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A Building Heating and Cooling Load Analysis of Super Tall Building considering the Vertical Micro-climate Change

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Doosam Song is a professor, Dept. of Mega buildings and Bridges, Sungkyunkwan University, Korea. He is a specialist for analyzing the air flow and energy demands in tall buildings. He has received several awards for his work, including the 2010 Best Paper Award from journal Building and Environment, Award of Technical Paper(Category in Academic Paper) of the SHASEJ(Society of Heating, Air-Conditioning and Sanitary Engineers of Japan) in 2009. He has published many papers on tall buildings, low energy building technologies and sustainable building design methods. Most recently he has been researching the air flow of tall buildings caused by stack effect and wind around the buildings. This has included the application of the E/L shaft cooling to such buildings with the aim of minimizing stack effect and its related problems. He also is carrying out the research on the effect of air flow on heating, cooling load in tall buildings.

Yang Su KIM
Yang Su Kim is a young engineer who has a passion of creating better built environment for human being. He started to study architectural engineering in Sungkyunkwan University from 2002, as an undergraduate including a semester in University of Nottingham as exchange student. Continual interest in architecture led him to Mega Buildings and Bridges, master's degree course in Sungkyunkwan University fully funded by Samsung C&T. High-rise building construction as well as the sustainability of the tall building is the main academic interest of him.

Abstract

In these days numerous super tall buildings are under construction or being planned in Middle East and Asian countries. Some of them are planned as a super tall building that goes over 600m tall, including Burj Khalifa, the tallest building in the world.

Despite the fact that tall buildings are effective way to use limited urban area providing more green places and reducing the expansion of the city, higher energy use have been continually issued as major defects of tall buildings.

External environment such as wind speed, temperature and humidity of the super tall building varies due to its vertical height. Therefore, it is necessary to consider these environmental changes to properly estimate the building heating and cooling load and minimize the energy demands for HVAC in super tall buildings.

This paper aims to analyze how vertical micro-climate change affects building heating and cooling load in super tall building by TAS energy simulation program. Radiosonde which observes atmospheric parameters of upper air have been used as weather conditions reference in simulation. Hypothetical super tall building is used in simulation to provide the quantified characteristics of heating and cooling load of the super tall building comparing the lower, middle and upper part of the building. Besides, the correlation between air-tightness of building envelope and building load was analyzed for a super tall building.

Keywords: Super tall building, Building load, Building envelope, Vertical climate, TAS
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1. Introduction

For a past few years, numerous tall buildings are under construction or being planned majorly in Asia and Middle East and some of these buildings are designed as super tall buildings. 828 meters high, the world's tallest building Burj Khalifa, had finished in January 2010. Other super tall buildings that is higher than 600 meters such as Kingdom Tower in Zeda, Saudi Arabia, Nakheel Tower in Dubai, UAE, Burj Mubarak Al Kabir, Lotte super tower in Seoul, South Korea are on the stage of construction or planning.

High-rise building can be a good landmark that represents a metropolitan city and the nation as well as effectively uses limited land area in dense city. Intensive land usage can not only create more green places in the city but also can save money, resources and carbon emission to build and maintain more infrastructures from expansion of the city.

Despite these advantages that high-rise buildings have, however, drastic increase of energy consumption happens in this type of buildings. Exposed area to external environment grows, especially more glazing area for a better view, results in poor energy performance from reduced insulation and negative stack effect in summer. Vertical transportation for building users and materials also cause much larger energy use compared to the lower buildings that has similar floor area. Therefore, thorough research and attempt to reduce building load is very important for enhancing sustainability of tall buildings.

For better analysis of building load to decrease energy use, distinctive method that satisfies different aspect of high-rise building has to be used. External environmental conditions such as wind speed, air temperature, humidity and solar radiation around the building differs due to the vertical micro climate change from height difference. Therefore, these different outdoor conditions have to be considered to minimize the energy demand for HVAC and lighting in super tall buildings.

A few paper reported for heating, cooling load in tall buildings. Peter G. Ellis (Peter G. Elis, et. al, 2005) evaluated Freedom tower in Manhattan by Energyplus, reviewing simulation method and how vertical difference and sun shading from surrounding buildings effects building load. Moti Segal (Moti Segal and et.al., 2000) reported radiosonde meteorological data to calculate building load for high-rise buildings.

In this paper, the effect of external micro-vertical climate change including wind speed, temperature to the cooling and heating load of a super tall building, using hypothetical 1,000 meter, 200 stories building by Thermal Analysis Simulation(TAS) program. The hypothetical building is vertically divided as five zones for each zone of 200 meters, 40 stories, using corresponding height's radiosonde weather data, to compare how vertical microclimate change affects by simulation. Vertically different aspect of building load is studied to evaluate variation tendency from the height, and compared with typical load analyze method with weather data near the ground level.

Table 1. Monthly Averaged Vertical climate data of Osan 2009, observed by radiosonde

	January			February			March			April			May			June		
Height	T (℃)	H (%)	W (m/s)	T (℃)	H (%)	W (m/s)	T (℃)	H (%)	W (m/s)	T (℃)	H (%)	W (m/s)	T (℃)	H (%)	W (m/s)	T (℃)	H (%)	W (m/s)
800~1000m	-7.0	50.4	7.7	-1.6	47.9	7.2	0.2	52.3	8.7	3.9	56.5	7.4	11.9	58.1	7.6	17.7	62.9	4.5
600~800m	-5.7	54.3	6.7	-0.9	55.5	6.0	1.7	54.6	7.8	5.2	54.5	6.6	13.4	58.7	6.7	19.2	61.2	4.0
400~600m	-4.1	54.0	5.3	0.3	60.9	4.7	3.2	55.8	6.5	6.6	55.4	5.4	14.6	59.1	5.3	20.5	61.1	3.2
200~400m	-2.3	53.6	3.2	1.5	65.1	3.4	4.6	57.4	4.9	8.0	57.6	4.0	15.7	62.1	3.7	21.6	62.4	2.4
0~200m	-3.2	67.7	2.1	1.9	74.0	2.1	5.4	64.2	3.4	9.1	62.7	2.7	17.0	68.0	2.1	23.2	68.7	1.6

	July			August			September			October			November			December		
Height	T (℃)	H (%)	W (m/s)	T (℃)	H (%)	W (m/s)	T (℃)	H (%)	W (m/s)	T (℃)	H (%)	W (m/s)	T (℃)	H (%)	W (m/s)	T (℃)	H (%)	W (m/s)
800~1000m	18.9	76.0	6.4	20.8	68.2	6.2	16.3	61.7	3.9	11.2	55.7	6.5	2.1	68.4	7.8	-4.7	54.7	8.6
600~800m	20.1	75.8	5.7	20.9	68.4	5.5	17.7	61.6	3.6	12.6	56.1	5.8	3.2	67.9	7.0	-4.1	59.9	7.8
400~600m	21.3	77.5	4.7	22.3	69.4	4.7	19.3	62.5	3.0	14.0	56.8	4.8	4.7	65.7	5.9	-2.8	60.6	6.2
200~400m	22.6	80.3	3.4	23.7	72.4	3.6	20.7	65.2	2.3	15.3	58.4	3.6	6.1	63.6	4.3	-1.4	60.4	4.3
0~200m	24.0	85.7	2.0	25.1	79.0	2.5	21.7	73.1	1.6	15.3	68.9	2.3	6.5	69.6	2.8	-1.0	69.0	2.4

(T : Temperature, H : Humidity, W : Wind speed)

2. Vertical micro climate change in super tall buildings

In order to analyze the effect of vertical micro climate change, weather data that has been measured by radiosonde has been used. Radiosonde is a weather observing device goes up to the higher atmospheric level to detect temperature, air pressure, wind speed, humidity etc. and transmit those data to the ground. Figure 1 shows radiosonde system. University of Wyoming, Department of Atmospheric Science provides weather data recorded by radiosondes from worldwide (see http://weather.uwyo.edu). In this paper, weather data that has been observed in 2009 by the radiosonde in Osan, where is near from Seoul metropolitan city, have been used as reference data. Table 1 contains monthly average data of temperature, humidity and wind speed for every 200 meters of height level from ground to 1,000 meters high. It shows that wind speed is positively proportional to the height, where temperature and humidity is reversely related with the height.

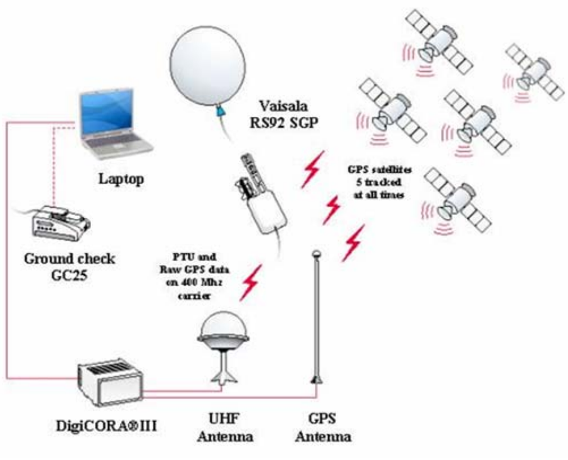

Figure 1. Radiosonde system

3. Simulation conditions

For building load simulation, 1,000 meters high, 200 stories hypothetical building has been modeled. Six meters inside from building envelope that is enormously affected from external condition has been zoned as perimeter zone. From perimeter zone to the building core and inside of the building core has been zoned as interior zone and core zone, respectively. From ground level, 200 meters, 40 stories are vertically zoned to divide whole building as five zones. Figure 2 shows the horizontal and vertical zoning of the analyzed building. Table 2, Table 3 and Table 4 shows information for simulation.

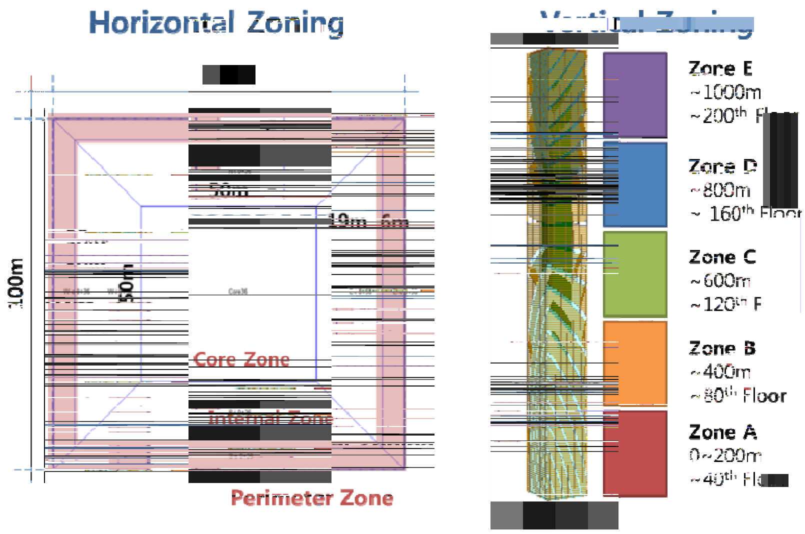

Figure 2. Zoning plan

Table 2. Modeling building information

Height	1,000m	
Floors	200 stories	
Typical Floor Area	Center Zone	2,500 m^2
	Perimeter Zone	554 m^2 for each direction
	Interior Zone	1,308.5 m^2 x each direction
Gross Floor Area	2,000,000 m^2	
Ceiling height	3.5m	
Usage	Office	

Table 3. Modeling building material

Component	Material	Thickness (mm)	U-Value (W/m²℃)
Glazing	Low-E	24	1.592

	(6CL+12Air+6LE)		(SHGC : 0.319)
Frame	Metal/Thermal break	100	3.115
Opaque Wall	Al sheet/Glass Wool	50	1.95
Internal Wall	Reinforced Concrete	500	2.5
Internal Floor	Reinforced Concrete /Air gap/Acoustic Tile	180	1.3

Table 4. Simulation conditions

Condition		Value
Weather data	Seoul Climate data(solar radiation) + Radiosonde Data, Osan, 2009(Temperature, Wind speed, Humidity, Wind direction)	
Latitude	37.3	
Longitude	127.0	
Heating set point	22°C , 40%	
Cooling set point	26°C , 60%	
Heat gain (ASHRAE, 2007)	Occupancy	Sensible heat Gain: 15[W/m^2] Latent heat Gain: 11[W]
	Lighting	Office: 12[W/m^2]
	Equipment	Office: 21.5[W/m^2]
Infiltration	0.3, 0.5, 0.7 ACH (When external wind speed is 3m/s)	
Cooling Schedule	9 a.m. ~ 8 p.m.	
Heating Schedule	8 a.m. ~ 8 p.m.	
Cooling and Heating period	01/01 ~ 12/31(Mon-Fri only)	
Simulation period	8760hours	

Since most of high-rise buildings are exposed to higher wind speed, higher infiltration, these changes should be considered to calculate building load properly. Infiltration is assumed as constant value in conventional building load simulations. However, infiltration rate is proportional to wind speed and super tall building is exposed to strong wind. Therefore, infiltration rate should be set at inconstant. Figure 3 shows the relationship between wind speed and infiltration used in simulation (ASHRAE, 2009). Infiltration coefficient is set at 0 when it is direct proportional to the wind speed, while it is 1 when there is no relationship with each other in TAS simulation. Three types of air-leakage rate, 0.3ACH, 0.5ACH, 0.7ACH were reviewed when the wind speed is 3m/s to analyze the effect of air-tightness on heating and cooling load. Infiltration coefficient is set at 0.5 in these cases.

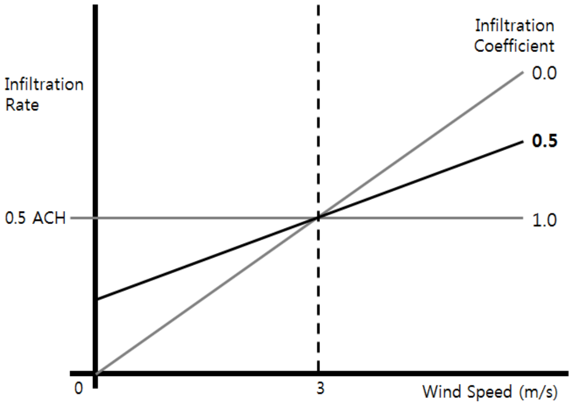

Figure 3. Infiltration change from wind speed

Total simulation cases are 16. The heating and cooling load for each five vertical zones were analyzed. For these five zones, the air leakage rate was changed as 0.3ACH, 0.5ACH, 0.7ACH, respectively when the wind speed is 3m/s. Also, the basic case that using conventional weather data was compared to the case that using radiosonde weather data when the infiltration rate was set at 0.5ACH.

4. Result

4.1 The heating and cooling load for five vertical zones

Monthly building load differences in perimeter zone for vertical zone are shown in Figure 4. From lower part of the building Zone A to higher part of the building Zone E, cooling load decreases while heating load increases. Infiltration level affects heating load upsurge in winter, from comparing the result of 0.3ACH and 0.7ACH conditions. Although cooling load does not radically increase from more infiltration, it also affects a lot for annual cooling load because of the higher cooling load in office building.

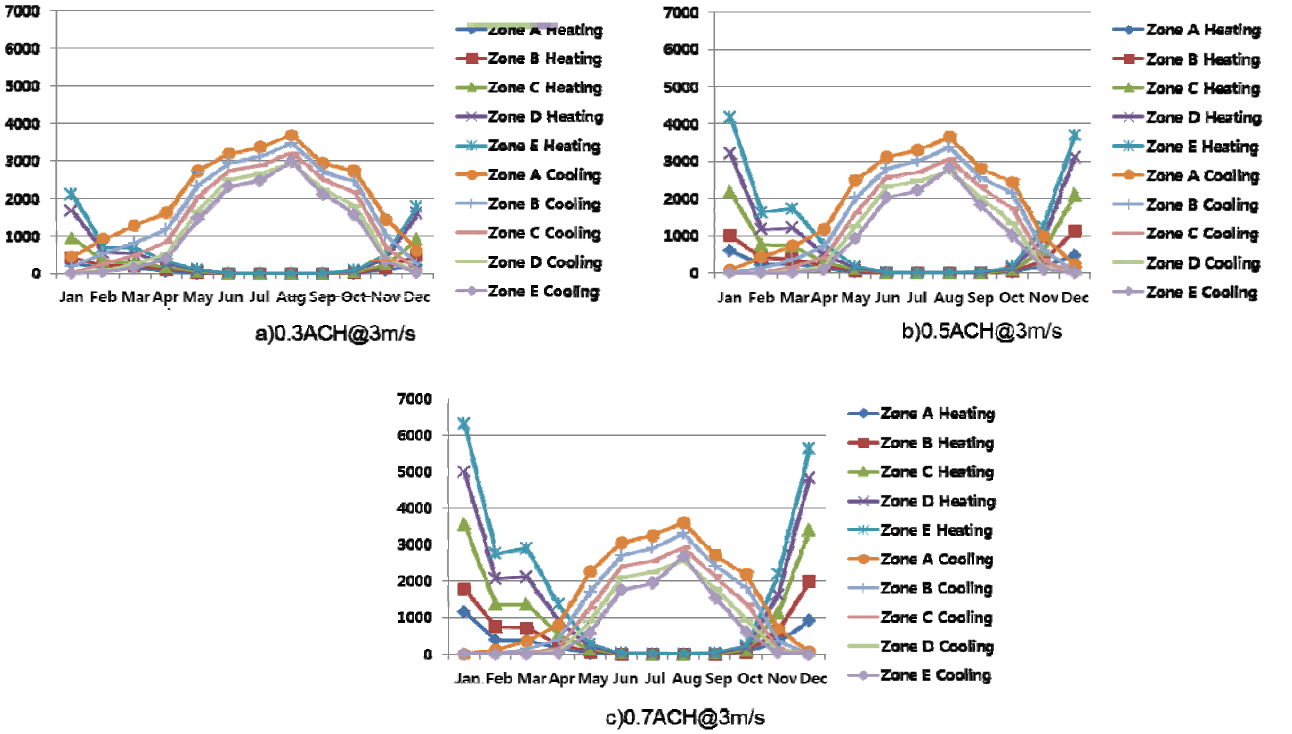

Figure 4. Monthly Building Load

Table 5. Load comparison between Zone A and other zones

kWh/m²year, (%)

0.3ACH @3m/s	Heating		Cooling		Total	
Zone A	3.24	100%	83.79	100%	87.03	100%
Zone B	5.42	167%	70.56	84%	75.97	87%
Zone C	9.87	304%	60.20	72%	70.07	81%
Zone D	17.39	536%	50.73	61%	68.11	78%
Zone E	21.19	654%	46.37	55%	67.57	78%
0.5ACH @3m/s	**Heating**		**Cooling**		**Total**	
Zone A	6.20	100%	71.61	100%	77.80	100%
Zone B	11.65	188%	59.53	83%	71.18	91%
Zone C	22.68	366%	49.92	70%	72.60	93%
Zone D	34.71	560%	42.05	59%	76.77	99%
Zone E	45.62	736%	36.89	52%	82.51	106%

0.7ACH @3m/s	Heating		Cooling		Total	
Zone A	11.49	100%	63.93	100%	75.42	100%
Zone B	21.14	184%	52.89	83%	74.03	98%
Zone C	38.88	338%	43.56	68%	82.45	109%
Zone D	56.93	495%	35.80	56%	92.72	123%
Zone E	73.10	636%	30.72	48%	103.81	138%

Table 5 compares building load of perimeter and internal zones between Zone A and the other zones. In 0.5ACH@3m/s condition, highest Zone E need 736% of heating load and 52% of cooling load compared to Zone A, the other zones show similar tendencies.

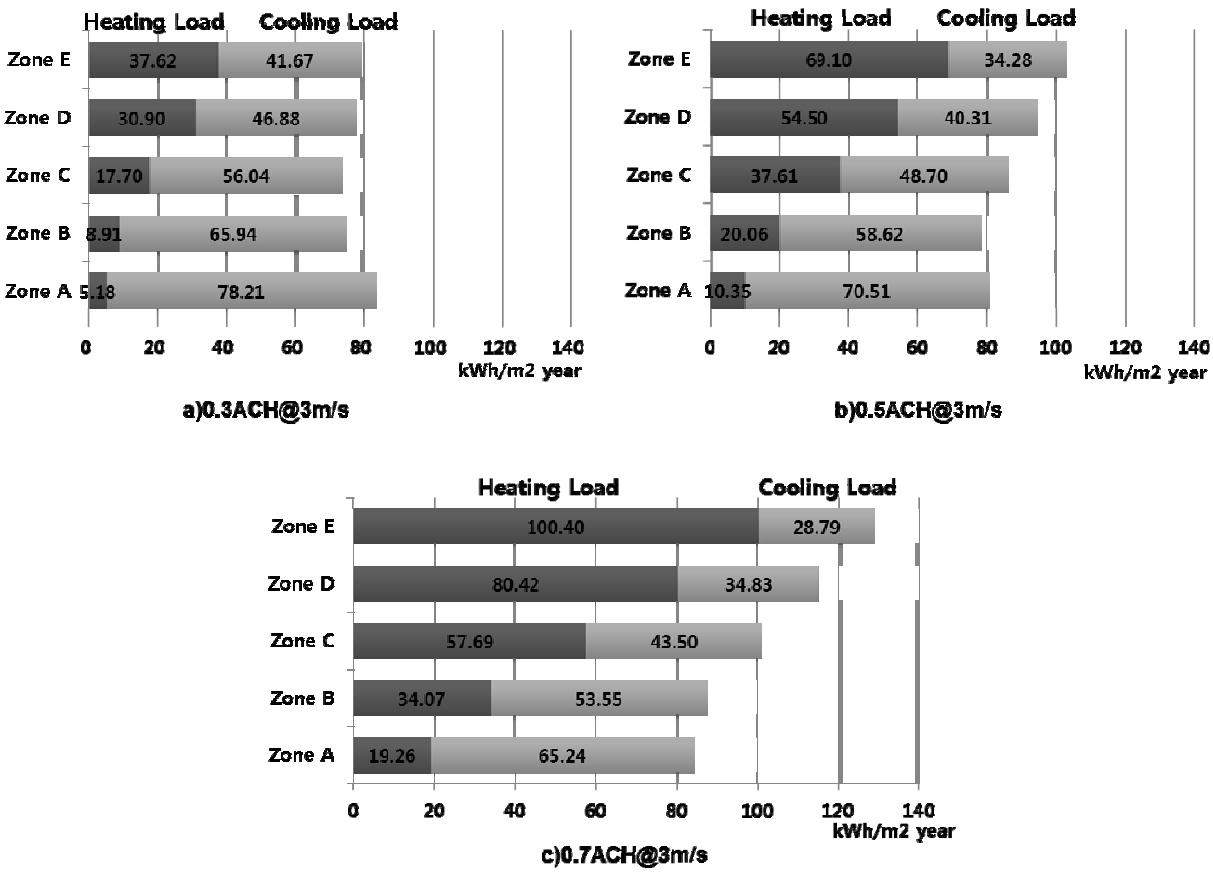

Figure 5. Annual heating and cooling load of perimeter zone

Figure 5 indicates the annual cooling and heating load per square meter of perimeter zone that is critically affected by external conditions. Although there are slight differences from air tightness differences, the increasing rate of heating is about 600% while the decreasing rate of cooling load is about 50% from lower to upper zone on average.

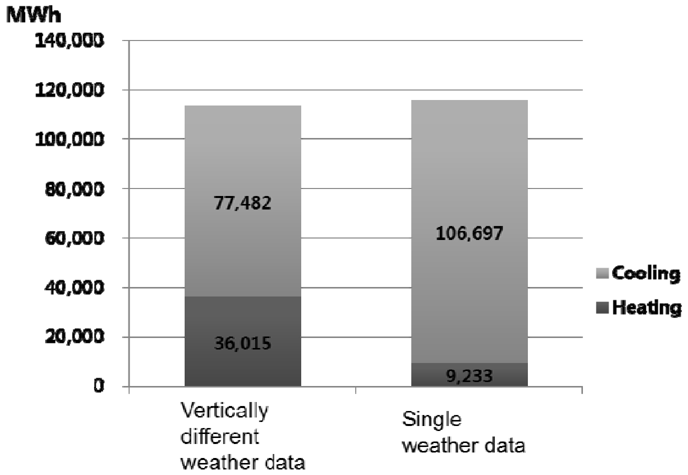

Figure 6. Total building load difference from weather data source

Figure 6 shows the heating and cooling difference between conventional way of simulation which based on single weather data and the new method proposed in this paper, this method reflects the changes in vertical climate. Cooling load decrease 27% and heating load increase 290% when vertical climate changes were considered. Therefore, if building envelop, HVAC systems are designed only based on single weather data that measured near the ground level, it results in inappropriate design of HVAC system capacity and out of the control of indoor environment.

In case of infiltration, fixed value of infiltration value may not properly predict increasing amount of infiltration in upper level of the building from wind speed, resulting missing assumption of radically growing heating load.

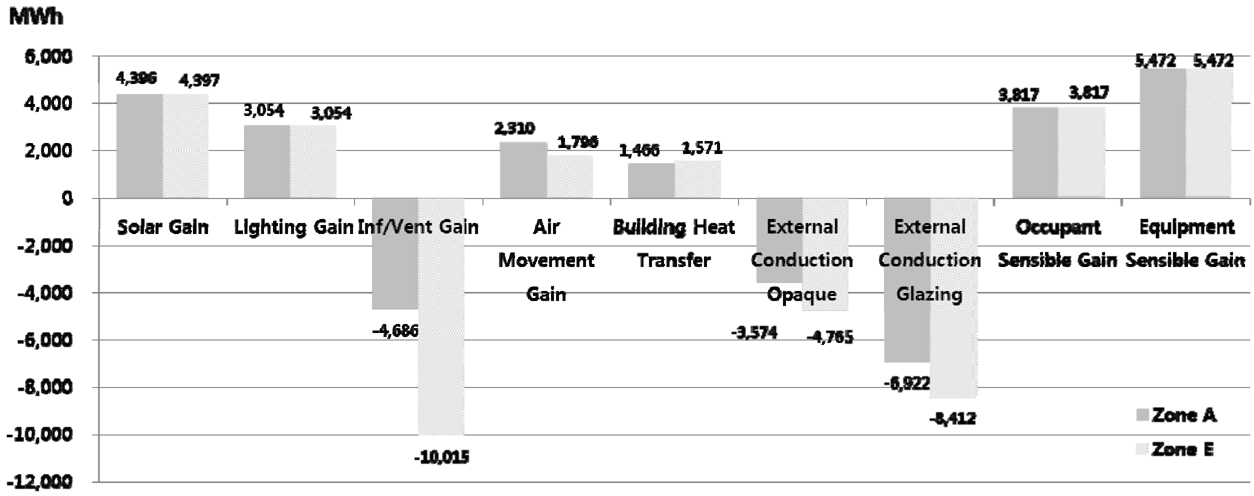

Figure 7. Load breakdown of Zone A and Zone E

Figure 7 analyzes load elements of the perimeter zone of Zone A and Zone E under infiltration rate was set at 0.5ACH. Internal heat gains from occupant, equipment and lighting are same in whole zones, also, solar heat gain found no significant difference since surrounding buildings are not concerned.

Highest part of the building Zone, E shows 213.7% of radical increase from infiltration and ventilation gain compared to Zone A because of faster wind speed. Also, energy loss caused by conduction rises 21.5% from glazing and 33.3% from opaque in Zone E. These results indicate that the air tightness and conduction performance of the higher part in super tall building is more important than lower part of the building.

5. Conclusion

In this study, the effect of vertical micro-climate changes on heating and cooling load in super tall building was analyzed by simulation. The results of this study are as follows.

(1) In super tall buildings, the simulation method should reflect the wind speed and temperature changes because these are dominantly affects heating and cooling load. In this study, the vertical climate changes were considered using radiosonde weather data in Korea.
(2) From the result of cooling and heating load for the perimeter zone where mainly influenced by external environment changes, cooling load is decreased while heating load is increased in higher part of the building Zone E compared to the lower part of the building Zone A. These are because of the low temperature and increasing heat loss from high infiltration caused by escalating wind speed.
(3) For the dependence of the infiltration rate on heating and cooling load, even though the cooling load is slightly decreased when the infiltration rate is changed from 0.3ACH to 0.7ACH, while the heating load is significantly increased as double.
(4) For the dependence of the weather data on heating and cooling load, the cooling load is decreased by 27% and heating load is increased by 290% when vertical climate change is considered compared to the conventional way of using single weather data.
(5) From the results of the building load factors, infiltration and conduction are main factor that arouse the heating and cooling load differences among the vertical zones. Therefore it is critical to enhancing insulation and air-tightness performance especially in higher part of the building in super tall building to minimize the energy consumption.

Acknowledgement

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