

Evaluation of Energy Efficiency and Thermal Performance for the Simplified Air-barrier System in Perimeter Zone

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ABSTRACT: Because the perimeter of buildings is strongly influenced by solar and outdoor air temperature, the area has different environmental properties compared to the interior of a building, as in summer heat gain, and in winter heat loss. In particular, if the external wall is glass, the characteristics of the glass material make it pervious to outside conditions, thereby making big changes to the thermal environment. A simplified air barrier system is developed with the idea that energy could be conserved by carefully and effectively blowing out the air caught between the glass surface and the roller blind. It is configured by making the roller blind's air-path, and by placing the exhaust air ducts in the most optimum positions. This simplified air barrier system will improve the thermal environment and reduce cooling/heating load of the parameter area strongly affected by solar and outdoor conditions.

Keywords: air-barrier system, perimeter zone, energy simulation, CFD analysis

1. INTRODUCTION

Recently, as more skyscrapers and larger buildings are built, lighter building envelopes are being demanded, and the resulting increase in window costs and reduction in insulation performance are becoming a problem. Viewed from a building energy perspective, building envelopes become a major factor in creating perimeter load and, in particular, take up a significant part of cooling load due to the influence of solar heat gain. Accordingly, efficient processing of load that occurs in the perimeter is becoming ever more important. Super airtight building envelopes also affect ventilation systems for improving indoor air quality, and they depend on

mechanical ventilation systems. For efficient perimeter load removing and improving the indoor air quality, high-rise buildings adopt all air systems and for perimeter air conditioning, the overhead HVAC system is generally being used. However, this system has the problem of not efficiently removing perimeter load and creating cold draft during winter. On the other hand, FCU that are applied to remove skin-load (conduction through the building envelope) can cause air mixing with heat loss between the interior and the perimeter, resulting in reduced energy efficiency [1]. To improve the condition, an air-barrier system or airflow-window can be proposed. However, these systems increase construction cost, and when that increase is

compared to their effectiveness, they are very rarely used [4]. In this paper, a simplified air-barrier system is proposed which considers energy efficiency and construction cost, with measuring the indoor environment of a building to which this system was actually applied and, using the results as a basis, analyzing the thermal environment and building load reduction in order to present a hybrid air-conditioning system for high-rise.

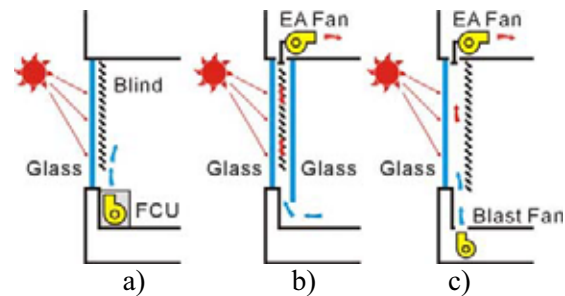


Figure 1: Types of perimeter air conditioning systems, a) fan coil unit, b) air flow window, c) air barrier system

2. SUMMARY OF CASE-STUDY BUILDING AND APPLIED SYSTEM

2.1 General Building Description

Case-study building was completed in 2007, has an adjacent ten-lane road to its west, and it was designed to face west in consideration of building approachability. Due to that factor, ways to counter the effects of solar heat gain from the west side of the perimeter was actively examined from the earliest design phase.

Table 1: Summary of a case-study building

Location	Jung-gu, Seoul, Korea
Building Types	Office
Number of Floors	B7F / 21F
Site Area	3,150 m ²
Built-up Area	73,000 m ²
Structure	RC+SS
Completion	2007



2.2 Summary of Air-conditioning System

The air-conditioning system is designed as a under flow air distribution (‘UFAD’ hereinafter) system that used a variable air volume system, and for the west direction, in order to effectively reduce solar heat gain, a simplified air-barrier system that has a perimeter exhaust air system is installed. This system has the ability to effectively remove perimeter load without significant increase in construction cost by combining UFAD system with motorized roller blind. This roller blind moves through a fixed guide rail, and it functions as an interior shading device and an airflow passageway by serving as inside glazing for the airflow-window. Also, fan terminal unit (‘FTU’ hereinafter) manage the blast fan function of origin air-barrier system, and an EA outlet is installed between the building envelope and the motorized roller blind to develop a typical push-and-pull air-barrier system.

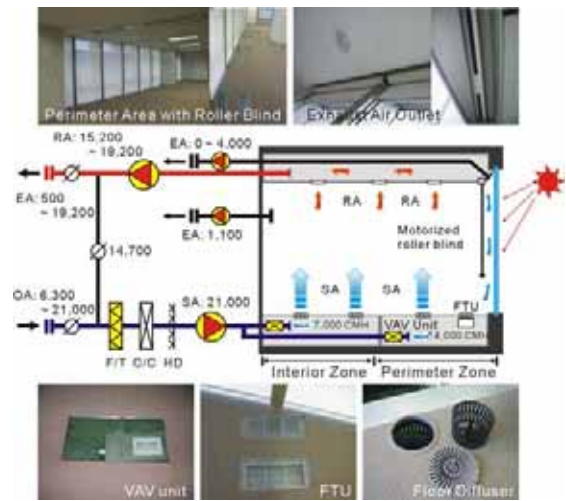


Figure 2: Schematic diagram of simplified air barrier system with UFAD and system configuration

3. COOLING AND HEATING LOAD REDUCTION ANALYSIS

3.1 Energy Conservation Standard

With the exception of residences, the building energy conservation standard

generally uses PAL (Perimeter Annual Load) and CEC (Coefficient of Energy Consumption) as judgment indices in Japan. And the range of perimeter is seen as 5m from the building envelope to the interior. This paper analyzed the energy efficiency of simplified air-barrier system with the PAL values, which are actual building load standards.

$$PAL = \frac{\text{Annual Load of Perimeter (kWh)}}{\text{Total Perimeter Area (m}^2\text{)}} \quad (1)$$

Table 2: PAL (Perimeter Annual Load) index [kWh/m²]

Category	PAL	Category	PAL
Hotel	117	Hospital	95
Retail	106	Office	84
School	89	Restaurant	153
Assembly	153	Factory	-

Ministry of land, infrastructure and transport of Japan

3.2 Energy Simulation Analysis

(1) Simulation Summary

In this research, the load reduction goal is set using values that satisfied the PAL standard, and the analysis of load and temperature reduction rates according to the perimeter air-conditioning system was carried out using the TRNSYS software. The energy simulation model compared two types of cases, namely the perimeter load elimination methods of the conventional HVAC system and the simplified air-barrier system in typical floors

(2) Simulation Boundary Conditions

In order to model the subject space for each case, the material property of the building envelope was obtained using the building's design plan as reference. The indoor design temperature is set at 26°C for cooling and 22°C for heating, and the load condition for internal heat gain was based on the mechanical system calculation sheet. As the case-study building is for business

use, the usage schedule for such factors as human bodies, lightings, and OA equipments are set at 8 hours per day, and the usage pattern are classified as weekdays and the weekend. Also, the maximum load removal efficiency and overheating air temperature reduction level for the air-barrier system were calculated using the airflow rate of perimeter exhaust system and the temperature of the interior air being provided as standards.



Figure 3: Typical office plan for simulation modeling

Table 3: Cases and boundary conditions for simulation

1. Perimeter area air-conditioning system	
Case1	UFAD + FTU with roller blind
Case2	Simplified air barrier system and UFAD + FTU with roller blind
2. Interior area air-conditioning system	
Case1&2	UFAD with VAV unit

(3) Simulation Results

The simplified air-barrier system is based on the concept of directing interior air to perimeter exhaust system and eliminating solar heat gain and building skin-load, and it can be operated both in winter and summer seasons. During summer, solar heat gain occurs between the building envelope and motorized roller blind and very high temperature forms, and it is effective to induct interior air (26°C) to remove the load while simultaneously discharging the heated air to reduce the temperature. In contrast, during winter, by creating an inflow of solar heat gain to the interior, the heating load is offset, and by operating the air-barrier

system and reusing the interior air (22°C), the building skin-load is eliminated while, at the same time, the cooled air is exhausted and prevents cold draft. Figure 4, a) shows the relationship of the temperature between the building envelope and the blind, and the perimeter cooling and heating load, and it also shows that when simplified air-barrier system is operating, it makes excellent load reduction effect both during winter and summer seasons. The annual load profile according to whether or not the simplified air-barrier system is operating is as shown in Figure 4, b).

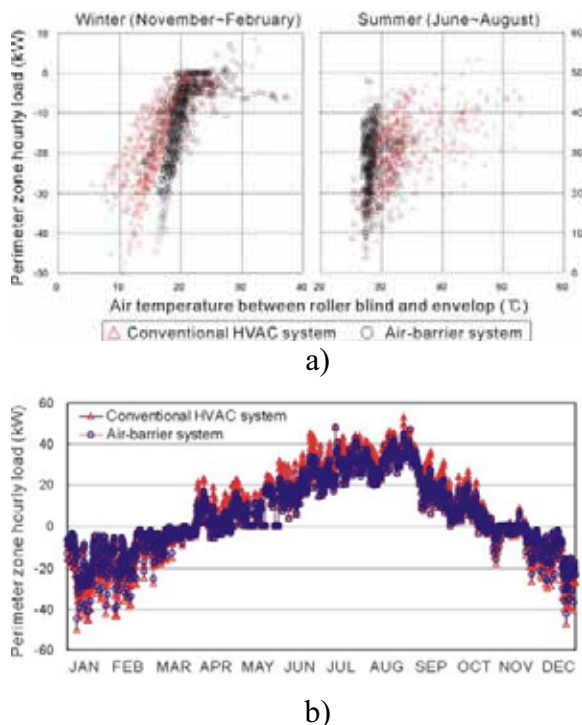


Figure 4: Result of hourly load and air temperature in perimeter, a) relationship between hourly load and air temperature, b) Annual load profile of case1 and case2

It is analyzed that the cooling peak load was reduced by about 16.0% and the heating peak load is reduced by about 10.5%. Cooling for the perimeter annual load are expected to be reduced by 15.8% while heating will be reduced by 12.2%, and thus a total of 14.6% reduction is expected. When the results are converted to PAL standards (office: 84 kWh/m²) and compared,

the value is 95.7 kWh/m² when the simplified air-barrier system is not applied, which exceed the recommended standard, but it is 81.7 kWh/m² when the system is used, which mean that maintenance below the recommended standard is possible and the building energy efficiency is superior.

Table 4: Simulation results of perimeter zone load

Category		Case1	Case2
		Conventional HVAC system	Air-barrier system
Peak load (W)	Cooling	53,307	44,760
	Heating	-49,824	-44,591
Annual load (kWh)	Cooling	25,562	21,532
	Heating	-12,731	-11,172
PAL(kWh/m ²)		95.7	81.7

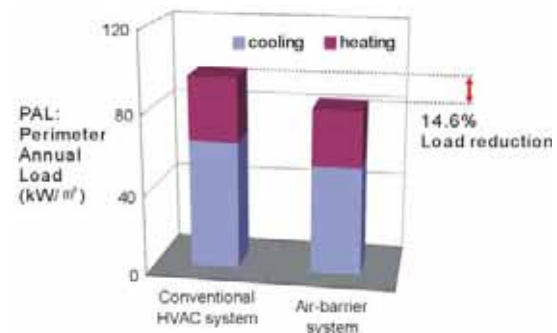


Figure 5: Comparison of PAL between case1 and case2

4. SYSTEM PERFORMANCE ANALYSIS FROM MEASUREMENTS

4.1 Summary of Experiment

In order to evaluate the performance of simplified air-barrier system, an experiment on perimeter exhaust system (on/off) was carried out, focusing on two typical floors (14th/15th floor) of case-study buildings. For measurements, the perpendicular temperature distributions of building envelope, space between blinds (point A), perimeter zone (point B), and interior zone

(point C) were measured. In order to objectively analyze the capacity of air-barrier system, measurements were carried out before residents moved in when no internal heat gain occurred. However, because the measurement period was in September and there was partly cloudy condition, solar heat gain was not so much and the outside temperature did not necessitate air-conditioning. Therefore, only the perimeter zone's overheated air reduction efficiency according to the exhaust system was observed.



Figure 6: Location of indoor air temperature measurement points

4.2 Measurement Results

The average air temperature of point A at peak load time (14:00 ~17:00) according to the on/off state of the perimeter exhaust fan were as follows: with the outside air temperature measurement at 25.3°C, the average air temperature when exhaust fan was operating was 27.1°C, and when the fan was not operating, it was 27.5°C. Also, the vertical air temperature difference of 0.1m~1.6m was 3.5°C and 5.5°C, showing that the difference was bigger and the vertical air temperature distribution was higher when the exhaust fan was not operating. This means the heat was forcibly exhausted upward when the exhaust fan was operating and formed a relatively low temperature distribution. The vertical air temperature distribution difference at point B was found to be almost nonexistent, and the characteristic of UFAD system, vertical

temperature stratification, was also not observed.

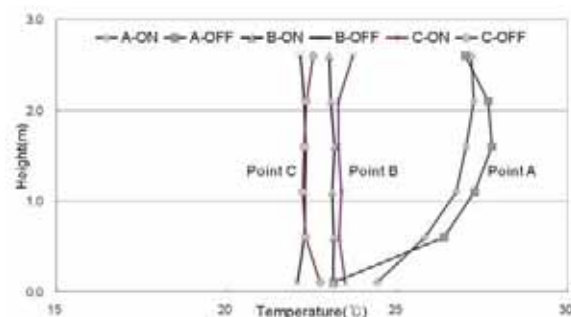


Figure 7: Vertical temperature distribution of each measurement points

It was judged that this was due to the fact that no interior load occurred because the experiment was carried out before residents moved into the case-study buildings, and that there was almost no influence from building skin load because the experiment was carried out with the roller blinds down. Also, the vertical air temperature distribution of point C in the same time period was found to have almost the same air temperature distribution with point B.

5. THERMAL ENVIRONMENT EVALUATION BY NUMERICAL ANALYSIS

5.1 Summary of Numerical Analysis

Applying the same conditions used for energy simulation, two types of cases were selected, such as the conventional HVAC System and the simplified air-barrier system for typical floors, and a Computational Fluid Dynamics simulation was carried out. For the simulation, Star-CCM+ software was used, and for the boundary conditions and input data of the space heat gain, and air flow rate of supply / exhaust air, the energy simulation results and the air conditioning heat load calculation sheet were used as standards.

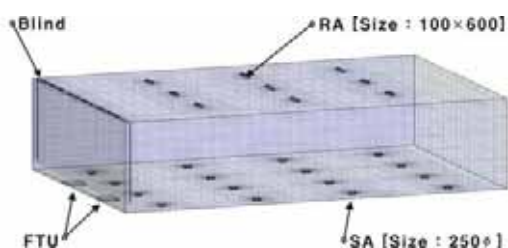
Table 5: Boundary conditions for CFD simulation

Category		Case1	Case2
		Conventional HVAC system	Air-barrier system
Air flow rate (m ³ /h)	Perimeter EA	-	1,080
	Supply air	2,400	2,400
	Return air	2,400	1,320
Air temp. (°C)	Perimeter EA	-	26
	Supply air	18	18

5.2 Simulation Method and Results

(1) Simulation Modeling and Conditions

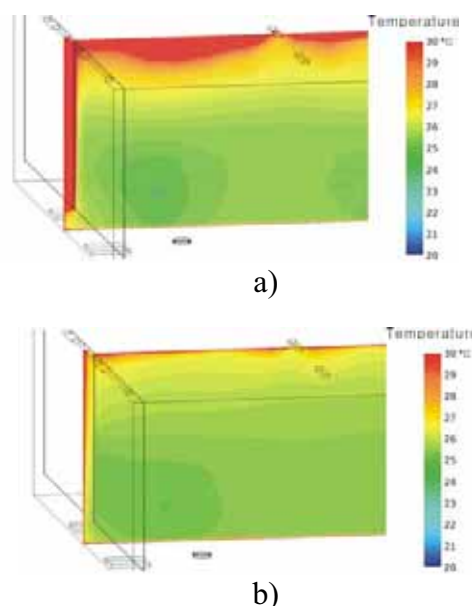
For the composition of the simulation modeling, one span of the typical floor is used, 8m×12m×2.7m rectangular form, with blinds installs 150mm away from the boundary layer of building envelope. The blinds are draped 2.4m long from the suspended ceiling. The volume of the analysis space is 260 m³, and an unstructured rectangular-hexahedron mesh is used.

**Figure 8:** Simulation model and condition

(2) Simulation Results

In case2 when simplified air-barrier system is operating, it is found that summer time skin-load and solar heat gain do not significantly flow into the interior zone. Looking at the air temperature distribution in Figure 7, it can be confirmed that air-conditioned room air is flowing in between the blind and the building envelope, and flowing out through the perimeter exhaust outlet slots. Moreover, the temperature distribution at 1.5m, which is the height of

the occupied zone, is about 25 °C, satisfying the design temperature 26 °C for the summer season, and it is analyzed to be effectively controlling the space to make it a thermal comfort.

**Figure 9:** Air temperature distribution of perimeter zone, (a) Case1: conventional HVAC system, (b) Case2: the simplified air-barrier system

On the other hand, in case1 with a conventional HVAC system, it can be seen that skin-load and solar heat gain affected the space area significantly. Looking at the air velocity distribution in Figure 8, an updraft of heated air is found to occur around the side of the blind in contact with the interior. Accordingly, the overheated air between the blind and the building envelope that is not removed either passes through the blind or is conducted and flows into the space, adding to the cooling load. This is judged to be an important variable that needs to be considered along with the space load changes during the summer cooling period. The temperature satisfies the design temperature of 26 °C, but it is expected that the hot air between the building envelope and the blind can be thermally stored in the structure and become a factor in increasing the cooling load in the interior and the upper floor.

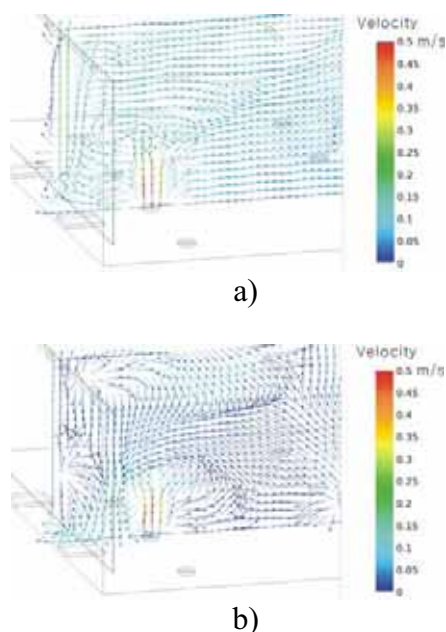


Figure 9: Air velocity distribution of perimeter zone, (a) Case1: conventional HVAC system, (b) Case2: the simplified air-barrier system

6. CONCLUSION

This study developed a simplified air-barrier system that combines motorized roller blind and exhaust-system and considers the perimeter load characteristics and give a direction toward selecting an energy conservational HVAC system and implementing a best design. The new system can effectively remove solar heat gain and building envelope load in summer and winter seasons, and the results of the research can be summarized as follows.

(1) It is analyzed that, depending on the installation of the simplified air-barrier system in the case-study building, it is possible to have a yearly perimeter load reduction of 15% in comparison to the conventional HVAC system.

(2) In summer by introducing the conditioned room air between the roller blind and the building envelope and discharging it through an exhaust air outlet, overheating due to solar heat gain can be prevented, while in winter, ventilating the

cold air around the building envelope can prevent cold draft in perimeter area.

(3) Therefore, by moderating the effect of heat gain or heat loss from the changes in outdoor environment, the thermal environment of the interior can be improved.

(4) Lastly, because the new simplified air-barrier system can minimize increase in construction cost and maximize the load reduction effects, we expect this system to be used widely.

The above research results were integrated and matters regarding the load reduction of the simplified air-barrier system and improvements in the interior thermal environment were derived. This paper primarily dealt with perimeter load, but in future studies, a more integrative analysis that includes air conditioning and plant systems is needed.

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