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Influence of Differences of Heat Insulation Methods on Thermal Comfort of Apartment Buildings

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***Abstract*—**The aim of this study is to analyze influence of differences of heat insulation methods on indoor thermal environment and comfort of apartment buildings.

This study analyzes indoor thermal environment and comfort on units of apartment buildings using calculation software "THERB" and compares three different kinds of heat insulation methods. Those are outside insulation on outside walls, inside insulation on outside walls and interior insulation.

In terms of indoor thermal environment, outside insulation is the best to stabilize room temperature. In winter, room temperature on outside insulation after heating is higher than other and it is kept 3-5 degrees higher through all night. But the surface temperature with outside insulation did not dramatically increase when heating was used, which was 3 to 5°C lower than the temperature with other insulation. The PMV of interior insulation fall nearly range of comfort when the heating and cooling was use.

***Keywords*—**Apartment Building, Indoor Thermal Environment, Insulation, PMV

I. INTRODUCTION

IN order to tackle global environmental issues in Japan, the "Act of The Rational Use of Energy" and the "Energy-Saving Standards for Houses and Buildings [1]" were reformed in May 2008 and January 2009 respectively. These were aimed not to improve energy conservation performance at individual houses, but rather to focus on promoting and spreading energy savings throughout the whole housing industry, indicating that further discussion of housing energy savings will be anticipated. Therefore, we once again need to clarify the features of different insulations in common housing complexes, as well as how insulation affects indoor thermal environment and energetic load. This study aimed indoor thermal environment and comfort. We need to coordinate indoor thermal environment that are looked around about thermal comfort. Three insulation methods were compared from an indoor thermal environment perspective in which the room temperature, surface temperature, operative temperature and PMV at a model dwelling was adjusted by Thermal Load Calculation Software (THERB) to modify conditions such as location, climate and air conditioning.

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II. RESEARCH OVERVIEW

A. Simulation software

This research used calculation software: THERB to calculate indoor temperature, relative humidity, absolute humidity, PMV. PPD, operative temperature, sensible heat load and latent heat load at intervals of 600 seconds.

B. Simulation model

The model dwelling used in this simulation was a common dwelling in a residential complex located in Tokyo. The target dwelling was located on the middle floor at the center of the building and on the top floor at the western end of the building, as this was expected to have the largest cooling and heating load. Figure 1 shows floor plan.

C. Climate condition

We used reference data from Expanded AMeDAS Weather Data from the period between 1981 and 2000 in this simulation [2]. The target areas consisted of Tokyo in the Fourth Area of Next Generation Energy-Saving Standards.

D. Insulation method

Three insulation methods - outside insulation, inside insulation and interior insulation - were compared. In the interior insulation method, not only areas exposed to the air such as external wall and roof but also confining wall, flooring and ceiling were insulated aiming to insulate the whole building from the inner side. We complied with the Next Generation Energy-Saving Standards regarding what materials were used [1], how thick they were or where they were installed. Three kinds of Class A Extruded Polystyrene Form Heat Insulation were mainly used as insulation materials. High Grade Glass Wool 16K was used on the flooring only for the interior insulation. Except for the external wall and roof for the interior insulation, the thicknesses of insulation materials were 30mm Class A Extruded Polystyrene Form Heat Insulation for walls and 50mm High Grade Glass Wool 16K insulation for flooring. Figure 1 and Table I show location and thickness of insulation materials.

E. Lifestyle pattern

To observe how difference in life style affects heat load, we prepared four different air-conditioned rooms where residents with a different lifestyle were allocated to live in an air-conditioned environment [3]. These conditions were as follows: A. No one is at home during the day, and the air-conditioner is not in use during sleeping hours. (A couple with dual income no kids – DINK); B. No one is at home during the day, and the air-conditioner is not in use during sleeping hours. (A family consisting of a husband, a full-time housewife and a primary school child.); C. No one is at home during the day, and the air-conditioner is in use during sleeping hours. (An elderly couple); D. 24-hour air-conditioning.

Period of heating is January-March and November-December. This period is that monthly average temperature are equal to or lower than 15 °C (preset temperature: 22°C, percentage humidity: 40%). Period of cooling is April-October (preset temperature: 26°C, percentage humidity: 60%).Additionally, all rooms were continuously ventilated once every two hours, as well as automatically ventilated on an as-needed basis in the living room, dining room, kitchen and bathroom. Table 2 shows the ventilation schedule by lifestyle.

III. Indoor Condition

A. Living room air temperature in the coldest season

Figure 2 shows the relationship between living room temperature fluctuation, external temperature and direct solar radiation on the top floor in the coldest season(1/30-31). Changes of indoor temperature in the figure highlight the features of each insulation. Changes in indoor temperature with the outside insulation had the smallest fluctuation and the highest indoor temperature when the heating was not in use. When I compare outside insulation with inside insulation, the living room temperature with inside insulation had more fluctuation by External air after turning off the heating. But the living room temperature with outside insulation had more stable. It kept the indoor temperature 2 to 3°C higher than inside insulations at 30th 7:00 before heating. With the interior insulation, the indoor temperature experienced a temporary drop after turning off the heating in the morning, but increased to approximately 21°C with the increasing external temperature. Then the temperature was the highest at 30th 19:00 before heating. This phenomenon was observed to a certain extent when the inside insulation was used. The living room temperature with inside insulation had lowest before heating, 10 °C at 6:00 in the morning. We discuss about decline of the living room temperature per hour after heating at 1/30 22:00. The temperature with outside insulation decreased most in an hour after heating. The temperature with outside insulation decreased 2.61 °C, with inside insulation decreased 1.97 °C, with interior insulation decreased 1.29 °C. Four hours later, the temperature with inside insulation had lowest and decreased 7.92 °C. After that time the thermal storage effect of outside insulation maintained stable fluctuation, the temperature had about 0.2 °C higher than interior insulation about 1.8 °C higher than inside insulation at 7:00. The features of the insulations were less distinguishable when the heating was used for a longer period. A similar trend was observed in the middle floor, so we discuss this research using data of top floor that the features of each insulation were shown.

B. Living room air temperature in the hottest season

Figure 3 shows the relationship between living room temperature fluctuation, external temperature and direct solar radiation on the top floor in the hottest season(7/27-28). The living room temperature with outside insulation had most stable. The interior insulation resulted in the largest rise in indoor temperature during the day when heating was not in use, followed by inside insulation and outside insulation. Sunlight significantly affected the indoor temperature when interior insulation or inside insulation was used, which led to a temperature increase of up to 34°C. Only the eaves on the south side of the room shielded the sunlight from the window in this simulation, so practically a further insulation effect is expected by installing blinds. As is the case with the coldest season, the features of the insulations were less distinguishable when the cooling was used for a longer period. We discuss about rise of the living room temperature per hour after cooling at 7/27 8:00. When it is compared to the coldest season, there were not differences of inside insulation and interior insulation. The temperature with outside insulation had about 2.2 °C lower than inside insulation about 3.0 °C lower than interior insulation at 17:00.

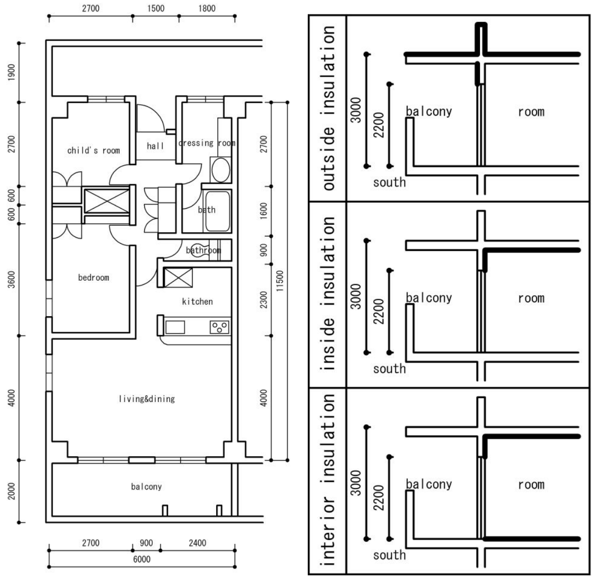
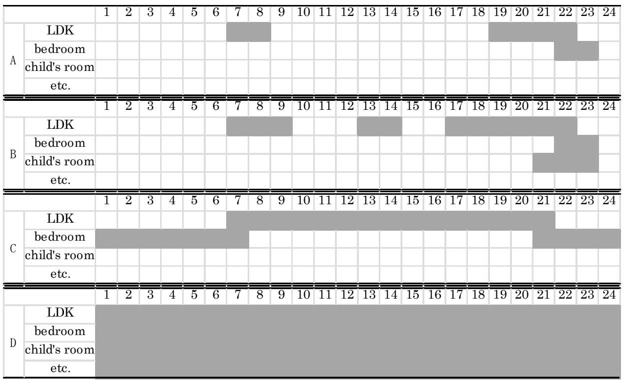


Fig. 1 Floor plan and Location of insulation

TABLE I
THICKNESS OF INSULATION

thickness(mm)	outside	inside	interior
outside wall	30	35	35
roof	60	70	70

TABLE II
VENTILATION SCHEDULE BY LIFESTYLE



C. Temperature in the corridor

Figure 4 shows the relationship between changes of temperature in the corridor, external temperature and direct solar radiation in the coldest season. The temperature in the corridor and living room were more stable with the outside insulation than other insulations. External air and living room air caused temperature fluctuations when inside insulation and interior insulation were used. The temperature in the corridor with inside insulation had the smallest before heating in the morning.

Figure 5 shows the relationship between changes of temperature in the corridor, external temperature and direct solar radiation in the hottest season. The temperature in the corridor was more stable with the outside insulation than other insulations. The temperature with outside insulation was lower than other insulations throughout the day.

D.Surface temperature of a external wall

Figure 6 shows the relationship between surface temperature of the inner wall on the west side in the living room and external temperature in the coldest season. There was a silimar fluctuation in any insulation as indoor temperature when heating was not in use. The surface temperature with outside insulation did not dramatically increase when heating was used, which was 3 to 5°C lower than the temperature with other insulation. The surface temperature with interior insulation was 0.6°C, with inside insulation was 1.8°C, with outside insulation was 5.5°C lower than the indoor temperature – 22°C(1/30 9:00). It is explained that the external wall was exposed to cooling radiation.

Figure 7 shows the relationship between surface temperature of the inner wall on the west side in the living room and external temperature in the hottest season. The surface temperature with outside insulation did not decrease when cooling was used. The surface temperature with interior insulation was 1.9°C, with inside insulation was 1.9°C, with outside insulation was 2.8°C higher than the indoor temperature – 26°C(7/27 21:00).

E. Surface temperature of a partition wall

Figure 8 shows the relationship between surface temperature of the partition wall on the east side in the living room and external temperature in the coldest season. The surface temperature fluctuation with outside insulation and inside insulation which are not located insulation materials on the partition wall show a similar trend.External air and living room air caused surface temperature fluctuations when interior insulation which is located insulation materials was used. The surface temperature with interior insulation was 2.4°C, with inside insulation was 9.4°C, with outside insulation was 9.8°C lower than the indoor temperature – 22°C(1/30 9:00).

Figure 9 shows the relationship between surface temperature of the partition wall on the east side in the living room and external temperature in the hottest season. The temperature of partition wall fluctuation in the hotteset season showed a similar trend with the Surface temperature of living room.The surface temperature with interior insulation was 1.3°C, with inside insulation was 3.3°C, with outside insulation was 3.0°C higher than the indoor temperature – 26°C(7/27 21:00).

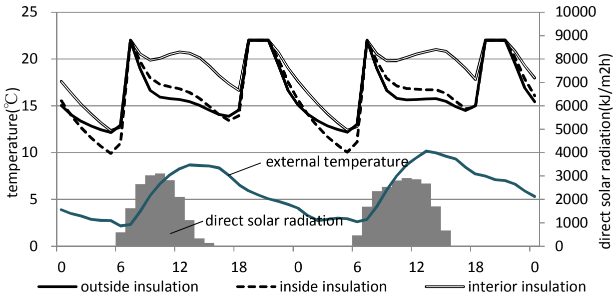


Fig. 2 Temperature of living room (1/30-31) (A)

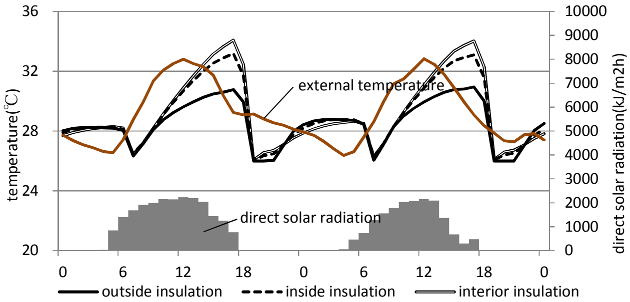


Fig. 3 Temperature of living room (7/27-28) (A)

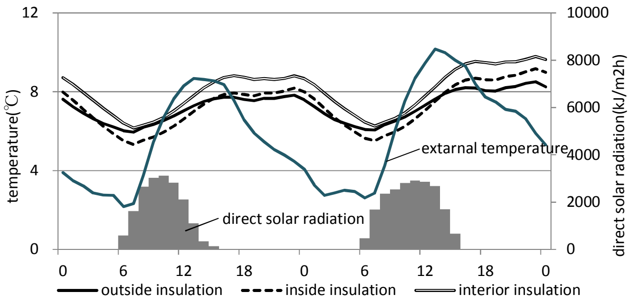


Fig. 4 Temperature of corridor (1/30-31) (A)

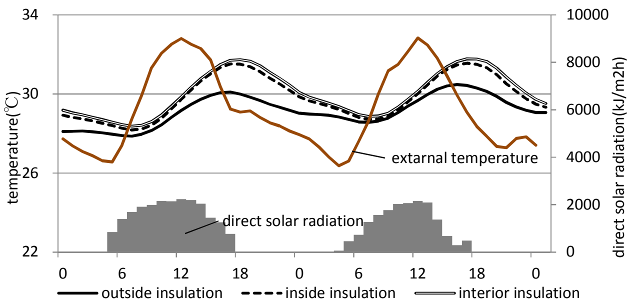


Fig. 5 Temperature of corridor (7/27-28) (A)

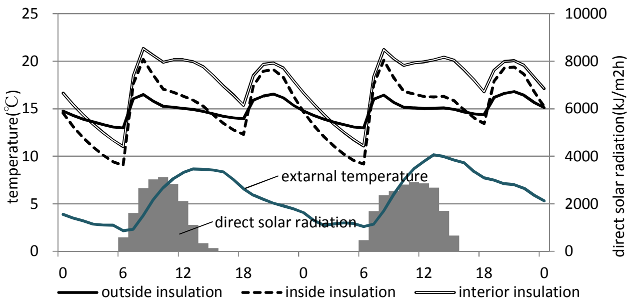


Fig. 6 Surface temperature of living room (1/30-31) (A)

IV. Thermal Comfort

A. Operative temperature

Figure 10 shows the relationship between living room temperature and operative temperature fluctuation in the coldest season(1/30 Lifestyle A).The living room temperature fluctuation and the operative temperature fluctuation show a similar trend when heating was not in use.The operative temperature is higher than the living room temperature in the daytime, the living room temperature is higher than the operative temperature in other time. The difference by each insulation method was seen when the heating was in use. The operative temperature with interior insulation was 2.5^{o}C, with inside insulation was 3.3^{o}C, with outside insulation was 3.5^{o}C lower than the indoor temperature – 22^{o}C(9:00).

Figure 11 shows the relationship between living room temperature fluctuation and operative temperature in the hottest season(7/27 Lifestyle A).The living room temperature and operative temperature fluctuation showed a similar trend when the cooling was not in use. The difference by each insulation method was not seen when the cooling was in use. The operative temperature was about 1.5^{o}C higher than the indoor temperature – 26^{o}C.

B. PMV

Figure 12 shows the indoor thermal environment of the living room in the coldest season(1/30 -31).
We used data of lifestyle C in this section to discuss the thermal comfort in the ventilation. The thermal storage effect of outside insulation maintained the warmest temperature and the most stable fluctuation in the living room when the heating was not in use. Therefore PMV with outside insulation was most near range of comfort that ISO-7730 set down it -0.5＜PMV＜0.5. The PMV with outside insulation was -2.17, inside insulation was -3.02 and interior insulation was -2.63 at 30th 7:00. The PMV of interior insulation fall nearly range of comfort when the heating was use. The PMV of inside insulation fall range of comfort when the heating was use and external air caused surface temperature fluctuations. The PMV with outside insulation was -0.50, inside insulation was -0.32 and interior insulation was -0.09 at 30th 12:00.

Figure 13 shows the indoor thermal environment of the living room in the hottest season(7/27 -28).The thermal storage effect of outside insulation maintained the lowest temperature and the most stable fluctuation in the living room when the cooling was not in use. Therefore PMV with outside insulation was most near range of comfort. When it is compared to heating season, there were not differences of insulation methods. The PMV with any insulation fall nearly range of comfort when the cooling was in use.

C. Rate of comfort hour

We defined it rate of comfort hour that the percentage of range of comfort.

$$Rate\ of\ comfort\ hour = \frac{comfort\ hour}{daily\ ventilatio\ n\ hour}$$

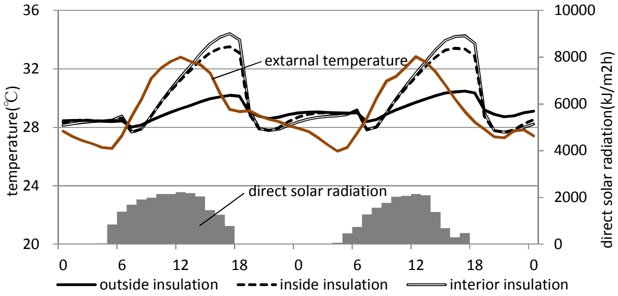


Fig. 7 Surface temperature of living room (7/27-28) (A)

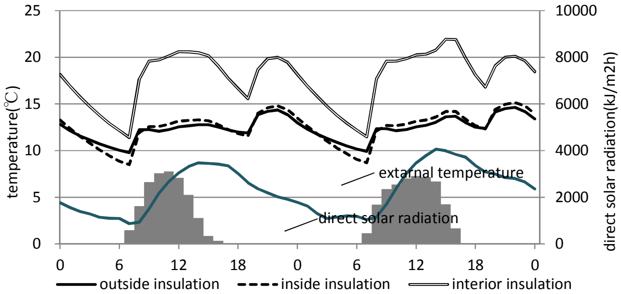


Fig. 8 Temperature of partition wall (1/30-31) (A)

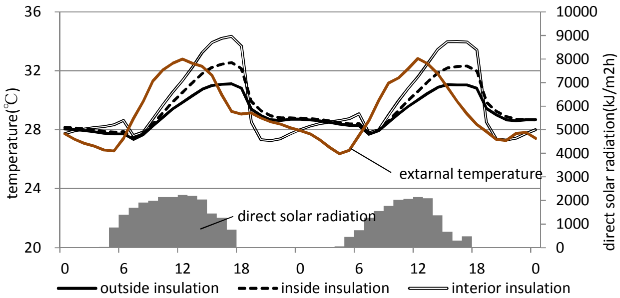


Fig. 9 Temperature of partition wall (7/27-28) (A)

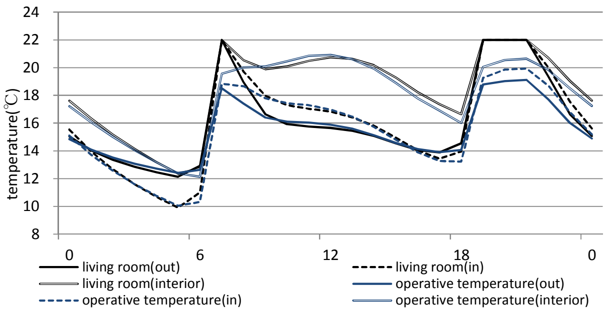


Fig. 10 Operative temperature (1/30) (A)

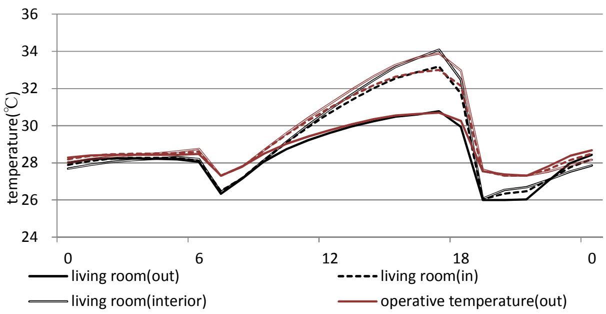


Fig. 11 Operative temperature (7/27) (A)

Figure 14 and Table III shows the rate of comfort hour of the living room in the coldest season(1/29 -31) and the hottest season(7/26-28) on the top floor(lifestyle C). There were differences of insulation methods in the coldest season. The rate of comfort hour with outside insulation was 10% on an average.

The rate of comfort hour with inside insulation was about 50%, with interior insulation was about 90%. In the hottest season, the rate of comfort hour with any insulation was over 80%.

V. Conclusion

A. Fluctuation in indoor temperature

Outside insulation was the most stable in maintaining indoor temperature throughout heating and cooling seasons. When the heating was turned off during the night in the heating season, the thermal storage effect of outside insulation maintained the warmest temperature in the living room and the corridor. During the day, the interior insulation was particularly affected by sunlight increasing the indoor temperature, which illustrated that there was a great fluctuation in room temperature with inside insulation and interior insulation. As was the case with the cooling season, indoor temperature was lowest when the cooling was not in use. Although outside insulation has more advantages from the viewpoint of indoor temperature fluctuation, we still need to take into account that external wall areas are difficult to warm up during the heating season due to the reasons stated under 4-3. Surface temperature.

B. Thermal comfort

There were differences of the indoor temperature and the operative temperature with any insulation methods. Especially, there were great differences of the indoor temperature and the operative temperature with outside insulation in the coldest season. Then the PMV with outside insulation hardly fall range of comfort when the heating was use. The PMV with any insulation fall nearly range of comfort when the cooling was use. Outside insulation have the most advantageous on thermal environment to keep high indoor temperature by thermal storage effect when the heating was not in use. But we need to look around about the differences of the indoor temperature and the operative temperature when the heating was in use.

Finally, as we discussed the features of the insulations, their advantages and disadvantages were expected to differ depending on various factors including regional characteristics, insulation efficiency levels and design conditions.

TABLE III
RATE OF COMFORT HOUR

Rate of comfort hour(%)	outside insulation	inside insulation	interior insulation
1/29	0.00	42.86	92.86
1/30	7.14	42.86	85.71
1/31	21.43	50.00	92.86
Average	9.52	45.24	90.48
7/26	100.00	100.00	100.00
7/27	100.00	85.71	100.00
7/28	100.00	78.57	100.00
Average	100.00	88.09	100.00

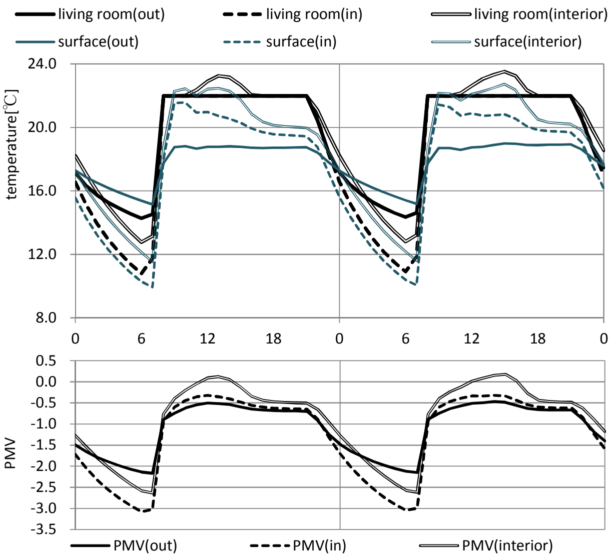


Fig. 12 Indoor thermal environment of living room (1/30-31) (C)

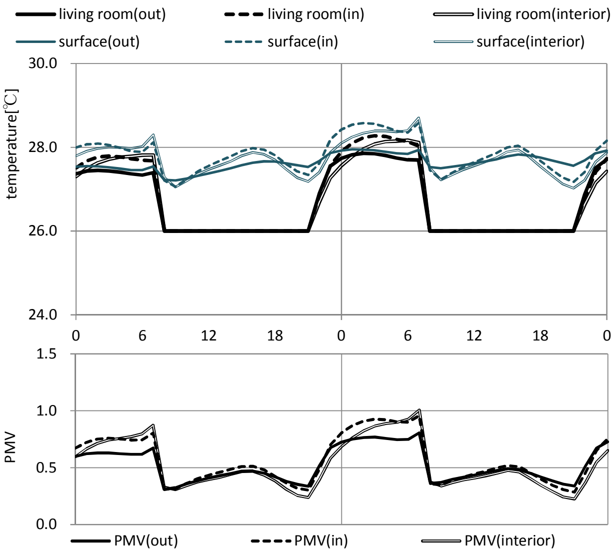


Fig. 13 Indoor thermal environment of living room (7/27-28) (C)

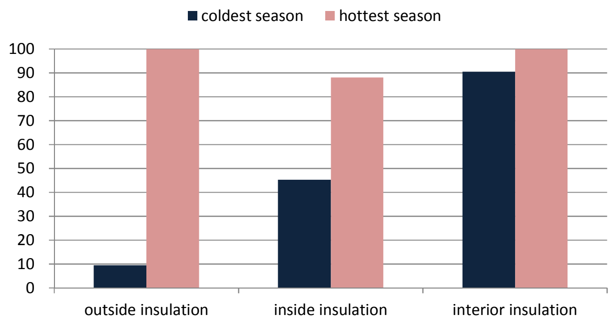


Fig. 14 Rate of comfort hour

REFERENCES

[1] Guideline of Housing Energy Conservation Standard Third edition by Institute for Building Environment and Energy Conservation – July 2009.
[2] Expanded AMeDAS Weather Data from 1981 to 2000 by Architectural Institute of Japan - August 2005.
[3] Journal of Architectural Knowledge September edition.
[4] Hasegawa, K. and other three authors. Consideration of Adequate Insulation Levels for Apartment Houses in view of Indoor Thermal Environment. Journal of Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan, 213-214.
[5] Architectural Environment Engineering by Morikita Publishing Co., Ltd - June 1996.

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