A STUDY ON THE PLANNING METHOD OF CAPACITY AND SIZE OF ROOM UNDER CONSIDERATION TO KEEP PERSONAL SPACE

Hiroyuki OTAKE
Tokyo University of Science
Yoshifumi WATANABE
Shimizu Corporation
Kazuhiro KUBOTA
Tokyo University of Science
Hideo NAOI
Tokyo University of Science

Abstract

Regarding the room sizes in architectural planning, room space areas are mainly decided according to physical measurements such as human body sizes, crowd densities, and the sizes of furniture necessary for the room. However, human beings are also psychological entities and naturally require psychological measurements[1),2)] as well, depending on the intended use of each room. This study confirms that the distribution of private spaces of persons can be approximated by the Poisson distribution based on previous crowd research data[3),4),5),6),7),8)]. Then it shows that the planning method of room capacity and size, aimed in this study, can be achieved with the distribution.

Keywords: Personal space, Distance of persons, Voronoi division, Crowd density, Planning method of capacity and size of room

1. OBJECTIVES OF THE RESEARCH

Regarding the room sizes in architectural planning, room space areas are mainly decided according to physical measurements such as human body sizes, crowd densities, and the sizes of furniture necessary for the room. However, human beings are also psychological entities and naturally require psychological measurements as well, depending on the intended use of each room. With regards to such issues, this study aims to incorporate the concept of personal spaces and distance between persons required by individuals in the crowd into the size planning of spaces. Our previous studies went as far as the tentative establishment of the intended planning method, representing the distribution of personal spaces by the Poisson distribution. This study moves on to examine the extent of applicability in various crowds, of which we already have the observation data, and also to further investigate the relations of personal spaces and the distance between persons, in order to enable planning by distance between persons. In the end of the study we conduct case studies using the proposed method.

2. CONSIDERATION OF THE CONFORMITY DEGREE OF THE DISTRIBUTION OF PERSONAL SPACE TO THE POISSON DISTRIBUTION IN VARIOUS CROWDS

2. 1. Method

(1) Targeted crowds

Four types of crowd data from previous studies were used. (Table 1)

—A crowd[4] of entrance examinees of our University, after the examination is over, hereinafter referred to as 'the crowd after the entrance exams'.

—A crowd[6] of people used to examine the change of crowd density in limited space, hereinafter referred to as 'the density change experiment crowd'.

—A crowd[6] of people waiting at the stop lights at the Shibuya station Hachi-ko-mae street crossing, hereinafter referred to as 'the crowd waiting at the Shibuya stop lights'.

—A crowd[8] of people at fire drill experiment, hereinafter referred to as 'the drill experiment crowd'.

Table 1 Attribute of targeted crowds

Type of crowds	State	Direction of the persons	Spatial limitation	Season	Indoor/ Ooutside	Crowd formation process	Prodensity	Age	Sex composition
The crowd after the entrance exams	Standstill	Multi directions	For all sides	Early summer	Indoor	Artificial	Small group	18 ~ 24	A lot of men
The density change experiment	Walk	One direction	Two directions (lateral)	Winter	Outdoor	Non-artificial	total stranger	18 ~ 20	A lot of men
The crowd waiting at the Shibuya stop lights	Standstill	Radiation direction	N/A	Autumn	Outdoor	Non-artificial	Small group or total stranger	Various	Equal
The refuge experiment	Standstill	One direction	N/A	Early summer	Indoor	Artificial	Small group	18 ~ 24	Equal

(2) The definition of personal space and distance of persons

We obtained the space closest to oneself than any other persons using Voronoi division, and defined the obtained area as the personal space. (Fig. 1)

We also defined the length of the lines connecting the individuals orthogonal to each side of Voronoi division as the distance of persons. (Fig. 2)

(3) The definition of peripheral and non-peripheral

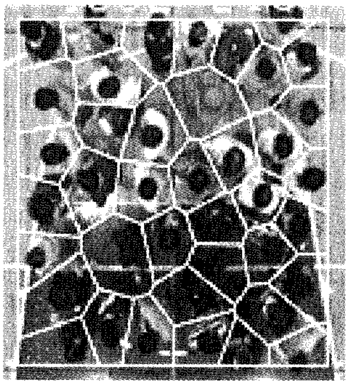


Fig. 1 Distribution of personal spaces

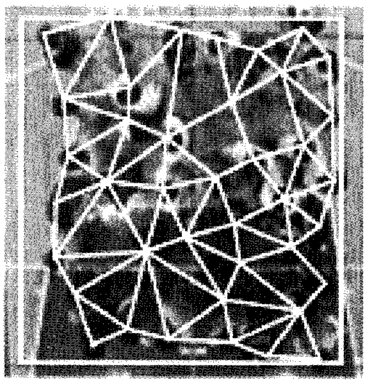
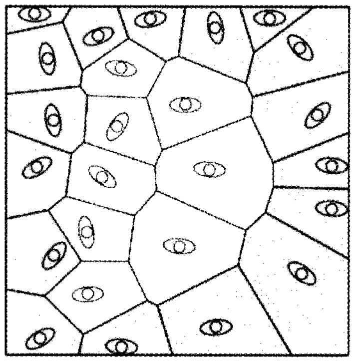


Fig. 2 Distance between persons



Non-Peripheral
Peripheral
Fig. 3 Models of peripheral and non-peripheral

In this consideration, we separated the peripheral and the non-peripheral assuming that the person adjacent to and not adjacent to the boundary in a crowd will come under different psychological influences when taking his/her personal space. We have defined Personal spaces in contact with the boarder of the surrounding space as peripheral, not in contact with the boarder as non-peripheral, and both parts combined as the whole crowd. (Fig. 3)

Table 2 Conformity degree of the targeted crowds in parts the whole crowd

	Whde crowd	Non-peripheral	Peripheral
The crowd after the entrance exams	31/31(100%)	10/10(100%)	17/17(100%)
The density change experiment crowd	97/119(81.5%)	109/119(91.6%)	32/119(26.9%)
The crowd waiting at the Shibuya stop lights		89/104(85.6%)	
The refuge experiment crowd		21/24(87.5%)	

(4) Prior conditions in conforming the distribution of personal spaces to the Poisson distribution

In our previous studies, we have set the origin shift to 0.3m^2 and the interval to 0.1m^2 in order for the density change experiment crowd to conform most to the Poisson distribution. We used the same parameter in this study to compare and to consider the conformity of the other crowd data.

(5) Examination of the conformity of the distribution of personal spaces to the Poisson distribution

The probability function of the Poisson distribution (the Gamma distribution) is expressed by the following formula:

$$P(n;\lambda) = \frac{\lambda^n}{n!}e^{-\lambda}$$

P: Significance probability
n: Detected number
λ: Average value
e: Base of natural logarithm

Normal testing method is used to verify conformity. The conformity is verified at Significance probability > Significance level 0.05.

2.2. Consideration results and discussion

Looking into the results by degree of density, conformity to the Poisson distribution showed downward trend as density decreased in 'the crowd after the entrance exams'. (Table 2) This is thought to be the effect of factors other than the chance factor. While the conformity degree for 'the crowd after the entrance exams' also showed markedly low rates in its peripheral, it achieved high rates of 80% (Fig. 4) or more conformity in other areas. Therefore it may well be said that this method can be applied to crowds formed in various scenes with the exception of specific crowds (for example, a very low-density crowd formed by colonies consisting of acquaintances). Following these results, figures 5 to 8 show the examination values replaced in the Poisson distribution. Fig. 5 shows the distribution of personal space according to each test density and distribution without the origin shift. Fig. 6 is the result of the same distribution with the origin shift of 0.3m^2. Fig. 7 shows the test values under the origin shift of 0.3m^2 approximated to the Poisson distribution. Fig. 8 is the theoretical Poisson distribution derived from average value λ (Poisson constant) obtained as reciprocal of density. Density degree 4.0 and 3.5 persons/m^2 did not satisfy $\lambda > 0$ because of the origin shift. Therefore, the distribution under this density degree could not be acquired.

Comparing Fig. 5 and Fig. 6, the peak value differences in relative frequency showed higher results as density increased, owing to the origin shift. It marked the highest at the density of 4.0 persons/m^2 with

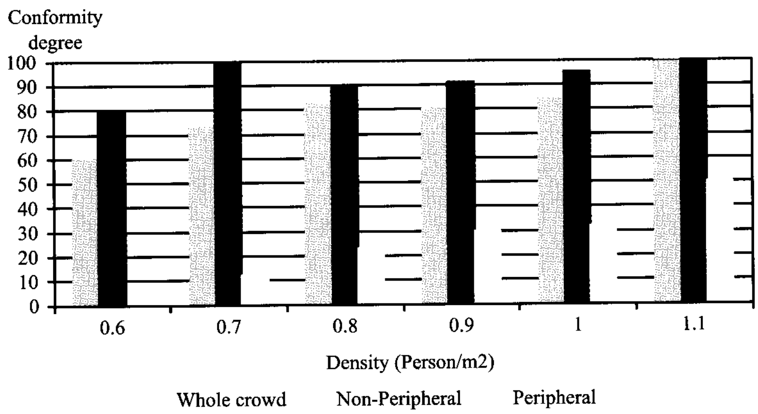


Fig. 4 Conformity degree of the crowd after the entrance exams

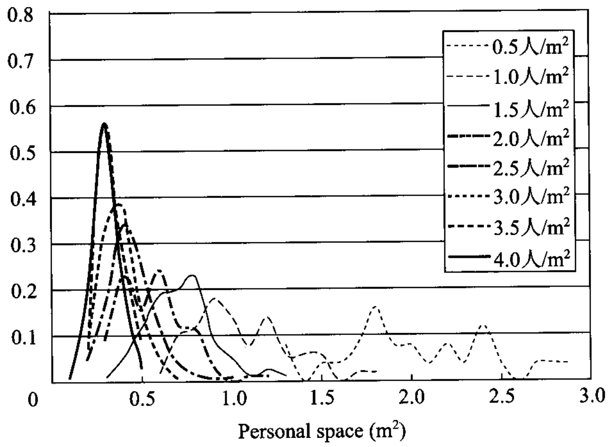
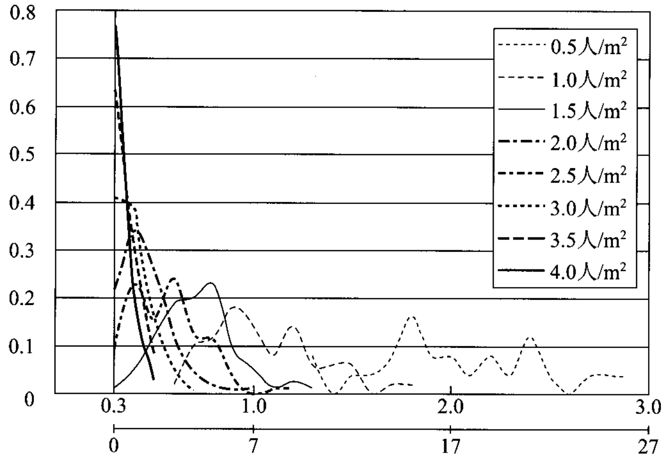


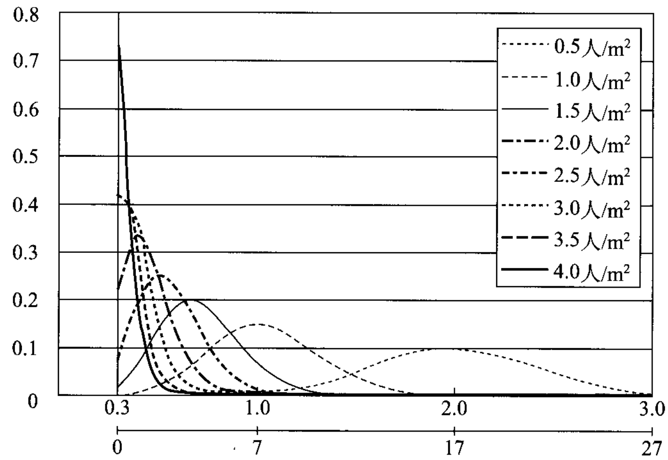
Fig. 5 Distribution of personal spaces in density change experiment (no origin shift)

approximately 0. 2. The distribution condition of Fig. 6 and Fig. 7 are considerably close; the measured values and the theoretical values of the distribution profiles are also close due to the origin shift. When comparing Fig. 7 and Fig. 8 by the average value λ (Poisson constant) in each density degree (Table 3), the difference was the largest at the density degree of 2. 0 person/m^2. However, as the difference was minimal, we have concluded that Fig. 8 distribution is sufficient to be used in place of Fig. 7 distribution considering the accuracy level of general architectural planning.



op axis: Personal space (m2), bottom axis: Poisson constant

Fig. 6 Distribution of personal spaces in density change experiment (with origin shift)



Top axis: Personal space (m2), bottom axis: Poisson constant

Fig. 7 Poisson distribution, approximated density change experiment values

3. CONSIDERATION OF REALATIONS BETWEEN THE PERSONAL SPACE AND THE DISTANCE OF PERSONS

3.1. Method

(1) Targeted crowds

Alike section 2, targets were the four crowds described in Table 1.

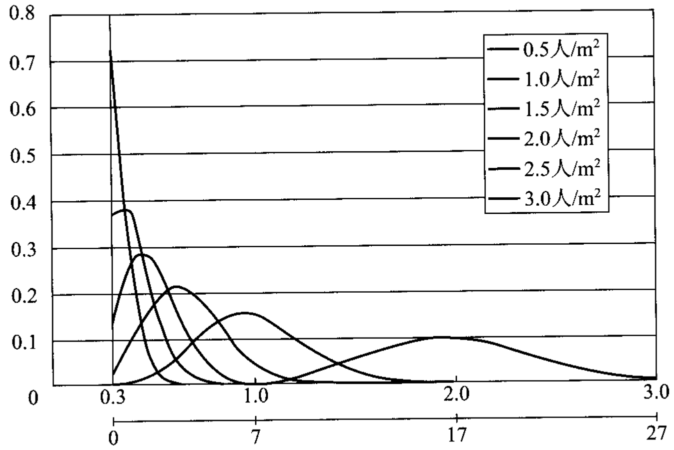


Fig. 8 Theoretical Poisson distribution obtained from density

Table 3 Differences between approximation distribution and average value λ (Poisson constant) of theoretical distribution

	0.5 persons/m^2	1.0 persons/m^2	1.5 persons/m^2	2.0 persons/m^2	2.5 persons/m^2	3.0 persons/m^2
λ of Fig. 7	2.04	2.06	0.72	0.57	0.46	0.39
λ of Fig. 8	2.00	2.00	0.67	0.50	0.40	0.33
Difference	0.04	0.06	0.05	0.07	0.06	0.06

(2) The definition of personal space and distance of persons

Defined in 2.1 (2).

(3) Details of consideration

We considered a geometrically equal placement best applied for the relations between the personal space and the distance of persons of the targeted crowds, and obtained relations of the two values from the results.

3.2. Consideration results and discussion

The graph shows the relations of the personal space and the distance of the persons on Fig. 10 obtained from the three types of equal placements (Fig. 9) and the reciprocal of density for each crowd. The value closest to that of the actual crowd was acquired in hexagonal shape layout. Therefore the graph for equal placement at hexagonal shape has been compared with the various crowds.

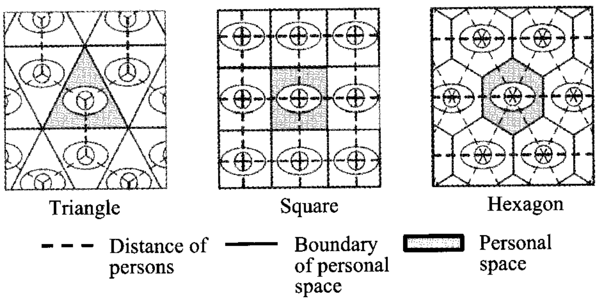


Fig. 9 Three types of geometrically equal placements (border of personal spaces)

Fig. 10 indicates that 'the density change experiment crowd' and 'the drill experiment crowd' came close to the hexagonal shape equal placement. However, 'the crowd waiting at the Shibuya stop lights' and 'the crowd after the entrance exams' proved to be less applicable. The crowds' characteristics may have had effect on the result as these crowds were observed outdoors. The reason why 'the crowd after the entrance exams' is straying far right from the hexagonal equal placement is because of the street boundary: the personal space of the persons near the boundary became smaller.

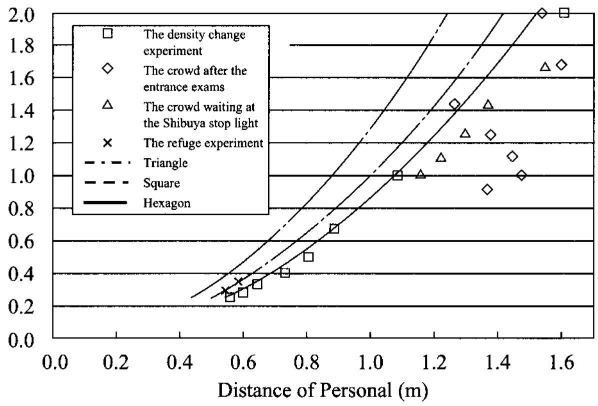


Fig. 10 Relations of personal space and distance of persons (equal placement)

Therefore we have confirmed that for the indoor crowds in static behavior, the 'distance of persons' axis can be added to the graph of 'theoretical Poisson distribution obtained from density' shown in our previous studies. (Fig. 11)

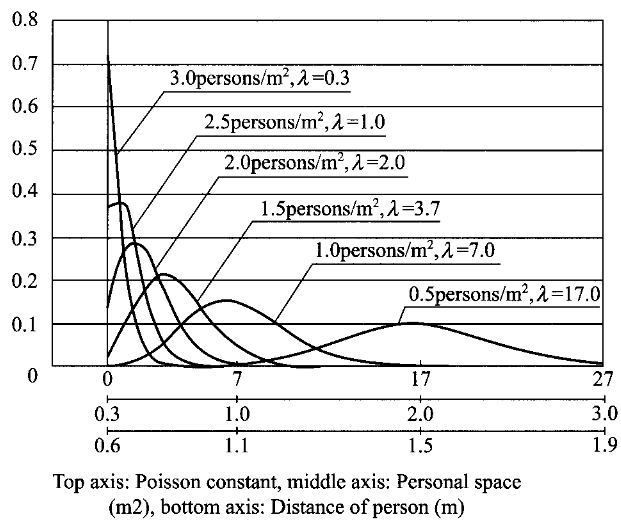
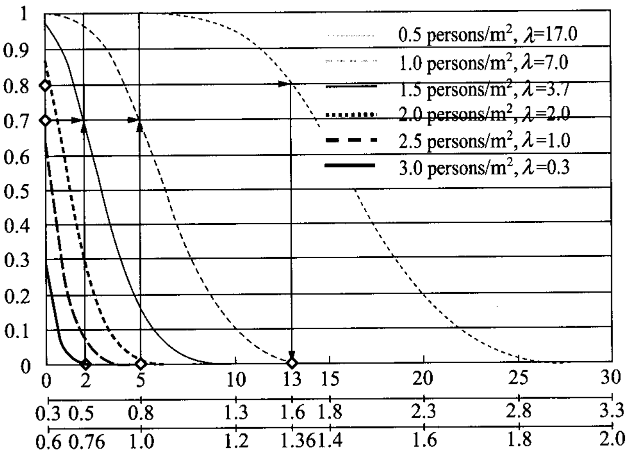


Fig. 11 Theoretical Poisson distribution (values in Poisson distribution)

4. CASE STUDIES OF THE PLANNING OF CAPACITY AND SIZE OF ROOM USING THE PROPOSED METHOD

Fig. 12 is the accumulation graph of the upper side of Fig. 11. If two out of the three items: the 'density degree of a certain space (obtained from space area and number of persons), the 'percentage of persons (that satisfies personal space)' and 'personal space or distance of persons': are given, the other remaining item can be obtained using Fig. 12. This means there are a total of eight types (Table 4) of planning patterns to which we can apply this planning method. We have focused on three cases shown in the shaded area of Table 4 and have conducted the following case studies.



Top axis: Poisson constant, middle axis: Personal space (m2), bottom axis: Distance of person (m)

Fig. 12 Accumulation graph of the upper side of the Poisson distribution

[Question 1] If a design is made to contain 50 persons in a room area of 100m^2 (density degree 0.5 persons/m^2), what will be the distance of persons (m) secured by 80% of the people?

[Answer 1] According to Fig. 12, when the density degree is 0.5 persons/m^2, the distance of persons that 80% of the people can secure will be 1.36m.

Relative frequency

[Question 2] How many square meters do we need for the room area in order to secure 1m distance of persons for the 70% of the 50 people?

[Answer 2] We can see that 1m distance of persons can be secured by 70% of the crowd at the density degree of 1.0 persons/m^2. (Fig. 12) Therefore, assigning the value to the formula: density degree = number of persons/ room area: the value for the room area obtained will be 50m^2.

[Question 3] How many people can be contained in a room area of 150m^2 if 0.5m^2 personal space needed to be secured for 70% of the people?

[Answer 3] We can see that 70% of the people can secure 0.5m^2 personal space at the density degree of 1.5 persons/m^2. (Fig. 12) Therefore, assigning the value to the formula: density = number of persons/ room area: the value for the number of persons obtained will be 225 persons.

Table 4 Cases that can be solved by this planning method

	Input	Output	Exercise
1	Density, Ratio of person	Distance of persons	If a design is made to contain XX persons in a room area of YYm^2 (density degree XX/YY persons/m^2), what will be the distance of persons (m) secured by ZZ% of the people?
2	Density, Ratio of person	Parsonal space	If a design is made to contain XX persons in a room area of YYm^2 (density degree XX/YY persons/m^2), what will be the personal spaces (m^2) secured by ZZ% of the people?
3	Density, Distance of persons	Ratio of person	How many people can be secured for XX% if YY persons in a room areas of ZZm^2 (density degree YY/ZZ persons/m^2) needed to be XYm pesonal distances?
4	Density, Parsonal space		How many people can be secured for XX% if YY persons in a room areas of ZZm^2 (density degree YY/ZZ persons/m^2) needed to be XYm^2 pesonal spaces?
5	Number of people, Ratio of person, Distance of persons	Required floor areas	How many square meters do we need for the room area in order to secure Xm distance of persons for the YY% of the ZZ people?
6	Number of people, Ratio of person, Parsonal		How many square meters do we need for the room area in order to secure XX square meters of persons space for the YY% of the ZZ people?
7	Floor areas, Ratio of person, Distance of persons	Number of people	How many people can be contained in a room area of XXm^2 if YYm personal distance neede to be secured for ZZ% of the people?
8	Floor areas, Ratio of person, Parsonal space		How many people can be contained in a room area of XXm^2 if YYm^2 personal space neede to be secured for ZZ% of the people?

5. SUMMARY

In this study, we have proposed the planning method as we aimed. This planning method is sufficiently applicable in the planning of the size of rooms containing crowds in a static condition.

ACKNOWLEDGEMENT

Note that this study is based on many crowd researches done in Naoi Lab, Tokyo University of Science. We express our appreciation to all who have been engaged in those researches.

REFERENCES

1. Edward T. HALL, The hidden dimension (1966).
2. Robert SOMMER, Personal Space (Prentice-Hall, 1969).
3. Koji KITADA, Norio YAJIMA, Kaori KAWAMURA, Hideo NAOI, Observation research about the individual distance of the human being who is in the passage space, Summaries of technical papers of annual meeting Architectural Institute of Japan 2001, E-1, pp. 715-716.
4. Takahiko MAEKAWA, Norio YAJIMA, Hideo NAOI, An observation research on distance of persons

in passage space (part 2), Summaries of technical papers of annual meeting Architectural Institute of Japan 2002, E-1, pp. 663-664.

5. Takahiko MAEKAWA, Norio YAJIMA, Hideo NAOI, An observation research on distance of persons in the passage space (part 3), Summaries of technical papers of annual meeting Architectural Institute of Japan 2003, E-1, pp. 839-840.
6. Yoshitaka MIKAMI, Norio YAJIMA, Hideo NAOI, A study on relation of crowd density and distance distribution of persons in limited space, Summaries of technical papers of annual meeting Architectural Institute of Japan 2004, E-1, pp. 893-894.
7. Yoshifumi WATANABE, Yoshitaka MIKAMI, Kazuhiro KUBOTA, Norio YAJIMA, Hideo NAOI, A study on relation of crowd density and distance distribution of personal area in limited space, Summaries of technical papers of annual meeting Architectural Institute of Japan 2005, E-1, pp. 915-916.
8. Taku SIMADA, Kazuhiro KUBOTA, Hideo NAOI, Grasp of the relative decreasing ratio of flow coefficient and proposal of the calculating formula, An experimental study on the escape flow of crowd including wheelchair users (Part 2), Journal of architecture and planning (622) pp. 71-76 20071230.
9. Tomohiko SANO, Kazuhiro KUBOTA, Hideo NAOI, A study on the planning method of capacity and size of space under consideration to keep the personal area, Summaries of technical papers of annual meeting Architectural Institute of Japan 2006, E-1, pp. 875-876.