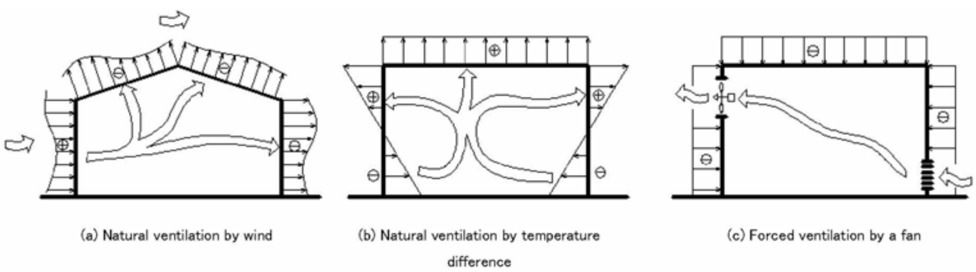

Figure 1: Natural ventilation and forced ventilation

2.2 Mechanical ventilation

Fans are often used for ventilation in a building. Indoor pressure increases when the ventilation fan is operated to supply outdoor air. On the other hand, indoor pressure decreases when the ventilation fan is operated to exhaust indoor air, (Figure 1-c). When ventilation fans are used both to supply outdoor air and exhaust indoor air, the indoor pressure depends on differences in power between the supply and the exhaust fan. Figure 2 shows the three types of mechanical ventilation systems.

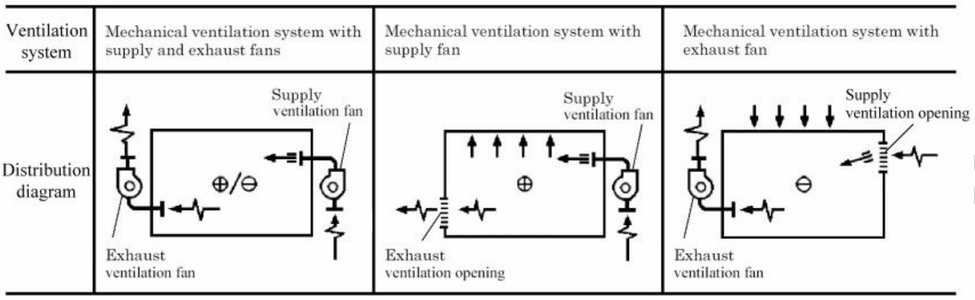

Figure 2: Three types of mechanical ventilation systems

When indoor pressure is positive, indoor moisture may penetrate into the wall, producing condensation within the envelope. It is therefore better to keep the indoor pressure slightly negative. However, this may cause contaminants contained in the wall to be emitted into the room. In addition, flow reversal may occur in chimney flues when the negative pressure is too large, resulting in imperfect combustion and poor IAQ, (see section 6.3).

3. Airtightness and ventilation

As airflow resulting from infiltration or exfiltration is proportional to opening area, the airtightness of a building envelope becomes a crucial performance parameter for energy efficient buildings. The goals of making airtight building envelopes are as follows:

1. Improving thermal comfort by preventing draughts;
2. Decreasing space heating and cooling loads due to air infiltration;
3. Preventing vapor condensation inside envelopes; and
4. Minimizing the impact of infiltration on the ventilation performance, such as intended at the design stage.

It is reasonable to improve thermal comfort by preventing the air infiltration from leaks and to decrease space heating and cooling loads due to the air infiltration. Prevention of vapor condensation inside the wall is very important. In order to take the outdoor air into the rooms from the air inlets, pass the air along the ventilation path in the building and exhaust the indoor polluted air through the outlets such as intended at the design stage, it is necessary to make the building envelope to be airtight.

4. Ventilation Design

Nowadays, a higher living standard has created a greater demand for better living conditions. A good ventilation design can be used to provide comfortable environment with minimum energy consumption. Thus, the understanding on how ventilation design should be implemented is described in this section.

4.3 Calculation of ventilation requirement

The primarily consideration of making calculation for ventilation design is straightforward. Ventilation design can be preceded as follows:

1. Calculate the ventilation airflow volume required for each room
2. Fix the ventilation airflow path
3. Choose the ventilation system
4. Select ventilation appliances

When the aim is to eliminate a specific pollutant, the ventilation airflow volume can be calculated on the basis of the emission rate and the acceptable concentration of the pollutant. Or, when the purpose of ventilation is to remove heat from a space, the ventilation airflow rate can be calculated based on the acceptable maximum temperature and the heat generation rate. Usually, the ventilation airflow volume can be calculated for the purpose of pollutant removal: in this case, heat can be considered as pollutant. However, information on both the emission rate and the acceptable concentration is available for a limited number of pollutants. The acceptable concentrations of several pollutants are available in regulations and guidebooks of several countries, such as *ASHRAE Standard 62-1999* and *SHASE Japan Standard 106-1996* (Murakami 1998).

As the information on emission rate is limited, it is difficult to calculate the ventilation airflow volume for each pollutant. One solution is to use carbon dioxide as an indoor air pollution index. The airflow volume is therefore calculated based on the acceptable concentration of carbon dioxide, i.e. 1000 ppm (Haghighat and Doninni, 1992). The ventilation requirement per person becomes 20 to 30 m^3/h. However, in the case of housing, general ventilation rates are often prescribed independently of specific pollutants and emission rates, such as the 0.5 air change rate per hour prescribed in the criteria for energy conservation of residential buildings in Japan (1999).

4.4 Ventilation Airflow Path

Ventilation airflow path describes the route of the ventilation air from the inlets to the outlets through various spaces in a residential unit. Essentially, the outdoor air should be supplied into spaces, referred to as clean zones, where the generation rate of pollutants, odors, vapor and heat is minimal, such as living rooms and bedrooms. Indoor air of spaces such as kitchens and bathrooms, referred to as dirty zones, where the generation is greater should be directly exhausted outside, without passing through clean zones.

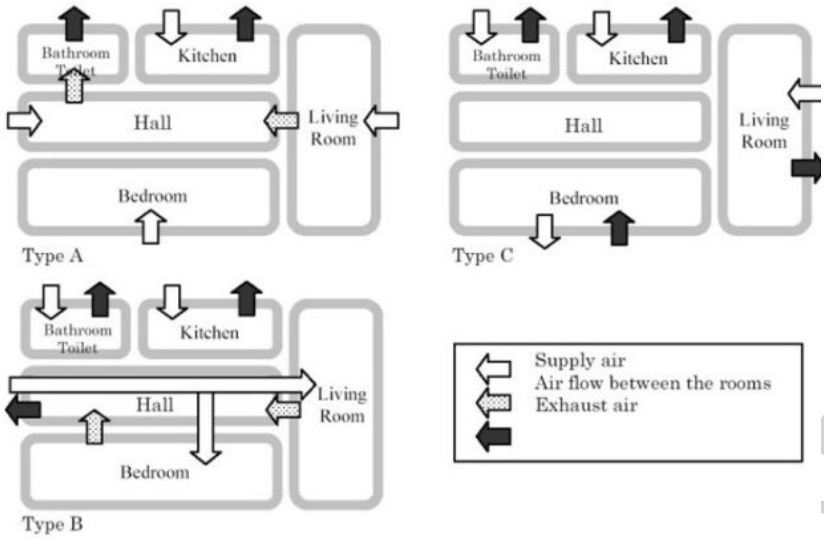

Figure 3: Typical ventilation airflow paths

It is difficult to satisfy the ventilation requirement in all rooms in a naturally ventilated building. Figure 3 shows three typical ventilation airflow paths. Here, the airflow path through the kitchen is independent from the other airflow path because the airflow volume of the kitchen fan is so great that the indoor environment in the living room and the bedrooms are disturbed in terms of thermal comfort and the operating period is very short.

Type A takes the outdoor air from the inlets installed on the walls of the living room and the bedrooms. But as outdoor air entering the room may cause cold drafts, it is necessary to pay attention to the location and the shape of the air inlets. The system is not stable compared to the others. It is influenced by the wind effect and the stack effect. Although it is easy to install and considered inexpensive, it is considered difficult to control airflow volume.

Type B ventilates each room independently. Ventilation fans should be installed in each room. Control of the airflow volume in each room is available.

Type C is a central ventilation system with supply ducts. The outdoor air is mechanically supplied to the living room and bedroom. A warm air heating system may be easily integrated. Control of the airflow volume in each room however is difficult.

Choosing one of the three types is a complex decision. It is necessary to take into account several parameters, such as climatic conditions, building plan, space heating system, and envelope airtightness level. It can be seen, in Fig. 3, that the airflow path for each unit of the house is independent from each other. For instance, the amount of airflow rate for the kitchen can be decreased, and then the centralized ventilation system can be used even in the kitchen area.

It is better to make the ventilation airflow path go through the closets to prevent vapor condensation and air pollution in these spaces. When the air pollution in the crawl space is suspected, indoor air should be also exhausted through the crawl space.

5. Ventilation systems

To date, ventilation system used around the world can be classified into 3 categories. They are known as Natural Ventilation System, Mechanical Ventilation System and Hybrid Ventilation System. Detail of these systems is described as follows.

5.1 Natural ventilation system

Table 1 shows various ventilation systems (Limb 1994) applied to residential buildings in various countries.

Country	Climate	Ventilation and air conditioning system				
		Natural	Opening and shutting of	Passive Chimney	Mechanical Exhaust	Mechanical Central
Norway	Temperate, Polar			O	O	O
Sweden	Temperate, Boreal			O		O
Finland	Temperate			O	O	O
Belgium	Temperate		O	O	O	
Switzerland	Temperate			O		
Denmark	Temperate	O				
Germany	Temperate		O			
Britain	Temperate		O			
Netherlands	Temperate		O			
France	Temperate Subtropical			O	O	O
Italy	Temperate Subtropical		O			

Table 1: Ventilation and air-conditioning systems used in various countries

5.1.1 Opening area and location of ventilation inlet

In order to ventilate naturally, it is necessary to install an adequate air inlet opening area at the suitable location in building envelope. Revised Japanese energy conservation guideline for residential buildings prescribed the opening area should be more than 4 cm^2 per floor area.

5.1.2 Passive ventilation system

Passive ventilation is a particular natural ventilation system with a vent, without a ventilation fan. The driving forces are the stack effects as well as the inducing effect of the outside wind. To optimize stack effect; the top of the exhaust vent should be installed as high as possible, while the air inlet should be installed as low as possible. Figure 4 shows an example of a passive ventilation system.

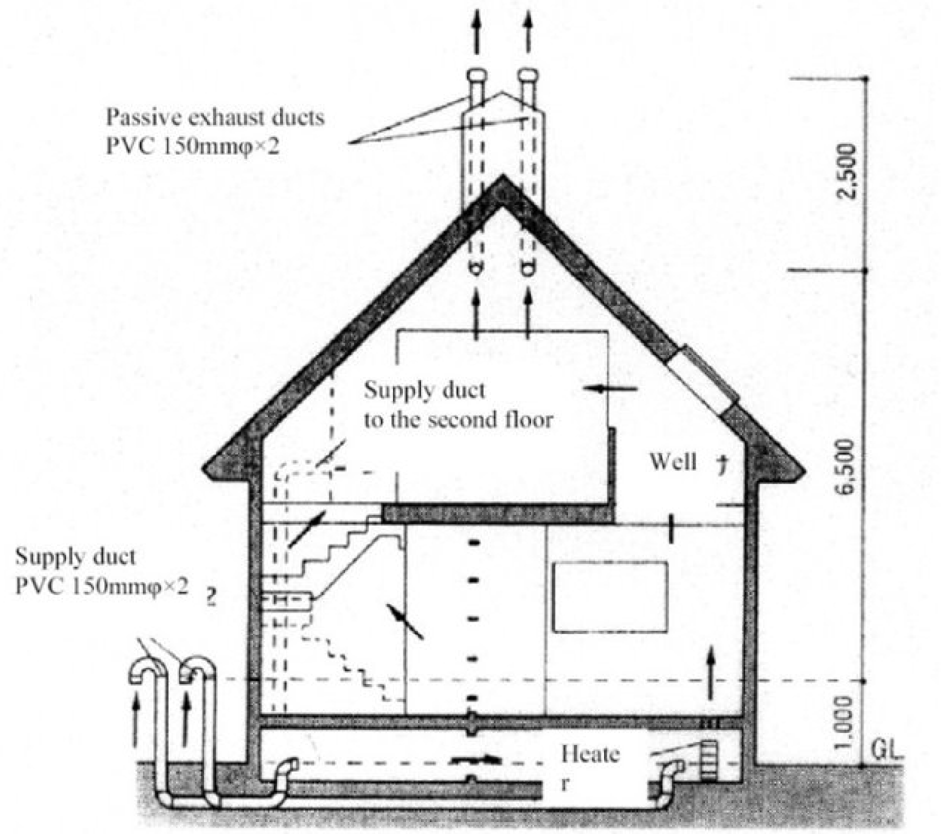

Figure 4: Example of Passive Ventilation System (Honma (1997))

The ventilation airflow volume varies due to changes in wind speed. Passive pre-heating of outdoor air is possible through the sub-floor or tubes embedded under the ground. However, air pollution in these spaces remains an issue. This system is installed in 30% of houses in Sweden. In Japan, this system is a popular choice in new residential buildings because there is no ventilation fan needed.

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Biographical Sketches

Dr. Hiroshi Yoshino received his Ph.D. from the University of Tokyo, Japan in 1976. Since then, he has been working in the area of indoor environment, ventilation and energy conservation in buildings. He has published extensively in scientific journals and via conference presentations. Dr. Yoshino holds the position of full professor at the Department of Architecture and Building Science, Tohoku University, Japan. He acted as chairman of many national and international committees, and represented Japan in many international meetings. Dr. Yoshino received many awards for his research contributions to the area of indoor environment, ventilation and energy conservation in buildings.

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