The influence of external environment characteristics on the heating and cooling load of super-tall residential building

Hyoeng-Tae Kim[1], Hee-Gang Kim[1], Chang-Ho Jeong[2], and Myoung-Souk Yeo[*3]

1 Department of Architecture and Architectural engineering, Graduate school, Seoul National University
39-418 Seoul National University, 1 Gwanakro, Gwanak-gu, Seoul, 08826, S. KOREA

2 Institute of construction and Environmental Engineering, Seoul National University
135-302 Seoul National University, 1 Gwanakro, Gwanak-gu, Seoul, 08826, S. KOREA

3 Department of Architecture and Architectural engineering, Seoul National University
39-428 Seoul National University, 1 Gwanakro, Gwanak-gu, Seoul, 08826, S. KOREA
**Corresponding author: msyeo@snu.ac.kr*

ABSTRACT

Upper floors of super-tall residential buildings have different characteristics of the exterior environment as compared to their low floors or low-rise residential buildings due to the high-rise. Upper floors are more affected by direct solar radiation due to the reduced number of adjacent shading buildings and by reflected solar radiation from rooftops. Super-tall buildings also have high level of airtightness because of higher wind speed with high-rise. Therefore, upper floors of super-tall residential buildings are expected to have different heating and cooling load characteristics as compared to low-rise residential buildings. In this study, the influence of external environment characteristics due to the high-rise on the heating and cooling loads of super-tall buildings were analysed. EnergyPlus was used for dynamic load analysis simulation, which showed that upper floors of super-tall residential building would have different heating and cooling load characteristic compared to low-rise building and low floors of super-tall building due to solar radiation and airtightness. In addition, it was expected that upper floor of super-tall residential building had different sensible heat ratio than low-rise residential building.
.

KEYWORDS

Super-tall building, Residential building, Solar radiation, Airtightness, Heating and cooling load

1 INTRODUCTION

1.1 Background and objective

Upper floors of super-tall residential buildings have different characteristics of exterior environment with respect to outside temperature, effect of solar radiation and wind speed as compared to low-rise buildings because of high-rise. Also, they have higher level of airtightness due to increased wind speed with high-rise than low-rise residential buildings. Therefore, upper floors of super-tall buildings should have different heating and cooling load characteristics as compared low-rise buildings. The objective of this study was to analyse the effect of the characteristics due to the high-rise on the heating and cooling loads of super-tall buildings for determining architectural and mechanical alternatives suitable for super-tall residential buildings.

1.2 Scope and methodology

Considering the external environment, temperature decrease while wind speed increase with high-rise. As buildings are concentrated in urban areas, solar radiation would affect the heating and cooling load. Also, Super-tall buildings have high level of airtightness and difficulty for ventilation due to change of exterior environment.

EnergyPlus, a heat balance based simulation program, was used for analysing heating and cooling load with respect to transient characteristics of the dynamic load. The influence of solar radiation and infiltration on the heating and cooling loads of super-tall building and low-rise building were analysed for a period of one year. The load of upper floor of super-tall building was compared with that of low floor, middle floor of super-tall building and low-rise building.

Both peak load and annual energy should be considered to estimate the required capacity of mechanical systems. In order to determine the cooling capacity, room latent cooling load should also be analysed. The sensible and latent load ratio are expected to be different due to the exterior environment (such as solar radiation and moisture of infiltration). Therefore, for efficient the system selection, sensible heat ratio (SHR) when peak cooling load occurred were analysed

2 SIMULATION FOR HEATING AND COOLING LOAD ANALYSIS

For the analysis of heating and cooling load, super-tall building and low-rise building were selected satisfying building code in Korea as shown in Table 1. Considering layout of city, high density of buildings, adjacent buildings were placed around the selected buildings. It was assumed that the super-tall building and low-rise building were built in the same location. The input data for the simulation were summarized as shown in Table 2. Heating and cooling load in the living room were analysed.

Table 1: Super-tall residential building and low-rise residential building for simualtion

	Super-tall building	**Low-rise building**
Floors(Height)	74 Floors(222m)	24 Floors(72m)
Airtightness (Effective Leakage Areas) [㎠/㎡]	1.4	2.8
Ventilation	No ventilation	Window open according to temperature in May, September and October (18°C~26°C)
Classify for load analysis	Upper floor: 70 Floor Middle floor: 50 Floor Low floor: 10 Floor	10 Floor

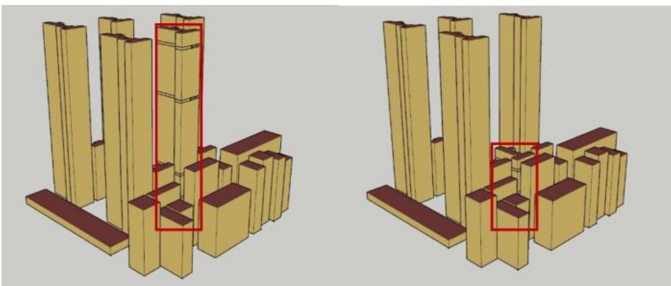
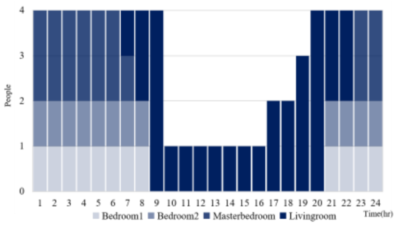


Figure 1: Layout of super-tall residential building and low-rise residential building

Table 2: Summary of input data for simulation

		Input Data
Model House	Orientation	South
	Area and height	140 m² / 3m
	Weather Data	Standard weather data for Seoul
Internal Loads	Number of Occupants	4 people
	Occupancy schedule[6]	
	People	120 W/person
	Light	6.19 W/m²
	Equipment	Sensible heat: 160W Work: 15W(Sensible heat 11.25W, Latent heat 3.75W)

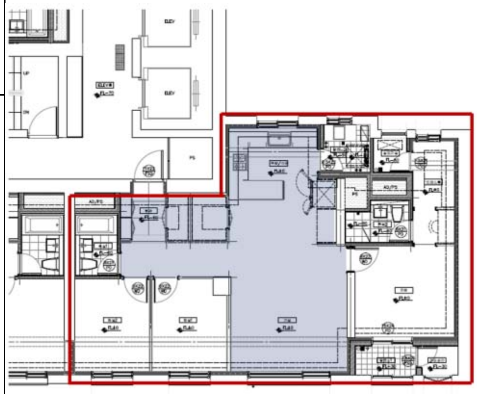


Figure 2: Plan of the simulation model

3 HEATING AND COOLING LOAD CHARACTERISTIC IN SUPER-TALL RESIDENTIAL BUILDING

Heating and cooling load analysis with respect to external environment characteristics and different airtightness was done. Table 3 shows the results for peak load and annual energy of the buildings.

According to the analysis, upper floor of super-tall building has larger peak heating and cooling load but lower annual heating energy than its low floor. As shown in Figures 3 and 4, upper floor of super-tall building has larger monthly peak heating energy than its low floor during winter. However, monthly heating energy less occurs in upper floor of super-tall building than in its low floor.

Table 3: Heating and cooling load of residential super-tall building and low-rise residentail building

	Cooling Load		Heating Load	
	Peak Load W/m²	Annual Energy Wh/m²(a)	Peak Load W/m²	Annual Energy Wh/m²(a)
Upper floor of super-tall building	**25**	**63,141**	**11**	**759**
Middle floor of super-tall building	**25**	**66,459**	**10**	**531**
Low floor of super-tall building	**21**	**42,227**	**6**	**906**
Low-rise building	**29**	**44,759**	**21**	**3,441**

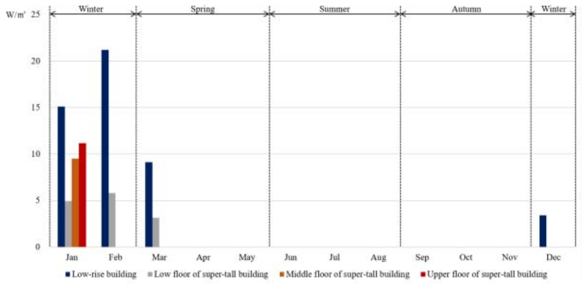


Figure 3: Monthly peak Heating load

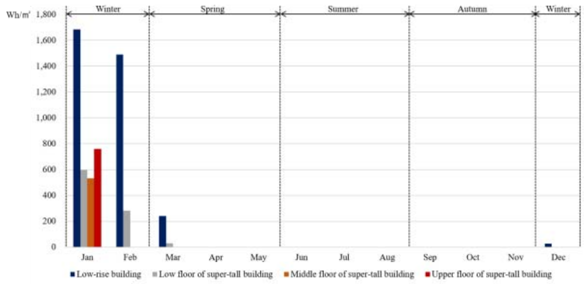


Figure 4: Monthly Heating Energy

Upper floor of super-tall building has lower peak heating and cooling load but larger annual cooling energy than low-rise building. Figures 5 and 6 shows that upper floor of super-tall building has lower monthly peak cooling load than low-rise building. However, upper floor of super-tall building has higher monthly cooling energy than low-rise building during all seasons except summer. In addition, monthly cooling energy more occurs in upper floor of super-tall building than in low-rise building.

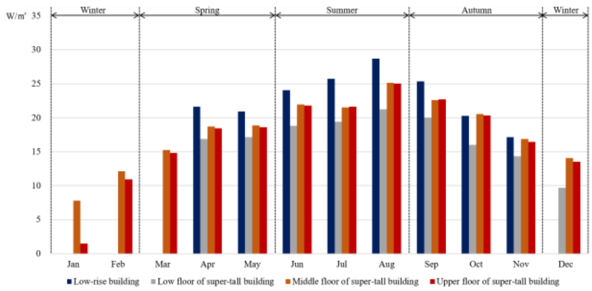


Figure 5: Monthly peak Cooling load

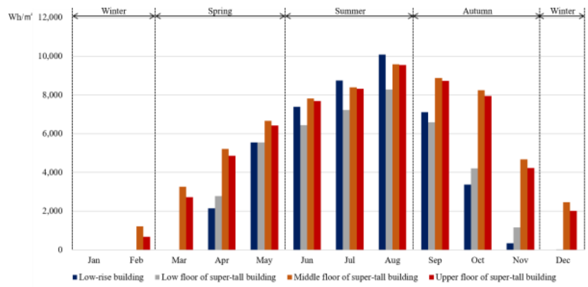


Figure 6: Monthly Cooling Energy

The result shows that the annual cooling energy is larger in upper floor of super tall building than low floor of super-tall building and low-rise building. Moreover, upper floor of super-tall building has larger annual cooling energy than annual heating energy.

4 INFLUENCE OF SOLAR AND INFILTRATION ON HEATING AND COOLING LOAD

According to table 4, upper floor of super-tall building has more beam and diffuse solar radiation than low floor of super-tall building and low-rise building. This would be due to reduction of adjacent shading buildings and reflections from adjacent rooftops. As average infiltration increases with high-rise in super-tall building, upper floor of super-tall building has more infiltration heat gain and heat loss than low floor of super-tall building but smaller heat gain than low-rise building due to high level of airtightness.

According to Figures 7 and 8, upper floor and middle floor of super-tall building have larger solar heat gain energy than low floor of super-tall building and low-rise building. Since outside temperature decreases and infiltration increases with high-rise, infiltration heat loss and heat gain are higher in upper floor of super-tall building than in low floor of super-tall building. Due to lager solar heat gain, upper floor of super-tall building has smaller annual heating energy but larger cooling energy than low-floor of super-tall building. Also, upper floor of super-tall building has smaller annual heating energy but larger annual cooling energy than low-rise building because of larger solar heat gain and smaller infiltration heat gain.

Table 4: Heating and cooling load of residential super-tall building and low-rise residentail building

	Annual Solar Radiation Wh/m²(a)		Infiltration Energy Wh/m²(a)	
	Beam Solar Radiation	Diffuse Solar Radiation	Heat gain	Heat loss
Upper floor of super-tall building	**6,125**	**10,135**	**25**	**4,883**
Middle floor of super-tall building	**6,125**	**9,868**	**25**	**4,165**
Low floor of super-tall building	**907**	**2,511**	**19**	**2,227**
Low-rise building	**907**	**2,704**	**43**	**3,968**

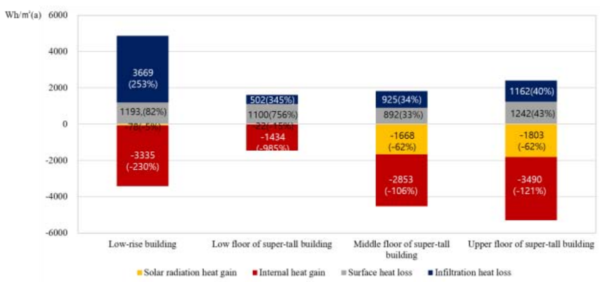


Figure 7: Annual Heating Energy components

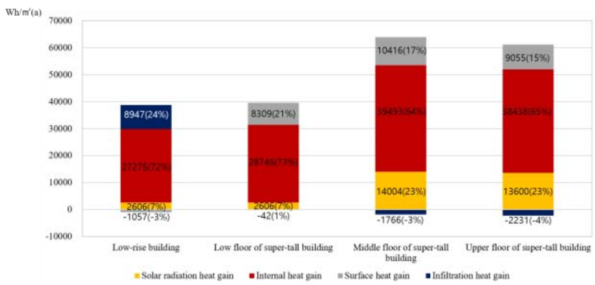


Figure 8: Annual Cooling Energy components

According to Figures 9 and 10, upper floor of super-tall building has larger infiltration heat loss and heat gain than low floor of super-tall building. This would be due to increased wind speed at the high-rise. However, upper floor of super-tall building has smaller infiltration heat loss and heat gain than low-rise building due to high level of air tightness. Therefore, upper floor of super-tall building has larger peak heating and cooling load than low floor of super-tall building but smaller than low-rise building due to infiltration.

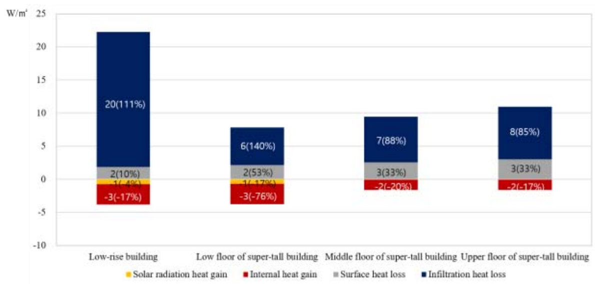


Figure 9: Peak Heating Load components

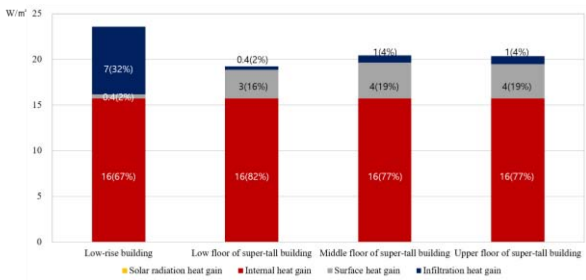


Figure 10: Peak Cooling Load components

With respect to change of solar radiation and infiltration, Figures 11 and 12 shows the difference in SHR when peak cooling load appeared in super-tall building and low-rise building. During the daytime, upper floor of super-tall building has larger sensible cooling load but during night time, it has smaller sensible and latent cooling load than low-rise building. In summer, solar radiation is expected to make larger sensible cooling load during daytime but under hot and humid weather, large amount of infiltration makes large sensible and latent cooling load in night time. It is the reason why upper floor of super-tall building has larger SHR than low-rise building but has smaller than low floor of super-tall building. Since variation of the SHR in the super-tall building is larger than that in the low-rise building, cooling system capable of coping with a change in sensible heat would be advantageous in the super-tall building.

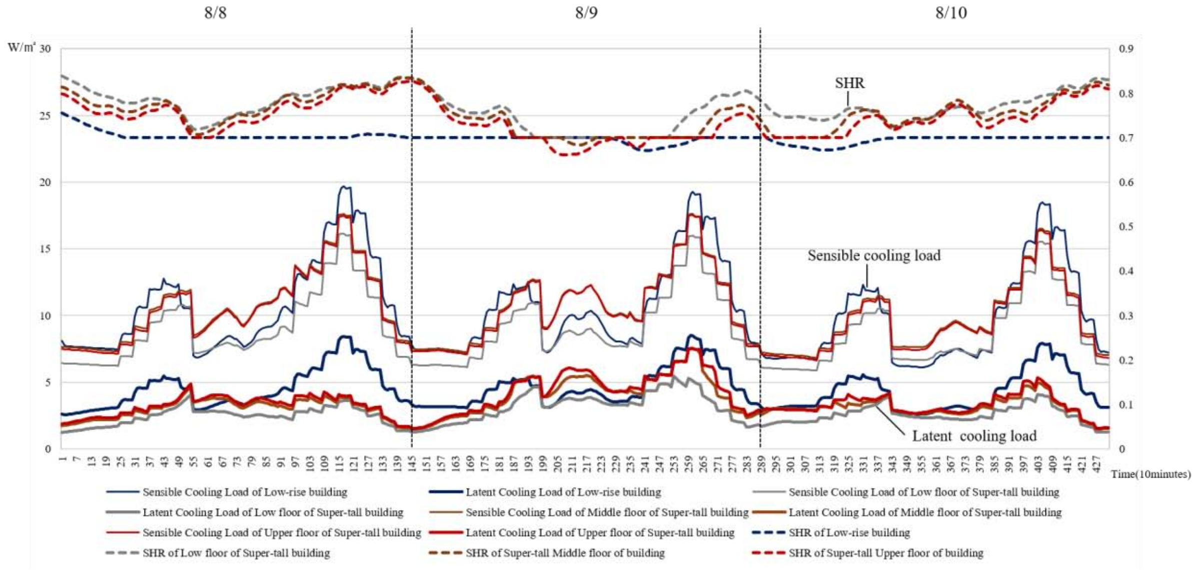


Figure 10: Cooling load and SHR when Peak Cooling load appeared in upper floor of super-tall building

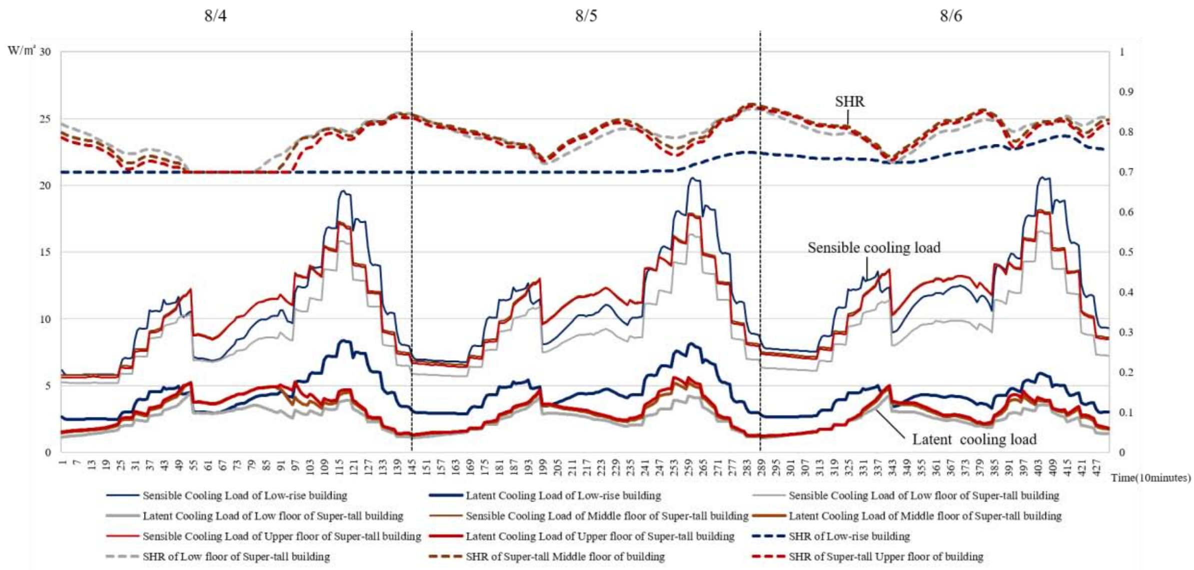


Figure 11: Cooling load and SHR when Peak Cooling load appeared in low-rise building

5 CONCLUSIONS

The objective of this study was to analyse the influence of external environment on heating and cooling load of super-tall building due to high-rise. Through a dynamic load analysis, heating and cooling load of super-tall residential building and low-rise residential building was examined.

The simulation results showed that upper floor of super-tall building has different heating and cooling load characteristic as compared low-rise building and low floor of super-tall building due to solar radiation and airtightness. Since solar radiation affect the annual heating and cooling energy, upper floor of super-tall building has larger annual cooling energy and smaller heating energy than low floor of super-tall building and low-rise building. Infiltration affect the peak heating and cooling load. Therefore, upper floor of super-tall building has larger peak heating and cooling load than low floor of super-tall building but smaller the peak loads than low-rise building.

It is considered mechanical operation plan for annual cooling energy is necessary in upper floor of super-tall building because cooling load more occurs in upper floor of super tall building than in low floor of super-tall building and low-rise building. Also, for cooling system, it is considered upper floor of super-tall building has larger SHR and variation of the SHR than low-rise building.

6 ACKNOWLEDGEMENTS

This research was supported by a grant (18AUDP-B106327-05) from Architecture & Urban Development Research Program funded by Ministry of Land, Infrastructure and Transport of Korean Government.

7 REFERENCES

Ellis, P. G., & Torcellini, P. A. (2005). Simulating Tall Buildings Using EnergyPlus: Preprint (No. NREL/CP-550-38133). National Renewable Energy Lab., Golden, CO (US).

Kim, K. W., Yeo, M. S., Ryu, S. R., Shin, M. S. (2007). Planning consideration for High-rise Buildings. Magazine of the SAREK, 36(2), 4-19

Kim, Y. S., Song, D. S. (2010). A building load analysis of ultra high-rise building under the effect of vertical microclimate change. 2010 The Society of Air-conditioning and Refrigerating Engineers of Korea Conference, 407-412

ASHRAE. (2013). 2013 ASHRAE Handbook Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc

M. S. Jung, Y. J. Choi, D. S. Song. (2006). A Study on Hybrid AC System Coupled with Natural Ventilation and Cooling System. 2006 The Society of Air-conditioning and Refrigerating Engineers of Korea Conference, , 351-358.

Yoon, D. W. (2011). Development of high-rise residential ventilation integrated HVAC system, Korean Institute of Architectural Sustainable Environment and Building Systems, 5(2), 57-65

Jeong, C. H., Lee, J. Y., Yeo, M. S., & Kim, K. W. (2007). Cooling load analysis of residential buildings for dehumidification/sub-cooling system in radiant cooling. *Sustainable Buildings (SB)*, *1*, 505-512.

Jo, J. H. (2010). Measurements of the Dwelling Unit Airtightness in High-rise Residential Buildings. JOURNAL OF THE ARCHITECTURAL INSTITUTE OF KOREA Planning & Design, 26(10), 337-344.

S, H. S., Kim, B. S. (2011). A Comparative Analysis of Energy Simulation Results and Actual Energy Consumption on Super High-rise Apartments. Journal of the Korean Solar Energy Society, 31(4), 34-40.