

RELATIONSHIP BETWEEN THE RESIDENT FLOOR AND THE THERMAL CONTROL USE IN SUMMER IN SUPER HIGH-RISE APARTMENTS

Noriko Umemiya^{*}, Yuki Nomura, Ryoji Okura and Xiaoyong Lin

*Osaka City University, Graduate School of Engineering,
3-3-138 Sugimoto, Sumiyoshi-ku, Osaka City, Japan*

^{}E-mail: umemiya@arch.eng.osaka-cu.ac.jp*

Abstract

A survey of residents of super high-rise apartment buildings was carried out in an urban area of Osaka. Relationships between the residences' height from the ground and energy consumption, thermal comfort, and use of mechanical and natural cooling were analyzed. 1) The average cooling expense was 1692 yen more for residents living on the 30th story or higher than for those living below the 10th floor. 2) The frequency of air conditioner use was higher for residents living on the 20th story or above than for those living lower. 3) Residents of the units on the 20th floor or above evaluated the ventilation of the units better than those living lower did. 4) Residents of units situated lower than 20 stories opened windows more frequently than those living in upper stories for both waking and sleeping.

1. Introduction

Super high-rise apartment buildings have been increasing in urban areas of Japan. Super high-rise apartment buildings are defined as apartment buildings of more than 20 stories in this study. Former studies investigated the lifestyles of residents of high-rise buildings for comparison to those of the lower buildings in relation to the community, child education, mental health, etc. The physical environment of living more than 60 m high from the ground somewhat affects residents' lifestyles. This study investigates the thermal environment, air conditioner use, window-opening behaviors, and energy costs in summer for super high-rise apartment buildings using a questionnaire survey and compares responses of residents of upper apartments and lower apartments.

2. Method

2.1 Investigation Object

For this study, 25 super high-rise apartment buildings in Osaka built before 2005 were selected. Six residents' associations related to the 25 buildings agreed to our survey. Questionnaire sheets were posted to all 2,235 apartments of the six buildings in September 2006; 297 sheets (13.3%) were returned by mail. Table 1 shows the outline of the buildings. Residents who had lived in the apartments less than one year were excluded from this study. The numbers of stories were 40, 40, 50, 25, 21, and 43. The completion years were 2004, 1999, 1993, 1976, 1994, and 1999.

2.2 Investigation Item

Investigation items were grouped into five categories. 1) Basic attributes of the apartment: area, planning, direction, floor, etc. 2) Subjective evaluation of the living environment of the apartment: sunshine, ventilation, view, glances from passersby from outside, sounds, summer heat, appearance of insects or mold, elevators and overall satisfaction with the living environment of the apartment, etc. 3) Situation of air conditioner use, window-opening, and electric fan use. 4) Electric and gas costs for January, May, June, July, and August in 2006. 5) Attributes of the respondents and families: age, sex, situation of health, family income, lifestyle, meal habits, ecological consciousness, etc.

3. Results

3.1 Attributes of the Respondents and the Apartments

3.1.1 Respondents

Of all respondents, females were 58.6% and males were 41.4%. Figure 1 shows the age of respondents. Respondents in the 40s, 50s, and 60s were respectively more than 20%. Figure 2 shows the number of households. Two household types were dominant. Single-person and two-person households collectively comprised 68.1% of all. In fact, 82.2% of the respondents were brought up in Osaka. Also, 39.0% had meals irregularly (5.5%) or slightly irregularly (32.5%). Of respondents, 40.0% answered they kept irregular (6.5%) or slightly irregular (33.6%) hours. Although 14.6% of the respondents had chronic illness, 30.6% were healthy and 55.9% were of ordinary health. Of respondents, 35.9% answered that they had poor circulation.

The following were also found: 64.2% would like to live with natural cooling rather than mechanical cooling; 57.8% liked to feel continuity with outdoors, even when they were indoors; 22.5% longed for rural life such as in a mountain cottage; 57.3% were careful not to waste water or electricity; 87.5% acknowledged urban warming; and 78.2% were interested in issues of urban warming or global warming.

For purposes of reporting results, residents were classified according to their floor of residence: 30+, high-uppers; 20+, uppers; 19-, lowers; 9-, down-lowers. Of course, some comparisons might group high-uppers among uppers (as all uppers), or lowers with down-lowers (as all lowers), etc.

3.1.2 Apartments

Figure 3 shows the frequency distribution of the respondents' floors of residence. Apartments situated on the 20th story or above housed 45.3% of the respondents. Figure 4 shows the dwelling area. The class of 70–79 m² was 27.2% and the most frequent. Planning of three bedrooms and a dining and kitchen area was the dominant type. In addition, the following were found: 32.3% of the apartments were located at corners of buildings; 42.8% of respondents bought apartments from private developers; and rented apartments were 17.6%. Apartments for which the main direction of the windows was west were 26.7%, east were 24.5%, and south were 20.2%. Apartments that were used as second houses were only 2.8%, although 34.3% of the respondents answered that they tended to be absent from the apartments rather than stay home.

3.2 Subjective Evaluation of the Living Environment

Subjective evaluation of the apartment living environment is presented in Fig. 5 for ventilation, view, summer heat, elevator, and overall satisfaction to the living environment. Ventilation was evaluated as “good” by 69.6% of respondents. On the other hand, the respondents who evaluated the indoor air speed as too high were 8.9%. Sunshine was evaluated as “good” by 75.8% of respondents. Outside air was evaluated as “clear” by only 6.9%. Mold was evaluated as “less appeared” by 71.6%. Insects were evaluated as “less appeared” by 85.3%. Drafts were evaluated as “not felt” by 78.4%. Furthermore, 24.3% felt solar heat to be “bothersome” in summer. 20.9% “felt” glare by sunshine from windows. Then, 29.0% evaluated summer heat of the apartment as “difficult to bear without air conditioners”, 57.7% evaluated as “bearable with air conditioners when hot”, 13.3% evaluated as “bearable using only natural ventilation”. Moreover, 56.5% were “satisfied” and 19.4% were “very satisfied” with the living environment.

3.3 Air-conditioner Use

Figure 6 shows the number of air conditioners. Of the respondents, 29.9% used two air conditioners; 26.5% used three. The following were also found: 3.4% of respondents had no air

conditioners; 98.9% were electric air conditioners. Figure 7 shows a subjective evaluation of the frequency of air conditioner use on a five-point scale: 41.2% answered they use air conditioners 'often'. Figure 8 shows the frequency of air conditioner use when sleeping. Only 2.2% had no air conditioners in bedrooms, but 20.1% did not use air-conditioners in the bedrooms; 29.9% used timers.

No significant differences were found in minimum and maximum setting temperatures for air conditioners between resident groups of uppers and lowers. However, a significant difference ($p < 0.05$) was recognized between lowers and high-uppers in the maximum setting temperature. Maximum and minimum setting temperatures were 26.92 and 25.45°C for high-uppers and 27.53 and 26.24°C for the down-lowers. The high-uppers tended to set cooling temperatures lower.

A distribution of air conditioning expenses during August–September is shown in Fig. 9. Air conditioning expenses are defined here as the difference in electrical expense in May from that in August. Electric expense in May was inferred to be the basic expense, i.e. not including cooling costs, although electric expenses in August were less than those in May for 6.5% of respondents. Respondents recording differences of 0–2,500 yen were 37.4%: the most numerous of all groups.

3.4 Window Opening in Summer

Figure 10 and Fig. 11 show subjective degrees of window opening in summer. 'Rather open' was 62.0% and 'rather closed' was 13.9% during waking. When sleeping, 'rather open' decreased, and 'rather closed' increased by about 10% compared to that during waking.

3.5 Use of Electric Fans

In fact, 12.6% of respondents did not have electric fans. The most frequent response was one fan – 48.8%; 38.7% answered that they 'frequently' used fans, although 26.0% answered 'seldom'. Also, 23.9% did not like fans because 'they are not as cool as air conditioners'. 'It is troublesome to take fans in and out' was selected by 4.9% of respondents.

4. Discussion

Thermal control use by residents was compared for four groupings by floor of residence: 1) 1–9, 10–19, 20–29, and 30–; 2) 1–19, 20–29 and 30– (i.e. uppers and high-uppers separate); 3) 1–9, 10–19 and 20– (i.e. uppers and high-uppers together); and 4) 1–19 and 20– (all lowers vs. all uppers). Chi-squared tests of independence were carried out; dependence was inferred for $p < 0.20$. Reported herein are all results of $p < 0.01$, 0.02, 0.05, 0.10, and 0.20.

4.1 Thermal Sensation in the Apartments in Summer and Resident Floors

The choices of thermal sensation in summer were, 'I can bear the heat with natural ventilation', 'I can bear the heat if I use air conditioners when it is hot', and 'I cannot bear the heat without air conditioners'. Figure 12 depicts a comparison between all uppers and all lowers, for which the strongest dependence was found: 33.6% of the occupants of the upper floors choose 'Not without air conditioners', whereas 22.8% of the lowers selected the choice. On the other hand, the ratios of choice of 'Only with natural ventilation' were almost the same among the uppers and lowers. Responses were, respectively, 12.7% and 14.6% for the uppers and the lowers ($p < 0.10$).

In spite of the good evaluation of summer heat, thermal conditions were presumed to be worse in summer for all lowers because 'Solar heat in summer is bothersome' was reported by 28.1% of all lowers and 18.1% of all uppers. The subjective evaluation of sunshine was independent of the residential floor. The presumed reasons are that the ratio of installation of curtains was slightly lower for the uppers. Another presumed reason is that 'Air conditioning is effective in summer' was reported by 60.2% for uppers and 48.1% for lowers.

4.2 Thermal Control Use and Resident Floors

4.2.1 Air-conditioner Use

The subjective rating of air conditioner use is shown for waking and sleeping times in Fig. 13. The uppers used air conditioners more frequently ($p<0.05$).

For the questionnaire ‘Are you concerned about cooling costs?’, the distribution of the ratio of choices ‘concerned, but there is nothing to do’, ‘anxious and saving’, ‘not so high’, and ‘not anxious at all’ were reported with almost equal frequency by uppers and the lowers.

Differences of cooling costs are shown in Table 2. Table 3 shows on the cooling cost per area. Although no significant difference was found between apartments of residence floors of lowers and uppers, a comparison between down-lowers and high-uppers is shown ($p<0.05$). Cooling costs per area and per person were also compared and differences between high-uppers and down-lowers were found.

4.2.2 Window Opening

Figure 14 compares the subjective rating of window opening in summer between all uppers and all lowers both for waking and sleeping hours. The lowers opened windows more frequently. They were inferred to be significantly different ($p<0.05$) for both waking and sleeping hours.

4.3 Factors That Effects the Difference

No significant difference in age, sex, family number, condition of health, resistance to cold, or frequency of catching cold was found between all uppers and all lowers, except goodness of night sleep during summer ($p<0.05$), resistance to heat ($p<0.20$), and rather nocturnal living ($p<0.20$).

Regarding ecological consciousness, 26.3% of lowers ‘try to adjust clothing and bedding’, where 18.6% for the uppers report doing so. Furthermore, 12.4% of uppers chose ‘not to try to adjust’, where 3.2% of the uppers did so ($p<0.05$). Also, 41.9% of the lowers ‘would like to live with natural wind rather than artificial cooling’, whereas 31.8% of the uppers reported that desire ($p<0.10$). Regarding circulation, 20.8% of the lowers reported ‘bad circulation’, where 11.6% of the uppers ($p<0.10$). However, no differences were found in responses to other questionnaire items related to ecological consciousness, continuity with outdoors, admiration for natural life, tendency to use ecological goods, anxiousness for global warming, and realization of urban warming.

The ratios of choices ‘ventilation is good’ were not so different for residents of different floors: 68.4% for the uppers and 60.8% for the lowers. Figure 15 shows an evaluation related to ventilation. The ratios of ‘wind is too strong’ were almost the same for the uppers (5.3%) and the lowers (5.1%). In contrast, conditions for opening windows were worse for the lowers. The ratios of choices of ‘air outside is dirty’ were 41.7% for the lowers and 28.8% for the uppers. Glances from outside are not bothersome were 73.9% of the lowers and 89.5% of the uppers; 12.8% of the lowers were ‘not so concerned about robbery’, whereas 19.7% for the uppers were, although the ratios of ‘concerned about robbery’ were almost the same (44.5% for uppers and 44.2% for lowers). Moreover, subjective evaluations of glare and sound outside were independent of the residence floor.

Results of this study show that high-rise dwelling encourages air conditioner use and raises their cooling costs in summer. However, 60.3% of the uppers ‘rather opened’ windows in autumn, whereas 50.3% of the lowers did so ($p<0.20$).

5. Conclusions

It can be said that the occupants of upper floors of super-high-rise apartment buildings tend to use air conditioners more frequently and open windows less often than the lowers in summer. Cooling costs, cooling costs per area, and cooling costs per person are higher for the uppers than for the lowers. Conditions are better in relation to solar heat, ventilation, air clearness outside, glances from passersby outside and concern about robbery, as shown by subjective evaluation. Nevertheless, thermal sensations are worse for the uppers. Uppers tend to respond that they cannot bear summer heat without air conditioners.

References

- [1] Ginjiro INOUE, Shoyu RIN, Noriko UMEMIYA: A study on relation between air conditioner use and window opening behavior in apartment house in summer, (SUMMARIES OF TECHNICAL PAPERS OF ANNUAL MEETING ARCHTECTURAL INSTITUTE OF JAPAN,D-2 pp193-194,Sep,2005)
- [2] Tamami SUZUKI, Noriko UMEMIYA and Harunori YOSHINDA: STRUCTURE OF THE CAUSES OF WINDOW OPENING AND CLOSING BEHAVIOR FROM SUMMER TO AUTUMN, (J.Archit. Plann. Environ. Eng,AIJ, No.556,91-98,Jun,2002)
- [3] Shoyu RIN, Ginjiro INOUE, Noriko UMEMIYA :Survey of life style in summer for apartment house occupants in Osaka City, (SUMMARIES OF TECHNICAL PAPERS OF ANNUAL MEETING ARCHTECTURAL INSTITUTE OF JAPAN,D-1 pp859-862,Sep,2005)

Table 1: Super high-rise apartment buildings for the survey

No	Place	Number of stories	Completion year	Number of distributions	Number of collections	Collection rate	Distribution day	Day of deadline
1	Osaka City Abeno Ward	40	2004	400	73	18.3%	9/8	10/24
2	Osaka City Joto Ward	40	1999	409	46	11.2%	9/8	10/24
3	Osaka City Minato Ward	50	1993	339	37	10.9%	9/8	10/24
4	Osaka City Joto Ward	25	1976	528	41	7.8%	9/15	10/24
5	Osaka City Minato Ward	21	1994	221	20	9.0%	9/22	10/24
6	Sakai City Sakai Ward	43	1999	338	80	23.7%	9/22	10/24
Total				2235	297	13.3%		

Table 2: Mean cooling costs by floors

Stories	N	Mean value (Yen)	Significance level
1~9	29	2241	5%
30~	23	3933	

Table 3: Mean cooling costs per area by floors

Stories	N	Mean value (Yen/m ²)	Significance level
1~9	27	32	5%
30~	22	50	

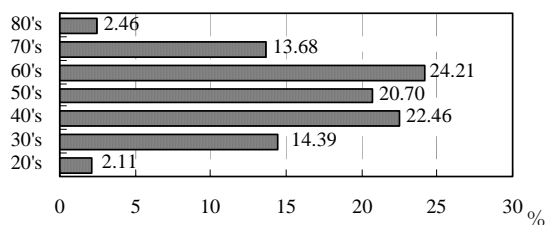


Figure 1: Ages of the respondents

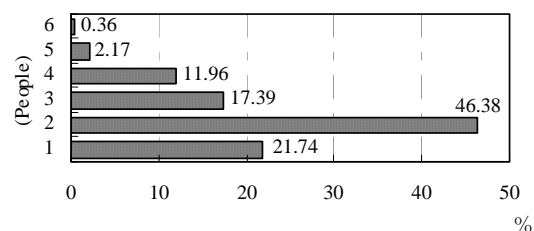


Figure 2: Numbers of the families

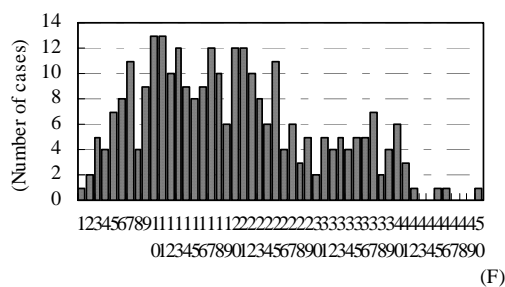


Figure 3: Resident floors

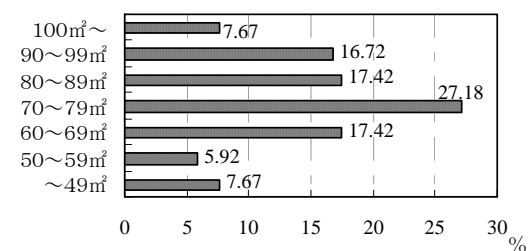


Figure 4: Areas of the apartments

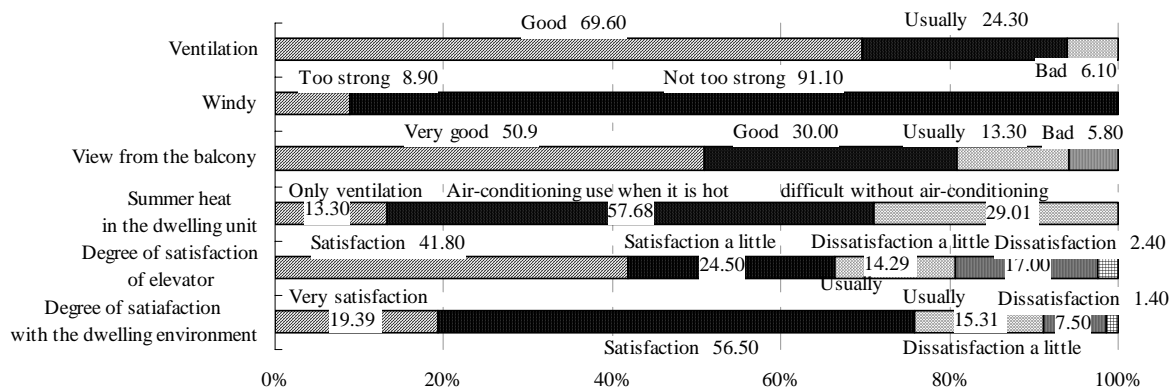


Figure 5: Subjective evaluation of the living environment

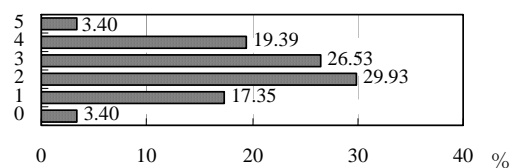


Figure 6: Number of air-conditioners

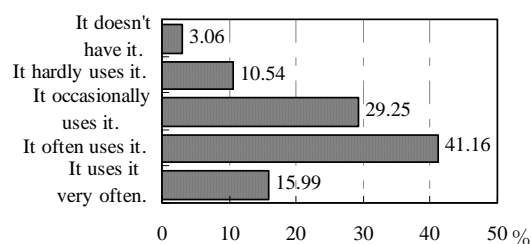


Figure 7: Frequency of air-conditioner use

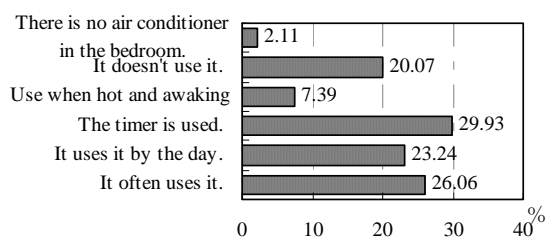


Figure 8: Frequency of air-conditioner use when sleeping

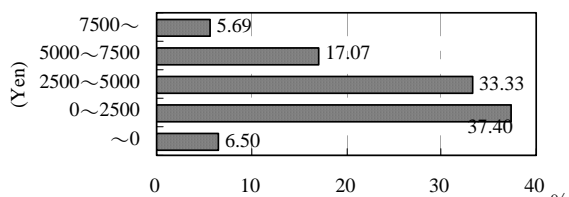


Figure 9: Cooling cost

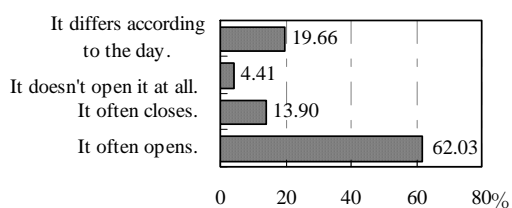


Figure 10: Window opening when waking in summer

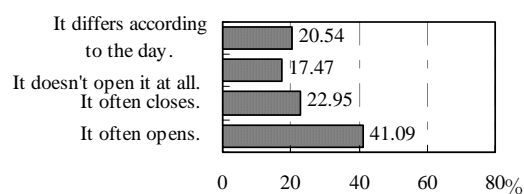


Figure 11: Window opening when sleeping in summer

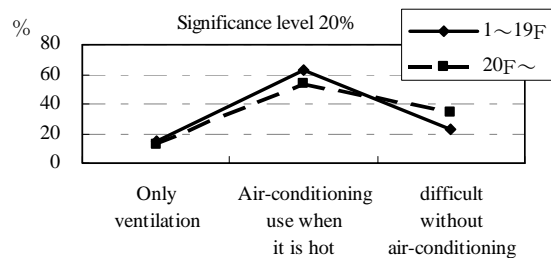


Figure 12: Thermal sensation indoors in summer

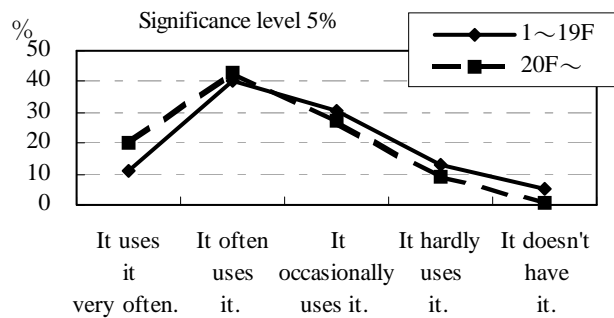


Figure 13: Difference of air-conditioner use in summer by floors

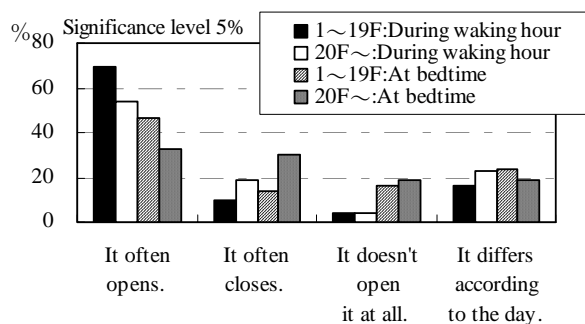


Figure 14: Difference of window opening in summer by floors

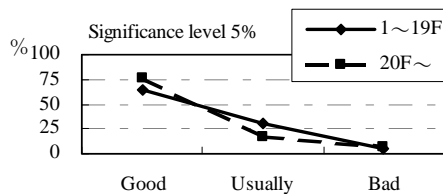


Figure 15: Difference of the evaluation of ventilation