Study of Air-Conditioning Load: Comparison of Steel and RC Residence Units

Yupeng Wang*[1], Hiroatsu Fukuda[2], Yuko Kuma[3] and Akihito Ozaki[4]

[1] Doctoral Candidate, The University of Kitakyushu, Japan
[2] Professor, Dr. Eng., The University of Kitakyushu, Japan
[3] Graduate School, The University of Kitakyushu, Japan
[4] Professor, Dr. Eng, Kyoto Prefectural University, Japan

Abstract

Recently, the fight against global warming is becoming increasingly important. Being major energy consumers, air-conditioning (AC) loads are gaining importance. Therefore, the effects of heat insulation methods and AC usage patterns on AC loads should be verified before a building is constructed.

This paper examines the AC loads of two typical residential units of steel (S) and reinforced concrete (RC). To compare and analyze these cases, THERB, software for dynamic simulation of the thermal environment of residential buildings, is employed to simulate the loads.

Three common patterns based on the lifestyle in Japan are applied in this study to show that different family makeup can lead to varying AC loads. Further, two RC units (exterior wall insulated on the inside/outside) and one S unit (exterior wall insulated on the inside) are studied. The results reveal that the high heat capacity of concrete influences the living environment and causes differences between the RC and S units. The AC load of an RC unit with an exterior wall that is insulated on the inside is lower than that of a unit with an exterior wall that is insulated on the outside and is almost equal to that of the S unit.

Keywords: AC load; temperature; heat capacity; AC usage patterns

1. Introduction

Recently, the fight against global warming is becoming increasingly important. Being major energy consumers, air-conditioning (AC) loads are gaining importance. Therefore, the effects of heat insulation methods and AC usage patterns on AC load should be verified before a building is constructed.

In this study, we examine AC loads of two different kinds of residence units, namely, steel (S) unit and reinforced concrete (RC) unit. The performance of the S unit is evaluated and compared with that of the RC unit. For this examination, the dynamic simulation software THERB, software for simulating the thermal environment of residential buildings, is employed.

2. Method of Simulation

THERB for this analysis is dynamic simulation software which can estimate temperature, humidity, sensible temperature, and heating/cooling loads for multiple-zone buildings. THERB has the following features:

1) Successive transition method and a trapezoid hold function that can adjust itself to a time-discrete domain are used.

2) Dimensionless equations are used to calculate convective heat transfer coefficients for every part of the unit under study.

3) Longwave and shortwave absorption coefficients are taken into account in order to simulate the net absorption of radiant heat and transmitted solar radiation.

4) A multilayer window model, which defines the overall transmittance, absorptance, and reflectance of solar radiation, is used. (At present, the model cannot account for window curtains.)

5) A network airflow model is used to calculate ventilation quantities.

2.1 Simulation Model

In this study, two typical residence units constructed with reinforced concrete (RC) and steel (S) structural fabric are examined. Tables 1. and 2. provide the detail

Table 1. Outline of Residence

Building Use	Residences	
Construction	RC	S
Stories	4 floors above ground	
Place	Kyushu, Japan	

*Contact Author: Yupeng Wang, Doctoral Candidate, The University of Kitakyushu, Hibikino 1-1, Wakamatsu-ku, Kitakyushu, Fukuoka, Japan
Tel: +81-93-695-3715 Fax: +81-93-695-3335
E-mail: wangyupeng-sky@hotmail.com
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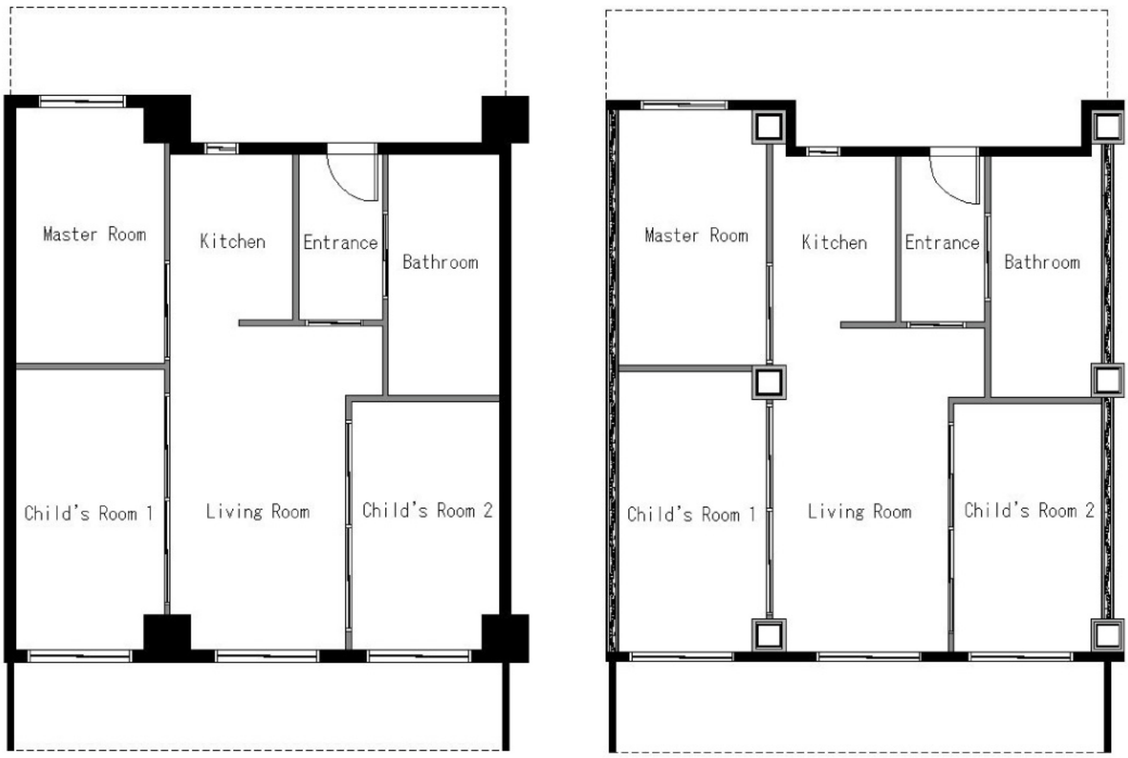
Table 2. Outline of Simulation

Floor Number	Second Floor
Room Number	Seven Rooms
Period of Time	One Year
Weather	Expaded A Me Das Weather Date
Interspace	One Hour
Floor area	$75m^2$

information of the two units employed for simulation. Fig.1. shows the floor plans of the two units.

3. Simulation Scenarios

Two units with different insulation methods and different AC patterns are examined; the study period is Jan. 1st to Dec. 31st. Table 3. summarizes these simulation scenarios.



RC Unit S Unit

Fig.1. Image of Two Units

Table 3. Particular about AC

Time		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Intermittent A	Child's Room 1							■											■	■	■	■	■		
	Living Room							■											■	■	■	■	■		
	Child's Room 2							■											■	■	■	■	■		
	Master Bedroom						■														■	■	■		
	Kitchen						■												■	■					
	Entrance																								
	Bathroom																								
Time		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Intermittent B	Child's Room 1							■											■	■	■	■	■		
	Living Room							■	■	■			■	■			■	■	■	■	■	■	■		
	Child's Room 2							■											■	■	■	■	■		
	Master Bedroom						■						■	■							■	■	■		
	Kitchen						■						■	■				■	■	■					
	Entrance																								
	Bathroom																								
Time		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
All Rooms	Child's Room 1						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
	Living Room						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
	Child's Room 2						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
	Master Bedroom						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
	Kitchen						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
	Entrance						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
	Bathroom						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		

※ ■ AC On
□ AC Off

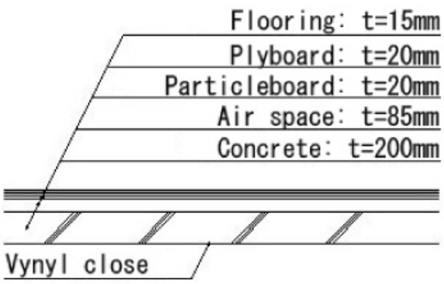


Fig.2. Ceilings and Floorings of RC Residence Units

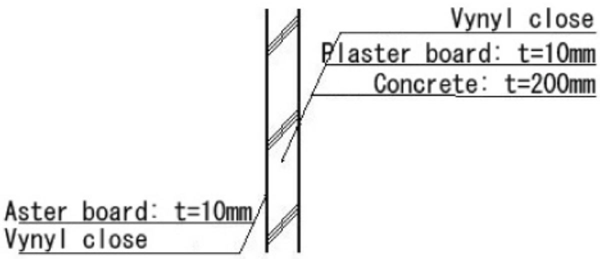


Fig.3. Interior Wall of RC Residence Unit

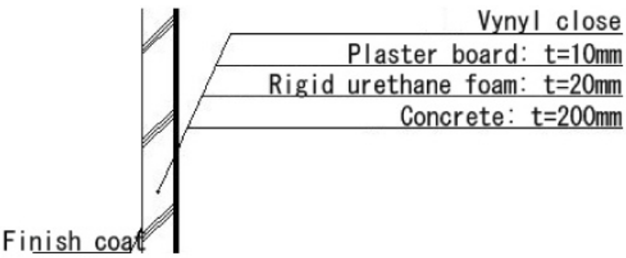


Fig.4. Exterior Wall of RC Residence Unit (Interior Insulation)

3.1 Heat Insulation of Exterior Wall

Two methods of insulating the exterior walls in the RC residence unit are examined. In one case the insulation is installed on the inside of the exterior walls; in the other case the insulation is installed on the outside of the exterior walls. Figs.2.-7. show these details.

3.2 Air-Conditioning Usage Patterns

Three AC usage patterns are investigated: two scenarios of intermittent operation in some rooms and one scenario of daytime constant operation in all rooms. As shown in Table 3., in Intermittent A pattern, the AC is used rarely during the day. In the Intermittent B pattern the AC is used more frequently than in Intermittent A. In the All Rooms pattern the AC is operated in all rooms during the daytime. The setting temperature for heating is assumed to be 17°C and that for AC cooling is 28°C.

Regarding AC usage patterns, three types of user family groups are shown in Table 3.:

Intermittent A: corporate rank husband, corporate rank wife, three children

Intermittent B: corporate rank husband, full-time housewife, three children

All Rooms: the same as Intermittent B.

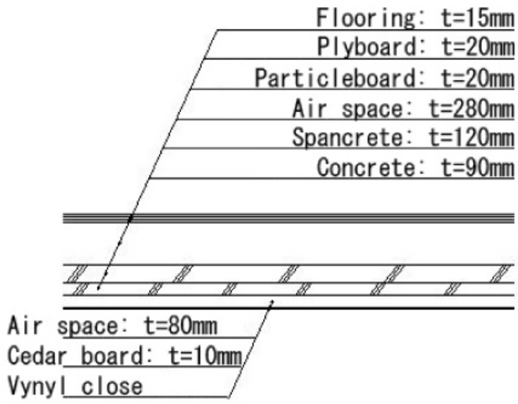


Fig.5. Ceilings and Floorings of S Residence Units

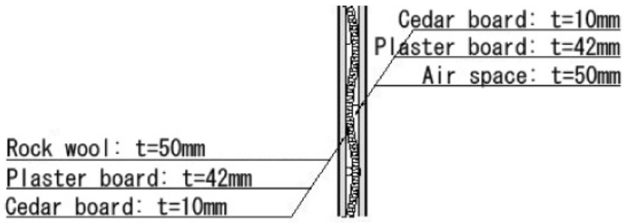


Fig.6. Interior Wall of S Residence Unit

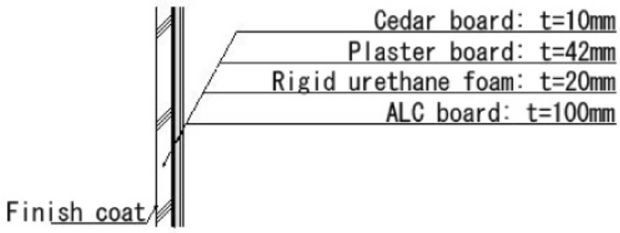


Fig.7. Exterior Wall of S Residence

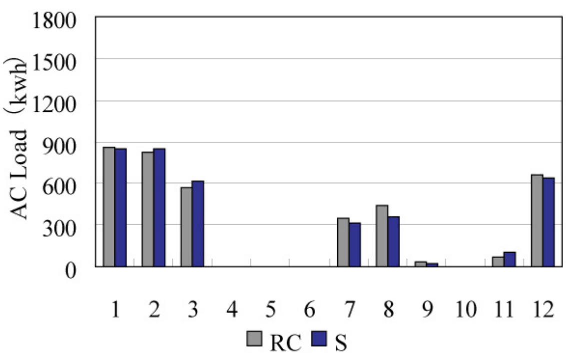


Fig.8. Monthly AC Loads of Various AC Patterns and Units (Intermittent A)

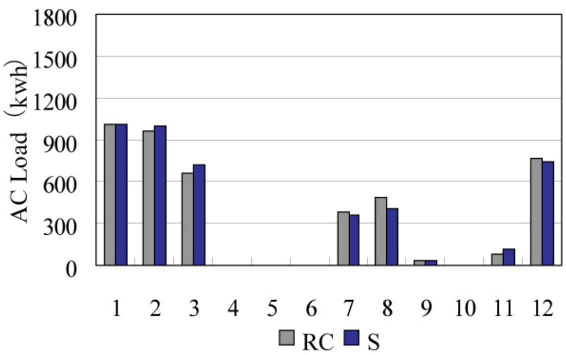


Fig.9. Monthly AC Loads of Various AC Patterns and Units (Intermittent B)

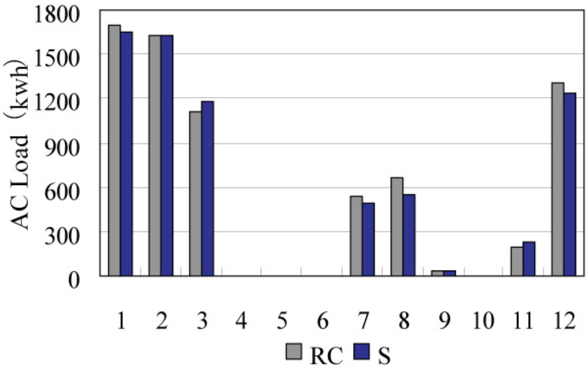


Fig.10. Monthly AC Loads of Various AC Patterns and Units (All Rooms)

4. Results of Simulation

4.1 The case of insulation inside the exterior wall of the RC residence

Figs.8.-10. compare the AC loads in the RC and S residence units in each month of the year. The heating load in December and January (winter) and the cooling load in July–September (summer) of the RC residence are higher than the S residence, but both are lower in the transition times in the year (spring and fall).

The heating loads of various insulation methods on Feb. 8th (winter) and the cooling loads of various insulation methods on Jul. 25th (summer) are evaluated in Figs.11. and 12.

In Fig.11., the AC load of the RC residence unit is higher than that of the S unit during the daytime in winter. This is because the heat capacity of the RC unit is greater than that of the S unit, meaning that the walls of the RC unit absorb more interior heat. The heat load of the RC unit is lower than the S unit at 6:00 AM, when AC is turned on, because the walls of the RC unit dissipate heat during the night.

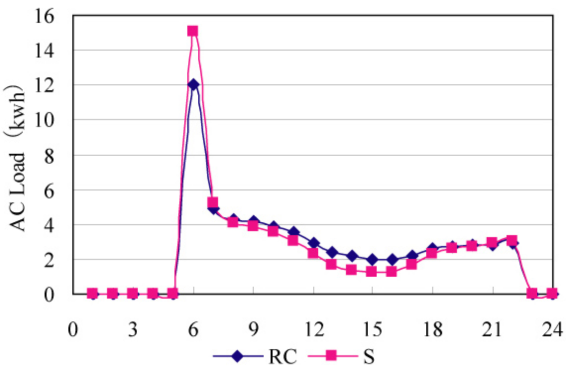


Fig.11. AC Loads of Two Types of Residence Units on Feb. 8th

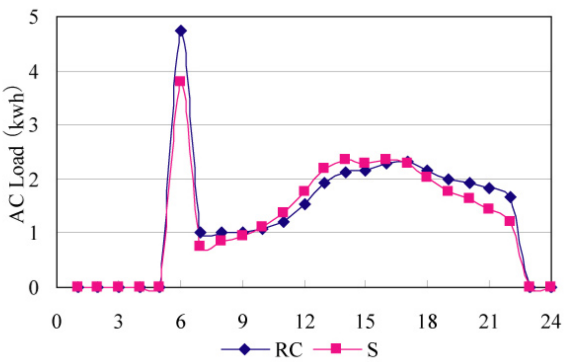


Fig.12. AC Loads of Two Types of Residence Units on Jul. 20th

In Fig.12., the AC load of the S residence unit is higher than that of the RC unit during the daytime in summer. This is because the heat capacity of the RC unit is greater than that of S unit, meaning that RC walls absorb more outside heat. In the evening the walls of the RC unit then dissipate this heat into the interior rooms, and thus the AC load of the RC unit is greater than that of the S unit in the evening and morning.

4.2 The case of insulation outside the exterior wall of the RC residence

Figs.13.-15. compare the AC loads of the RC and S units in each month of the year. The heat load in

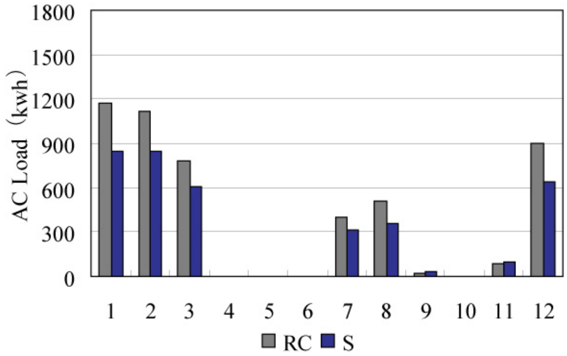


Fig.13. Monthly AC Loads of Various AC Patterns and Units (Intermittent A)

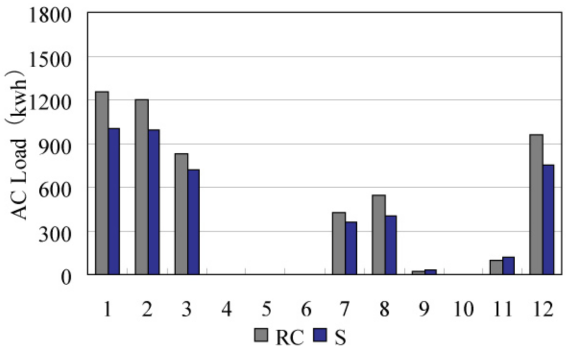


Fig.14. Monthly AC Loads of Various AC Patterns and Units (Intermittent B)

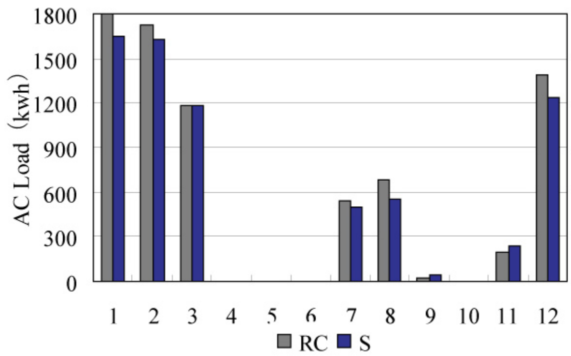


Fig.15. Monthly AC Loads of Various AC Patterns and Units (All Rooms)

December to March (winter) and July to August (summer) of the RC residence is higher than the S residence, but it is lower in the transition seasons (spring and fall). This is because the high heat capacity of RC absorbs the heat from inside the rooms in winter and dissipates heat into the rooms in summer. This effect is more pronounced in the case of insulation installed outside the exterior walls.

Figs.16. and 17. show annual heating (November to March) and cooling (April to October) loads of the various AC usage patterns and residence units.

In Fig.16., the heating load of the RC unit is 5.7% to 25.0% higher than the S unit for all three AC patterns. In Fig.17., the cooling load of the RC unit is 11.9% to 23.6% higher than the S unit for all three AC patterns. Thus, both the heating load and the cooling load of the S unit are lower than the RC unit because the RC skeleton, with its high heat capacity, absorbs interior heat in the winter and dissipates heat into interior rooms during summer nights.

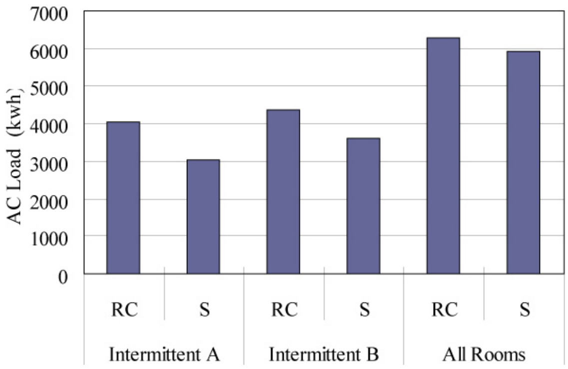


Fig.16. Annual Heating Loads (November to March)

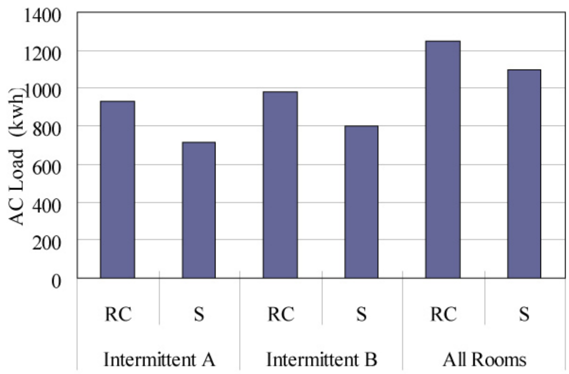


Fig.17. Annual Cooling Loads (April to October)

4.3 Comparison of RC residence units with exterior walls that are insulated on the inside and on outside

Fig.18. compares the ratios of decreased AC load when insulation is installed inside vs. outside the exterior wall of the RC residence. The ratios are computed with the following equation:

$$\frac{\text{AC load (outside insulation) - AC load (inside insulation)}}{\text{AC load (outside insulation)}} \times 100 = \boxed{\begin{array}{c}\text{Ratio of Decreased AC Load}\\ \text{with inside insulation}\end{array}} \quad (1)$$

The AC load of insulation installed inside the exterior wall is lower than that of outside insulation, except in summer in the All Rooms scenario. Further, the ratio of decreased AC load decreases with increasing AC usage. This is because of the effect of the high heat capacity of exterior walls of the RC unit. The AC load increases rapidly when AC is turned on. Therefore, the AC load with intermittent AC is higher than that of the All Rooms/Constant AC scenario (data not shown).

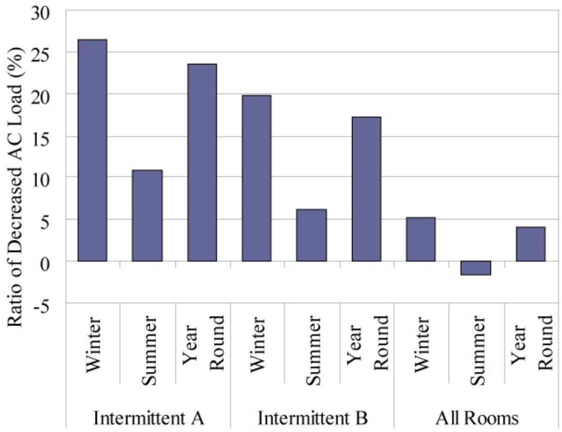


Fig.18. Ratio of Decreased AC Loads of Two Insulation Methods

Figs.19.-21. compare the ratios of decreased AC load of the S residence and the RC residence with different insulation methods. The ratios are computed with following equation:

$$\frac{\text{AC load (RC Residence) - AC load (S Residence)}}{\text{AC load (RC Residence)}} \times 100 = \boxed{\begin{array}{c}\text{Ratio of Decreased AC Load}\\ \text{with S insulation}\end{array}} \quad (2)$$

When both the S residence and the RC residence have insulation installed outside the walls, the ratio of decreased AC load of higher than that of when

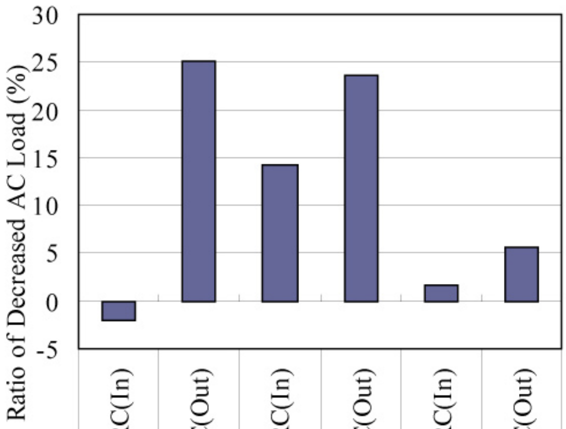


Fig.19. Ratio of Decreased AC Loads of S Residence Unit and RC Residence Unit (Intermittent A)

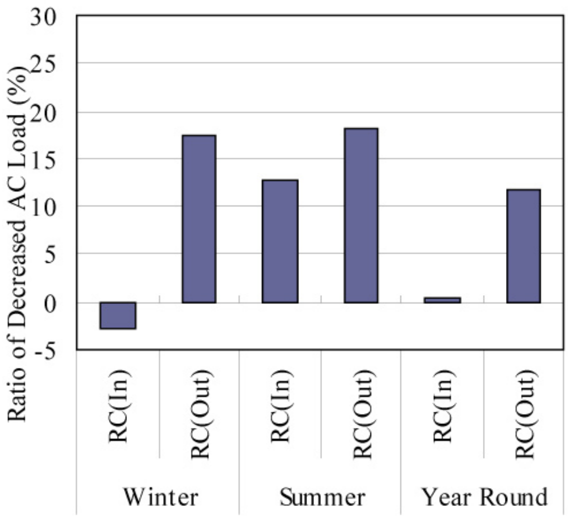


Fig.20. Ratio of Decreased AC Loads of S Residence Unit and RC Residence Unit (Intermittent B)

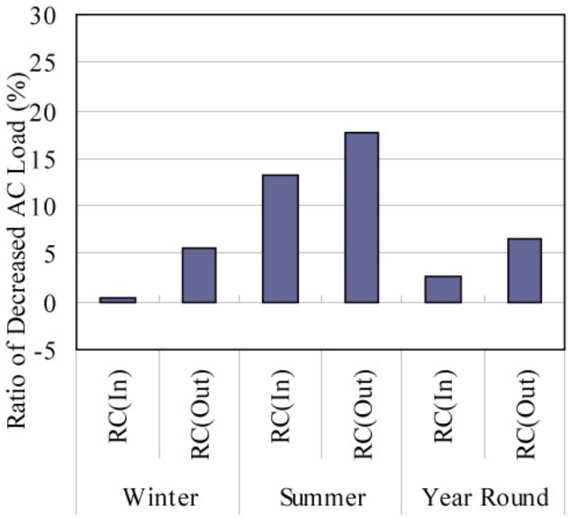


Fig.21. Ratio of Decreased AC Loads of S Residence Unit and RC Residence Unit (All Rooms)

insulation is installed inside the walls. Thus, the environmental load of the S residence is lower than the RC residence, and this is most evident when comparing it to the RC residence with outside insulation.

5. Conclusions

In this paper, the environmental features of a residential unit constructed with a steel structural fabric (the S unit) have been verified by comparison with a residential unit constructed with a reinforced concrete structural fabric (the RC unit). In the summer, because of the low heat capacity of the S unit, the average room temperature is lower than in the RC unit during the night, and the AC load is notably lower. In the winter, the AC load of the RC unit less than that of the S unit only when the exterior walls are insulated on the inside and the AC load is intermittent.

The method of insulation (either inside or outside the exterior wall) has a pronounced effect on the AC load. When the insulation is installed inside the exterior walls of the RC unit, the AC load is lower than when it is installed outside the exterior walls, and is somewhat close to the AC load of the S unit.

In Japan, S-type residences are often considered to have uncomfortable living environments compared to RC-type residences. This is due to old-style construction methods that allow significant air infiltration and heat-bridge, then, provide poor insulation. However, this research suggests that the high heat capacity of concrete leads to higher AC loads in RC-type residences in both winter and summer. Further, S-type residences can provide high-quality living environments if they have appropriate wall installation and utilize new-style construction methods. This paper verifies that insulated an S-type residence is not inferior to an RC-type residence in terms of indoor environment and energy.

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