PERGAMON

Building and Environment 38 (2003) 283–289

BUILDING AND ENVIRONMENT

www.elsevier.com/locate/buildenv

Environmental assessment of light well in high-rise apartment building

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Received 2 August 2001; received in revised form 4 October 2001; accepted 17 January 2002

Abstract

A growing number of high-rise apartment buildings each with a light well in the center of them are designed in accordance with the structural design and planning for the last 10 years in Japan. This light well is defined as an intermediate space between outdoor and indoor. The questionnaire surveys to four apartment buildings that have different sizes of the light well were conducted to make clear the occupants' evaluation about the actual environmental conditions. As a result, the environment of light well is almost clearly satisfied except for some matters.

Keywords: High-rise apartment building; Light well; Environmental assessment

1. Introduction

A new type of high-rise apartment building is being constructed in Japan for these 10 years. It has a deep light well at the center of it. This light well is also called void or courtyard in Japan. The buildings have over 30 or 40 stories, so that the light well is a very slender and an empty space without ceiling or floors from bottom to top (see Fig. 1). The reasons that this light well is planned in a high-rise apartment building in Japan ware explained by Takai [1] as follows.

1. Summer in Japan is so hot and humid that Japanese houses need many openings for natural ventilation to avoid a severe climate. The light well that opens to outdoor air can increase the flexibility of opening position.
2. As earthquakes occur frequently in Japan, a structural design to meet the severe condition is required. A large and symmetrical plan that includes a light well at the center of the building has an advantage for the resistant power against the horizontal force of the earthquake.

An open corridor is usually laid out around the light well as shown in Fig. 2, and this corridor acts as public space for the daily activity of occupants. Though this light well opens to the outside at the top and the bottom, it is not regarded as a true outdoor but as a semi-outdoor, because the shape surrounded by open corridors of many apartments is so slender. Therefore, this light well is defined as an intermediate space between outdoor and indoor, and in many respects, the light well has quite different environmental condition from those of outdoor or indoor.

Walker et al. [2] have mentioned the many doubts and gaps that still remain about the regulations concerning residential buildings which are naturally ventilated via courtyards and their motivation to clarify the aerodynamic characteristics in courtyards of less than about 10-storied buildings. Some similar studies about ventilation characteristics of the light well have been conducted. For instance, Hayakawa [3] and Kobayashi [4] made the wind tunnel tests to clarify the wind-induced ventilation characteristics, Ohira and Omori [5] made a model experiment and the CFD simulation for the ventilation only by thermal buoyancy. The authors have also made the model experiments and calculation studies for estimating the validity of the simple calculation method of the airflow rates of the light well in a 40-storied building. As a basic study, Kotani et al. [6] investigated the

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0360-1323/03/$ - see front matter
PII: S0360-1323(02)00033-1

Fig. 1. Example of light well (view from the top).

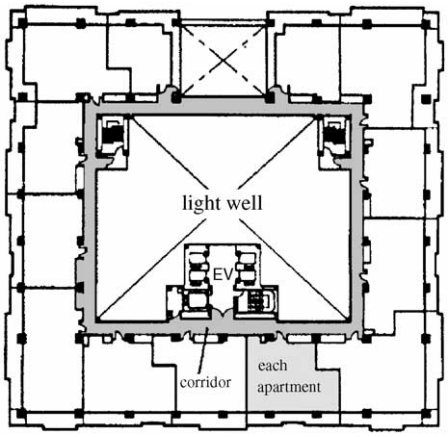

Fig. 2. Plan of buildings with light well.

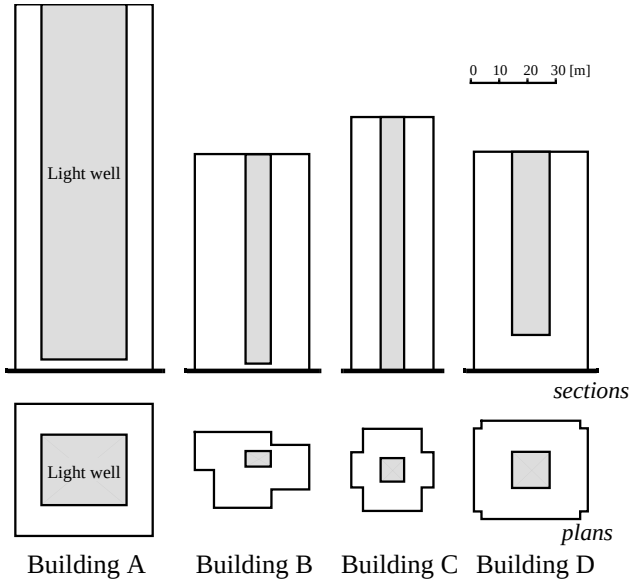

Fig. 3. Plans and sections of four buildings.

ventilation caused by thermal buoyancy and Nakamura et al. [7] made a wind tunnel test for the wind-induced ventilation, respectively. The combined effect of the wind force and the thermal buoyancy has also been tested and the validity of the calculation method by means of the multi-zone model was proved by Kotani et al. [8].

Due to the fact that we have never seen such deep light well in over 40-storied buildings, we know less about them and have no regulations or standards on environmental condition with regard to them. Therefore, the studies only on the physical characteristics of this light well are insufficient. Many aspects or approaches are needed to establish the regulations of this new type of building. From this standpoint and with a background of the above-mentioned physical studies, another approach is needed for the healthy environment of the light well.

The purpose of this study is to assess the actual environmental condition of this new type of space as the first step of another approach for future purposes. The authors [9] made a questionnaire survey to two apartment buildings with the light well to know the occupants' evaluation of their living environment. It was clearly revealed that more than two-thirds of the occupants are almost satisfied with the present conditions except for the noise and the air quality. In this paper, the additional questionnaire surveys of two different buildings and some measurements are carried out, and some evaluations of the main environment of the light well are presented.

2. Outline of survey

The questionnaire survey was carried out from 1992 to 1994. The questionnaire sheets are posted to the objective apartments, and the respondents are asked to return their sheets by mail. Outlines of the four objective buildings and the questionnaire replies are summarized in Table 1. As shown in Fig. 3 of the plans and sections of the four buildings, the light well of Bldg. A is incomparably larger than the others. Then the next large one is in Bldg. D, and that in Bldgs. B and C are almost of the same size.

The questionnaire includes a brief description of the light well and the point of answer as a guide, and simple questions relating to the following aspects:

(a) The attribute and the way of thinking of the respondent's household.
(b) Subjective evaluation about the size and the shape of their light wells, and the luminous environment, the air quality and movement, thermal environment and sonic environment in their light wells including the corridors.
(c) The frequency of the 12 daily uses of the corridor and the activities in the corridor.

Some measurements of the physical condition were also carried out. Night illuminances in corridors were measured by the illuminance meter at eight points on the floor surface of the eighth floor in each building. The noise sources were written down by investigators at two floors of the lower and

Table 1
Outlines of four buildings and the questionnaire replies

	Building A	Building B	Building C	Building D
Location	Kobe City, Hyogo	Osaka City, Osaka	Kaizuka City, Osaka	Osaka City, Osaka
Condition	Urban reclaimed island	Urban area	Suburban reclaimed area	Urban area
Year of completion	1991	1992	1993	1987
Number of floors	41	27	26	24
Number of apartments	465	175	105	184
Size of light well (m)	29.4 × 24 × 121 (height)	8.6 × 5.3 × 71.2 (height)	8 × 8 × 86.6 (height)	12.8 × 12.3 × 62.4 (height)
Width of corridor (m)	1.39	2.22	2.16	1.37
Lighting control in corridor	Illuminance control	Illuminance control (regular lighting under the 24th floor)	Time control (all lighting at morning and night, 1/3 lighting at other times)	Illuminance control (regular lighting under the I4th floor)
Notes	Glazed window up to the 29th floor	—	—	Sunlight reflecting mirror on the top of light well
Distributed sheets	465	160	90	183
Replied sheets	215	54	25	77
Percentage of reply	46.2 (%)	33.8 (%)	27.8 (%)	42.1 (%)

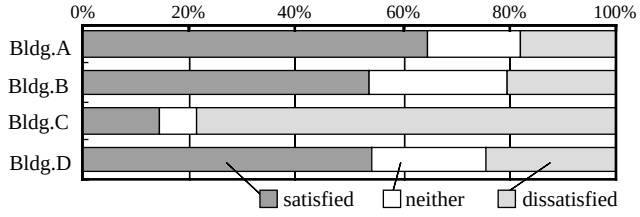

Fig. 4. Brightness during the daytime.

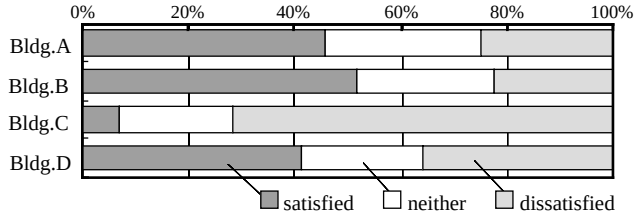

Fig. 5. Brightness on a rainy or cloudy day.

Fig. 6. Glazing up to the 29th floor on the north side of Bldg. A.

higher floor separately, and the noise levels of sources were measured by the sound level meter at the same time.

3. Results and discussion

3.1. Luminous environment

The evaluations of the luminous environment during the daytime are shown in Fig. 4. About 80% of occupants are dissatisfied with the brightness of their light well in Bldg. C. Satisfied occupants are no more than 13%. On the other hand, more than half of the occupants are satisfied in the other buildings. As shown in Fig. 5, this tendency is the same on a rainy or cloudy day, but the percentage of satisfaction is lower than that of the daytime. There might be many reasons for the difference between buildings. First of all, it must be mentioned that the lighting control systems in the corridors are different. As shown in Table 1, the lighting of Bldg. C depends on the time. All lighting apparatuses are turned on at morning and night, but one-third of them are controlled to be turned off at other times on the assumption of the occupants' absence. It means that although it is dark in the daytime, only one-third of lights will be turned on. This might be the main reason of the dissatisfaction in Bldg. C. On the other hand, each building except for Bldg. C uses some means to improve the luminous environment during the daytime. Bldg. A has a slender glazing up to the 29th floor on the north side to lead the daylight as shown in Fig. 6. Fig. 7 shows the reflecting mirrors of the direct sunlight settled at the top of Bldg. D, which are controlled automatically. Bldgs. B and D also have regular lighting on the lower floors. The

Fig. 7. Sunlight reflecting mirrors at the top of Bldg. D.

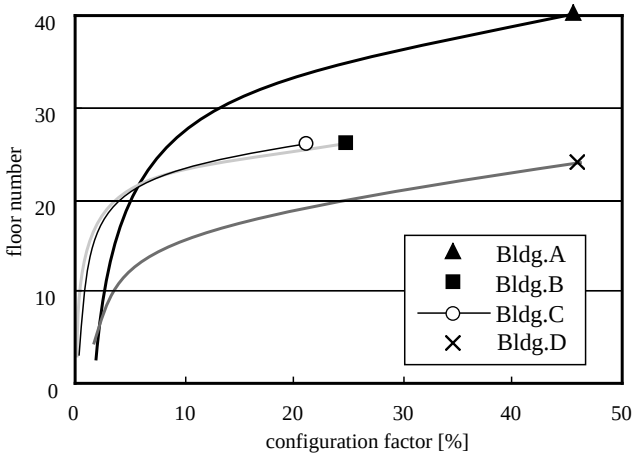

Fig. 8. Maximum configuration factor at the edge of corridors to the top opening of the light well.

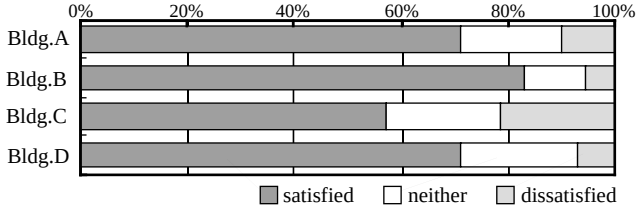

Fig. 9. Brightness during the night.

occupants seem greatly satisfied with the above-mentioned property of their building during the daytime.

Fig. 8 shows the configuration factors at the edge of corridors to the top opening of the light well. Those of Bldgs. B and C are almost the same, but the evaluations on brightness are different. Similarly, those of Bldgs. A and D have no relations to evaluations. Therefore, the daylight from the top opening of the light well seems to be not important for the evaluation of the brightness. Some improvements are needed in order to raise satisfaction with the luminous environment.

Fig. 9 shows the evaluations during the night. Some differences are found in each building, but Fig. 10 shows that the evaluations do not correspond to the actual illuminances

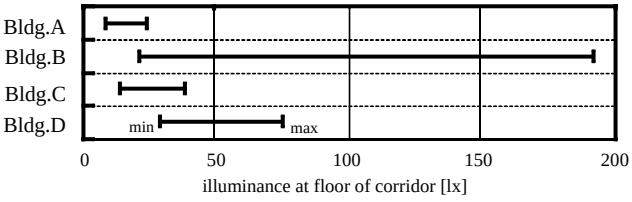

Fig. 10. Measured night illuminance in corridors.

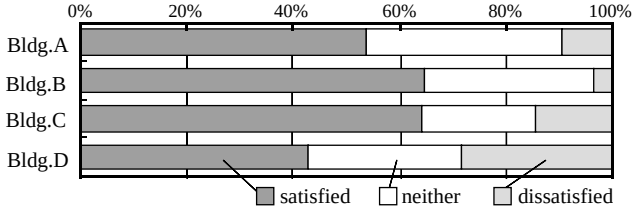

Fig. 11. Air quality in light well.

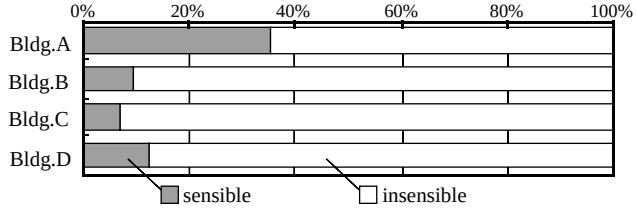

Fig. 12. Odor sensibility in corridors.

measured at eight points on the floor surface of the eighth floor. Dissatisfaction percentage is small in each building so that the minimum illuminance levels seem to be sufficient.

3.2. Air quality and air movement

The evaluations of the air quality are shown in Fig. 11. The percentage of dissatisfaction with the air quality in Bldg. D is higher than the others. It seems that the difference is caused by the air quality of the surroundings, that is only Bldg. D faces the road where the traffic is heavy, and the outdoor air itself is probably dirty. Through detailed analysis, it is also found that the dissatisfactions obtained are from the lower floors in each building which are stuffy.

As for the odor sensibility, Fig. 12 shows that the evaluation of Bldg. A is two or three times as much as the other three buildings. This seems to be caused by the location of the exhaust from apartments, that is, a part of the exhaust of Bldg. A is located at the corridors and those of other buildings are at the balconies which are opened to outdoors.

The air movement sensibilities differ evidently as shown in Fig. 13. This means that there are obvious differences with the air movement in the light well among the four buildings by its physical conditions and outdoor conditions. It must be interesting to find out the reason. In Bldg. A, the above-mentioned odor sensibility also seems to be dependent upon the insensibility of air movement, that is the

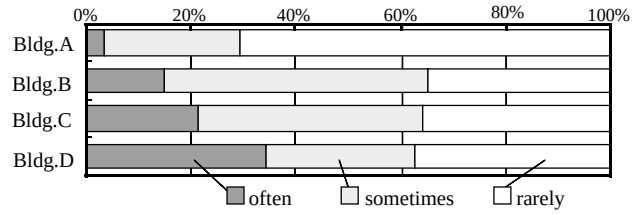

Fig. 13. Air movement sensibility in corridors.

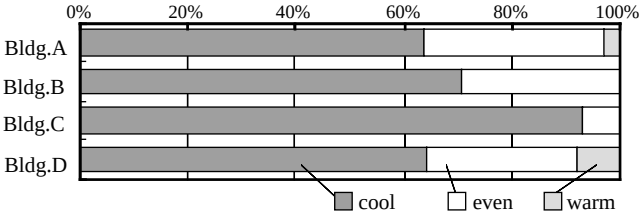

Fig. 14. Thermal sensation in summer compared to the outdoors.

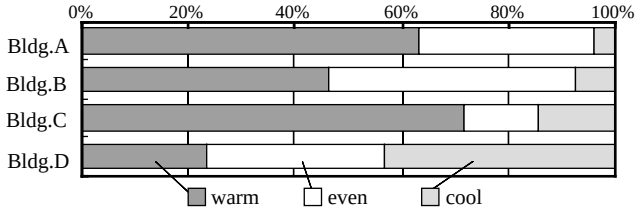

Fig. 15. Thermal sensation in winter compared to the outdoors.

ventilation performance might be insufficient to remove the contaminant. Anyhow, it must be clarified by physical analysis of model experiments or physical calculations [6–8].

3.3. Thermal environment

The evaluations of the thermal environment in the light well compared to outdoors are shown in Figs. 14 and 15. In summer, most occupants evaluate that the light well is cooler than the outdoors in all buildings. This can be anticipated from the thermal capacities of the building themselves by the surrounding apartments, since the occupants seem to evaluate the thermal environment during the daytime when there is the possibility for them to stay in corridors. In winter, on the other hand, the opposite evaluation is obtained in Bldg. D, that is about one-third of the occupants evaluate that the light well is chillier than the outdoors. Although the conditions of Bldgs. B and C are almost the same, the percentage of the dissatisfaction differs. The causes of these evaluations are not clear at present. This result must be clarified by physical analysis, although it has to be connected with the air movement in the light well.

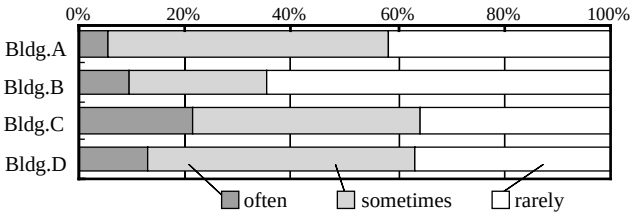

Fig. 16. Noise sensibility in corridors.

3.4. Sonic environment

The evaluations of the noise sensibility are shown in Fig. 16. The noise sensibility means noisiness or annoyance. More than half of the occupants feel some noisiness except Bldg. B. This means that the noise in the light well creates many problems as expected.

"Children's voice" is picked out as the top noise source voted by occupants themselves in almost every building as shown in Fig. 17, followed by "conversation", "footstep" and "door of apartment". As all of these sounds are generated from daily life and the light well is a semi-enclosed space, it would be difficult to improve the noise problems substantially. Though the reverberation of the sound seems to be unavoidable, some strategy must be made for reduction of the noise level at least to the allowable level.

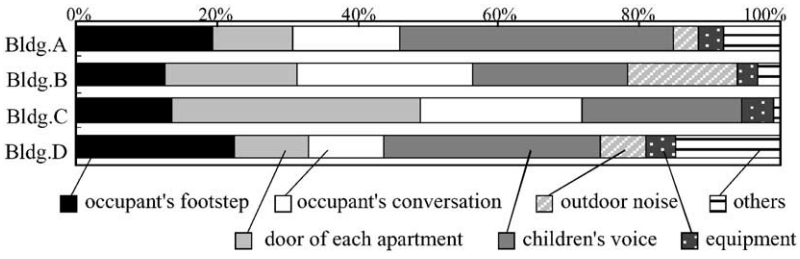

Fig. 17. Noise source in light well.

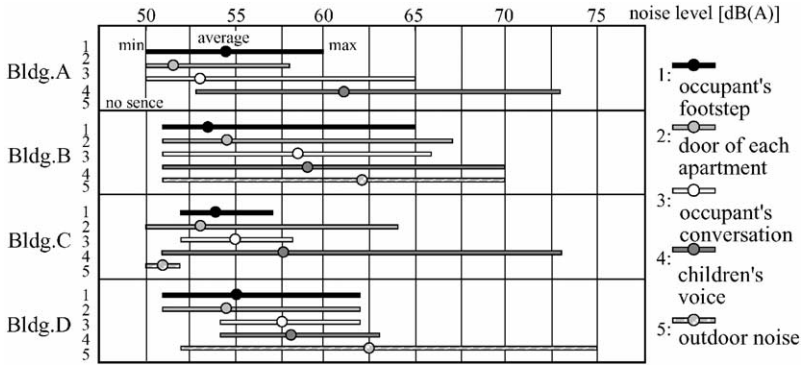

Fig. 18. Measured noise level in light well (plots mean the average; bars are minima and maxima).

Separately, the actual noise levels are measured at the two floors of the lower and higher floors in each building as shown in Fig. 18. For 30 min, the noise sources and their noise levels are measured by the investigators, and the values of the two floors are averaged. For instance, the average values of "children's voice" in Bldgs. A and B are so high as the occupants' evaluations, but those of Bldgs. C and D do not correspond to the evaluations. In Bldg. A, the order of the measurement values corresponds to the order of the voted source by occupants. However in other buildings, the measurement values cannot explain the occupants' votes. Further study by long-term measurement is needed to explain the occupants' evaluations.

4. Conclusions

The assessment of the actual environmental condition of the new type of space was conducted. Although the light well is like the deep well, it turned out that the environment is almost satisfactory in general. However, it also turned out that there is the difference among the subjective four buildings in their satisfactions. This seems to be caused by their different physical conditions.

In the luminous environment, some means to lead the daylight or sunlight inside the light well increase the satisfaction of occupants. It turned out that the building without any means or devices was assessed unfavorably. The daylight from the top opening of the light well seems to be not important for the evaluation of the brightness. During the night, the environment is almost satisfactory.

The air quality itself is almost satisfied in every building. The lack of the ventilation rate possibly causes the odor sensibility, and it may cause the discomfort of occupants.

The evaluation of the thermal environment is not easy to explain. Thermal sensation seems to depend on the physical situation directly and the physical environments of four buildings are quite different by their construction and location. These evaluations must be understood by their physical analysis using simulations or experiments.

The noises generated in the light well are sensible and these seem to be a problem as expected. Occupants pick up the children's voice as the top noise source. The noise of conversation, from footstep and doors of apartments follows. It would be difficult to improve the noise problems significantly due to the shape of the light well itself, but some strategy must be made for reduction in the noise level.

The environmental level of this new space is grouped now. The actual situation brought out in this paper has the possibility to indicate some guidelines. That is to say, the perfect level in the environment is not needed but the level can be roughly set at the allowable level at least. On the other hand, further studies will focus on connecting the results of the physical analysis to clarify the physical situation.

Acknowledgements

The authors would like to acknowledge the following people for their assistance with survey and analysis: Mr. Hiroaki Ichihara (Graduate of Osaka Univ.), Mr. Kazutoyo Otani and Mr. Koichiro Taniguchi (Graduates of Setsunan Univ.).

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