

Natural and Hybrid Ventilation Aided by Solar Cells and Low Pressure Fans in an Atrium

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ABSTRACT: In office buildings, an atrium has great potential for employing natural ventilation aided by the buoyancy effect. The architectural design of an atrium is critical in order to maximize the amount of natural ventilation..

However, in terms of both aesthetics and economy, it is difficult to design an atrium shape that will optimize natural ventilation. Taking this constraint into consideration, in this study a strategy is suggested whereby natural ventilation can be adopted with minimal change to the design of the atrium.

Initially, a BIPV was installed on the top of an atrium in order to strengthen the buoyancy effect. This was then combined with forced ventilation by using a low pressure fan. To evaluate the performance of this measure, a CFD simulation and an Energy-Airflow analysis were carried out.

Keywords: Natural Ventilation, Hybrid Ventilation, Atrium, Energy, CFD

1. INTRODUCTION

The use of an atrium is becoming more common due to the advantages it provides in terms of natural ventilation, daylighting and an open view as well as its role as a central space in a building. In particular, there is a great potential for an atrium to provide natural ventilation promoted by the stack effect, which plays a role as a vertical ventilation flow path.

The amount of natural ventilation created is influenced by the shape of the atrium in terms of the plan, the section and the relationship between the atrium and adjacent rooms. Thus, factors that influence environmental performance need to be taken into consideration in the initial stage of architectural design. However, the integrated design process, which makes this consideration possible, is not commonly used in Korea, while sustainability is not yet given priority over aesthetics and construction cost. Consequently, in many

projects it is difficult to optimize the shape of an atrium for natural ventilation. To cope with this situation, supplementary strategies for natural ventilation are necessary that can be applied without a major design change, even after the main shape of the atrium is fixed at the initial design stage.

In this study, a strategy is proposed to promote natural ventilation for a real building project and its performance is evaluated. A simulation analysis is carried out in order to compare the hours when natural ventilation is possible between the case of the original atrium and the case where the atrium has been altered. An investigation is also carried out to determine the distribution of indoor temperature and airflow in each case.

2. OVERVIEW OF CASE BUILDING

The application of this study is based on a real building project though the building was designed only to the design develop

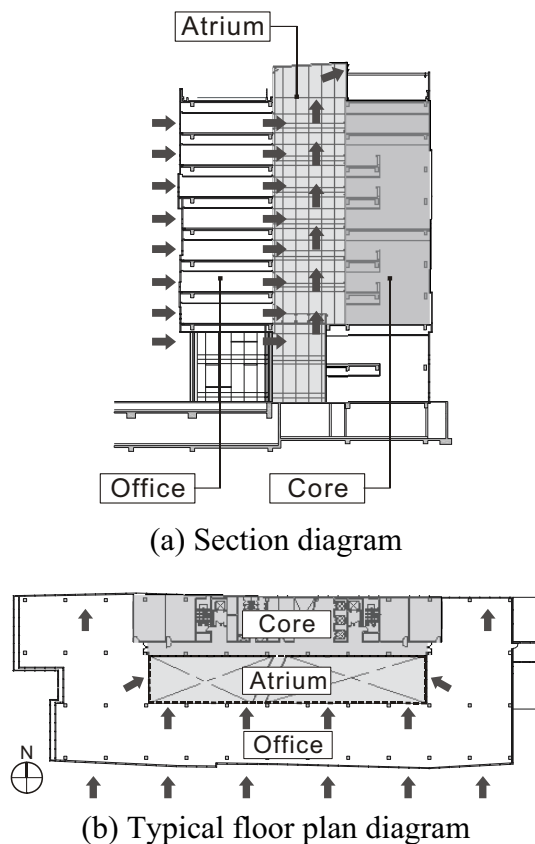


Figure 1: Natural ventilation diagram at the case building.

stage. The case building is a typical office building in Korea. The building has 8 floors and each floor consists of an atrium in the center and an office area adjacent to the atrium (see Fig. 1). The office area directly faces the atrium without an intermediate aisle. Therefore, it is possible to achieve cross ventilation from the exterior to the atrium through the office.

An improvement in indoor thermal comfort and saving in energy consumption is expected in this case, provided that natural ventilation is well organized through the use of the stack effect in the atrium.

3. ANALYSIS OF ORIGINAL CASE AND CHOOSING IMPROVED ALTERNATIVES

3.1 Analysis of original atrium design

In order to evaluate natural ventilation in the original design, the indoor temperature

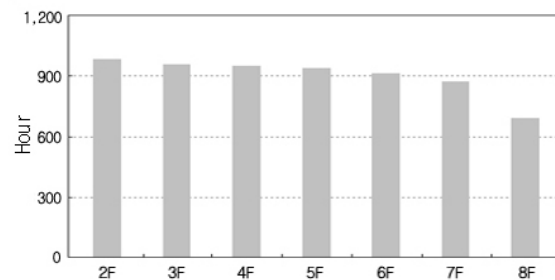


Figure 2: Hours of possible natural ventilation

in the office is calculated at each floor by using the TRNSYS energy analysis program. The TRNFLOW module is used to couple the airflow model with the thermal model. The analysis is based on the climate data for Seoul and on the condition where the HVAC system is not in operation.

The balance point temperature of 18°C for heating and the regulated set point temperature of 26°C for cooling are generally used in Korea. Therefore, when outdoor temperatures range between 18°C and 26°C, it is expected that occupied spaces can draw natural ventilation.

While this condition for the outdoor temperature of Seoul occurs for 1,061 hours a year, natural ventilation is only possible for 65~95% of these hours, and the indoor temperature in other hours exceeds 26°C. Fig. 2 indicates the hours in which the indoor temperature is below 26°C at each floor.

An imbalance occurs in the hours of natural ventilation between the lower and the higher floors. This can be caused by a decrease in pressure difference due to the stack effect at the higher floors.

In eq. 1, the pressure difference due to the stack effect, Δp_s is determined by the height difference between the inlet on the facade and the outlet on the atrium top and by the density difference between the indoor and outdoor air.

$$\Delta p_s = (\rho_o - \rho_i)g \cdot \Delta z \quad (1)$$

ρ_o	Density of outdoor air [kg/m^3]
ρ_i	Density of indoor air [kg/m^3]
Δz	Height difference between inlet and outlet [m]
g	Acceleration of gravity [m/s^2]

Therefore, the performance of natural ventilation within the atrium increases with a higher outlet position. However, factors such as aesthetics, construction costs, and, especially in Korea, height regulations, tend to limit the design of a higher atrium.

3.2 Choosing improved alternatives

In this case study, because it is not possible to raise the top of the atrium any further due to legislative height restrictions, two alternative strategies are chosen to improve natural ventilation.

The first alternative is a passive system that utilizes solar energy. In order to increase the difference between ρ_o and ρ_i in Eq. 1 (since Δz cannot be changed), solar energy is collected at the top of the atrium by installing a BIPV (Building Integrated Photovoltaic). In a BIPV, only a small portion of collected solar energy is converted into electricity, while the remaining portion is lost to indoor or outdoor air in the form of heat. This heat loss improves the generation efficiency of the photovoltaic by cooling the back of the

BIPV, and decreases the air density by raising the air temperature at the top of the atrium.

The second alternative is an active system that compensates the first system through the installation of low pressure fans, which are particularly necessary when insolation is insufficient. This is a hybrid ventilation system that combines natural and forced ventilation. Although low pressure fans consume electric power, they have lower energy consumption than that of an AHU or a chiller, even when the AHU operates in the economizer cycle.

4. EVALUATION OF ALTERNATIVES

4.1 Installation of BIPV

It is necessary to install a shading device at the top of the atrium because of the discomfort of glare and overheating caused by incoming direct sunrays. While the roll screen is a common and simple shading device, the BIPV can also act as a shading device (see Fig. 4). A comparison is therefore made between the case in which a roll screen is used and that when a BIPV is installed at the top of the atrium.

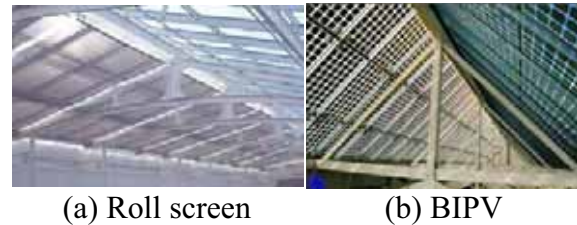


Figure 4: Example of shading devices

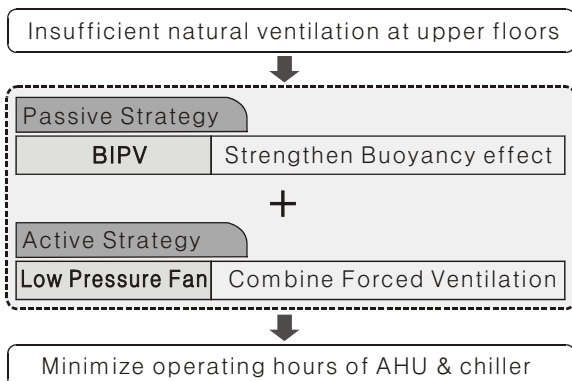


Figure 3: Alternatives to promote natural ventilation

The STAR-CD commercial CFD program was adopted in order to analyze the local temperature and airflow distribution resulting from incoming solar radiation within the atrium. The boundary condition is shown in Table 1. The outdoor condition used for this analysis is that for the hour when the higher floors are not completely naturally ventilated, as determined from the previous energy analysis. Other boundary conditions such as the wall flux are also derived from this energy analysis.

Table I: Boundary condition for CFD Simulation.

Case	Case 1	Case 2
Roof	Glass +Roll screen	BIPV
Outdoor air temp	24 °C	
Wind speed / Wind direction	1.6 m/s / Southwest	
Horizontal total insolation	813 W/m ²	
Internal heat gain	Person 0.1 p/m ² , 75 W/p Light 20 W/ m ² , OA 20 W/ m ²	

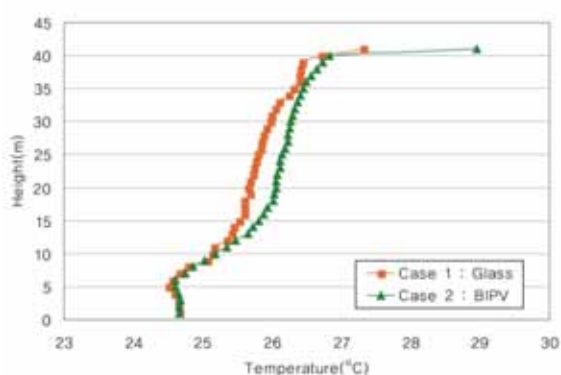
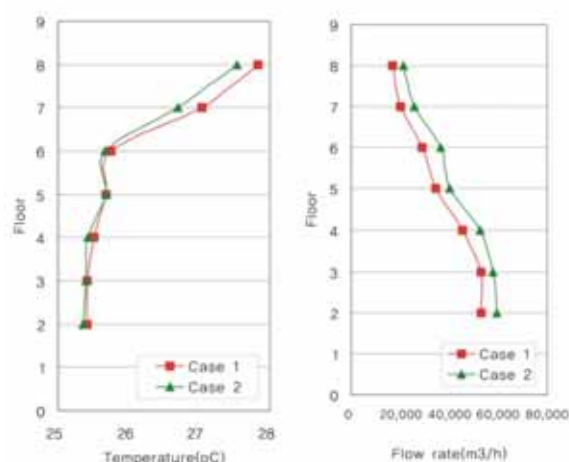
Fig. 5 provides the results of the simulation, showing the vertical temperature profile in the atrium. In the case where a BIPV was installed, there was only a slight difference in temperature in the lower area, while a rising temperature is shown in the higher area. This causes an increase in the amount of solar energy absorbed by the airflow in the atrium, and results in a raised temperature and an increased airflow rate at the top outlet (see Table II)

Fig. 6 shows the results obtained for each floor. The airflow rate from each office to the atrium increased for all the floors, while

Table II: Airflow condition at top outlet

Case	Case 1	Case 2
Air temperature*	27.5 °C	29.1 °C
Air velocity*	0.96 m/s	0.96 m/s

* Mean value at the north outlet of the atrium top

**Figure 5:** Vertical temperature profile within atrium

(a) Air temperature (b) Exhaust air flow rate

Figure 6: Mean air temperature and exhaust air flow rate in offices (Case 1, Case 2)

the mean air temperature decreased at the occupied zone of the 7~8th floors. It can therefore be inferred that collecting solar energy in a BIPV can help to promote the stack effect and natural ventilation in the atrium. However, the temperature at the 7~8th floors is over 26 °C, indicating that the natural ventilation is insufficient.

This result can be improved if the top space of the atrium is large enough to collect solar energy and heat airflow. However, because it is not possible to increase the size of the top of the atrium in this building, this system needs to be supplemented by other alternative systems.

4.2 Installation of low pressure fans

In this alternative, low pressure fans are installed facing the atrium in the ceiling space, thus increasing the pressure difference between each office and the atrium to create sufficient ventilation (see Fig. 7). The low pressure fans should be operated only when the occupied area is not fully ventilated and they should have the capacity to compensate only for the difference of airflow rate from the lower floors. However, for a simple operation, the fans are arranged so that they each have the same capacity because the difference

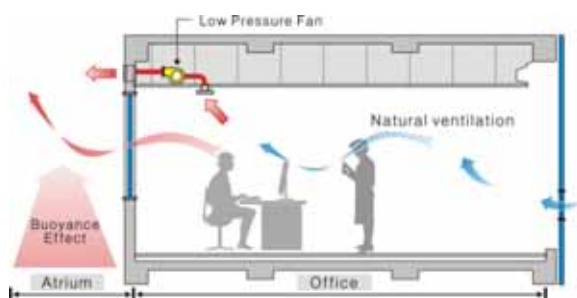


Figure 7: Diagram of hybrid Ventilation

continuously varies according to floors and time.

A simulation analysis was carried out on case 3 where low pressure fans were included, under the same boundary conditions as for case 2. In this simulation, only the fans on the 7~8th floors are operated.

In Fig. 8, simulation results show the airflow rate from each office to the atrium and the mean air temperature at the occupied zone. Compared with case 2, where the mean air temperature at the higher two floors is over 27°C , the situation in case 3 has improved somewhat with the operation of low pressure fans. However, the drop in temperature is less than was expected and the temperature at the 8th floor is slightly over 26°C . One of the reasons for this is caused by the airflow of the outlet in

the top of the atrium. In Fig. 8(b), it can be seen that the airflow rate at the lower floors decreased, while it increased at the higher two floors. This shows that the increased pressure due to the fan operation does not only increase the exhaust airflow at the outlet, but also influences the airflow from the lower floors to the atrium. To achieve full hybrid ventilation, the pressure difference at the outlet should be increased according to the increase at each floor. Therefore, it is necessary to install an additional fan at the outlet that will operate together with the low pressure fans at each floor.

4.3 Evaluation of improvement in annual natural and hybrid ventilation

Due to the improvement in natural and hybrid ventilation, energy saving is expected with the two alternatives described above. In order to evaluate energy saving, an investigation was carried out to determine the hours when the occupied zone can be conditioned by using only natural or hybrid ventilation, without the operation of either an AHU or a chiller.

For this analysis, the TRNSYS program with the TRNFLOW module is used, similarly to the previous energy analysis. This analysis is also based on the same conditions as that of the previous analysis, except with the addition of the BIPV and low pressure fans. The low pressure fans are controlled to operate when the indoor temperature is over the setpoint temperature, 26°C .

Fig. 9 indicates the hours for which the indoor temperature is maintained below 26°C for the application of each alternative case. The value of the base case is the same as that shown in Fig. 2. While the possible hours for which natural ventilation can operate in the case of BIPV is somewhat higher than the base case, the difference between these two cases is not large. However, this difference becomes significantly larger in the case where a BIPV and low pressure fans are installed.

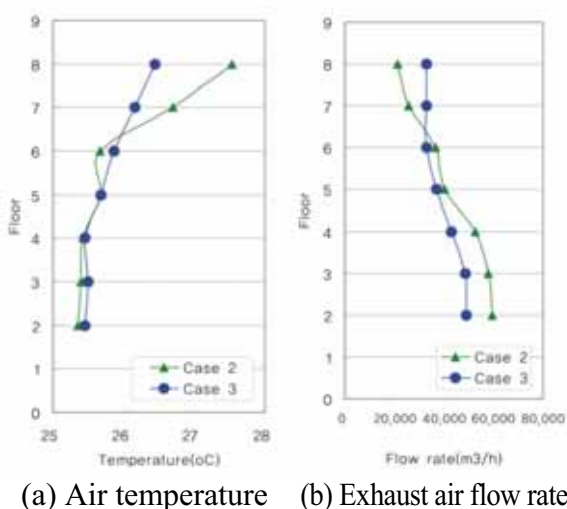


Figure 8: Mean air temperature and exhaust air flow rates in offices (Case 2, Case 3)

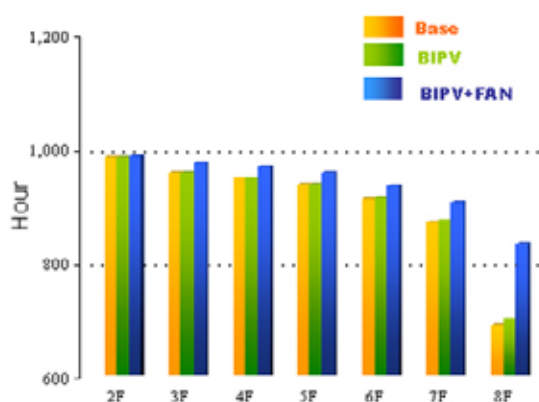


Figure 9: Comparison of the total hours when natural or hybrid ventilation is possible

Therefore, the hours when the HVAC system would need to operate are considerably reduced, and this is made possible by adopting the hybrid ventilation system.

In particular, for the 8th floor, the hours in which the occupied space need not to be conditioned by the HVAC system increases by about 150 hours per year, which is about 20% more than that in the base case. Consequently, the balance of the hours at each floor improved to 80~95%, compared

with that of 65~95% in the base case. This means that the central HVAC system does not need to be operated for those hours to condition only small part of the building.

Additional energy is consumed to operate the central HVAC system. Moreover the efficiency of the equipment at part load operation is lower than that at full load. Thus, this hybrid ventilation has a strong advantage in terms of reducing part load situation.

Fig. 10 shows a comparison in energy consumption for the 8th floor between a hybrid ventilation system with low pressure fans and an AHU system operating in an economizer cycle. The AHU uses more fan power than the low pressure fans due to the high pressure loss in the coil, and the filter etc. Table III shows a comparison of the electric power used by these two systems. The results show that about 1800 kWh can be saved annually by using hybrid ventilation. If the AHU does not run in the economizer cycle, the difference in energy consumption between these two systems can be greater, including the energy required for operating the chiller.

Table III: Fan schedule of the 8th floor

Item	No of unit	Type	Electric power(kW)
Low pressure fan	5	In line	0.75
AHU	SF	Air foil	11
	RF	Sirocco	3.7

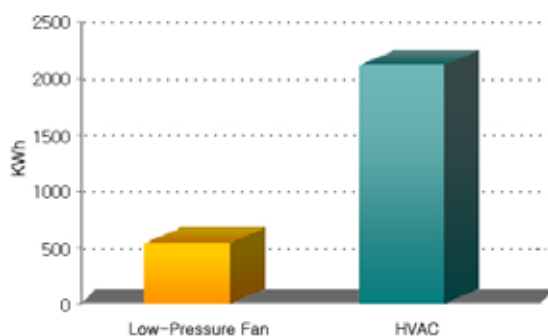


Figure 10: Comparison of fan energy consumption

5. CONCLUSION

In this study, a proposal was made to promote natural and hybrid ventilation for the case of an atrium that does not have an ideal form. For the first alternative, a BIPV was applied at the top of the atrium in order to increase the buoyancy effect. For the second alternatives, hybrid ventilation with low pressure fans was combined to supplement insufficient natural ventilation. The results of the evaluation for the two alternatives are summarized below.

(1) The installation of a BIPV on the top of an atrium increases the buoyancy effect and increases the airflow rate at the atrium outlet by heating the upper part of the atrium. However, due to the insufficient increase of airflow rate at the higher floor, it is not valid to use this alternative without any supplementary system.

(2) The hybrid operation that combines natural and enforced ventilation by the installation of low pressure fans effectively solves the problem of the insufficient airflow rate at the higher floors. However, the increased air pressure in the atrium caused by the fan operation can influence the airflow rate at those lower floors where fans do not operate. Therefore, it is necessary to install an additional fan at the atrium outlet and for it to be operated in conjunction with the fans at each floor.

(3) By using the alternatives of installing a BIPV and low pressure fans presented in this study, it is possible to reduce the period in which it is necessary to condition the occupied space with an HVAC system. In particular, the improvement in ventilation provided by the alternatives is greater at the highest floor than at any of the other floors, contributing to a balance of ventilation at each floor and reduce the part load condition.

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