Evaluation of the Impacts of Stack Effect in High-Rise Buildings

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ABSTRACT: The objective of this study is to analyze and evaluate the impact of the stack effect in high-rise buildings for solving the various problems resulting from it. For the evaluation of the impacts on the stack effect, computer program simulations based on the network model were performed for a typical high-rise office building. The results of the simulations show that the impact caused by the stack effect is mainly dependent on building envelope air-tightness and internal air flow resistance. Therefore the problems due to the stack effect may be solved to some extent by installing vestibules around entrance doors and doors serving elevators, and by zoning the elevators.

Nomenclature

- $F_{k,j}$: airflow rate from zone k to zone j [kg/s]
- g : acceleration of gravity 9.81 [m/s^2]
- h : measuring height [m]
- m_j : the mass of air in zone j [kg]
- N : neutral pressure level [m]
- P : pressure [Pa]
- ΔP_{st} : pressure difference caused by stack effect [Pa]
- R : air gas constant [J/kgK]
- T : indoor temperature [K]
- t : time [sec]
- V_j : the volume of zone j [m^3]

Greeks symbols

- ρ : air density [kg/m^3]
- υ : dynamic viscosity

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Subscripts

- i : indoor
- j : zone j
- k : zone k
- o : outdoor

1. Introduction

Recently the construction of the high-rise building has been increased in Korea. High-rise buildings have vertical airflow paths such as the elevator shaft, mechanical and electrical shaft, staircase, and other shafts in them.

But during the winter, there is a strong inflow of air on the lower floors due to the difference of pressure between the exterior and the interior of the building, which is caused by the difference of temperature between the interior and the exterior. This causes a stack effect, which makes inflow of air go up through the vertical airflow path.

Stack effect mainly occurs in the core area, i.e, the stairwell or the elevator shaft. This results in energy loss and elevator door sticking problem, also it causes difficulty in opening doors of the room around the core, noise regenerated by infiltration and uncomfortable airflow of outdoor air.

But it lacks domestically understanding about stack effect, and the research about this subject has been rare from the analysis of the examples.[1] In abroad, stack effects have been studied[2-4] and it was shown that stack effect solutions, resolved after the building is constructed, only provide imperfect solutions.

Controlling the indoor pressure by mechanical air conditioning system[5-6] could be a solution of the problems of stack effect, but this solution causes problems in another part of the building, and its lacks in efficiency has proven that it was not an appropriate solution.

Therfore in order to solve the stack effect problems of high-rise building, architectural design should be reconsidered at the early design stage so that the problems may be minimized. For this, a guideline for planning and design to prevent from stack effect should be needed in order to be used at the planning and design stage. For developing this guideline, an evaluation on general effect will be needed.

The force causing the airflow between the interior and the exterior of building, produces the stack effect. The force is such as force acting on the envelope due to the wind, buoyancy of air resulting from the difference of density between the indoor and the outdoor, and the changes in pressure by HVAC system.

The air distribution inside the building through various channels by those forces, produces various distribution of pressure.

Therefore all of the above should be considered to perform an airflow analysis for the evaluation of stack effect.

First of all, a simulation factor that can have an influence on the airflow should be chosen, and then each variable and input data should be arranged. Then it is desirable that architectural factors come into the first consideration, because it is much easier to adjust the plan at the early design stage.

Therefore, this study evaluates the influence of stack effect through the airflow analysis simulation after choosing architectural factors affecting the stack effect. It is to prevent from design errors before the construction by considering the problems of stack effect at the early design stage.

2. Theoretical review of stack effect

2.1 Principle of stack effect

Stack effect is caused by pressure difference between the weight of the outdoor and indoor air column. Due to this pressure difference, during the winter season when the inside of the building is warmer than the outside, indoor air pressure is lower than the outdoor air pressure at the bottom of the building. This pressure difference makes the air entering the building on the ground level, and the air moves up to the upper level by the buoyancy force with the changes in density. But the real effects can vary depending on the height of the building, and upper/lower level's infiltration/exfiltration rate.

The theoretical pressure difference caused by stack effect can be expressed by the following Eq. (1).

$$\Delta P_{st} = g\Delta\rho(N-h) = g\rho_o(\Delta T/T_i)(N-h) \quad (1)$$

2.2 Analysis program

In this study, CONTAMW program[7] based on the network model, which was developed by NIST, and recommended by many researches, was used.

2.3 Methods for the evaluation of stack effect

Generally, airflows inside the buildings are

Table 1 Prediction models of airflow

Models	Control volume	Application
Zone model	One or many numbers	Airflow analysis of a large space in a single zone such as atrium or hall
Field model	Many mesh points	
Network model	One per zone	Airflow analysis of a high-rise building having multi-zones and vertical shafts

predictable in various methods as shown in Table 1. In multi zone buildings, for example high-rise buildings, airflow through the envelope, openings and adjacent spaces are affected by the resistance of shape according to the parts of building, opening area, etc.

Therefore, network model method to analyze multi zones is suitable for predicting airflow rate on the analysis of stack effect.

The basic equation of the network model is represented by the relationship between the conservation of mass and the function of airflow rate by the pressure difference.

Airflow rate between zone-j and zone-k airflow and air mass on the zone-j produces the following Eqs. (2) and (3).

$$F_{k,j} = f(P_k - P_j) \qquad (2)$$

$$m_j = \rho_j V_j = \frac{P_j V_j}{R T_j} \qquad (3)$$

The analysis on unsteady state produces Eq. (4), using the law of mass conservation.

$$\frac{\partial m_j}{\partial t} = \rho_j \frac{\partial V_j}{\partial t} = \sum_k F_{k,j} \qquad (4)$$

Supposing that the airflow is on the quasi-steady state condition, the airflow rate of the entire zones can be represented by the following Eq. (5).

$$\sum_k F_{k,j} = 0 \qquad (5)$$

In this equation, because the airflow rate is non-linear, to get the final solution, this equation is needed numerical analysis by the iteration using Newton-Raphson method.

3. Stack effect simulation

3.1 Simulation factor and variables

During the winter season, when stack effect problems occur most frequently, the main path of airflow inside the building can be divided into three parts: inflow part (R1), upward flow part (R2), and outflow part (R3) as shown in Fig. 1. Additionally, considering the entire building, the building envelope (R), where infiltration and exfiltration are formed and by which building airflow is influenced, can be classified as another factor.

Previous case studies and research[8] in abroad have shown that architectural element that can be easily changed at the early design stage, is the most important function affecting the stack effect.

Reviewing the research documents and considering the architectural elements, factors and

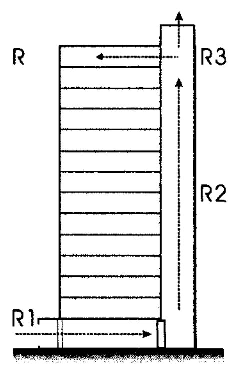


Fig. 1 Main path of airflow.

Table 2 Factors and variables for simulation

Airflow	Factors		Variables
Inflow (R1)	Entrance door	Vestibuledoor	: swing+swing (S+S) : swing+revolving (S+R)
		General entrance door	· Swing door (S) · Revolving door (R)
	Elevator anteroom		Yes (○), No (×)
Upward flow (R2)	Elevator door		Loose (L), Average (A), Tight (T)
	Staircase door		Loose (L), Average (A), Tight (T)
	Elevator zoning		Yes (○), No (×)
Outflow (R3)	Opening of elevator mechanical room		Yes (○), No (×)
	Entrance door of rooftop floor		Closed door (Dc), Open door (Do), Anteroom
Building envelope (R)	Air tightness of envelope		Loose (L), Average (A), Tight (T)
Etc.	Number of door on the first floor		See Table 9
	Elevator zoning		See Table 11
	Opening rate of upper and lower floors		See Table 4 (Case V-3)

Floor height of lobby: 5.5 m, Floor height of typical floor: 4.5 m

Table 3 Indoor and outdoor conditions for simulation

Classification	Conditions	Remarks
Outdoor air temperature	−11.9℃	Seoul, TAC 2.5%
Indoor air temperature	22.0℃	Ministry of construction and transportation, design standards of energy conservation in building, 2001.5. [Appendix Table 7]
Temperature difference	33.9℃	22.0−(−11.9)
Atmospheric pressure	101.30 kPa	Standard condition

variables for the stack effect simulation were established as shown Table 2.

3.1.1 Indoor and outdoor conditions for simulation

Although it fluctuates with time, the outdoor temperature is set at the lowest design temperature in winter and the indoor temperature is set at the design temperature for heating in offices and apartments as shown in Table 3.

3.1.2 Simulation model

Simulation models deal with high-rise office buildings. Especially, when the office has an open plan, problems caused by the stack effect occur more seriously due to the little resistance in the path of airflow between the core and building envelope.

Thus open plan office is selected for the simulation model. To reflect the architectural characteristics of real buildings, offices and mixed-use building in which the problems of stack effects have occurred, are considered. Floor plan

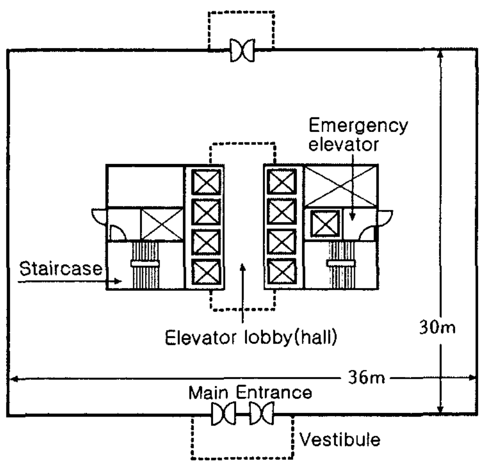


Fig. 2 First floor plan of simulation model.

of the simulation model is as shown in Fig. 2.

The lobby of the first floor has a main entrance toward the south and a rear gate toward the north. The floor height of each floor is 5.5 m at the 1st floor and 4.5 m at the typical floor. The model building has 45 stories, but the height is changed, if required, to evaluate the impact on stack effect.

3.1.3 Criteria for the evaluation

All problems caused by stack effects are concerned with the pressure difference which causes an airflow. Therefore, it can be known that the solution for problems concentrates on the pressure difference.

In this study, to evaluate stack effects, the results of the simulation are evaluated with regard to the pressure difference which can cause problems at some doors in the building. According to the related documents, the doors in staircase require less than 50 Pa[3] of pressure difference, and the doors of elevator, less than 25 Pa[5] of pressure difference.

3.1.4 Simulation cases

Simulations to evaluate the impact on stack effect are performed with the variation of the factors along with the path of airflow. Moreover, to evaluate the impact on stack effects, the height of building is varied by 5 stories and in other cases it is fixed at 45 stories.

Generally, the airflow in a building is influenced by a lot of indoor or outdoor factors. In this study, however, simulations are performed with regard to the impact on stack effects according to architectural elements, in order to suggest the guide which can give the countermeasure at the design stage. The simulation cases are as in Table 4.

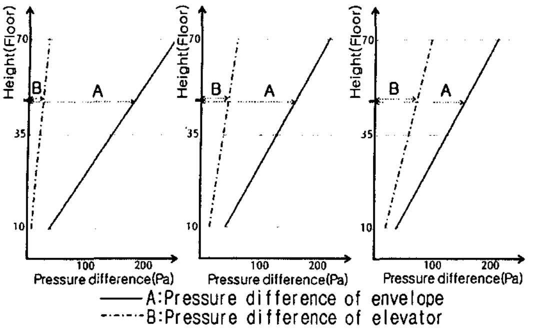
3.2 Analysis of simulation results

3.2.1 Effect from the air tightness of envelope (Case I)

In an office building, it is known that the air tightness of envelope according to the materials of envelope, and the detail of construction. Also the air tightness decreases as time goes by. The method of measuring the exact air tightness is to directly find it out by experiments on relevant envelopes. However, in this study simulations are performed according to

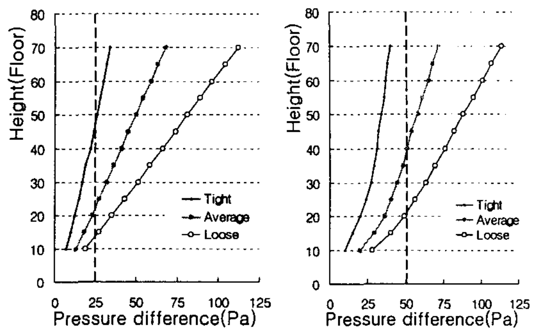
Table 4 Simulation cases

Airflow	Factors	Case I			Case II		Case III			Case IV		Case V-3		Remarks
		I-1	I-2	I-3	II-1	II-2	III-1	III-2	III-3	IV-1	IV-2	a	b	
Inflow (R1)	Vestibule door	×	×	×	S+R	S+R	S+R	S+R	S+R	S+R	S+R	S+R	Opened	(S+S), (S+R)
	General entrance door	S+S	S+S	S+S	S+S	S+S	S+S	S+S	S+S	S+S	S+S	S+S	Opened	Swing door (S), Revolving door (R)
	Elevator hall	×	×	×	×	O	×	×	×	×	×	×	×	Yes (O), No (×)
Upward flow (R2)	Elevator door	A	A	A	A	A	L,A,T	A	A	A	A	A	A	Loose (L), Average (A), Tight (T)
	Staircase door	A	A	A	A	A	A	L,A,T	A	A	A	A	A	Loose (L), Average (A), Tight (T)
	Elevator zoning	×	×	×	×	×	×	×	O	×	×	×	×	Yes (O), No (×)
Outflow (R3)	Opening of elevator mechanical room	O	O	O	O	O	×	×	×	O	×	×	×	Yes (O), No (×)
	Enterance door of rooftop floor	1 Dc	1 Dc	1 Dc	1 Dc	1 Dc	1 Dc	1 Dc	1 Dc	1 Dc	1 Do, 1 Dc, 2 Dc	Opened	Closed	Opened (1 Do), Closed (1 Dc)
Other (R)	Air-tightness of envelope	L	A	T	L,A,T		A	A	A	A		A		Loose (L), Average (A), Tight (T)
	Height	10 F~70 F			10 F~70 F		45 F			45 F		45 F		Floor height of lobby 5.5 m Floor height of typical floor 4.5 m



(a) Tight (b) Average (c) Loose

Fig. 3 Pressure differences according to air tightness of envelope on the first floor.



(a) Elevator door (b) Staircase door

Fig. 4 Pressure differences on the first floor.

the standards of the air tightness adopted by ASHRAE[9] and measured by Tamaru and Shaw, for the absence of data about the air tightness of envelopes according to the building types.

Fig. 3 shows comparisons of pressure difference between envelope and elevator door according to the building height and the air tightness of envelopes on the first floor resulting in the highest pressure. In result, as the air tightness goes high, the pressure difference between elevator shaft and indoor increases.

This pressure difference increases with the increase of the building height. As the air tightness increases, the pressure difference becomes higher but small pressure difference appears in architectural elements around the elevator. Thus in case of buildings with loose envelopes, stack effect problems by pressure differences on elevator doors of the top floor and the first floor, occurred on lower floors.

Pressure difference exerted at interior architectural elements in buildings with loose envelope grows more than buildings that have average and tight air tightness. In result, it is shown that improving the air tightness of envelopes is an important countermeasure.

Fig. 4 shows pressure differences of the elevator door and staircase door located at the core of the first floor. The pressure difference in the buildings with loose air tightness is twice as large as that in the tight air tightness. Therefore improving the air tightness of envelopes is the most important.

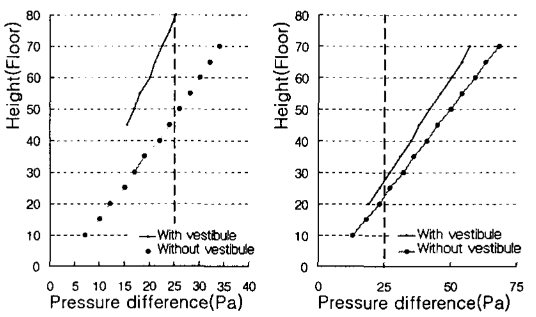
In conclusion, the simulation shows that the problem on elevator doors occurs over the 50th floor (230 m) in the building with tight envelope, and there is no problem at staircase doors. Buildings with average air tightness have a problem of elevator doors over the 23rd floor (100 m) and have problems in staircase over the 39th floor (180 m).

3.2.2 Effect from the changes in architectural elements of inflow part (Case II)

The impact on stack effects is evaluated with changes of architectural elements to solve problems at doors in the core, which has been analyzed through the simulation with the variation of air tightness in envelopes. Simulations to evaluate stack effects are performed with the installation of architectural barriers (i.e., vestibule, elevator hall) lest the air should flow a lot and go directly to the core, where indoor air rises.

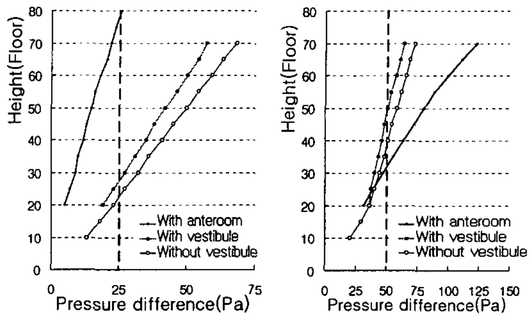
(1) Installation of vestibule at the entrance (Case II-1)

To solve the problem of excessive pressure differences of staircase doors and elevator doors in the simulation according to the air tightness of envelope (Case I), a vestibule is installed at the main entrance of a building in Case I and then the impact is evaluated.



(a) Tight (b) Average

Fig. 5 Pressure differences of elevator door with and without a vestibule.



(a) Elevator (b) Staircase door

Fig. 6 Pressure differences on the first floor with and without a vestibule.

In case of buildings with tight envelopes, the result of the simulations shows that installing a vestibule can solve the problem caused by large pressure differences of a elevator door occurring over the 50th floor (See Fig. 5 (a)).

In case of buildings with average air tightness, the problem does not occur under the 28th floor, because pressure difference decreases by about 7 Pa (See Fig. 5 (b)). On the other hand, in case of buildings with loose air tightness, installing a vestibule does not affect inside and outside pressure of doors. It is concluded that the advantage of installing vestibule decreases as the air tightness of envelopes gets lower and lower.

(2) Installation of the elevator hall (Case II-2)

In the buildings with envelopes of loose and average air tightness, which is analyzed in Case II-1, installing the entrance vestibules with automatic doors could not solve the problem of excessive pressure difference across the elevator door. Additionally, a simulation in the case of installing elevator hall is performed.

In result, the problem of pressure differences in the elevator doors of floors over the 28th floor (Case II-1) could be solved by installing elevator hall in the buildings with the envelope of average air tightness (See Fig. 6 (a)). But, it is found that pressure difference in staircase doors increase excessively in this case, though the pressure difference decreases to some extent by installing vestibules around entrance door in Case II-1. It is resulting from the reason that the interior air rises up through the staircases rather than through the elevator shafts, if the envelope is tighter (See Fig. 6 (b)).

In the case of buildings with envelope of loose air tightness, it is difficult and less effective to solve the stack effect problem of pressure differences by the installation of elevator hall.

Thus, it is thought that the improvement of overall air tightness of building envelopes is preferentially needed.

3.2.3 Effect from the changes in architectural elements of the upward flow part (Case III)

In this section, the change of pressure differences due to the changes in air tightness of doors around the core (the upward flow part) is analyzed, and simulations to grasp the problem caused by pressure difference are performed. In this study, Tamura's data,[10] calculated by the infiltration area per unit area, are used for the air tightness of elevator doors and staircase doors.

(1) Air tightness of elevator doors (Case III-1)

In order to evaluate the impact on stack effect, air tightness of elevator doors is set at tight (0.020 m^2/m^2), average (0.024 m^2/m^2), and loose

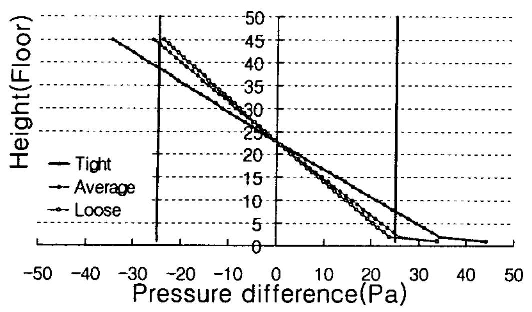


Fig. 7 Pressure differences of elevator door according to air tightness.

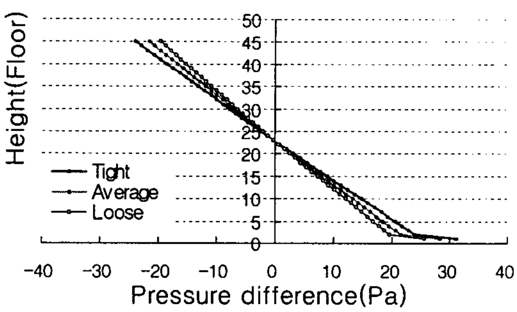


Fig. 8 Pressure differences of staircase door according to air tightness.

(0.028 m^2/m^2) by infiltration area per unit area.

The pressure difference of elevator doors on each floor shows that the lower the air tightness becomes, the less the pressure difference is (See Fig. 7). In the case of buildings higher than 45 stories with average air tightness (tight), it is possible that the problem occurs in the elevator doors of the floors under the 8 F and over the 38 F. This resulted from high air pressure made by air flow through the tight elevator doors, under the situation of no changes in exfiltration through outlets of upper floors and infiltration through inlets of lower floors. There is little decrease of airflow rate, but changes in tightness of elevator doors (the path of airflow to vertical shafts) makes this pressure. It can be explained by the similar phenomenon that installing elevator hall causes an excessive pressure in staircase doors.

(2) Air tightness of staircase doors (Case III-2)

In order to evaluate the impact on stack effect, air tightness of staircase doors is set at tight (0.0087 m^2/m^2), average (0.013 m^2/m^2), and loose (0.018 m^2/m^2) by infiltration area per unit area. The result of the simulation shows that the pressure difference is less than 50 Pa, the standard value, then there is no problem caused by the stack effect, as shown in Fig. 8.

As for changes in pressure difference, similarly in the simulation according to air tightness of elevator doors, it is shown that the lower the air-tightness is, the less the pressure difference is.

3.2.4 Effect from the changes in architectural elements of the outflow part (Case IV)

In this section, for the purpose of evaluating the impact of the outflow part, the simulation is performed to evaluate the impact on stack effect in the case of open and close of a rooftop door which is a main path of upper floors as an outlet on the way of airflow. Also the simulation is performed in case of the installation of opening for natural ventilation in an elevator machine room.

(1) Opening in elevator machine room (Case IV-1)

In order to evaluate the impact of the outflow part by the installation of an opening for natural ventilation in an elevator machine room, the case with the opening in the top side of elevator shaft and the elevator machine room is compared.

In result, the pressure difference of elevator door with an opening increase by 34 Pa, as in Fig. 9. The problem by pressure difference of elevator doors that occurs only up to the 2nd floor in the case with no opening, occurs up to the 5th floor. This is thought to be caused by the increase of inflow at the bottom part of an elevator shaft, just as outflow through an opening at the upper part of an elevator shaft promotes the stack effect. From this result, the reason of elevator door sticking problem on

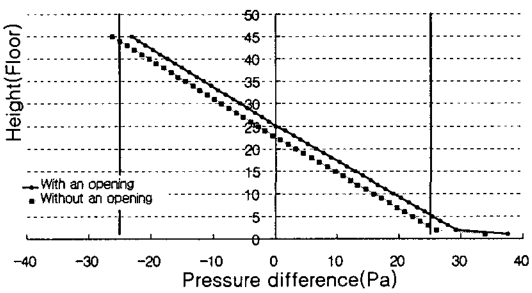


Fig. 9 Pressure differences of elevator door with and without an opening in elevator mechanical room.

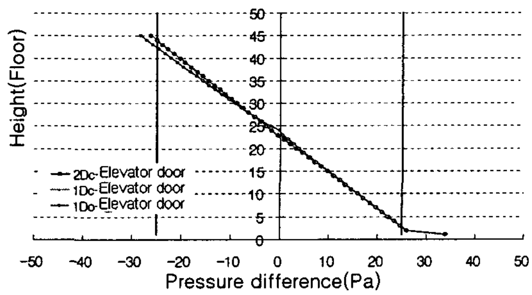


Fig. 10 Pressure differences of elevator door according to opening and closing of rooftop door.

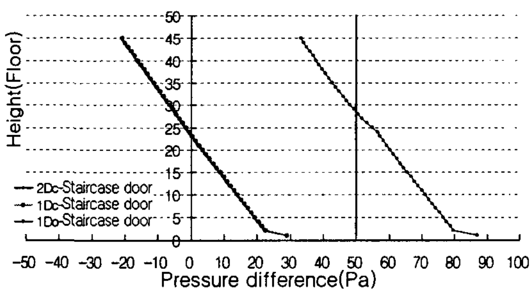


Fig. 11 Pressure differences of staircase door according to opening and closing of rooftop door.

lower floors when doors of upper floors are open can be found. Thus, an opening at the upper part of an elevator shaft is disadvantageous from a viewpoint of the stack effect. Therefore mechanical cooling of elevator machine room by packaged air-conditioner is more desirable than the natural ventilation through the openings.

The detail is required to reduce the outflow to upper part by minimizing the openings between the floor of machine room and the elevator shaft.

(2) Open and close of rooftop door (Case IV-2)

In order to evaluate the impact on stack effect by open and close the door on a rooftop floor, the simulation is performed with the door of a rooftop floor opened (1 Do), with the door closed (1 Dc), and with the doors of vestibule closed (2 Dc).

Fig. 10 shows the pressure difference of elevator doors with both the rooftop door opened and closed. In case of the rooftop door opened, it is found that the pressure difference on upper floors decreases to some extent, but it does not change on the whole. This is thought to be caused by the exit door on the rooftop floor which is linked with the staircase which is separated from the elevator shaft. However the pressure difference of a staircase door on every floor increases excessively when the door of a rooftop floor is opened, as in Fig. 11.

Moreover, it makes such a serious problem that it is difficult to open the door for emergency exit on lower floors because airflow goes from interior toward a staircase in every staircase.

3.2.5 Other effects (Case V)

In this case, the other factors on the stack effect were evaluated such as the number of doors, elevator zoning, and the portion of upper and lower openings, from the 1st floor entrance to the elevator door. The envelope of the model building is set to have average air tightness, and the simulation condition is the same as that of Case II-1.

(1) Number of doors the entrance to the elevator door on the 1st floor

In order to determine the number of zones required to solve the problem made by the pres-

Table 5 Simulation cases (Case V-1)

Case	Vestibule door 1	Main entrance door	Vestibule door 2	Elevator anteroom door
a	×	-DXDX-	×	×
b	-DXDX-	-DXDX-	×	×
c	-DXDX-	-DXDX-	-DXDX-	×
d	-DXDX-	-DXDX-	-DXDX-	-DXDX-
e	-DXDX-	-DX⊗-	×	×
f	-DX⊗-	-DXDX-	×	×

-DXDX- (S+S), -DX⊗- (S+R)
Swing door (S), Revolving door (R)

sure difference according to the airflow through the main path of air inflow (that is, from the main entrance to the elevator shaft of the ground floor), the pressure difference of each door is examined in case that the door for zoning is installed as in Table 5.

Through this simulation, the advantage is examined when elevator hall and the second vestibule door are installed. In case of installing vestibule, it is examined which of two cases (placing the revolving door in front of vestibule and behind the vestibule), is more reasonable from a viewpoint of preventing stack effect.

The pressure difference of swing door is less in case of the vestibule with swing door and main entrance with revolving door rather than the revolving door in the vestibule. Thus Case V-1e is considered to be more desirable than Case V-1f.

Table 6 Pressure difference at each door (Pa, Case V-1)

Case	Vestibule door 1	Main entrance door	Vestibule door 2	Elevator anteroom door	Elevator door
a	·	111	·	·	38
b	54	60	·	·	35
c	36	40	40	·	33
d	23	25	·	95	8
e	75	40	·	·	34
f	36	80	·	·	34

According to the result of the simulation, Table 6 shows that the pressure difference of the elevator door does not decrease profoundly except the case of installing the vestibule. Thus additional zoning such as installation of vestibule is not considered to be effective.

From a viewpoint of stack effect, it is most advantageous that the elevator hall door is placed, for measures of zoning the ground level. Because installing elevator hall reduces the pressure difference of not only elevator door but also the entrance door, consequently it lessens the infiltration through the entrance door.

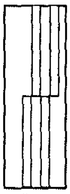
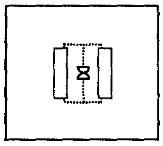
In addition, the pressure difference of each entrance door comes out to decrease more effectively in case of installing elevator hall rather than installing two vestibules in the entrance. Although it is somewhat slight, the pressure difference across swing door is less in case of designing the vestibule with swing door and the main entrance with revolving door than installing revolving door in the vestibule. Thus Case V-1e is considered to be more desirable than Case V-1f.

(2) Elevator zoning

In order to evaluate the influence of stack effect according to the vertical zoning of elevator shaft, elevator banks are divided into the upper part (right bank) and the lower part (left bank) in 45-story building. The simulation was done about four alternatives of elevator zoning (Case V-2a: no zoning, Case V-2b: two banks are zoned into 1st~23rd floor and 24th~45th floor, Case V-2c: lower part is zoned only in 1st~23rd floor, Case V-2d: the lower part is zoned in 1st~23rd floor and the upper part is zoned in 1st~23rd floor and 23rd~45th floor). Table 7 explains each case of the simulation, and the conditions of other buildings are just as in those of Case II-1.

The result of the simulation shows that the elevator door sticking problem, caused by the pressure difference, does not occur if the ele-

Table 7 Simulation conditions (Case V-2)

Case		Zoning of elevator shaft: a	Zoning of elevator shaft: b	Zoning of elevator shaft: c	Zoning of elevator shaft: d	Division of elevator lobby: e	Division of elevator lobby: f
Division of service floor	Left bank	1 F~45 F	1 F~23 F 23 F~45 F	1 F~23 F	1 F~23 F	Case V-2a elevator zoning, division with two banks	Case V-2c elevator zoning, division with two banks
	Right bank	1 F~45 F	1 F~23 F 23 F~45 F	1 F~45 F	1 F~23 F 23 F~45 F		
Concept diagram							

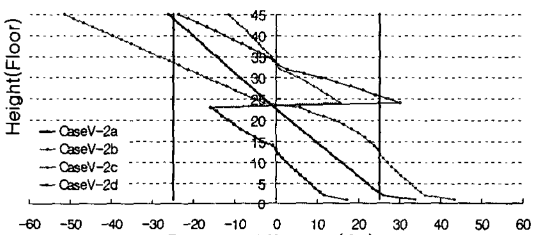


Fig. 12 Pressure differences of elevator door according to zoning of elevator shaft.

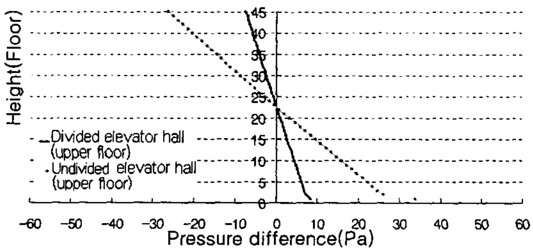


Fig. 13 Pressure differences of elevator door (Case V-2e).

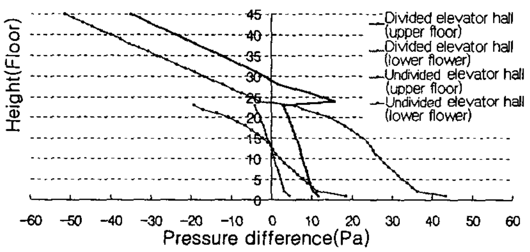


Fig. 14 Pressure differences of elevator door (Case V-2f).

vators are zoned in the general pattern as shown in Fig. 12, and the pressure difference of elevator door in elevator bank of the upper part increases excessively. Among the cases, zoning strategies that make no problem on the pressure difference of elevator door, are Case V-2b and Case V-2d.

Fig. 13 and Fig. 14 show the results of the simulation for the case with and without zoning the elevator lobby in order to solve the problem on the pressure difference of elevator door (Case V-2a and Case V-2c).

The result shows that the pressure difference of elevator doors in the upper elevator bank of Case V-2c is the potential problem only on the upper 5 floors. However, most floors do not make any problem.

(3) Opening size of the upper and the lower part (Case V-3)

In this simulation, it is examined how the pressure distribution in a building changes if there is a large opening on the highest and lowest floor respectively. Simulation for evaluating the consequent problems is performed.

1) Large opening on the highest floor (Case V-3a)

In case of a large opening as in Fig. 15, the profile of indoor pressure approaches to that of outdoor pressure. Elevator door sticking pro-

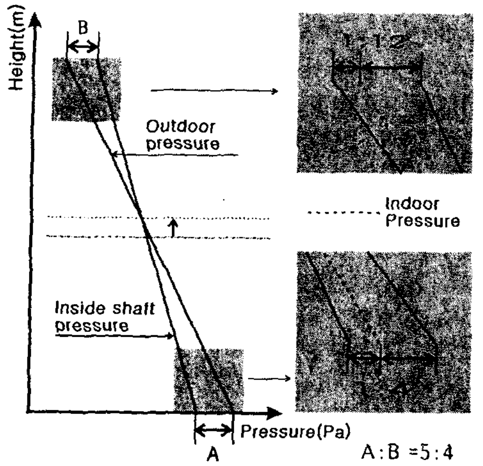


Fig. 15 Pressure distribution with large opening on the first floor (Case V-3a).

blem is expected and it is thought to be hard to open the staircase door because the pressure difference between a vertical shaft and indoor space increases a lot. On the opposite side of the large opening, much pressure difference is developed on the external wall because the profile of indoor pressure approaches to that of the shaft.

2) Large opening on the lowest floor (1st floor)

If there is large opening on the first floor,

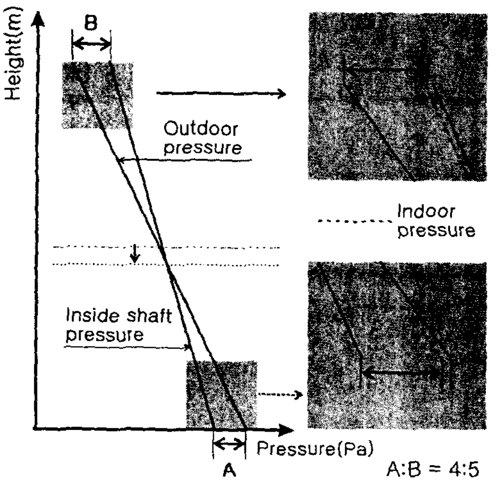


Fig. 16 Pressure distribution with large opening on the first floor (Case V-3b).

the pressure is so high that rooftop doors or the windows on upper floors cannot be closed. The elevator door sticking problems on the lowest floor happen, because of the high pressure on the door (See Fig. 16).

According to the result of the simulation, it is important to make both of the upper and lower floors air-tight. However, because there are more openings on the lower floors in general buildings, it is useful to shift neutral pressure level to the half of the building's height by making the lower floors air-tight so that the pressure difference may be decreased.

4. Conclusion

In this study, stack effect is examined for central-core-type building through network model simulation. The results are summarized as follows.

(1) In the buildings with air-tight envelope, the elevator door sticking problems occur above the 50th floor (about 230 m), and there is no problem on the staircase door. In the buildings with average air tightness, the elevator door sticking problems occur above the 23rd floor (about 100 m), and the problem on the staircase door occurs above the 39th floor (about 180 m).

(2) In case of installing the vestibule or elevator hall, the problems caused by the stack effect can be settled to the height of the 28th story (about 120 m) in usual office buildings.

(3) As the air tightness of the elevator door gets lower, the pressure difference of elevator door turns out to be lower. In 45-story building (about 200 m) that has average air tightness, the elevator door can make problems under the 8th floor (40 m) and above the 38th floor (179 m) if the infiltration through elevator doors is not so much.

(4) It is advantageous that opening is not made at the upper part of elevator shaft, because it is unfavorable in terms of stack effect. It can be seen that the pressure difference on

each floor increases excessively.

(5) When the first floor is zoned, the stack effect can be lessened by placing elevator hall door and zoning the floor adequately.

Acknowledgement

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References

1. Korea Facility Management Association, 2000, Final Report of Impact Analysis on Stack Effect in Suwon Hwasung Tower.
2. Tamura, G. T. and Wilson, A. G., 1967, Pressure differences caused by chimney effect in three high buildings, ASHRAE Transactions, Vol. 73, Part 2.
3. ASHRAE, 1993, Field verification and simulation of problems caused by stack effect in tall buildings, ASHRAE Research Project 661, p. 33.
4. Lovatt, J. E., 1994, Stack effect in tall buildings, ASHRAE Transactions, Vol. 100, Part 2.
5. Tamblyn, R. T., 1991, Coping with air pressure problems in tall buildings, ASHRAE Transactions, Vol. 97, Part 1, p. 826.
6. Tamblyn, R. T., 1993, HVAC system effects for tall buildings, ASHRAE Transactions, Vol. 99, Part 2.
7. Walton, G. N., 2000, CONTAMW-User manual, NISTIR 6476, National Institute of Standards and Technology.
8. Korea Facility Management Association, 2001, Development of Architectural Design Guideline against the Stack Effect in High-rise Buildings.
9. ASHRAE, 1997, ASHRAE Handbook Fundamentals, ASHRAE, Atlanta, GA, p. 25.19.
10. Tamura, G. T., 1994, Smoke Movement and Control in High-Rise Buildings, National Fire Protection Association, Quincy, Massachusetts, pp. 38-41.