The 2014 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM14)
Busan, Korea, August 24-28, 2014

A Proposal of Heating Load Calculation considering Stack Effect in High-rise Buildings

*Doosam Song[1] and Tae-Hyuk Kang[2]

[1] *Department of Architectural Engineering, Sungkyunkwan University, 2066 Seobu-ro, Jangan-gu, Suwon, 440-746, Korea*
[2] *Civil and Architectural Engineering Part, Samsung Heavy Industries Co. Ltd., 74-gill 4 Seocho-daero, Secho-gu Seoul, 137-955, Korea*

[1] *dssong@skku.edu*

ABSTRACT

With the building height is higher, the possibility of stack effect increases. Stack effect is the air movement in the building, caused by temperature (or pressure) difference between indoor and outdoor air. When the temperature difference between indoors and outdoors is become large, the outdoor air flows into indoors at the lower floor through air-leakage of building envelope and doors. The air moved to upper level thorough shaft space and flowed into indoors. Stack effect arouses the related problems such as strong wind from doors, unpleasant noise, malfunction in opening and closing of the elevator and hall door, troublesome in controlling indoor temperature and ventilation system. Also, increase the building heating load or energy demand.

But, conventional building heating load calculation method cannot consider the effect of stack effect and it may result in low-efficiency in heating. In this paper, heating load calculation method considering stack effect in high-rise residential building was suggested. The proposed method was validated by comparison between the actual energy usage data and simulation results. The result shows that the proposed heating load calculation method was more matched than that of the conventional calculation method.

1. INTRODUCTION

Due to the concentration of population in urban areas, high-rise residential buildings have been increasing in number recently. Many problems that have not appeared in low-rise residential buildings are appearing in high-rise residential buildings. Among them, a representative one is stack effect. Stack effect refers to air movements in buildings, in particular, vertical air movements due to temperature and density differences between indoor and outdoor atmospheres. Although it appears in summer

---

[1] Professor
[2] Researcher

too, it appears prominently in winter when differences between indoor and outdoor temperatures are large. Since stack effects affects residential performance with noises, strong air currents, and difficulties in opening/closing doors or elevator doors among others, many countermeasures have been devised to reduce stack effects in high-rise buildings that have been built recently (Lee, 2010). However, these countermeasures can not fundamentally solve the problem of stack effect although they can reduce the intensity of expression of stack effect a little.

The most fundamental problem in high-rise buildings caused by stack effect is the inflow of large amounts of outdoor air into indoor areas. This can cause problems such as excessive heating loads in winter and improper operations of ventilating systems or air conditioning systems due to excessive pressure. However, countermeasures against stack effect made thus far have mainly focused on only solving the problem of low residential performance related to noises and air currents, etc. that can be perceived by occupants.

This study is intended to analyze the effects of inflows of large amounts of outdoor air in winter due to stack effect on heating energy demand in high-rise residential buildings. The analysis will be conducted on a high-rise multi-residential building because room cooling loads occur even in winter in the case of high-rise office buildings since internal heating ratios are high in these buildings.

In this study, with a view to considering stack effect in calculating heating loads, limitations in existing heating load calculation methods will be defined and a new method of calculating heating loads that will solve the limitations will be presented. In addition, actual energy usage data by floor in analyzed high-rise buildings was gathered to compare the results of calculations using existing methods and the results of the proposed method considering stack effect.

2. HEATING LOAD CALCULATION METHOD CONSIDERING STACK EFFECT

2.1 Existing heating load calculation method

Heating load calculation methods for multi-residential buildings currently in use are generally two methods; a unit household method and a unit building method. In these two methods, the same equations are used to calculate heating loads. Among the equations for calculating heating loads, equations for calculating the loads generated by air movements between indoor and outdoor areas, that is infiltration loads are defined as follows:

$$q_s = c_p \cdot \rho \cdot Q(T_o - T_i) \quad (1)$$

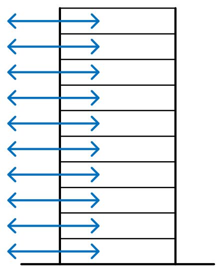
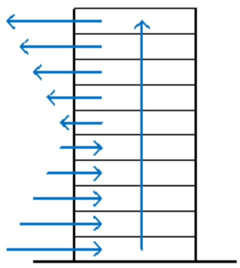
$$q_l = h_{fg} \cdot \rho \cdot Q(x_o - x_i) \quad (2)$$

$$q = q_s + q_l \quad (3)$$

where q_s is sensible infiltration load [kcal/h], q_l is latent infiltration load [kcal/h], c_p is specific heat under constant pressure [kcal/kg·^{o}C], ρ is air density [kg/m^3], Q is infiltration rate [m3/s], h_{fg} is enthalpy of evaporation [kcal/kg], x_o is specific humidity of outside air [kg/kg'], x_i is specific humidity of indoor air [kg/kg'], T_o is air temperature of outside [^oC], T_i is air temperature of inside [^oC]

As shown in Table 1, conventional heating load calculation methods define infiltration rates based on differences in temperatures and humidity between indoor and outdoor areas and calculate infiltration loads through sensible infiltration loads and latent infiltration loads obtained using the infiltration rates. However, conventional infiltration load calculation methods have a limitation of being unable to express differences in infiltration rates among floors, changes infiltration rates by floor resulting from vertical air movements inside the building. In the case of high-rise residential buildings in which stack effect cannot be ignored. However, changes in heating loads due to the inflows of outdoor air and the vertical air movements caused by stack effect cannot be considered through existing infiltration calculation method.

Table 1 Concept of the heating load calculation method

Heating load calculation	Conventional method	Proposed method
Concept		
Infiltration in heating load calculation	-constant air flow by pressure difference between indoor and outdoors -airflow at every floor is constant -vertical airflow in building is not considered.	-airflow caused by stack effect -airflow at every floor is not constant -vertical airflow in building is considered.

2.2 Calculation of heating loads considering stack effect

The equation of pressure differences that induce stack effect in buildings that will affect the calculation of heating loads can be defined as follows.

$$\Delta P_s = (\rho_o - \rho_i) g (H_{NPL} - H) \tag{4}$$

Where ΔP_s is pressure difference by stack effect [Pa], ρ_o, ρ_i is outdoor and indoor air density [kg/m^3], g is acceleration due to gravity [9.8m/s^2], H_{NPL} is height at neutral pressure level [m], H is height at target level [m]

To change equation (4) into an equation to determine the relationships between pressure differences and temperatures, equation (5) can be substituted into equation (4) using the fact that density change rates are the same as absolute temperature changes and the resultant equation is equation (6).

$$(\rho_o - \rho_i)/\rho_i = (T_i - T_o)/T_o \tag{5}$$

$$\Delta P_s = \rho_i (\frac{T_i - T_o}{T_o}) g (H_{NPL} - H) \tag{6}$$

In equations (1) and (2) above, infiltration rate can be expressed as equation (7).

$$Q = C_D A \sqrt{2\Delta P / \rho} \tag{7}$$

Where Q is infiltration rate [m^3/s], C_D is discharge coefficient [-], A is leakage area [m^2], ΔP is pressure difference [Pa]

If equation (6) for pressure differences resulting from stack effect is substituted in equation (7), infiltration rate in the lower part (Q_{low}) based on the neutral zone will be as follows.

$$Q_{low} = C_{Di} A_i \sqrt{2g\Delta(H_{NPL} - H)(T_o - T_i)/T_o} \tag{8}$$

Also, the infiltration rate in the upper part (Q_{hi}) based on the neutral zone will be as follows.

$$Q_{hi} = C_{D\,j} A_j \sqrt{2g\Delta(H_j - H_{NPL})(T_{core} - T_i)/T_{core}} \tag{9}$$

Therefore, if the heating load (sensible heat) resulting from air infiltration in the upper part and lower part of the neutral zone is to be calculated using the basic formula (1), the following equation should be

$$q_{s-hi} = c_p \cdot \rho \cdot Q_{hi} (T_{core} - T_i) \tag{10}$$

$$q_{s-low} = c_p \cdot \rho \cdot Q_{low} (T_o - T_i) \tag{11}$$

Also, the same concept can be used to calculate the latent heating load caused by infiltration with stack effect.

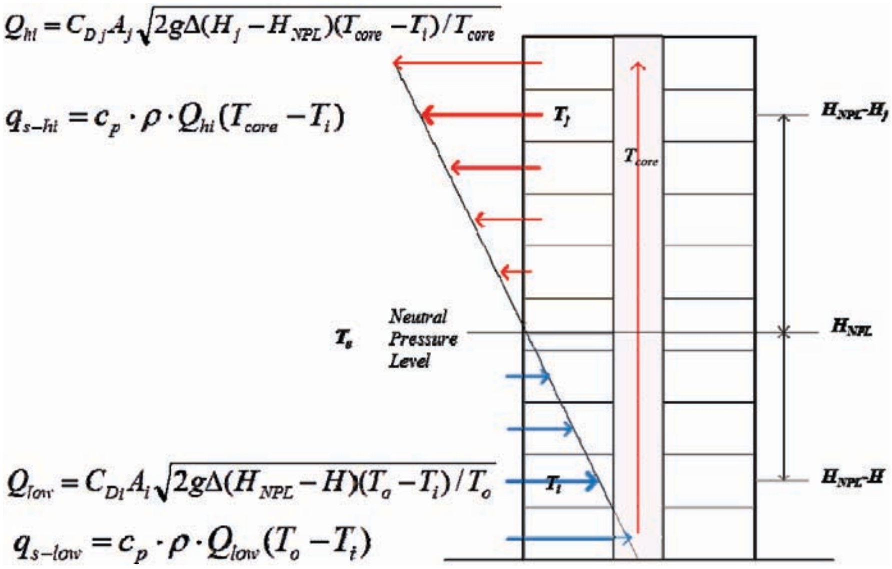


Fig. 1 Heating load calculation considering the stack effect in high-rise residential building

3. CASE STUDY

3.1 Overview of the simulation

To analyze the stack effect on heating load in high-rise residential building, VE (IES Virtual Environment) simulation program was used that enables understanding the characteristics of air movements as well as analyses of energy consumption. An outline of the analysed building is shown in Table 2 and Fig. 2.

In the simulation, the results of calculation of heating loads (energy) using the existing heating load calculation method and the results of the proposed calculation method were compared with actual heating energy usage data in the analysed building. The simulation period was three months from December to February corresponding to winter in Korea.

Table 2 Outline of the analyzed building

Index	Contents
Building type	Tower type
Size	2 basement floor 32 ground floor (107m)
Floor composition	· Central core · 5 houses in 1 floor · E/V shaft : 2ea · Stair : 2ea
Layout	Southeast

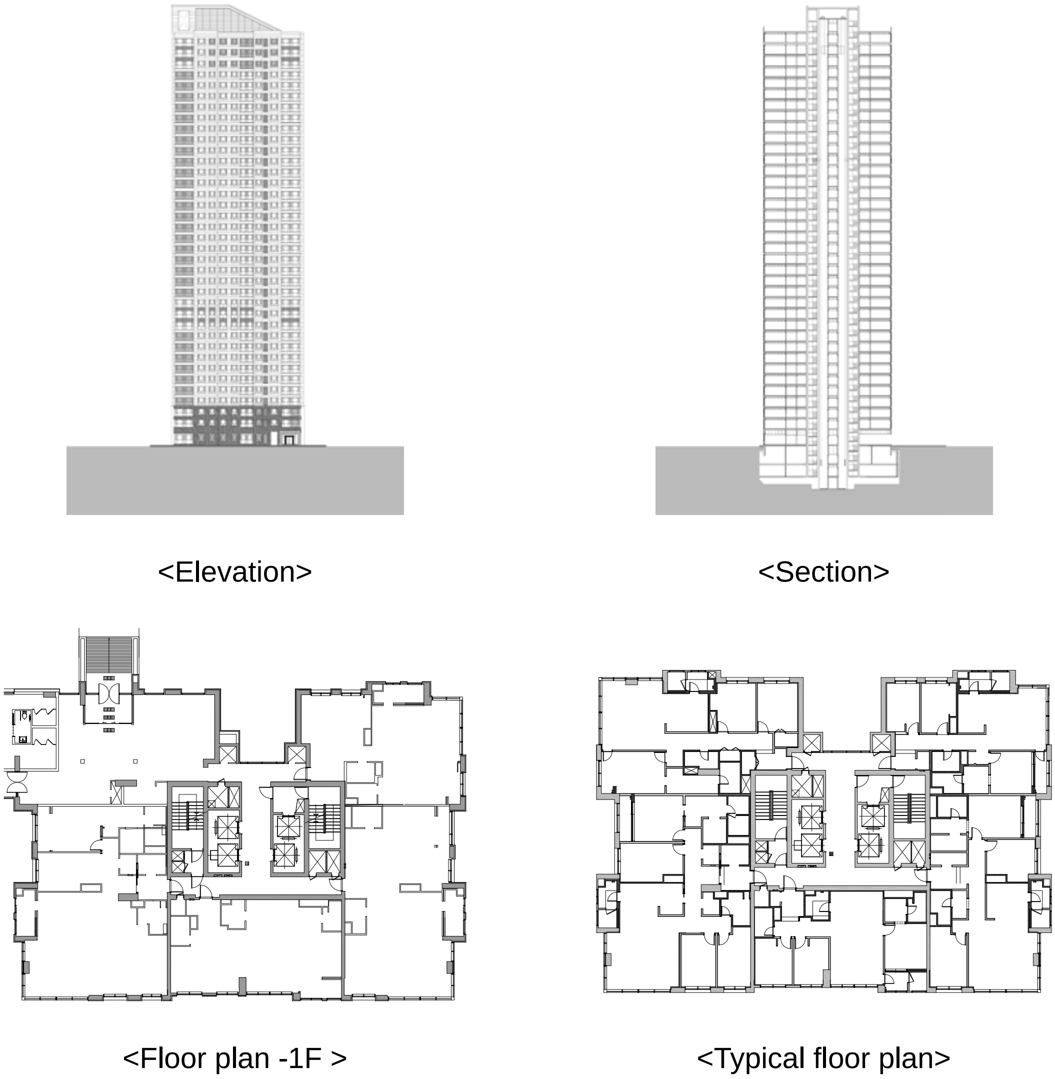


Fig. 2 Analyzed building

3.2 Simulation results

Fig. 3 shows the comparisons between actual energy consumption and simulation results in the analysed apartment building during January. The simulation results were obtained using the conventional heating energy calculation method (without stack effect) and the proposed calculation method (with stack effect) in this study.

The heating load (energy) calculation method presented in this study that considers stack effect shows results closer the actual heating energy consumption in the analyzed building compared to the conventional method that considers only the infiltration roads by unit household.

NMSE(Normalised Mean Square Error) (Emmerich, 2001) which is a method of evaluating errors in simulation results compared to actually measured values was calculated. According to the results, the NMSE of the conventional heating road(energy) calculation method was 0.15 and that of the proposed calculation method considering stack effect was 0.08 indicating that the results of the proposed calculation method involve smaller errors compared to the conventional method.

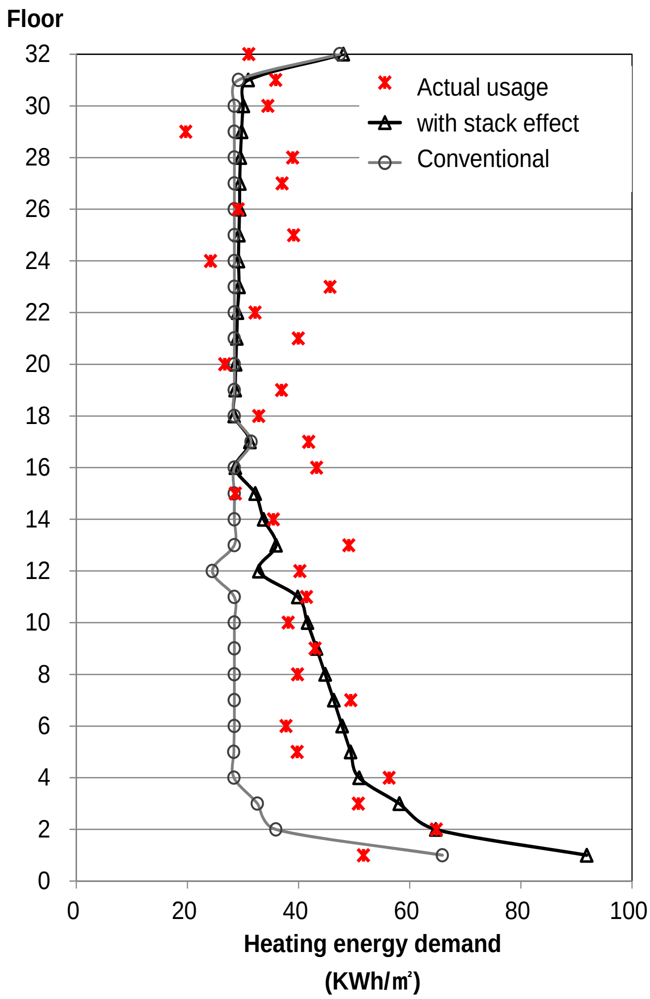


Fig. 3 Heating energy demand (actual usage, with or without stack effect(conventional))

Table. 3 Comparison between actual usage and simulation results

Case	Heating energy demand (MWh)	(%)
Actual energy usage	610.37	100
with stack effect	583.26	95.6
Conventional	466.98	76.5

Table 3 shows a comparison of total room heating energy used in analyzed apartment building for three months. Compared to the actual consumption, the conventional heating energy calculation method produced approximately 76.5%, while the proposed method considering stack effect produced approximately 95.6%. That is, in terms of the total amount, the heating energy calculation method considering stack effect showed closer results to actual values.

4. CONCLUSIONS

In this study, a heating load (energy) calculation method for considering the effects of air movements in buildings such as stack effect in high-rise residential buildings was presented and the validity of the proposed calculation method in this study was verified through comparison of results obtained using the proposed method with actually measured values.

REFERENCES

Lee, J.H., Song, D.S. and Park, D.Y. (2010), “A study on the development and application of the E/V shaft cooling system to reduce stack effect in high-rise buildings”, *Building and Environment.,* Vol. 45(2), 311-319.

Emmerich S.J. (2001), “Validation of multizone IAQ modeling of residential-scale buildings: a review”, *ASHRAE Trans.,* Vol. 107(2), Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.