International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:5, No:12, 2011

Simulation Study on the Indoor Thermal Comfort with Insulation on Interior Structural Components of Super High-Rise Residences

Y. Wang, H. Fukuda, A. Ozaki, H. Sato

***Abstract*—**In this study, we discussed the effects on the thermal comfort of super high-rise residences that how effected by the high thermal capacity structural components. We considered different building orientations, structures, and insulation methods. We used the dynamic simulation software THERB (simulation of the thermal environment of residential buildings). It can estimate the temperature, humidity, sensible temperature, and heating/cooling load for multiple buildings. In the past studies, we examined the impact of air-conditioning loads (hereinafter referred to as AC loads) on the interior structural parts and the AC-usage patterns of super-high-rise residences.

Super-high-rise residences have more structural components such as pillars and beams than do ordinary apartment buildings. The skeleton is generally made of concrete and steel, which have high thermal-storage capacities. The thermal-storage capacity of super-high-rise residences is considered to have a larger impact on the AC load and thermal comfort than that of ordinary residences.

We show that the AC load of super-high-rise units would be reduced by installing insulation on the surfaces of interior walls that are not usually insulated in Japan.

***Keywords*—**High-rise Residences, AC Load, Thermal Comfort, Thermal Storage, Insulation Patterns

I. Introduction

THE number of super-high-rise residences has increased. According to statistics for 2008 obtained from MIC (Ministry of Internal Affairs and Communications) of Japan, the number of residences with more than 11 floors is 34.2% higher than that in 2003 and 88.3% higher than that in 2000[1]. Furthermore, in metropolitan areas such as Tokyo and Osaka, more than half the residences are multifamily buildings. Most of these multifamily buildings use exterior wall outside insulation, which is not appropriate for energy saving. The number of residences with more than 20 floors has increased rapidly since 2000, and this trend is expected to continue [2]. For high-rise buildings, the area ratio of pillars and slabs is higher than that for other building styles. The pillar dimensions for a super-high-rise residence reach up to 1 m × 1 m, roughly 2.8 times that for low-rise apartment buildings (normally 0.6 m × 0.6 m) [3]. Given the high thermal-storage capacity of concrete, the impact of pillars and slabs on the AC load is significant. Therefore, the effects of heat-insulation methods and AC-usage patterns on AC loads should be verified before a building is constructed [11]. Studies on insulation styles and the indoor environment of super-high-rise residences are still in progress. In my past studies, it was investigated that with intermittent AC, the annual AC load of out-frame units with a small thermal storage capacity is 0.6-2.4% lower than that of in-frame units. The annual AC of interior-insulation units is lower than that of outside- and inside-insulation units. The annual AC of inside-insulation units is 0.3-2.4% lower than that of outside-insulation units; that of interior-insulation units is 15-40% lower than that of outside-insulation units [12, 13]. In this paper, we investigate the aspect of the relation between thermal storage and thermal comfort, this is a new contribution.

This study contributes to the basic research on energy-saving standards for super-high-rise residences.

Y. Wang is with the Faculty of Environmental Engineering of the University of Kitakyushu, Japan (phone: 81-3901-8206; fax: 81-93-695-3343; e-mail: y09e0101@hibikino.ne.jp).

H. Fukuda, J is with the University of Kitakyushu, 808-0135, Japan (e-mail: fukuda@env.kitakyu-u.ac.jp).

A. Ozaki is with the Graduate School of Life and Environmental Sciences, Kyoto Prefectural University, Japan (e-mail: ozaki@kpu.ac.jp).

H. Sato is with the Faculty of Environmental Engineering of the University of Kitakyushu, Japan (e-mail: m10e1601@hibikino.ne.jp).

II. Details of the Simulation

A. Software

THERB is a dynamic simulation software that can estimate temperature, humidity, sensible temperature, and heating/cooling loads for multiple-zone buildings [4, 5].

B. Simulation Model

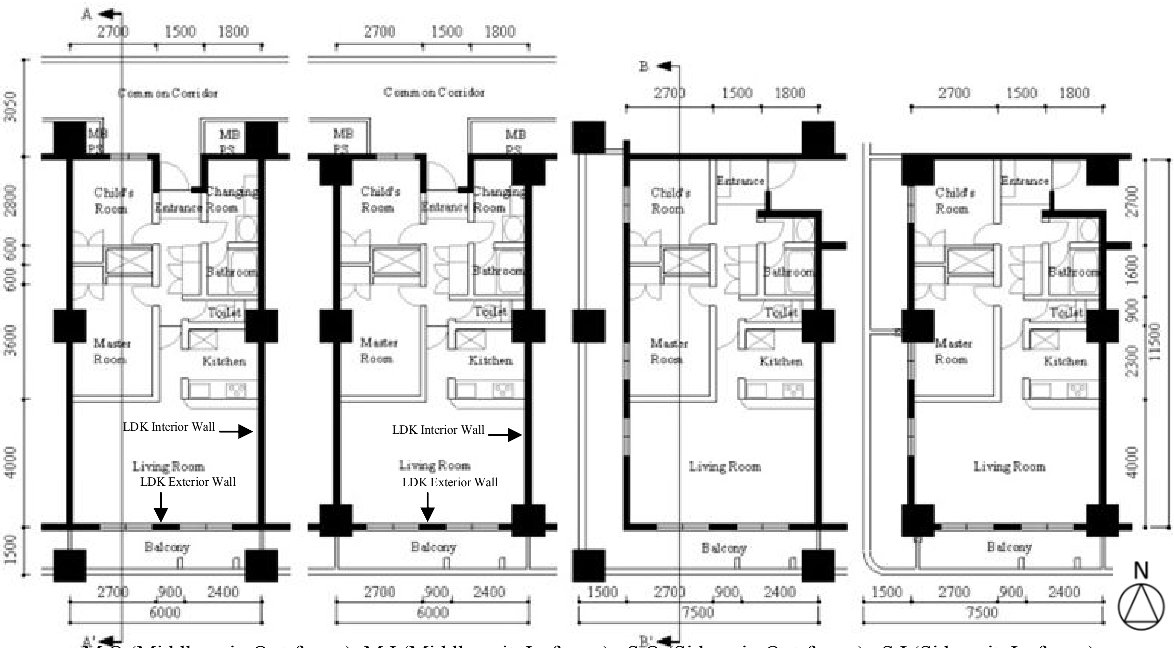
Following the Record of High-Rise Residential Design [3], we design general unit plans for this simulation. We examine two typical units situated on the side and in the middle of a middle floor of a building, and we consider both in-frame and out-frame constructions. Fig. 1 shows the floor plans of these four units.

III. Simulation Scenarios

We examined four different types of units with different orientations, AC-usage patterns, and insulation methods. The expanded AMeDAS Weather date [6] of Fukuoka city (the average weather for the years between 1981 and 2000) is used in this paper's simulation.

A. Orientations

We investigate four unit orientations: east-facing, south-facing, west-facing, and north-facing. Fig. 1 shows south-facing units.



M.O.(Middle unit, Out-frame) M.I.(Middle unit, In-frame) S.O.(Side unit, Out-frame) S.I.(Side unit, In-frame)
Fig.1. Four Units (South-Facing)

TABLE I
AC DETAILS

AC①:Two-career	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Living Room							■	■											■	■	■	■			6 hours
Master Room																						■	■		2 hours
Child's Room																									0 hours
The Others																									0 hours
AC②:Family	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	
Living Room							■	■	■				■	■			■	■	■	■	■	■			11 hours
Master Room																						■	■		2 hours
Child's Room																					■	■	■		3 hours
The Others																									0 hours
AC③:Aging Family	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	
Living Room							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				15 hours
Master Room	■	■	■	■	■	■	■														■	■	■	■	11 hours
Child's Room																									0 hours
The Others																									0 hours
AC④:Continuous	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	
Living Room	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24 hours
Master Room	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24 hours
Child's Room	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24 hours
The Others	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24 hours

※ Heating :20℃ (Nov. to Mar.) Cooling :26℃ (Jun. to Sep.) ■ AC on □ AC off

TABLE II
DETAILS OF INSULATION STYLES

		Structure Parts			
		Outside of Exterior Wall	Inside of Exterior Wall	Interior Wall	Floor
Insulation Styles	Outside	■			
	Inside		■		
	Interior		■	■	■

■ Insulated □ Not Insulated

TABLE III
DETAILS OF MATERIALS

	Thermal conductivity [W/(m·K)]	Specific heat [J/(kg·K)]	Specific weight [kg/m3)]	Moisture conductivity [kg/m·s·Pa)]
Concrete	1.600	840.0	2200.0	7.61E-12
Plaster board	0.220	870.0	700.0	2.28E-11
Flooring	0.046	1300.0	300.0	1.90E-12
Plyboard	0.160	1300.0	550.0	1.90E-12
Particle board	0.150	1300.0	700.0	1.90E-12
Air	0.022	1000.0	1.2	0.00E+00
Glass	0.780	770.0	2540.0	0.00E+00
Extruded poly styrene foam blocks A-3	0.028	1470.0	28.0	1.20E-12

B. AC Usage Patterns

We investigate four AC-usage patterns: three scenarios (AC①, AC②, AC③) of intermittent operation in some rooms and one scenario (AC④) of twenty-four-hour operation in all rooms. As given in Table 1, in AC①, the AC is used rarely during the day. In AC②, the AC is used more frequently. In AC③, the AC is operated the entire day in the living room and the entire night in the master room. In AC④, the AC is operated continuously in all rooms. The same AC-usage patterns are used in the next units, the units above, and those below.

The AC-usage patterns correspond to four different family groups, as also given in Table 1[6, 7, 8]:

AC①: corporate-rank husband, corporate-rank wife, no child

AC②: corporate-rank husband, full-time housewife, two children

AC③: retired husband, housewife, no child.

AC④: identical to AC②.

C. Heat-Insulation Styles

We investigate super-high-rise units with different heat-insulation styles [9]. The details of heat-insulation styles are shown in Table 2. The type and thickness of the insulation materials of each part are chosen according to those in [Explanation of the Energy-Saving Standards for Houses] [10] and are given in Table III.

IV. SIMULATION RESULTS

Fig. 2 shows the annual AC load of units for different situations, orientations, AC-usage patterns, and insulation

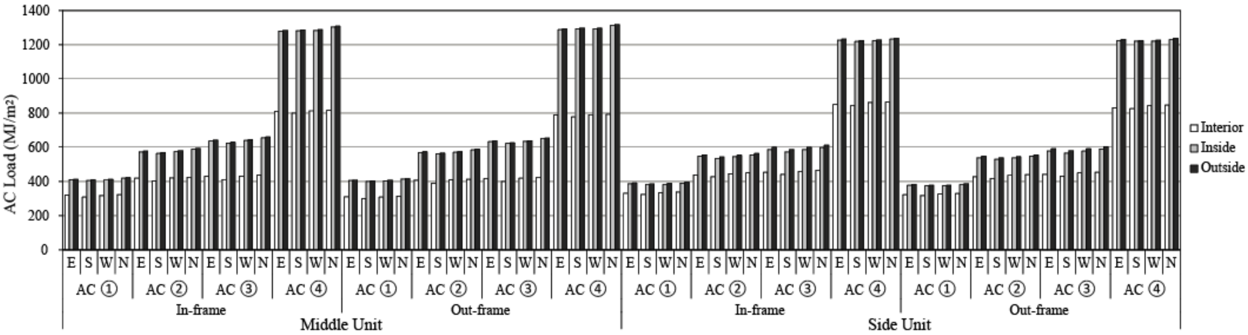
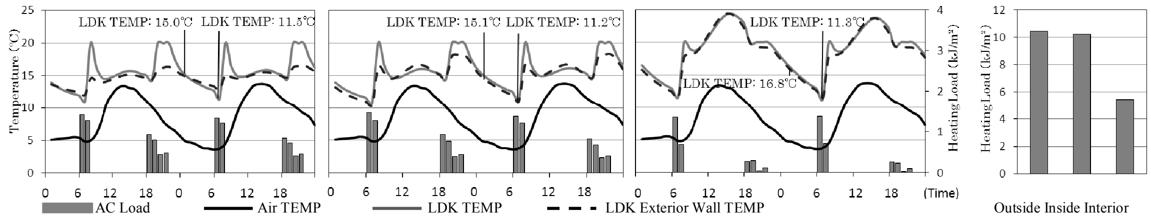
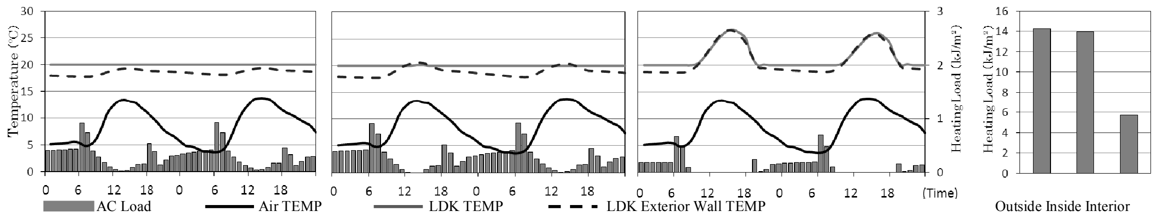


Fig. 2 Annual AC Load of Four Units with All AC-Usage Patterns



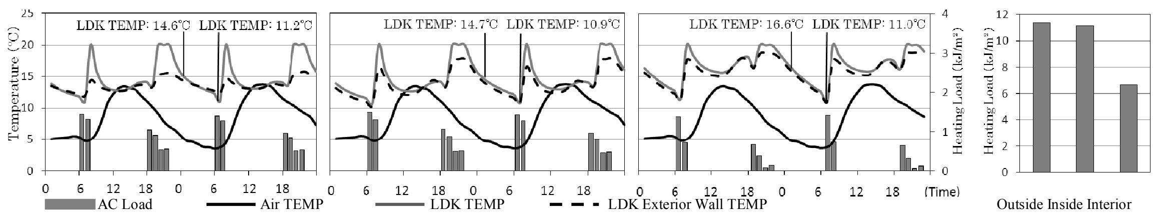
(1) Outside Insulation (2) Inside Insulation (3) Interior Insulation (4) AC Load of 9-10.Jan.

Fig. 3 Relation Between Walls-Surface Temperature and Heating Load (Middle Unit, South -Facing, AC①, 9-10.Jan.)



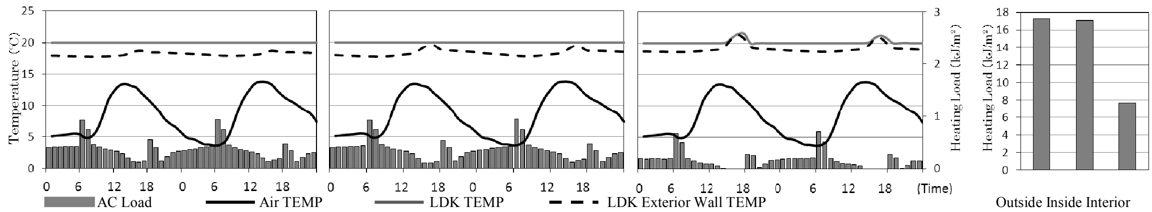
(1) Outside Insulation (2) Inside Insulation (3) Interior Insulation (4) AC Load of 9-10.Jan.

Fig. 4 Relation Between Walls-Surface Temperature and Heating Load (Middle Unit, South -Facing, AC④, 9-10.Jan.)



(1) Outside Insulation (2) Inside Insulation (3) Interior Insulation (4) AC Load of 9-10.Jan.

Fig. 5 Relation Between Walls-Surface Temperature and Heating Load (Middle Unit, West-Facing, AC①, 9-10.Jan.)



(1) Outside Insulation (2) Inside Insulation (3) Interior Insulation (4) AC Load of 9-10.Jan.

Fig. 6 Relation Between Walls-Surface Temperature and Heating Load (Middle Unit, West-Facing, AC④, 9-10.Jan.)

International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:5, No:12, 2011

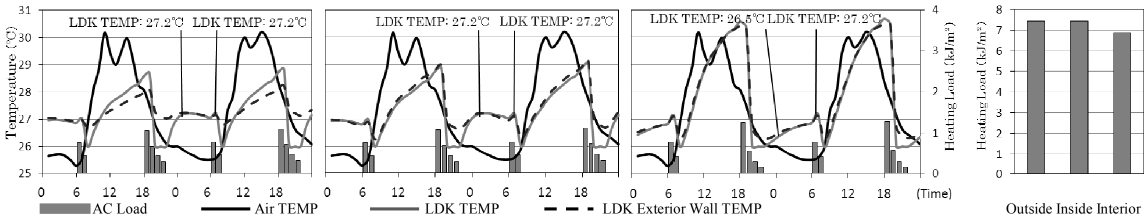
styles. The annual AC load of AC④ is significantly higher than that of the intermittent patterns (AC①,②,③). The annual AC load of inside-insulation units is lower than that of outside-insulation units, and the load of interior-insulation units is significantly lower than that of inside-insulation units. The annual AC load of the north-facing unit is the highest and that of the south-facing unit is the lowest.

Two days in winter (January 9 and 10) and in summer (August 15 and 16) are chosen for further investigation.

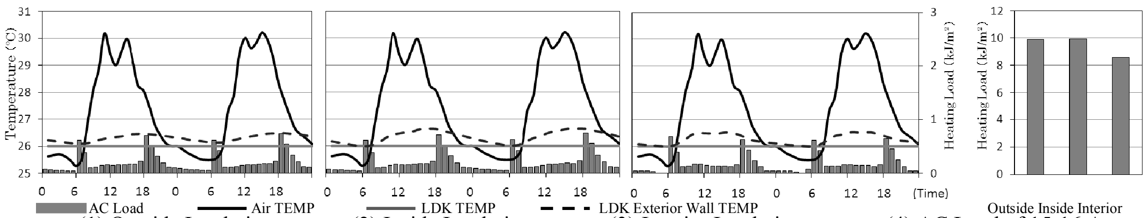
A. Thermal Comfort in Winter

Figs. 3 to 6 show the wall-surface temperature and the heating load of a middle unit during winter (January 9 and 10). During winter, structural components absorb the heat in the indoor air because of the high thermal storage. As shown in Fig.3, when the AC is on during the day, structure-surface temperatures do not reach the LDK level. In interior-insulation units, there is little to no difference between structure-surface temperatures and the LDK temperature. Because of the insulation, the LDK temperature rises to over 20ºC in about 7 hours during the day. This provides comfort without requiring the AC. Figure 5 shows how, in the west-facing outside- and inside-insulation units, the LDK temperature drops rapidly through the effect of thermal storage, going even lower than the outside air temperature, after the AC is turned off at 9:00 a.m. In the interior insulated unit, the LDK temperature does not change rapidly, maintaining just over 15ºC throughout the day.

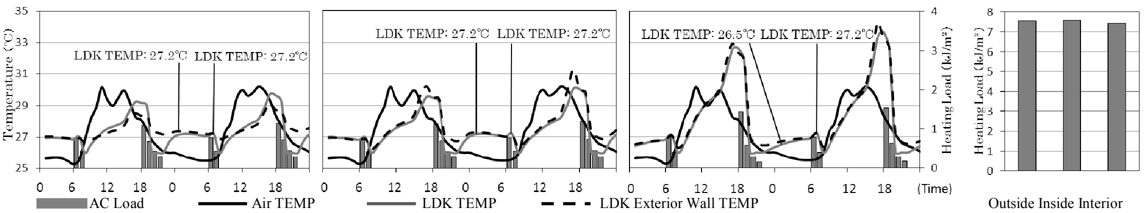
During winter nights, the LDK temperature keeps dropping from the time the AC is turned off until the next morning. As shown in Fig.3, the LDK temperature drops when the AC is turned off at 11:00 p.m. In the outside-insulation and inside-insulation units, the rate is rapid until the LDK



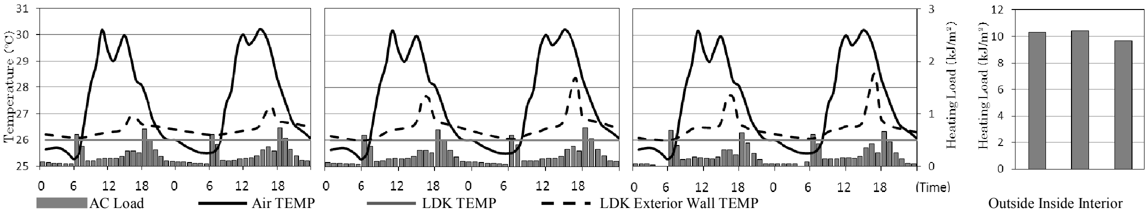
(1) Outside Insulation (2) Inside Insulation (3) Interior Insulation (4) AC Load of 15-16.Aug.
Fig.7 Relation Between Walls-Surface Temperature and Heating Load (Middle Unit, South-Facing, AC①, 15-16.Aug.)



(1) Outside Insulation (2) Inside Insulation (3) Interior Insulation (4) AC Load of 15-16.Aug.
Fig.8 Relation Between Walls-Surface Temperature and Heating Load (Middle Unit, South-Facing, AC④, 15-16.Aug.)



(1) Outside Insulation (2) Inside Insulation (3) Interior Insulation (4) AC Load of 15-16.Aug.
Fig. 9 Relation Between Walls-Surface Temperature and Heating Load (Middle Unit, West-Facing, AC①, 15-16.Aug.)



(1) Outside Insulation (2) Inside Insulation (3) Interior Insulation (4) AC Load of 15-16.Aug.
Fig.10 Relation Between Walls-Surface Temperature and Heating Load (Middle Unit, West-Facing, AC④, 15-16.Aug.)

temperature drops close to the structure-surface temperature and becomes gradual afterwards. However, in the interior-insulation unit, the rate of LDK temperature descent is not as rapid as are the others. At 1:00 a.m., the LDK is 16.8ºC, 2ºC higher than in the outside- and inside-insulation units. We see the same result with using AC② and AC③. At 7:00 a.m., the LDK temperature in the interior-insulation unit is 0.5ºC higher than that in the outside-insulation unit before the AC is turned on, while using AC①, and while using the AC briefly (6 hours) during the day. This is because the cold structure frame absorbs the heat in the indoor air if it is not insulated inside the room The LDK temperature in the interior-insulation unit is 0.3 ºC lower than that in the outside-insulation unit when AC② is on, and when AC③ is on for longer hours during the day (between 11 and 12 hours). This is because the structure frame is warmed through the AC's long running time: this helps maintain the room's temperature.

B. Thermal Comfort in Summer

Figs. 7 to 10 show the wall-surface temperatures and cooling loads of middle units during summer (August 15 and 16). Fig.7 shows that the LDK temperature in interior-insulation units rises more rapidly than in units with other insulation styles after the AC is turned off at 9:00 a.m. Thus, during summer days, when residents stay in their houses after turning off the AC, the indoor air temperature will rise rapidly, going above 30ºC, making it necessary to turn on the AC again.

Fig.7 shows that, after the AC is turned off for the night in outside- and inside-insulation units, the LDK temperature rises rapidly until it approximates the exterior wall surface temperature. At 1:00 a.m., the LDK temperature rises to 27.2ºC. In interior-insulation units, however, the LDK temperature does not rise rapidly. At 1:00 a.m., the LDK temperature rises to 26.5ºC, 0.7ºC lower than in units with other insulation styles. From when the AC is turned off at 11:00 p.m. until it is turned on again at 7:00 a.m., the LDK temperature rises above 27ºC by 6:00 a.m. in interior-insulation units; in units with other insulation styles, it rises above 27ºC in 7 hours . We see the same result with using AC ② and AC ③ . Thus, interior-insulation units provide a higher thermal comfort level than do the units with other insulation styles during summer nights.

C. Annual AC Loads of Three Insulation Styles

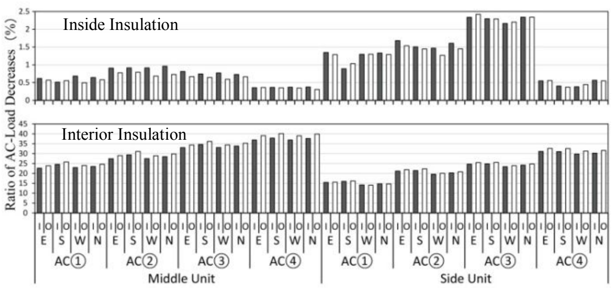


Fig. 11 Ratio of Annual AC-Load Decreases (to Outside Insulation)

Fig. 11 shows the ratio of decreased annual AC loads for inside and interior insulation to the AC load for outside insulation[Note2), Note3)]. The annual AC loads of inside-insulation units are slightly lower than those of outside-insulation units. In middle units, the AC loads of inside-insulation units are lower than those of outside-insulation by no more than 1%. The difference is about 2.5% in side units. For interior insulation, the ratio of the decreased annual AC load to the annual AC load for outside insulation reaches 40% in middle units. It is on average more than 15% in side units.

By reducing the effect of high thermal-storage capacity, inside- and interior-insulation units have lower AC loads than outside-insulation units.

V. CONSIDERATIONS

The high thermal comfort of the interior-insulation super-high-rise residential unit has been verified in this paper. When not using the AC at night in the winter, directly after turning off the AC (11:00 p.m. to 1:00 a.m.), LDK temperature in the interior-insulation unit does not drop as rapidly as that in outside- and inside-insulation units which are affected by structure frames like floors and interior walls and so on. However, the LDK temperature in outside- and inside-insulation units drops slowly after 2 or 3 hours. When the AC is not used on summer nights, because the outside air temperature is lower than the inside, LDK temperature in interior insulation unit rises slowly. LDK temperatures in outside- and inside-insulation units rise rapidly after the AC is turned off. This causes uncomfortable thermal temperature longer than that in the interior insulation unit. In daytime in winter, when the AC is turned on, the temperature of the wall surface is close to the temperature of the room. This is because thermal storage does not affect indoor air environment in interior-insulation units.

VI. CONCLUSION

We performed a simulation study using THERB to investigate the relation between the structural frame thermal-storage capacity and the AC load of super-high-rise units. We considered different AC-usage patterns, situations, orientations, and insulation styles.

In the south-facing middle units, with varied AC usage-patterns, when the AC is turned on, in winter, wall surface temperature is on average 0.4℃ (AC①,AC②,AC③), 0.6℃（AC④）, maximum 2.2℃ lower than LDK temperature in the interior insulation unit, and it is on average 0.7℃（AC①）, 0.9℃ (AC②) , 1.0℃ (AC③) , 1.3℃ (AC④) , maximum 5.4℃ lower in outside- and inside insulation units. When the AC is not used at night in winter, at 1:00 a.m., the LDK temperature in the interior insulation unit is 0.5-2℃ higher than that in outside- and inside-insulation units. However, LDK temperature in outside- and inside-insulation units drops slowly after 2 or 3 hours. When the AC is not used on summer nights, at 1:00 a.m., LDK temperature in the interior insulation unit is 0.2-0.5℃ lower than that in outside- and inside-insulation units.

Except in day time in summer, thermal comfort of the interior-insulated unit is better than units with other insulation styles, even at night time when the AC or AC is not being used.

The above demonstrates that this interior insulation style should be considered a new energy-saving standard for super-high-rise residences.

REFERENCES

[1] Statistics Bureau, Ministry of Internal Affairs and Communications: Housing and Land Survey, 1988, 2003, 2008,
[2] Real Estate Economic Institute Co. LTD: Statistical Data of Japanese Real Estate, Apr. 2010.
[3] The Housing and Urban Development Corporation of Japan: Record of High-rise Residential Design, Mar. 1997.
[4] Ozaki Akihito: Simulation Software of the Hygrothermal Environment of Buildings Based on Detailed Thermodynamic Models, eSim 2004, TheCanadian Conference on Building Energy Simulation, pp.45-54, 2004.
[5] Ozaki Akihito, Tsujimaru T.: Prediction of Hygrothermal Environment of Buildings Based upon Combined Simulation of Heat and Moisture Transfer and Airflow, The Journal of the International Building Performance Simulation Association, Vol.16, No.2, pp.30-37, 2006.
[6] AIJ.: Expanded AMeDAS Weather Data (1981-2000), 2005.
[7] The NHK Broadcasting Culture Research Institute: Japanese life style research report, 2005.
[8] Yuko Tsukiyama, Nobuyuki Sunaga, Akiko Suzuki, Tamaki Fukazawa and Yosuke Chiba: Study on Thermal Storage Characteristics of AAC Floor Panels Using an Actual Test Rooms, Journal of Environmental Engineering, AIJ. Vol. 75 No. 648, pp. 149-156, Feb. 2010.
[9] M. Kumar KUMARAN: Material Properties, Architectural Institute of Japan, Oct. 2001
[10] The Institute for Building Environment and Energy Conservation: Explanation of the energy-saving standards for houses, 2002.
[11] Yuko Kuma, Akihito Ozaki, Harumi OZASA (KAGAWA), Hiroatsu Fukuda: Influence of Moisture Sorption and Desorption of Walls on Space Conditioning Load, Journal of Environmental Engineering, AIJ. Vol. 73 No. 632, pp. 1171-1178, Oct. 2008.
[12] Yupeng Wang, Hiroatsu Fukuda, Yuko Kuma and Akihito Ozaki: Study of Air-Conditioning Load: Comparison of Steel and RC Residence Units, Journal of Asian Architecture and Building Engineering, Vol. 9 No. 2 pp.571-576, 2010.
[13] Yupeng Wang, Hiroatsu Fukuda, Akihito Ozaki, Yuko Kuma: An Analysis of Energy Load for a Unit of Super High-rise Residences by Dynamic Simulation, Journal of South China University of Technology(Natural Science Edition), Vol.35, No.z1, pp.223-226, 2007.11