FACTORS IN THE PLUMBED INSTALLATIONS POSITIONING OF MULTI-UNIT RESIDENTIAL BUILDINGS

Kozo KADOWAKI M.Eng.[1]
Seiichi FUKAO Dr.Eng.[2]

[1] Research Associate, Department of Architecture and Building Science, Tokyo Metropolitan University, 1-1 Minami-osawa, Hachioji-shi, Tokyo 192-0397, Japan, kkad@ecomp.metro-u.ac.jp
[2] Professor, Department of Architecture and Building Science, Tokyo Metropolitan University, 1-1 Minami-osawa, Hachioji-shi, Tokyo 192-0397, Japan, sfukao@ecomp.metro-u.ac.jp

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Summary

There are have been remarkable achievements in terms of technological development for adaptable residential buildings in Japan. One of the principal subjects in recent research and development programs concerning adaptable residential buildings has involved developing technologies to allow the user to decide the positioning of baths, washbasins, sinks, washing machine pans and other plumbed installations: technologies allowing free layout of such plumbed installations within each dwelling unit and plumbed installations laid out such as to facilitate replacement. However, the numerous factors applicable to plumbed installations positioning mean that free layouts of installations are likely to require more than simply technological solutions alone. This paper aims to analyze the factors concerning the positioning of plumbed installations within multi-unit residential buildings. Firstly, we found that there were various relevant factors concerning the positioning of installations when taking an overview of the history of Japanese residential buildings' construction. Secondly, we showed the influence of building characteristics on the installations positioning quantitatively, through a statistical analysis of existing residential buildings and a theoretical analysis. Through these analyses, the need for a comprehensive approach in designing adaptable buildings to ensure success became clear.

1. Introduction

There are have been remarkable achievements in terms of technological development for adaptable residential buildings in Japan. Following the initial research and development program concerning adaptable residential buildings led by public sectors and commencing from the early 1970s, numerous programs followed on a continual basis in order to resolve diverse problems faced by adaptable residential buildings.

One of the principal subjects in recent programs has involved developing technologies to allow the user to decide the positioning of baths, washbasins, sinks, washing machine pans and other plumbed installations: technologies allowing free layout of such plumbed installations within each dwelling unit and plumbed installations laid out such as to facilitate replacement. These efforts brought new methods and technologies for the base building and fit-out design, and have also being generally adopted for the construction of multi-unit residential buildings since about 1999.

However, the numerous factors applicable to plumbed installations positioning mean that free layouts of installations are likely to require more than simply technological solutions alone. This paper aims to analyze the factors concerning the positioning of plumbed installations within multi-unit residential buildings. Through this analysis, the need for a comprehensive approach in designing adaptable buildings to ensure success will become clear.

2. Building Construction and Layout of Installations

2.1 The Initial and Developmental Stages

We will start by providing a context to the construction of residential buildings and plumbed installations layouts in Japan in chronological order.

Multistoried residential buildings appeared around 1925 and became widespread after WWII in Japan. Since reinforced concrete construction had already been introduced into Japan in 1925, the building frames have been made from reinforced concrete right from the start. Following generalization, multistoried residential buildings in Japan are characterized by the inclusion of a fully waterproofed bathroom within each dwelling unit (Fukao 1992). Concerning mechanical systems, the absence of the central water heating system in Japan saw each new dwelling unit equipped with a water heating system, and the mechanical systems involved were the object of considerable and rapid development.

The problem arising when heating water in each dwelling unit was the means of allowing noxious fumes from burning fuel to escape and how to ensure a supply of fresh air. Although the advent of balanced flue boilers in the 1960s enabled safe fuel burning indoors, the bathroom had to look onto an outside wall, to allow the boilers to exhaust polluted air and supply fresh air. An additional reason for the bathroom layout looking onto the outside was the natural ventilation via an exterior wall, required due to the humidity of the Japanese climate. Consequently, dwelling units of this time were designed with wide frontages to ensure rooms were well-lit and well-ventilated.

To ensure residents' privacy as well as natural lighting and ventilation, stairway access type buildings, where twin dwelling units on the same floor were connected with a single stairway, were designed. Since including an elevator in individual stairways of such buildings would be inefficient, residential buildings of the time were generally limited to four or five story constructions.

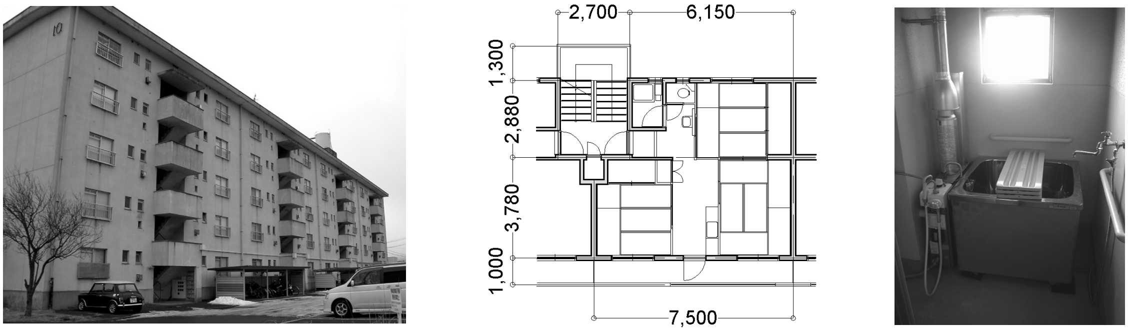

Figure 1 A Residential Building, a Dwelling Unit Plan, and a Bathroom Constructed in the Early 1970s

2.2 The Establishing Stage

From then onwards, technologies for bathrooms and other plumbed installations made remarkable progress in the pre-1980 period: with the appearance of bath units developed from bathrooms using pan panels, compact electronically-controlled boilers which could be installed outside, and mechanical ventilation systems using ducts. Bath units also enabled fully waterproofed bathrooms without the need for problematic asphalt waterproofing. Compact boilers and mechanical ventilation systems, meanwhile, enabled bathrooms without requiring windows looking onto the outside. These technologies succeeded in achieving new freedom for freely plumbed installation layouts.

During this period, there was one additional dramatic change in the height of general residential buildings; namely from mid- to high-rise buildings. Since climbing the stairs in such high-rise buildings would be tiring, elevators had to be installed. Although Japanese elevators boast the strictest global safety standards, maintenance costs are high. In terms of running costs, it is said that those for a single elevator should be divided by more than 60 families. Accordingly, this ensures effective passageway access to dwelling units within high-rise residential buildings. In most high-rise residential buildings in Japan, the access axis was arranged outside rather than within a building, in order to maximize natural lighting.

Subsequently, the next change involved a revised standardization of bathroom positioning. Since Japanese people favor south-facing dwellings, it became necessary to narrow the width of dwelling units to pack the maximum possible number of south-facing units into the building, as we shall see later in chapter 4. The narrow unit means the bathroom positioning is restricted to the center of unit and without natural light.

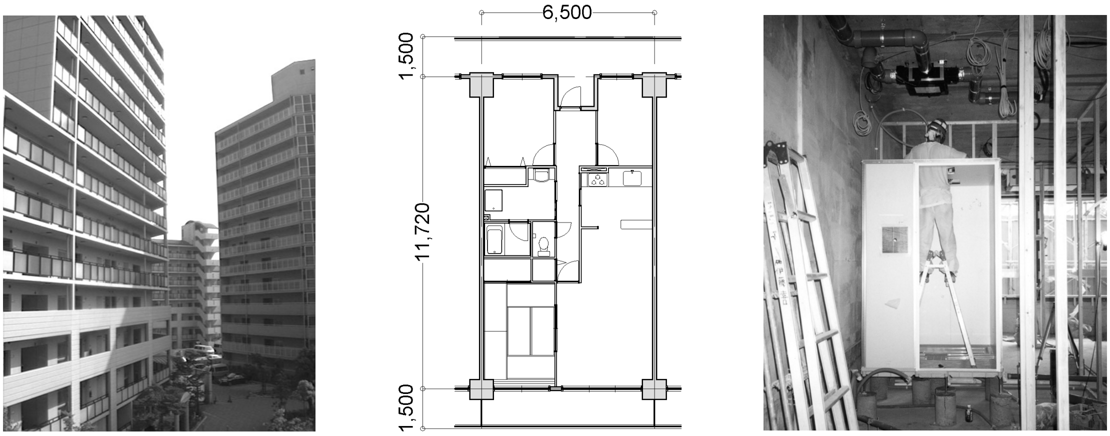

Figure 2 Residential Buildings, a Dwelling Unit Plan, and a Bath Unit Constructed in the Post-1980 Period

2.3 The Present Situation

As an opposition to standardized bathrooms, certain architects have recently argued that bathrooms should be designed to look on to the outside. With this in mind, the supply of so-called non-standardized dwelling units in central Tokyo, targeting young rich families, is beginning to grow. In addition, there is a slight tendency for rooms, which do not legally require natural lighting, for example laundry rooms, to look onto the outside (Waku et al. 2003). Based on these remarks, you may say that the positioning of plumbed installations in Japan can be said to demonstrate diversity.

Turning now to adaptable buildings in Japan, the development of technologies for free plumbed layouts, in renovation as well as new constructions, began in late 1980s and have now become established as general technologies. Their advent has signaled dramatic changes in the base building design. In particular, it has become seemingly important to secure a large and deep underfloor space in order to accommodate long horizontal pipes, and to design a flat slab without a beam to avoid ducting obstructions. Figure 4 shows a cross-section of a typical latest base building structural design, namely an "Inverted Slab / Beam Structure" designed to enable free layouts of plumbed installations.

Figure 3 A Bathroom Designed to Look on to the Outside Constructed in 2003

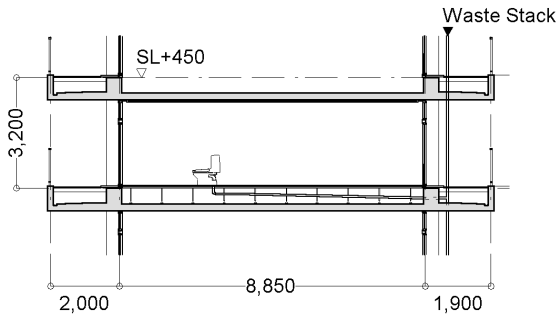

Figure 4 Cross-section of a Dwelling Unit with the Inverted Slab / Beam Structure

3. Statistical Analysis

3.1 Procedure for Analysis

In the former chapter, we found that there were various relevant factors concerning the positioning of plumbed installations when taking an overview of the history of Japanese residential buildings' construction. In this chapter, we will show the influence of such building characteristics on the plumbed installations positioning quantitatively, through a statistical analysis of existing residential buildings.

Table 1 The Definitions and Statistics of the Variables Used in Chapter 3

Variable	Definition	Unit	Statistics	
			Min. Max.	Ave. Sta. Dev.
Story Height	The floor-to-floor height of the base building.	mm	2650.0 3600.0	2833.6 169.6
Available Depth of Underfloor Space for Piping	The maximum depth of a raised floor for piping.	mm	30.0 730.0	233.1 98.6
Slab Level Difference	The level difference of slab surfaces where applicable. For Inverted Slab / Beam Structure, the length between the beam top surface and slab top surface.	mm	0.0 600.0	105.4 124.3
Maximum Distance between Plumbed Installations and Drainage Stacks	The maximum horizontal distance between plumbed installations and waste stacks connected to the equipment by underfloor piping.	m	0.000 13.299	3.049 1.658
Minimum distance between Plumbed Installations and Peripheral Walls	The minimum distance between plumbed installations excepting the kitchen unit and the peripheral walls of the dwelling unit.	m	0.000 4.700	1.315 1.571
Length of Wall Surface Capable of Natural Lighting per Unit Area	The total horizontal cross-sectional length of walls in which openings can be designed divided by the area of the dwelling unit.	m / m^2	0.065 0.478	0.228 0.093
Dwelling Unit Area	The total area of the dwelling unit.	m^2	31.540 167.296	80.196 19.746
Number of Private Rooms per Unit Area	The number of private rooms per dwelling unit area.	$1 / m^2$	0.015 0.056	0.037 0.008
Average Area of Private Rooms	The average area of private rooms.	m^2	9.119 20.223	12.300 1.933

This analysis deals with reinforced and steel-framed reinforced concrete (including concrete-filled steel tube structures) medium- to high-rise post-1980 multi-storied residential buildings built in Japan, whose blueprints (plans, cross-sections and elevations of the buildings and dwelling units) were collected. One hundred and sixty dwelling units were selected by extracting a single unit from each building for analysis. However, dwelling units on the top or bottom floors and duplex units were excluded, since they seemed to be designed differently from the flat units on the middle floors. In addition, the survey was limited to buildings constructed post-1980 since they would be likely to contain utilities and structural framing methods affecting the plumbed installations layouts similar to those currently used for general residential buildings, due to the standardization of bath units, compact boilers, and mechanical ventilation systems.

In addition to the basic information concerning the 160 cases including the owner and year of construction, the value of variables characterizing the design of each dwelling unit was then measured based on documentations such as the drawings. To obtain numerical data, we calculated the correlation coefficient of each combination, and analyzed the scatter diagram to investigate the influence of the building characteristics on the positioning of the plumbed installations. The definitions and statistics used in this chapter are listed in Table 1.

3.2 Influence of the Building Characteristics on the Installations Layouts

To design plumbed installations layouts freely or to alter their positioning, a large and deep underfloor space is required in order to accommodate the long waste branches connected with the stacks. The relationship between the available depth of underfloor space and the maximum distance between the plumbed installation and waste stacks reveals that the deeper the underfloor space, the further plumbed installations can be located from the stack (Figure 5). However, conversely, there is a strong correlation apparent and increased scatter, as the maximum distance between the plumbed installation and waste stack and the

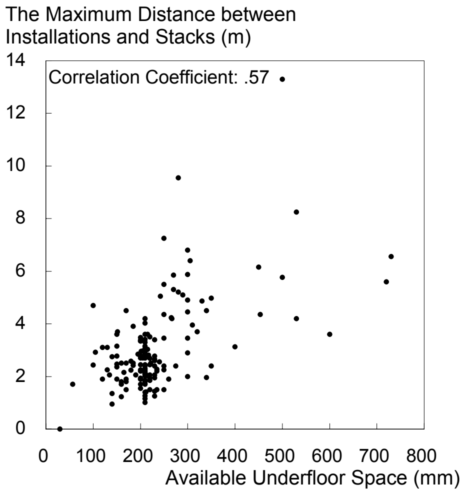

Figure 5 The Available Underfloor Space and the Maximum Distance between the Installations and Stacks

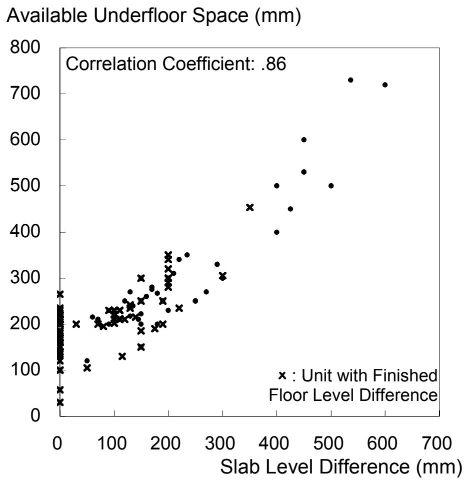

Figure 6 The Slab Level Difference and the Available Underfloor Space

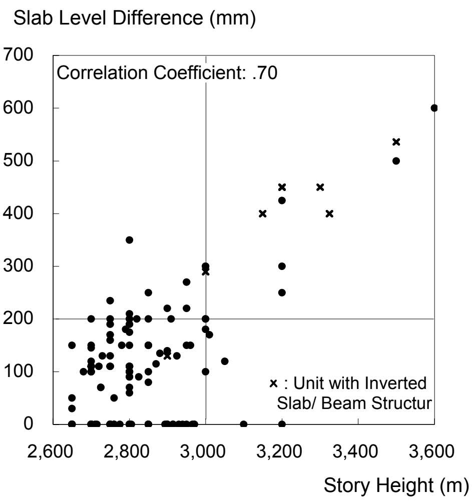

Figure 7 The Story Height (Floor-to-floor Height) and the Slab Level Difference

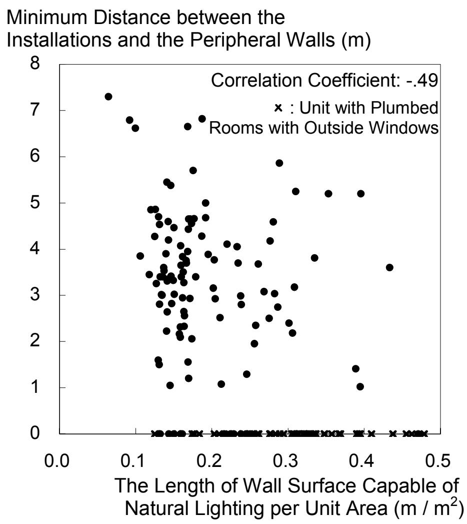

Figure 8 The Length of Wall Surface Capable of Natural Lighting per Unit Area and the Minimum Distance between the Installations and the Peripheral Walls

maximum depth of the underfloor space rise in tandem. This may be due to the fact that once ample underfloor space is secured, the depth of such space is determined not only by the requirement of the present plan designs but also consideration of the future variability of the plumbed areas.

To secure a deep underfloor space, the floor slab level is sometimes lowered below the beam's top level, for example, in the aforementioned Inverted Slab / Beam Structure. The slab level difference is found to be directly proportional to the depth of underfloor space (Figure 6), with a very strong correlation between the two. To accommodate the branch pipes, the end floor level of the rooms in the plumbed section, for example the washroom, is sometimes raised higher than that of the habitable rooms, although this is considered undesirable when considering the needs of elderly residents. When stratifying the relationship in terms of the presence / absence of differences in the finished floor level, findings showed that a difference of 200mm in slab level was required to secure a free plumbed installations layout while maintaining the finished floor level entirely flat.

The slab level difference and the story (floor-to-floor) height of the dwelling unit also show a strong positive correlation (Figure 7), indicating that the higher the story, the greater the depth at which secure slab level difference is possible, and the greater the scope for a deeper underfloor space to be designed. Thus we see that it is important to design a high story unit in order to improve the degree of freedom concerning the layout of plumbed installations.

To secure a slab level difference exceeding 200mm in order to flatten the finished floor level, the dwelling unit should be more than 3m in story height. In addition, Inverted Slab / Beam Structures are often adopted for cases where the slab level difference exceeds 400mm.

A relatively strong negative correlation is observed between the length of wall surface capable of natural lighting per unit area, which represents the index of unit lighting conditions, and the minimum distance between plumbed installations and the peripheral walls (Figure 8). This indicates that plumbed installations tend to be designed in the center of a unit in the case of insufficient natural lighting. In order to improve the degree of freedom concerning the layout of plumbed installations, it is important not only to secure a large story height and ample underfloor space, but also to design a unit with a wide frontage to allow sufficient natural lighting.

3.3 Comparative Analysis in Building Characteristics

Now, let's compare the building characteristics of two groups: Group I where the rooms in the plumbed section, for example the bathroom, are designed to be outward-looking while Group II features plumbed rooms without outside windows. Group I includes 48 dwelling units, while Group II includes 112. We examined the presence of any significant differences between Groups I and II in terms of the dwelling unit area, the number of private rooms per unit area, the average area of private rooms, and the length of wall surface capable of natural lighting per unit area (table 2).

Table 2 Statistical Comparisons between Group I and Group II

Statistics \ Variables		Dwelling Unit Area	Number of Private Rooms per Unit Area	Average Area of Private Rooms	Length of Wall Surface Capable of Natural Lighting per Unit Area
Average: x	Group I	86.5541	0.0378	12.7724	0.3068
	Group II	77.4708	0.0371	12.0974	0.1941
Standard Deviation: s	Group I	19.6981	0.0081	2.3554	0.0806
	Group II	19.2161	0.0081	1.6934	0.0753
Difference of Sample Means: X_1-X_2		9.0833	0.0007	0.6750	0.1126
Standard Error: SE(X_1-X_2)		3.3735	0.0014	0.3757	0.0136
Test Statistic: Z_{OBS}		2.6925	0.4940	1.7964	8.2614
P-Value		0.0035	0.3106	0.0362	0.0000
.05 Level of Significance		**Significant**	Insignificant	**Significant**	**Significant**
.01 Level of Significance		**Significant**	Insignificant	Insignificant	**Significant**

The results were as follows:

- The dwelling units in Group I tended to be larger in terms of dwelling unit area than those in Group II at an .01 level of significance.
- There was no significant difference in the number of private rooms per unit area.
- The average area of private rooms tended to be larger in Group I than in Group II at an .05 level of significance.
- The length of wall surface capable of natural lighting per unit area tended to be longer in Grope I than in Group II at an .01 level of significance.

It is therefore reasonable to conclude that it is also important to design a spacious dwelling unit in order to improve the degree of freedom concerning the layout of the rooms in the plumbed section.

4. Lighting Condition and Density of Dwelling Units

In the former chapter, we obtained the following result: in order to design plumbed installations layouts in freedom, it is important not only to secure a large story height but also to design well-lit dwelling units. Well, as was suggested in chapter 2, the density of dwelling units has an impact on the lighting conditions of the same, rendering this subject worthy of further attention.

Let us now consider a residential building constructed in Japan, as shown in Figure 9. The building lot is W in length from east to west, D from north to south, and with an area S. The building is m-storied, and there are n dwelling units, of the same proportions, on each building floor.

Because Japanese people prefer south-facing dwellings, all dwelling units in this building face due south to avoid any decline in the real estate value of the building. External passageway access is adopted in this building, and each dwelling unit has natural lighting from the windows in the north and south unit-wide exterior walls. To maximize the number of dwelling units, the building width is almost equal to that of the building lot itself.

This building is of a standard height for this city, with another building of the same height on the neighboring lot to the south. In Japan, one of the standards generally regarded as important, in terms of lighting for the home, is to ensure more than four hours sunlight is available in the principal rooms daily during the winter solstice. To ensure this, it is necessary to maintain an angle between the horizontal plane and oblique line directed due south from the far south end of the residential building to far north end of the next building below θ.

In addition, each dwelling unit includes the dimensions w in width, d in depth and s in area.

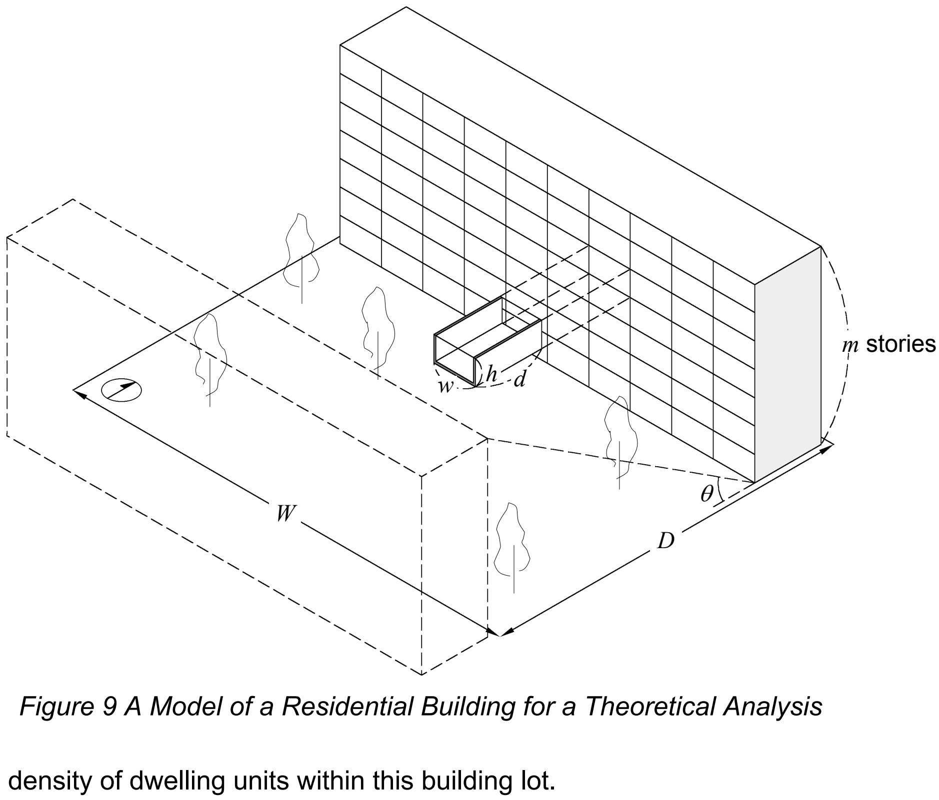

Figure 9 A Model of a Residential Building for a Theoretical Analysis

Consider now the density of dwelling units within this building lot.

If N expresses the number of dwelling units in this building, N / S expresses the number of dwelling units per lot area, in other words, the density of dwelling units for the building lot. There are n dwelling units in each building floor. Besides, the relation among n, W and w is $n = W / w$. Accordingly, N can be revealed using the following equation:

$$N = mn = mW / w \qquad (1)$$

Well, $S = WD$, and D is a factor of the height of the neighbouring building to the south, meaning angle θ will satisfy the lighting condition standard. The relationship can be shown using the following equation:

$$D - d \geq \frac{H}{\tan\theta} \tag{2}$$

Hence it follows that the minimum value of D is $H / \tan\theta + d$. Accordingly, S can be revealed by the following equation:

$$S = WD = W\left(\frac{H}{\tan\theta} + d\right) \tag{3}$$

Therefore, the density of dwelling units N / S can be calculated using the following equation:

$$N / S = \frac{mW / w}{W\left(\frac{H}{\tan\theta} + d\right)} = \frac{m}{w\left(\frac{H}{\tan\theta} + d\right)} \tag{4}$$

The following equation is then obtained on referring to $H = mh$ and $d = s / w$:

$$N / S = \frac{m}{w\left(\frac{mh}{\tan\theta} + \frac{s}{w}\right)} = \frac{m}{\frac{mhw}{\tan\theta} + s} \tag{5}$$

The relation among the density of dwelling units, the width of dwelling units w, and the number of building stories m can be represented as Figure 10, assuming the area of each dwelling unit s as 70m^2, the story height h as 3 meters, and a tanθ of below 0.6 in this city.

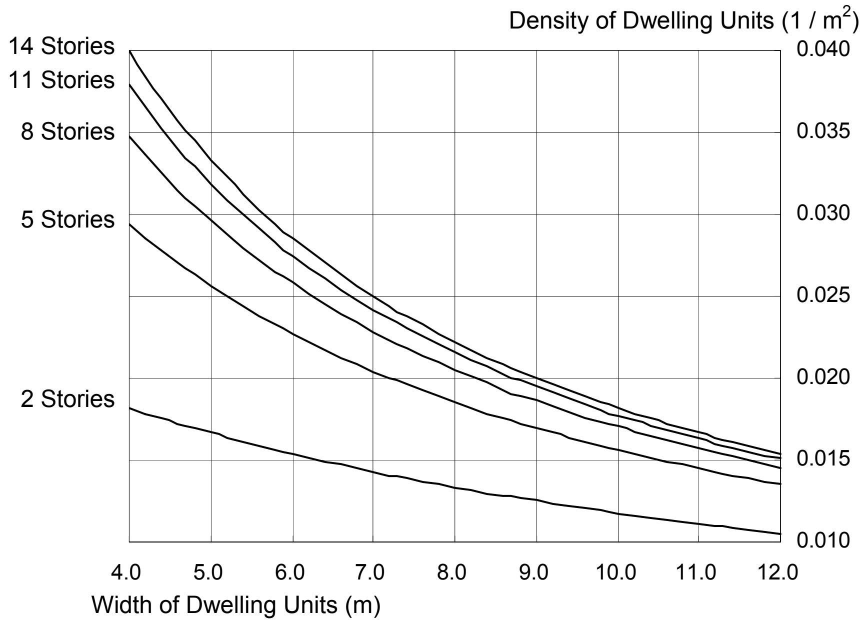

Figure 10 The Relation among the Density of Units, the Width of Units, and the Number of Building Stories

As Figure 10 shows, as the dwelling units narrow, their density increases. As the number of building stories m increases, meanwhile, the slope of the density curve gets steeper. This indicates an intensification of the narrowing effect causing the dwelling units' density to climb in the high-rise city areas. These results can be said to effectively represent the characteristics of post-1980 dwelling unit design in Japan.

5. Conclusion

The results of this research are as follows:

1) The most significant factor affecting the positioning of plumbed installations in multi-unit residential buildings was the volume of underfloor space available for piping. It indicated that adaptable base buildings should have large floor-to-floor height.

2) Well-lit dwelling units, for example those having a wide frontage, were also strongly affected in terms of the positioning of plumbed installations. Plumbed installations in narrow units tended to lie on sunless centers.

3) Accordingly, a narrow unit with a large floor-to-floor height would not always allow free installations layouts. It might be just considered an overinvestment.

4) The rooms in the plumbed sections, for example bathrooms, tended to be restricted into central areas in the units with limited unit areas. It indicated that adaptable residential building should have spacious dwelling units. Besides, the tendency for installations to look onto the outside in recent years was interpreted as a manifestation of improved living conditions in Japan.

5) They also tended to be centrally located in high dense buildings. It in important to consider building site plans and so on in order to conserve urban residential buildings of high density as valuable property in future.

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