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# 루버를 이용한 대형공장 내부 자연환기유동 개선에 관한 연구

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# Improvement for Natural Ventilation Flow inside a Large Factory Building Using Louver-type Ventilator

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***Keywords :*** *Natural ventilation (자연환기), Louver(루버), Particle image velocimetry (입자영상유속계)*

**Abstract**

When heat generated inside a large factory building is not discharged due to a stagnant flow, the working environment of workers becomes worse and the cooling of high-temperature products such as hot-rolling coils is delayed. To investigate the natural ventilation inside a large factory building, experimental studies were carried out using wind-tunnel tests. The scale-down factory building models were placed in an atmospheric boundary layer (ABL) and the mean and fluctuating velocity fields were measured using a particle image velocimetry (PIV) technique. For the prototype factory model, the outdoor air is only entrained into the factory building through the one-third open windward wall, and stagnant flow is formed in the rear part of the target area. In order to improve the indoor ventilation environment of the factory building, three different louver-type ventilators were attached at the upper one-third open windward wall of the factory model. Among the three louver ventilators tested in this study, the ventilator model #3 with the outer louver ($\theta_o$ = 90°) and the inner louver ($\theta_i$ = -70°) was found to improve the natural ventilation inside the factory building model effectively. The flow rate of the entrained air was increased with aligning the outer louver blades with the oncoming wind and guiding the entrained air down to the ground surface with elongated inner louver blades.

## 1. Introduction

The ventilation problem in a large factory building usually results from heated gas, fume, dusts, and high temperature steam. In addition, the stagnant flow inside the factory building results in a high humidity level and brings about a severe working environment. These ventilation problems may reduce the working efficiency of the in-plant workers. However, at the expense of economic development, the ventilation problems in industrial workplaces have mostly been neglected for a long period of time. Air ventilation is responsible for intake, transport, and removal of airborne hazardous substances. With recent emphasis on improving the working environment of in-plant workplaces, large efforts are being made to solve the industrial ventilation problems.

In general, there are two methods used to improve ventilation flow inside a large factory building: mechanical ventilation and natural ventilation. The mechanical ventilation method is commonly employed to provide thermal comfort and improve air quality in relatively small confined spaces. The energy consumption for the operation of heating, ventilation, and air conditioning systems (HVAC) is considerable. According to recent studies, nearly 68% of the total energy consumption in service and residential buildings is attributed to HVAC systems. On the other hand, the natural ventilation method is an economical means to resolve the ventilation problem at low cost. It provides a comfortable environment by refreshing the indoor air with outdoor air without any additional power input, thus saving on energy consumption.

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Factory buildings are actually embedded in an atmospheric boundary layer (ABL) of a city suburb. In order to understand the flow characteristics inside a large factory building more accurately, the wind tunnel model test should be performed in ABL simulating the area where the factory building is located. Based on our survey, there is no previous study in the literature that experimentally resolves the environmental ventilation problem in a large factory building using a louver-type ventilator. In this study, we tried to improve the natural ventilation efficiency in the tested factory building model by increasing the entrainment of ambient flow blowing in the prevailing wind direction into the factory building. The scale-down factory building models were embedded in a simulated ABL and the whole velocity fields of the ventilation flow were experimentally measured using a two-frame PIV technique. Three kinds of louver ventilators having different inclining angles and blade lengths were tested to find out the optimal configuration for improving the indoor environment of the target area in the large factory building.

## 2. Experimental apparatus and Methods

To simulate a stable ABL, spires of $h_v$ = 0.28 m in height were used and the factory building model was placed 4.5 m downstream from the spires. The adjustment distance from the spires to the factory model was more than 16 $h_v$. The local turbulence intensity of the simulated ABL on the ground surface was about 20%.

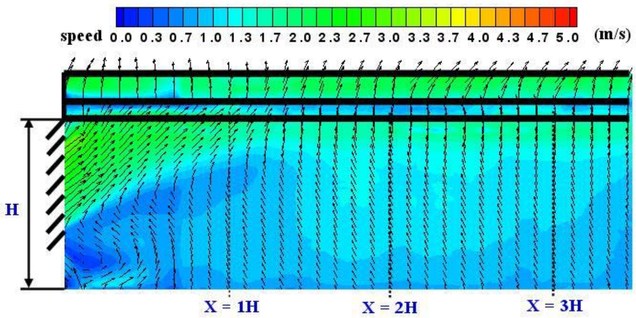
It is nearly impossible to measure the whole flow field inside the factory building model with a point-wise measurement device such as a hot-wire anemometry and a laser doppler velocimetry (LDV). Due to the rapid advances of computer systems, as well as optics and digital image processing techniques, instantaneous velocity fields of flows could be captured by using a PIV velocity field measurement technique. The two-frame cross-correlation PIV method was employed to get instantaneous velocity fields inside the factory building model embedded in an atmospheric boundary layer.

## 3. Results and Discussion

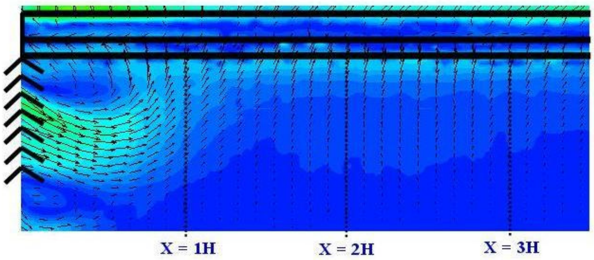
The natural ventilation in the present factory building model is not very effective due to the blockage of oncoming wind by the office building in the front. In addition, because the real factory building is embedded in the atmospheric boundary layer, the speed of oncoming wind in the opening vent near the ground surface is relatively small. As a consequence, the flow momentum of the entrained air is not enough to push the stagnant flow inside the factory. Accordingly, to entrain the outdoor air as much as possible into the present factory building, the louver-type ventilator was suggested to be installed at the upper wall of the factory building. The velocity fields of flow inside the modified factory model with louver ventilators were measured by varying the length and angle of the louver blades.

To find the optimum configuration, three different types of louver ventilators were suggested. The mean velocity fields inside the three modified factory models with different configurations of louver ventilator are shown in Fig. 1.

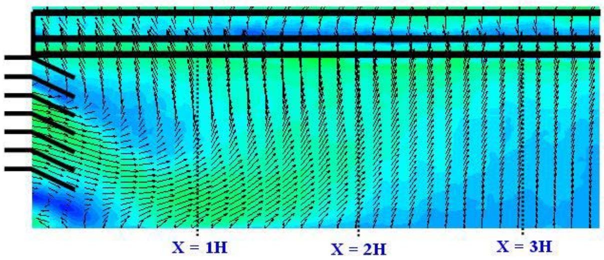
In the case of the modified factory model #3, the blades of the outer louver are aligned with the oncoming wind by installing them at θo = 90°. The inner louver is inclined about θi = -70° and its length is twice as long of that from model #2. Compared with modified models #1 and




**(a)** Model #1




**(b)** Model #2




**(c)** Model #3

**Fig. 1** Mean velocity field distributions inside the modified factory models

#2, the flow rate of the entrained air passing through the modified louver is increased to about 50% by simple modification of the blade angle of the outer louver (θo = 90°) parallel to the streamwise wind direction. As shown in Figure 10(c), the high-speed entrained air reaches the ground surface by the inner louver, thereafter, it ascends gradually. On average, the wind speed of the entrained air y/h = 0.5 is reduced to about 12% and 40% at the downstream locations of X = 1H and X = 2H, respectively, compared with the inlet speed of oncoming wind passing the louver ventilator. As shown in Figure 11(b), the streamwise turbulence intensity of the entrained air slightly fluctuates with a mean value of about 17% in the target area. The increase of turbulence intensity is about 60%, compared with the original factory model. This indicates that the entrained air is mixed actively with the indoor air. The mixing between the entrained air and the indoor air is important in order to improve the natural ventilation inside the factory building. The stagnant flow region which appeared in the modified model #2 nearly disappeared due to the penetration of the entrained air down to the downstream end of the target area.

Conclusively, the louver ventilator of model #3 proposed in this study seems to greatly improve the ventilation flow inside the target area of the factory building.

## 4. Conclusions

In this study, wind tunnel tests were carried out to investigate the ventilation flow inside a factory building model and to determine prevailing wind direction. Based on the velocity field data inside the model of the original factory building, we tried to find the optimal condition for improving the natural ventilation inside the target area of the building. For the case of modified model #3, the entrained air reaches the ground surface successfully. This results from the increased flow rate of the entrained air due to the alignment of the blades of the outer louver (θo = 90°) and the excellent guidance of flow by the elongated inner louver blades. Thereafter, the air gradually ascends toward the roof. The speed of the entrained air is decreased to about 12% and 40% on average at the target of y/h = 0.5 at the downstream locations of X = 1H and X = 2H, respectively, compared with the wind velocity passing the louver ventilator.

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