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Experimental study on Venturi-type natural ventilator

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ABSTRACT

With the vigorous spread of renewable energy, much attention has been paid to natural ventilation. The natural ventilator is usually classified into a passive type and an active type. In this study, the Venturi-type ventilator, which is one of the passive type and basically operated by the Bernoulli's principle, was experimentally investigated to evaluate the ventilation characteristics according to the outdoor wind velocities and the opening area of a wall. It was confirmed from the experimental results that the ventilation rate of the Venturi-type ventilator was linearly increased and that the ventilation rate was affected by an intake opening area. The wider the intake opening size gets, the more the ventilation rate increases. Furthermore, the new coefficient of β, which reflects the pressure loss from the intake opening to the mixing zone of the Venturi-type ventilator was introduced and experimentally evaluated. The value of β, which was evaluated as about 0.08, provides the simple calculation means to estimate the ventilation rate through the Venturi-type ventilator only if the geometric dimensions are known.

1. Introduction

The meanings of ventilation can be variously defined depending on the applicable discipline. For example, in the mining industry, the ventilation may mean the air circulation for diluting any noxious gas or for removing dust while it means to expel heat and smoke from a fired compartment in the fire fighting field. However, the traditional definition of ventilation will be the air supply from the outdoor to the indoor to supply the thermal comfort and the fresh air to the indoor occupants.

Unlike the past, ventilation is considered to be a necessity for the health and comfortability of occupants in the closed accommodation. If the outdoor air is clean and fresh, the outdoor air can be intaked by natural ventilation devices such as windows, openings on the wall or natural ventilators. The natural ventilation means that the indoor-outdoor air exchange is performed by using an outdoor wind and an indoor-outdoor temperature difference [1–6]. When the external air conditions are bad or the interior air conditions are severe, it is common that the forced ventilation is adopted. Forced ventilation uses fans, blowers to exchange air and filters to maintain air qualities [7,8]. However, even though the interior air conditions are really poor, the natural ventilation is often adopted in the special workshops for casting, melting pot or heat treatment for natural cooling. Trying to apply the forced ventilation to such workshops would be rather uneconomic or would affect the product quality.

Although the meaning of ventilation was ambiguous when its concept was established, the first schematic survey might be done by Antoine Lavoisier in 1775 [9,10]. He was reported that the bad air quality in the crowded room was resulted from the carbon dioxide. About a hundred years later, T. Tredgold, who was a mining engineer of Cornish in England, established the first quantitative ventilation rate in 1836. His recommendation was 7.2 m^3/h (2 l/s) per occupant. After Tredgold, J. Billings proposed in 1893 that the minimum venting rate per occupant should be 15 l/s and his recommended value was 30 l/s [11].

In the several times of war such as the Crimean War and the US Civil War started from 1850, the disease was rapidly spread in the hospitals full of wounded soldiers. Due to this observation, the ventilation rate of 50 m^3/hr (14 l/s) per occupant was recommended, which was accepted as the requirement in 1914 by the American Society of Heating and Ventilation Engineers (ASHVE) [10]. At present, ANSI/ASHRAE Standard 62–2001, Ventilation for Acceptable Indoor Air Quality, regulates the various minimum ventilation rates according to the conditions of places, purpose, occupants, and floor areas [12]. For example, the code requires the ventilation rate

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Nomenclature

Alphabet

A	Area (m^2)
AR	Area ratio (–)
d	Diameter (m)
g	Gravitational acceleration (9.8 m/s^2)
h	Height (m)
l	Length (m)
p	Pressure (Pa)
V	Velocity (m/s)
Q	Volumetric flowrate (m^3/s)

Greek

α	Velocity coefficient by flow resistance
ρ	Density (kg/m^3)

Subscript

air	Dry air
atm	Atmosphere
ave	Average
b	Buoyancy
dis	Discharge
ent	Entrance
ex	External
h	Half
i	Nozzle inlet
in	Intake
loss	Loss
o	Nozzle outlet
suc	Suction
ven	Ventilation
w	Wind

of 13 l/s per occupant for a patient room and the intermittent ventilation rate of 50 l/s or the continuous ventilation rate of 25 l/s for a kitchen. Fig. 1 shows the recommendation of a ventilation rate according to the times.

At present, the ventilation, which introduces a fresh air to an indoor and discharges an indoor polluted air to the outdoor, is considered to be a crucial factor for providing a physical comfortability and a mental health to the indoor residents. Since we have stayed most time of daily life in the closed space such as houses, buildings, offices or workplaces, an improper ventilation scheme will be the causes of the sick building syndrome or the sick housing syndrome [8,13], and therefore it will bring the occupants to be exposed to a potential threat. Furthermore, it was reported that the proper control of the indoor air temperature and humidity improves strongly the workers' productivity [14] and the students' learning achievement [15,16].

Unlike natural ventilation, the forced ventilation utilizes the mechanical devices for flowing air, which means that the forced ventilation requires the high expenses for the installation and operation. However, the forced ventilation has the merit to regulate effectively the ventilation rate and the indoor air quality and temperature even including the relative humidity depending on exterior climate [1,8].

Before 21 century, the ventilation had been performed through the mechanical system because it was suitable for the large scale buildings, accommodation facilities and workplaces. Up to that date, the human's perception about the nature and the environment was not matured. However, with the recently growing interest in the eco-friendly sustainable society, natural ventilation have been begun to be re-recognized. Nowadays, the energy consumption ratio for the ventilation of a building, which is usually for the operation of HVAC system, is approaching nearly 50% of the total energy required to maintain a building in the developed countries and the rest is used for a lighting and other utilities [17]. If the natural ventilation can effectively assist HVAC system, the energy consumption for a building maintenance will be reduced to somewhat extent.

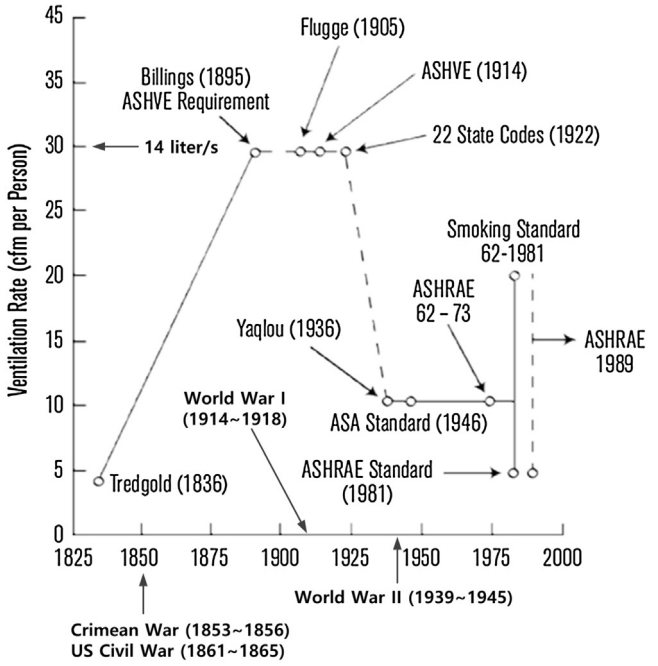

Fig. 1. Recommended ventilation rate with time. This figure was reproduced from the work by John E. Janssen [3].

At present, the concepts of a green building and a zero energy building have been introduced and the related attempts and studies have been tried [18–21], all of which are closely related to the efforts for reducing the energy consumption for a building maintenance. The mentioned situations make the people re-recognize the importance of natural ventilation. Since a natural ventilator does not use any power, the characteristics of natural ventilation are usually dependent on the building structures, the exterior climate and the opening sizes of windows and so on. No power for a natural ventilator means that it is impossible to control the flowrate and quality of airflow. Therefore, investigating the ventilation characteristics of a natural ventilator is very important before installation. If not so, the ventilation requirement cannot be achieved, which will cause an undesirable impact to the residents' feelings or health; in the worst case, the installed natural ventilators should be replaced with the forced ventilators [13,22].

If briefly mentioning the recent researches on natural ventilation, some studies focused on the shape of a building roof to enhance a natural ventilation rate. T. Van Hooff et al. [23] simulated the natural ventilation effects by Venturi-shape roof for a large building while Lin Chin How et al. [24] applied Venturi-shaped roof to the ordinary scale of a house. Their results indicated that Venturi-shaped roof appreciably improved a natural ventilation rate. Other studies were the application of a renewable energy to a natural ventilator, which are called the hybrid ventilators. S. Antvorskov [25] and Tzyy-hwang Shieh et al. [26] performed the studies the wind turbine type natural ventilator combined with the electrical fan, which is powered by the photovoltaic panel. According to Tzyy-hwang Shieh et al. [26], their experiment results showed the four times increased ventilation rate compared to the conventional wind turbine with the same size. However, letting us say the