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Influence of Architectural Elements on Stack Effect Problems in Tall Residential Building

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Abstract

Many studies have been done on the problems caused by the stack effect in office buildings, and several solutions have been proposed. There have also been reports of problems arising due to stack effect in tall residential building, however, it is not well known where exactly and how extensive, these problems are in such building. The tightness of architectural elements that comprise a building is known to be the important parameters in minimizing the stack effect problems; how a building is designed can affect the extent of the pressure difference caused by stack effect. To verify this, we surveyed two buildings having different phases of stack effect problem through drawing examinations and field examinations, and conducted field measurements on these buildings. Through these processes, the authors verified the problems caused by stack effect and the influence of the building designs on the extent of such problems. Finally, this paper presents the elements that require tightening in order to prevent the problems caused by stack effect from occurring in tall residential buildings.

Keywords: stack effect, field measurement, tall building, tightness

1. Introduction

In recent years, many tall residential buildings have been constructed in Korea recently. These buildings comprise of over 30 or 40 floors and due to this height, they form a tall air column inside the building and another outside. During the winter season, the differential weight of these two columns of air, where if one is warm the other is cold causes a pressure difference between the inside and outside of the building. This brings about the so-called stack effect.

It is known that there are many problems caused by the stack effect such as elevator door sticking problem, washroom exhaust imbalance, air leakage, difficulty in opening doors, noise resulting from air flowing through cracks, and so forth. Thus, many studies have been done to solve these problems in office buildings, and several solutions have been proposed. In the office building, as there is usually no compartment between the core and working area one possible solution could be improving the airtightness of the exterior wall[1][2]. For this reason, the National Association of Architectural Metal Manufacturers set a limit on the maximum leakage per unit of exterior wall area as 1.10 CMH/m^2(0.06 CFM/ft^2) at pressure difference of 75 Pa(0.3 in. of water), exclusive of leakage through operable windows[3].

However, in the case of residential buildings, as residents of residential buildings demand for openable windows which they can use even during the cold season, it makes it that much more difficult to maintain airtightness of the envelope of residential building of the same level as that of office building with fixed windows[4]. Therefore, improving just the airtightness of the envelope is not a viable solution resolving the problems due to stack effect in tall residential buildings. Since, tall residential building consist of many units surrounding the core, the pressure profile of the tall residential building appear differently from that of office building. Accordingly, the problems caused by stack effect would differ as well and thereby requiring different approaches to be developed for resolving such problems in tall residential buildings.

The main objective of this study is to obtain the actual pressure difference across the architectural elements (exterior wall, entrance door, elevator door) in tall residential building as a preliminary examination to develop the guideline to prevent the stack effect problems.

In this paper, we will begin by discussing the various problems that exist due to pressure difference and how architectural designs influence the extent of such problems.

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2. Survey

2.1 Survey Outline

We conducted surveys on two test buildings beginning from December 2003 to February 2004.

First, the architectural drawings were examined to identify where the problems due to stack effect could occur. We particularly focused on the entrance doors, especially when the door is connected to outside, on each floors and core area were checked mainly.

After examining the drawings, we conducted field investigations of the two test buildings several times during the winter season. We verified suspected problems and measured the airflow rate. Finally the quality of construction of the two test buildings with respect to airtightness was evaluated.

2.2 Building Descriptions

Two newly built tall residential buildings in Seoul were selected as the test sample for our field measurements. The test buildings that were selected were both built recently and have similar type of envelope. However, it was reported that the two buildings had different problems due to stack effect in different places. The information on these two buildings are given in Table 1.

Building A(40 story) and building B(69 story) are both residential buildings; typical floor plans and sections of each building are given in Fig.2 and Fig.3, respectively, which has been simplified to show the zone easily (i.e. each residence is regarded as a single zone).

Both buildings A and B have two main mechanical equipment floors. In building A, one is at the top floor and the other on the 8^{th} floor, and in building B, one is on the 16^{th} floor and the other on the 55^{th} floor. HVAC systems and exhaust fans for washrooms are also located on these floors.

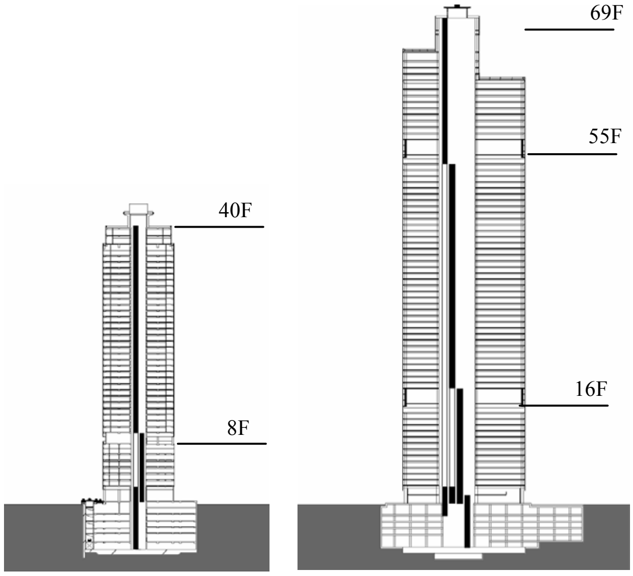
There is no vertical zoning in the elevator shaft in building A; the elevators are serving all floors (B5 to 40F). In building B, there are 4 vertical zones of elevator shaft, which are shuttle elevator (B5 to 1F), low-rise elevator (1F-15F), middle-rise elevator(1F, 2F, 16F to 54F), and high-rise elevator(B1-2F, 54F-69F).

Table 1. Building description

	Building A	Building B
Location	Seoul	Seoul
Structure	SRC	SRC
Height	146 m	263 m
No. of floors above ground	40	69
No. of basement floors	5	5
Exterior walls	Al. Curtain Wall + pair glass	Al. Curtain Wall + pair glass
Date of completion	2003.12.	2004.2.

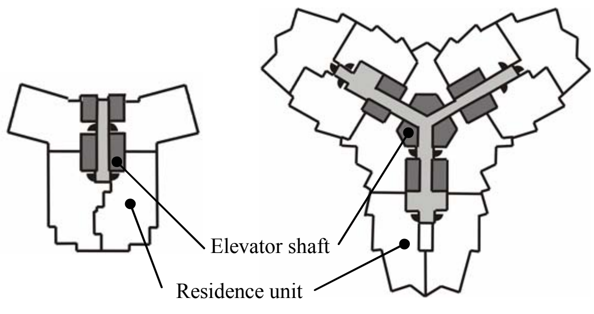
Building A Building B

Fig. 1. Two test buildings



Building A Building B

Fig. 2. Vertical zonings of two test buildings



Building A Building B

Fig. 3. Typical plans of two test buildings

2.3 Survey Results

a. Examination of architectural drawings

To minimize the problems caused by stack effect, the airtightness of whole building must be improved. It is very important to reduce the inflow and outflow of air, thus, design of architectural factors which can decrease the airflow should be considered.

Table 2. Comparison of architectural plan of building A and building B

	Location	Building A	Building B
Inflow part	Entrance on basement floor	-Not installed(vestibule) + Automatic door(entrance)	-Swing door(vestibule) + swing door(entrance)
	Main entrance on 1st floor	-Swing door(vestibule) + automatic door(main entrance)	-Swing door(vestibule) + revolving door (main entrance)
	Elevator hall on 1st floor	-Automatic door installed	-Swing door installed
Upward part	Elevator shaft	-3 Passenger elevator serving all floors, B5-40F	-3 shuttle elevator serving B5 to 1F -4 high-rise elevator serving B1 to 2F and 54F to 69F -9 middle-rise elevator serving 1F, 2F, and 15F to 54F -4 low-rise elevator serving 1F-15F
	Stairwell shaft	-Serving all floors, B5 to 40F	-Serving all floors, B5 to 69F
	Mechanical shaft	-No caulking work on slab penetration part	-Caulking work on slab penetration part
Outflow part	Elevator air hole	-Elevator air hole on the shaft wall -Ventilation fan for elevator machine room	-No elevator air hole -Ventilation fan for elevator machine room
Envelope	Condenser room in residence unit	-Double weather strip installed on the door	-Triple weather strip installed on the door
	Exterior wall	-Aluminum curtain wall + pair glass -Manual operating window	-Aluminum curtain wall + pair glass -Automatic operating window

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) [5] as shown in Fig.4. Architectural drawings of buildings A and B were examined from this point of view as shown in Table 2.

For the most part, we found that building B was more airtight than building A.

On the 1st floor which is the inflow part, the doors for elevator hall are installed at both test buildings, and no conspicuous difference is observed except that building B has revolving door installed while building A has automatic door at the main entrance.

However, there are some differences between the two buildings at the entrance for the parking lot on the basement floor; vestibule with double swing door is installed in building B, while only single automatic door and no vestibule is installed in building A.

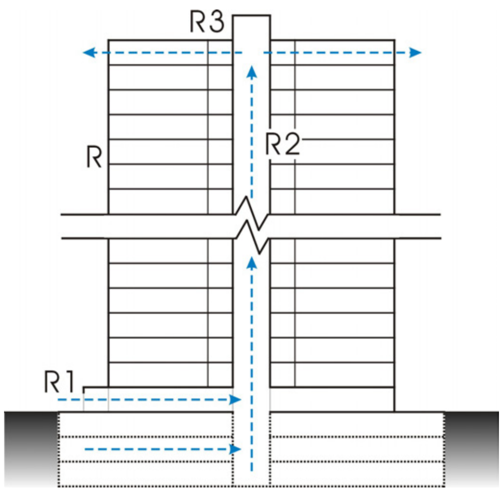


Fig. 4. Diagram of airflow path due to stack effect

There is also a distinction between elevator zonings of the two test buildings which is upward flow part. In building B, 4 different elevators, namely, a shuttle elevator, low-rise elevator, middle-rise elevator, and high-rise elevator serve the basement floors, low part, middle part and high part of the building separately. In building A, however, 3 passenger elevators serve the entire residential floors from the 5th basement floor to the 40th floor.

The doors in the machine room at the top floor are one of the essential outflow paths from the inside to the outside of the building. That is, these doors need to be sufficiently airtight in order to prevent stack effect problems from occurring. In building B, one needs to go open two or three airtight doors to go to rooftop, whereas in building A, there is only single loose door that need to be opened.

b. Field Examination

During the winter from December 2003 to January 2004, the authors conducted several field examinations of the two test buildings. Based on these examinations, the author was able to be verify the extent and locations on the problems caused by stack effect which we had anticipated during the architectural drawing examination.

In building A, as shown in the architectural drawings, the entrance of the parking lot on basement floor was compartmentalized by a single automatic door without vestibule, which allowed only little airflow to pass through with some noise. There was also loud noise exceeding 60 or 70 dB at the elevator doors on the lower floors and entrances for residence on higher floors.

Although building B was constructed more tightly than building A, a slight noise resulting from air flowing through elevator doors was heard on lower

Building A Building B

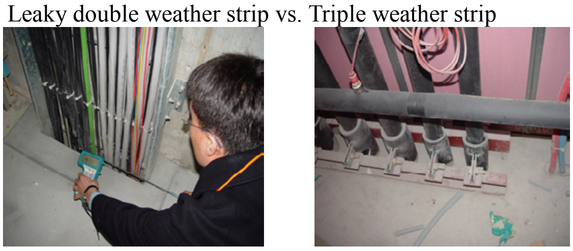
Fig. 5. Entrance for parking lot on basement floor (inflow part): Leaky automatic door vs. Double airtight swing door

Building A Building B

Fig. 6. Door for elevator hall on 1st floor(inflow part): Leaky automatic door vs. Airtight swing door

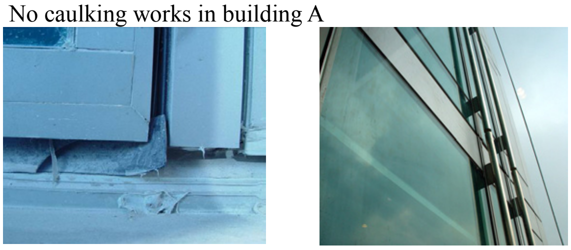
Building A Building B

Fig. 7. Door for condenser room(upward part): Leaky double weather strip vs. Triple weather strip



Building A Building B

Fig. 8. Electrical pipes through the slab(upward part): No caulking works in building A



Building A Building B

Fig. 9. Exterior wall(outflow part): Noticeable difference of construction qualities

Building A Building B

Fig. 10. Ventilation fan for Elev. machine room(outflow part) Leaky fan vs. Fan with airtight damper

floors. Particularly on the transfer floor (55th) where passengers can transfer to high-rise elevator from middle-rise elevator, airflow from middle-rise elevator shaft to high-rise elevator shaft was detected, and there were some noises caused by this airflow.

Additionally, the two test buildings were compared in terms of the quality of the construction based on some architectural elements that can be an essential airflow path due to stack effect. The two buildings differed significantly as shown in Fig.5 to Fig.10.

In building A, there are numerous pipes and electric lines passing through the upper part of the entrance doors for the parking lot on the basement floor. Without caulking work, this part can be a main inflow path of outside air entering from the parking lot which in turn can influence the pressure difference of the whole building.

In building B, triple weather strip was tightly installed on the door for multi-air-conditioner condenser room, while double weather strip was installed with some gap at the corner of the door in building A.

3. Field Measurement

3.1 Outline of field measurement

Field measurement was carried out on several occasions in January 2004 to verify the problems caused by stack effect and to obtain the pressure profile of the building. Absolute pressures of essential zones on the airflow path; for example the elevator shaft, hallway, residence unit, and outdoors, were measured. The authors measured the absolute pressure of zones on single floor simultaneously going down from top to bottom of the building; pressure differences were calculated by these absolute pressure data.

Field measurement was carried out at dawn under mild but cold weather to minimize the influence of exterior conditions such as a sudden gust of wind, elevator use of dwellers, opening of entrance door, and so forth.

3.2 Field measurement results

Among the various measurement results, one with least affected by exterior influence is shown in Fig.11 and Fig.12. The y-axis shows the pressure of elevator shaft, and each line represents the pressure difference from elevator shaft pressure. For example, “a” in Fig.11 is the pressure difference between the outside and inside the residence, which in other words is the pressure difference of the exterior wall.

Although, building A is lower than building B by over 100 m, building A apparently displays serious problems due to stack effect. It should be noted that the pressure difference of the residence entrance door is bigger than that of exterior wall for both test buildings.

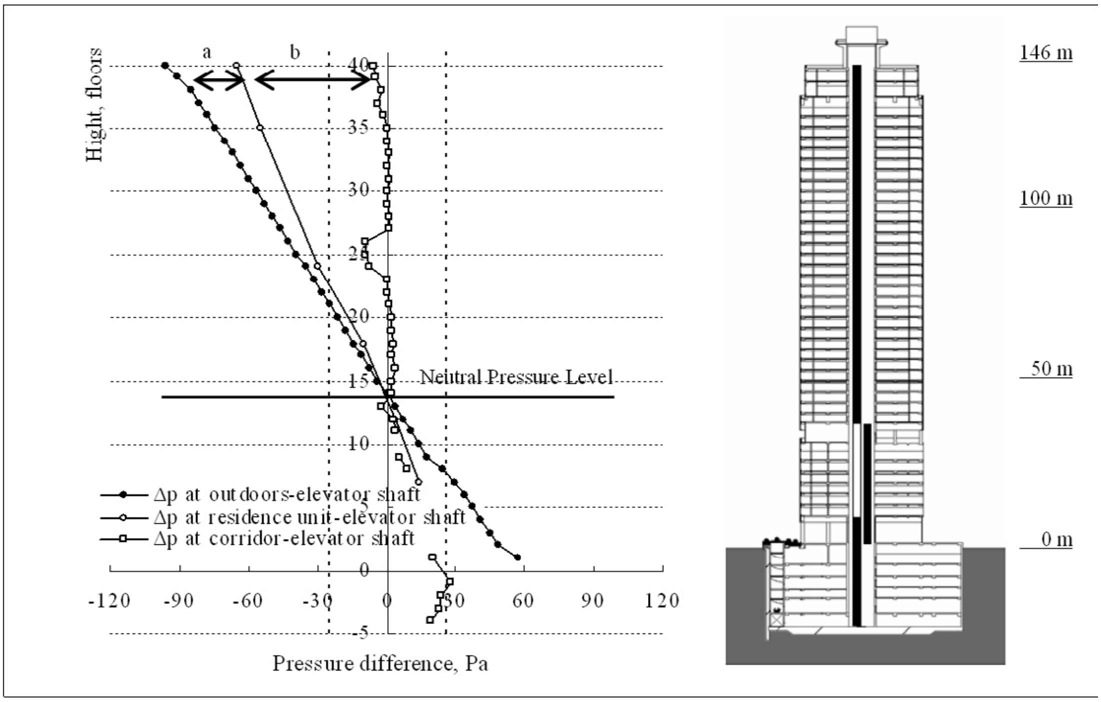


Fig. 11. Field measurement results of building A

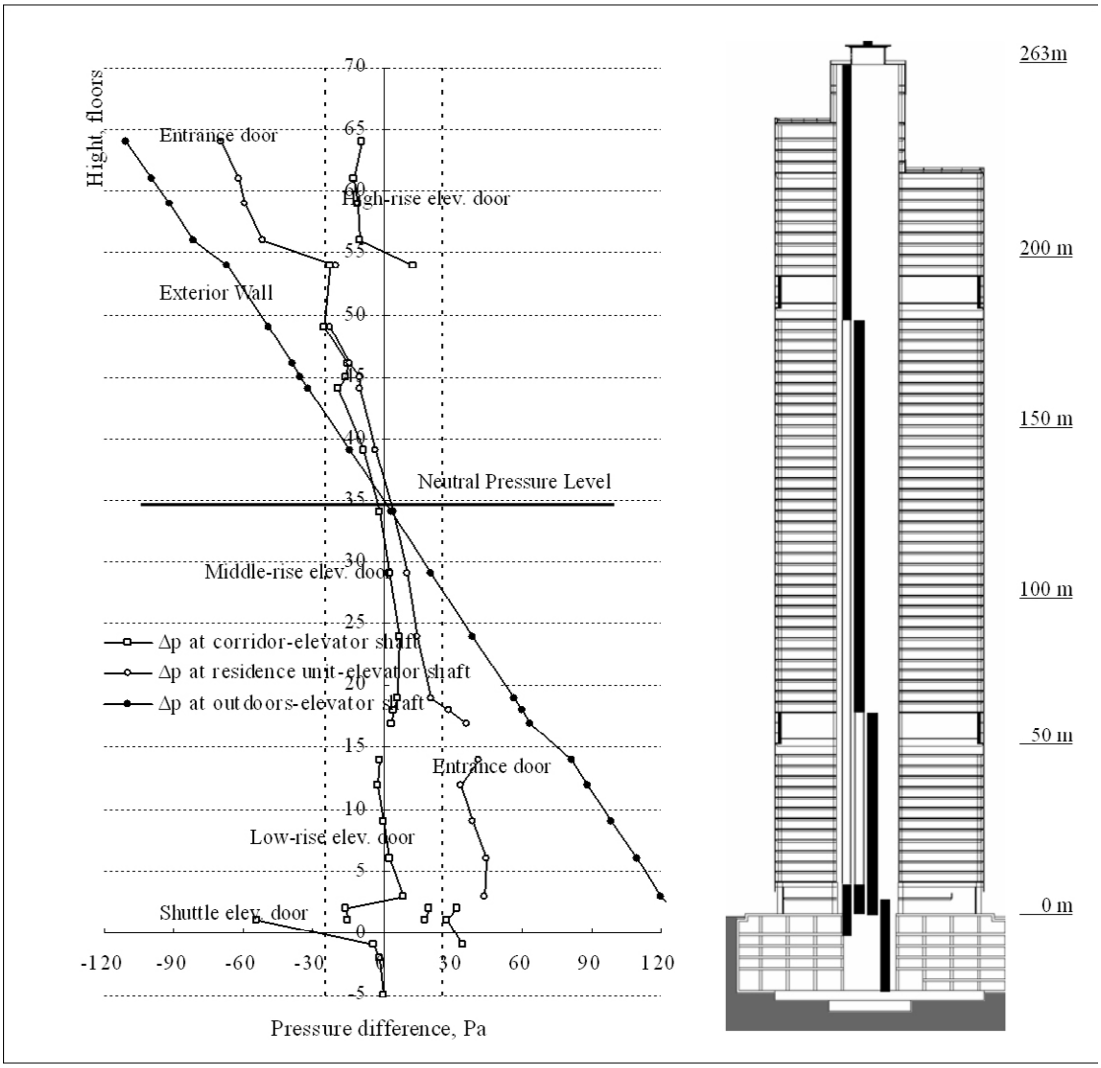


Fig. 12. Field measurement results of building B

a. Building A

As shown in Fig.11, elevator door has no significant problem on most floors; however, pressure differences are relatively high of almost 25 Pa on most basement floors. On the 1st basement floor, the pressure difference was over 25 Pa; problems such as elevator door sticking problem and noise may occur under this kind of pressure difference.

Pressure difference at the residence entrance ("a" in the Fig.11) can be sent to be twice as big as that of the exterior wall("b" in the Fig.11). On the 35th floor, for example, the pressure difference at the entrance door is about 50 Pa, while that of exterior wall is about 25 Pa. the entrance doors at higher part of the building having a pressure difference of over 50 Pa cause difficulties in opening doors and will cause serious problems under emergency conditions.

The height of the Neutral Pressure Level (NPL) was lower than the center of the building height, such that pressure difference at entrance door and exterior wall increased at the higher part of the building than at the lower part. This in turn means that the bottom of the building experienced more leakages.

b. Building B

In building B, different types of elevators separate the elevator shaft vertically and serve each part of the building(as shown in Fig.11): the upper part, the middle part, lower part, and basement part of the building. For this reason, the pressure difference of elevator doors in building B is generally lower than that of building A.

There are two floors where more than one elevator meets together. These are transfer elevators which passengers use to transfer to the other elevator. One is on the 1st and 2nd floor where the lobby is, and the other is on the 55th floor where passengers can transfer to high-rise elevator from middle-rise elevator. On these floors, the pressure difference of the elevator door is more than 25 Pa which is over the standard limit. This may cause the elevator door to not operate well. Particularly, on the 55th floor, air flows from the middle-rise elevator shaft to hallway then into high-rise elevator shaft, causing low noise to be heard constantly during the field measurement.

Pressure difference at the entrance door in building B was not as great as in the building A; We observed similar aspects in that there were more pressure difference at the entrance door than on exterior wall.

4. Discussion

Problems at the residence entrance door and at the elevator door were verified by the field examinations and field measurements; these problems are caused by excessive pressure difference due to stack effect.

Since, there are interior wall and entrance doors surrounding the core area, compartmentalizing residential area and common area can form an airtight air barrier there reduces the difference in pressure that acts on these air barriers of the building. If the entrance door or the elevator door is open when the pressure is acting on it, excessive pressure will act on the other closed door, which may cause serious problems. In order to solve those problems, it has been suggested that vestibules be installed around the elevator hall to create resistance to airflow from the shaft to each floor[6].

The reason why problems were observed on higher floors of the two test buildings is that airflow on lower floors increases because there are parking lots on the basement floors. Without sufficient compartment on these floors, great amount of air will flow in and this can lower the Neutral Pressure Level of the building. The problems caused by pressure difference on higher floors increase if the Neutral Pressure Level of the building is lowered. To prevent this, vertical zoning is needed such as shuttle elevator in building B which can restrict great amount of airflow passing from the basement floor into passenger elevator shaft.

In building B, there were several problems on lobby floor(1st floor) and transfer floor(55th floor); on these floors, more than two elevator shafts with different height serves these floors. The difference of the shaft's height brings about a difference in the buoyancy force, which in turn causes pressure difference between two shafts. Therefore compartmentalizing the hall between these two shafts will help break up the pressure differential at the elevator door, thereby reducing pressure difference.

5. Conclusion

In this paper, stack effect problems in tall residential buildings were discussed by analyzing the results of pressure profiles obtained through field measurements of two test buildings.

As shown in the field measurement results, several problems due to excessive pressure difference caused by stack effect was found to occur near the core area: entrance door for residence unit and elevator door. Mostly, the problems occurred at the elevator door at the lower part of the building (lobby floor, basement floors) and at the residence entrance door on higher part of the building.

High buildings tend to experience more stack effect problems than low buildings; however, building B showed lesser problems due to stack effects because of the architectural aspects of the building that were designed in such a way to overcome such problems: improving airtightness of entrances on lower part of the building, vertical shaft zoning, and efforts to achieve airtightness of whole building during construction.

These efforts at the design and construction stage are an efficient way to prevent the problems caused by stack effect from occurring.

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