The Method for Optimum Vertical Layout of High-rise Apartment Buildings to Improve Indoor Comfort

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SUMMARY

The objective of this paper is to develop a method for achieving optimum vertical layout of apartment buildings that can provide proper design alternatives and useful information by its application in order to improve indoor comfort and to verify the efficiency and the validity of the objective method. The result of this research can be used as supporting information to reach an amicable settlement against civil petitions and disputes. This will consequently reduce waste of the time and money, enhance the efficiency of work, and improve indoor comfort.

1. INTRODUCTION

In Korea, as the social phenomenon of the drift of the population to major cities began to appear from 1970's, a number of high-rise apartment buildings have been constructed in major cities such as Seoul. Following the recent improvements in living standards, there has been growing interest in indoor comfort. Especially, one of the most important issues related to indoor comfort is solar access. These social tendencies have brought about residential environment problems such as violation of solar rights. The number of civil petitions and disputes over solar rights has increased recently. These problems have negatively affected human health, work productivity, thermal comfort, and visual comfort. So, the solar rights analysis system (*HELIOS*) had been developed by research team to evaluate the solar rights of residential buildings, quantitatively (Seong et al., 2006). Furthermore, this solar rights analysis system had been applied to many practical affairs up to recently.

But, as the problems related civil petitions and disputes over solar rights are becoming more complicated and diverse, it is demanded that proper design alternatives should be suggested and active design methods of vertical layout of the apartment buildings should be studied in order to reduce the solar rights violation for neighboring area within the acceptable limits. However, the present solar rights analysis system has some limitations. That is, this system analyzes only the original design condition, and provides only the information on whether violations of solar rights have occurred or not. The information of optimum vertical layout in high-rise apartment buildings to assure the solar rights is deduced from repetitive manual process. To establish alternatives and vertical layout for solar rights assessment, for example, available alternative examined first of all, that experts must participated in. Then, solar rights analysis result about survey buildings is thoroughly examined by an expert. If the results are not acceptable, geometric information is changed and reflected in solar rights analysis system. If the result of analysis is not satisfactory, the above process is repeated again and again until acceptable result is deduced. These problems bring about economic loss of productivity and efficiency.

For these reasons, this study is intended to develop the method for the optimum vertical layout of the apartment buildings that can provide proper design alternatives automatically and the useful information to improve solar access. The result of this research can then be used to furnish advanced information for an amicable settlement against the civil petitions and disputes, to reduce waste of the time and money, to enhance the efficiency of work, and to improve indoor comfort.

2. SOLAR RIGHTS AND ASSESSMENT METHODS

2.1. SOLAR RIGHTS

The definition of solar rights varies for different localities and situations. In Europe and U.S.A, ‘solar right’ is generally defined as the occupant's right to unobstructed light from the sun, i.e., the rights to light (Building Performance Research Unit, 1972). In New Mexico, U.S.A, it is considered as a form of property right for renewable energy source, and thus an owner of a real property where a solar collector is installed may claim its solar rights. In Korea, solar rights are generally associated to human health, work productivity, thermal comfort, and visual comfort in apartment buildings.

However, the Korean laws do not clearly stipulate the regulations on solar rights, and so, solar rights are interpreted in various ways based on the theories related to an occupant’s solar access. First, solar right is defined as the right to remove an occupant's disadvantages from interference with direct solar access by obstructions (Choi et al., 2000). Since Korea is located in the northern hemisphere, the residents living in the northern site of the building are generally obstructed from solar access if another building is built in the southern site. Based on this definition, the residents living on the northern site of the building can file a formal complaint to the property owner of the southern site as provided in the Korean building code 53 provision. Solar right is also defined as the right to ensure that neighbors have access to natural lighting, ventilation, and field of vision by limiting the height of adjacent buildings. Also, it is defined as the right to ensure sunshine duration for usual residential living in buildings, and also, the right to enjoy high standard of living in terms of health associated with the direct solar radiation. This last definition, in turn, means that a property owner should not infringe upon another property owner's right to direct solar light access when building a new building next to an existing apartment complex.

In Korea, sunshine duration should be maintained consecutively for more than 2 hours in every housing unit during the winter solstice from 9 a.m. to 15 p.m. (during 6 hours). In addition, the distance between each block should be kept to more than 0.8 times of a building’s height to the south from the adjacent apartment building. In a densely-populated city with high-rise apartment buildings such as Seoul, it is particularly important to dispute settlements over solar rights for every housing unit in an apartment building. Therefore, an analysis method for assessing the solar rights and a simulation program to quantitatively evaluate the solar rights of each housing unit in an apartment building is necessary.

2.2. ASSESSMENT METHODS FOR SOLAR RIGHTS

The analysis methods for solar rights assessment are generally classified as sun-path diagram method (i.e. solar position diagram) (Goswami et al., 1999; Duffie and Beckman, 1991) and shadow diagram method. The sun-path diagram methods can be subdivided into the horizontal sun-path diagram method and vertical sun-path diagram method (i.e. *WALDRAM* diagram method) (Lechner, 2001). The shadow diagram methods can be subdivided into the plan shadow diagram method, the elevation shadow diagram method, the section shadow diagram method, and the perspective (3D) shadow diagram method depending on the point of view. However, only two of the methods can be used to quantitatively compute the sunshine duration for all housing units in an apartment building: the *WALDRAM* diagram method and the 3D SHADOW diagram method. Based on the comparison results (Seong et al., 2006), the *WALDRAM* diagram method was more suitable than the 3D shadow diagram method. In addition, the *WALDRAM* diagram method provided more accurate results, especially in computing the sunshine duration on a specified day. In terms of analysis accuracy, however, the *WALDRAM* diagram method could analyze more dense time interval than the 3D shadow diagram method, and in terms analysis processing time, the *WALDRAM* diagram method required less time than the 3D shadow diagram method, because the rendering process took a long time to make a 3D shadow diagram. Lastly, in terms of the analysis processing steps, the *WALDRAM* diagram method was two steps faster. As such, the *WALDRAM* diagram method was clearly more suitable than the 3D shadow diagram method for assessing the solar rights in apartment buildings.

3. METHOD FOR THE OPTIMUM VERTICAL LAYOUT

In this chapter, we have chosen a real case for vertical layout to develop a method for the optimum vertical layout. According to this case study, we propose a method for the optimum vertical layout in high-rise apartment buildings. An objective for the optimum vertical layout is that all housing units in survey building must be satisfied within acceptable limits for solar rights. In the case study, the survey objects were all housing units in C apartment building 202(i.e. Bldg.202) and obstruction buildings were T apartment buildings 103 & 105(i.e. Bldg.103 & Bldg.105). By figure 1, you can find out the geographical situation.

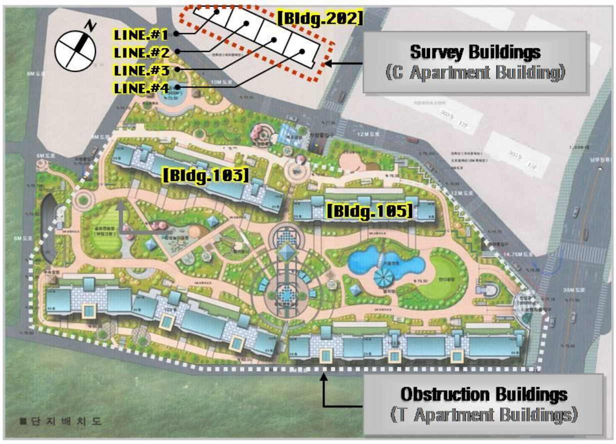

Figure 1. Geographical information of survey building and obstruction buildings

3.1. Method of Vertical Layout by Manual Process for Solar Rights

In this chapter, we briefly described the method of vertical layout by manual process for survey objects (all housing units in C apartment building) to assure the solar rights, and discussed some predictable problems in manual process.

(1) Vertical Layout by Manual Process

To find out the process of vertical layout manually, we described the process that our research team executed in the past.

A) In order to deduce alternatives that the solar rights at all housing units in survey building(C apartment building 202, i.e. Bldg.202) can be satisfied within acceptable limits, it is necessary that 1st floor housing units in Bldg.202, which have the worst condition, are investigated first. So, we selected housing units #101, #102, #103, #105(i.e. survey unit #101, #102, #103, #105) in survey Bldg.202, as shown as in figure 1, from the selected survey housing units, and derived the possible alternatives to assure the solar rights at survey unit #101, #102, #103, #105 by repetitively comparing and investigating the *WALDRAM* diagram, which is the result of the many predictable design alternatives.

B) In vertical layout for solar rights, obstruction buildings, which are the vertical layout object, consist of two Bldg.103 and bldg.105. The vertical layout of obstruction buildings should be classified in 3 parts, 103 only, 105only, and 103,105 together.

C) [Design Step.1]: First to know the influence of obstruction Bldg.105 to survey units, we performed the solar rights at survey units against various vertical layout alternatives. The number of cases expected is 24,696,000(all cases which can be generated by product with story numbers of housing lines including story number 0, that is, all cases = 21*21*20*20*14*10). We examined the *WALDRAM* diagram, continuous sunshine duration, and accumulative sunshine duration. We found that obstruction Bldg.105 did not show any improvements in solar rights for all survey units. From this, we can conclude that vertical layout of obstruction Bldg.105 did not have any influence on solar rights improvement and can exclude obstruction Bldg.105 from the vertical layout.

D) [Design Step.2] : By reviewing results of [Design Step.1], and *WALDRAM* diagrams, it is expected that proper alternatives for vertical layout which every survey units could assure the solar rights within the acceptable limits would be deduced through reducing stories of the line number 1(i.e. LINE.#1) and the line number 2(i.e. LINE.#2) in Bldg.103. So we analyzed various expected alternatives in [Design Step.2] by reducing stories of LINE.#1) and LINE.#2. But it turned out that there were no suitable alternatives. However, by reviewing the *WALDRAM* diagram (refer to figure 2) of alternatives, we found that LINE.#1 and LINE.#2 did not interrupt the solar rights in survey unit #105 and the maximum allowable stories for every survey units to assure the solar rights in LINE.#1 and LINE.#2 were 12.

E) [Design Step.3] : By the result [Design Step.1], in order to confirm an additional continuous sunshine duration, stories of LINE.#1, and LINE.#2 should remain as a 12 and we derived several alternatives("Alt.B-105", "Alt.B-106", "Alt.B-107" and "Alt.B-108") by changing the story of LINE.#3 and performed solar rights assessment for all survey units. By comparing the results, we derived the plan that minimizes the loss of story comparing with the original design condition. Results of "Alt.B-105", "Alt.B-106", "Alt.B-107" and "Alt.B-108" are shown as Table 1. "Alt.B-105" and "Alt.B-108" were suitable for every survey units to be satisfied the solar right. The loss of stories in alternative "Alt.B-105" was 24 and the loss of stories in alternative "Alt.B-108" was 22 compared to the original design condition. Finally, among the alternatives ("Alt.B-105" and "Alt.B-108"), we suggested "Alt.B-108" as the best alternative for vertical layout of obstruction buildings (T apartment Buildings). The loss of story "Alt.B-108" was 22 compared to the original design condition.

As above mentioned, by manual process, it needs professional knowledge, complex and continuous analyzing process and lots of time to deduce the alterative through vertical layout.

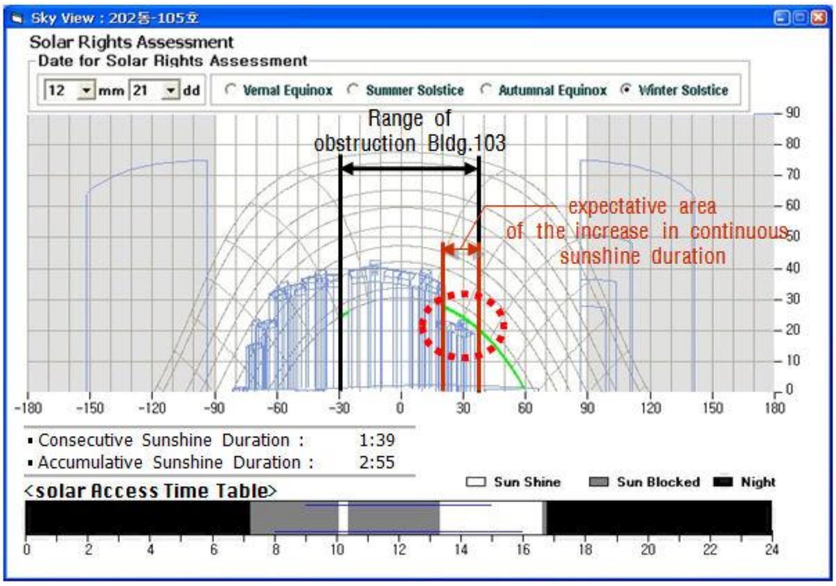

Figure 2. Analysis of *WALDRAM* diagram in [Design Step.2]

Table 1. Results of Vertical Layout by manual process

Designs	Building	Stories						Suitability	Loss*	Remarks
		LINE.1	LINE.2	LINE.3	LINE.4	LINE.5	LINE.6			
Original	Bldg.103	20	20	20	20	20	20	-	-	-
	Bldg.105	20	20	19	19	13	9			
Alt.B-105	Bldg.103	12	12	12	20	20	20	○	-24	-
	Bldg.105	20	20	19	19	13	9			
Alt.B-106	Bldg.103	12	12	16	20	20	20	×	-20	-
	Bldg.105	20	20	19	19	13	9			
Alt.B-107	Bldg.103	12	12	15	20	20	20	×	-21	-
	Bldg.105	20	20	19	19	13	9			
Alt.B-108	Bldg.103	12	12	14	20	20	20	○	-22	Best Alternative
	Bldg.105	20	20	19	19	13	9			

*: Loss of stories compared with the original design condition

(2) Problems of Vertical Layout by Manual Process

We have performed a case study through the methods for the vertical layout by manual process to assure the solar rights in survey units. As above mentioned, a manual process for vertical layout is summarized as follows:

A) Review alternatives step by step;

B) Change stories of LINEs or BUILDINGs in obstruction buildings and reflects the modified geometric information in the solar rights analysis system;

C) Analyze on the basis of reflected data, and estimate the result; and

D) To get the best result, feedback process in analyzing and reviewing should be done continuously.

By a manual process in vertical layout, it not only lowers productivity, efficiency in researching but also requires lots of time and experts. Furthermore, it also includes possibilities of mistakes such as an error of judgment. So, in order to minimize these problems, our research team suggests a methodology in automated vertical layout of high-rise apartment buildings by using computer. This helps us improve the solar rights and the waste of material and business efficiency.

3.2. Method for Vertical Layout by General Automation for Solar Rights

(1) Geometric Characteristics of the High-rise Apartment Buildings Design

In order to design proper stories of apartment building, geometric composition elements should be extracted and the hierarchy of the elements needs to be clarified systematically. The elements that compose an apartment building, the hierarchy of the elements and the organic relations are defined as follows:

A) An apartment building (i.e. **[BUILDING]**) is composed of several buildings. A **[BUILDING]** consists of housing unit(i.e. **[UNIT]**), common space(i.e. **[CORE]**) and housing unit line(i.e. **[LINE]**) (See Figure 3)

B) A **[BUILDING]** is composed of multiple **[LINE]**s, and each **[LINE]** comprises the repetitious **[UNIT]**s.

C) The height of an apartment building is determined by the vertical variation of the **[UNIT]** that composes each **[LINE]**. And the **[UNIT]**s, which are distributed uniformly along the vertical line, can be considered as elements of corresponding **[LINE]**.

D) In an arbitrary **[LINE]**, the building geometry cannot be generated if a lower **[UNIT]** does not exist. Therefore, in case of n stories, the elements of universal set "***L***" are 0, 1, … , n-1, n stories. And the number of possible subsets is n+1 ($\boldsymbol{u}_0$, $\boldsymbol{u}_1$, … , $\boldsymbol{u}_{n-1}$, $\boldsymbol{u}_n$).

E) A **[UNIT]** is the main space that composes the building and a **[CORE]** is the auxiliary space that serves the main space.

F) The height of a **[CORE]** is determined by the vertical variation of the relevant **[UNIT]**s.

G) In a word, the vertical space of the apartment building is determined mainly by the vertical variation of the **[UNIT]**, which decides the vertical height of the **[CORE]**.

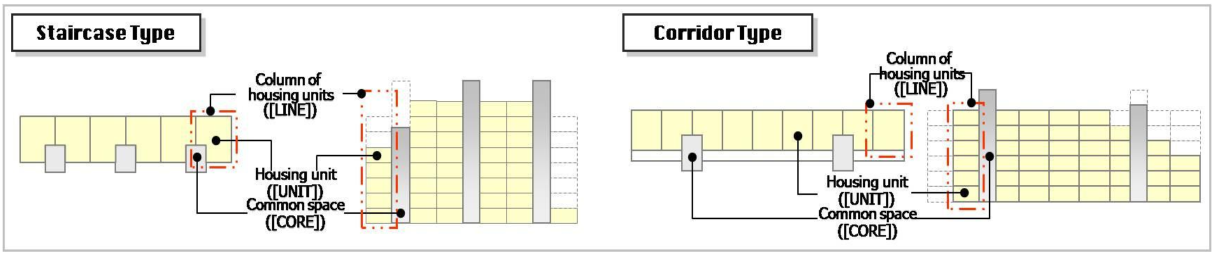

Figure 3. Elements of an apartment building (**[BUILDING]**, **[LINE]**, **[UNIT]** and **[CORE]**)

(2) Definition of High-rise Apartment Buildings Components

To set plan of method for the vertical layout, the **[CORE]** should be excluded from the building set because it is determined by the **[UNIT]**. It is necessary that the **[BUILDING]** set should be classified by each line that is working equal vertical movement. To sum up, the set of **[BUILDING]**, ***B***, which is composed of several **[LINE]** components, can be defined as in equation (1). Each **[LINE]** set, ***L***, can be defined like equation (2), is located on the same horizontal plane, and composed by several **[UNIT]** elements which are on the same vertical line.

$\boldsymbol{B}$ = {x|x ∈ all **[LINE]**s of housing units in the **[BUILDING]**} = $\{L_1, L_2, L_3, \cdots, L_n\}$ (1)

$\boldsymbol{L}$ = {x|x ∈ all **[UNIT]**s in the **[LINE]**} = {x|x ∈ all stories which can be generated} (2)

$= \{u_0, u_1, u_2, \cdots, u_n\} = \{0_{Floor}, 1_{Floor}, 2_{Floor}, \cdots, n_{Floor}\}$

Where,

B: set of apartment building (**[BUILDING]**)
L: set of housing unit line (**[LINE]**) in the apartment building
u: element of a housing unit in the housing unit line (**[LINE]**)

(3) Algorithm for Vertical Layout by General Automation

Based on elements and sets which are the composition of the apartment defined on the Chap 2, $\boldsymbol{R}_{\mathbf{B}}$ (equation (3))which is the algorithm of possible alternatives of all layer-adjustment about an arbitrary building from the apartment can be defined the subsets of Cartesian product from the given sets like equation (3). When there are many buildings, $\boldsymbol{R}_{\mathbf{T}}$ (equation (4)) that is the set of possible alternatives of all layer-adjustment is able to be defined as equation (3). Figure 4 illustrates this logic in the form of a graph.

$$\boldsymbol{R}_{\mathbf{B}} = \boldsymbol{L}_{\mathbf{1}} \times \boldsymbol{L}_{\mathbf{2}} \times \cdots \times \boldsymbol{L}_{\mathbf{n-1}} \times \boldsymbol{L}_{\mathbf{n}} \quad (3)$$

$$\boldsymbol{R}_{\mathbf{T}} = \boldsymbol{R}_{\mathbf{B1}} \times \boldsymbol{R}_{\mathbf{B2}} \times \cdots \times \boldsymbol{R}_{\mathbf{Bn-1}} \times \boldsymbol{R}_{\mathbf{Bn}} \quad (4)$$

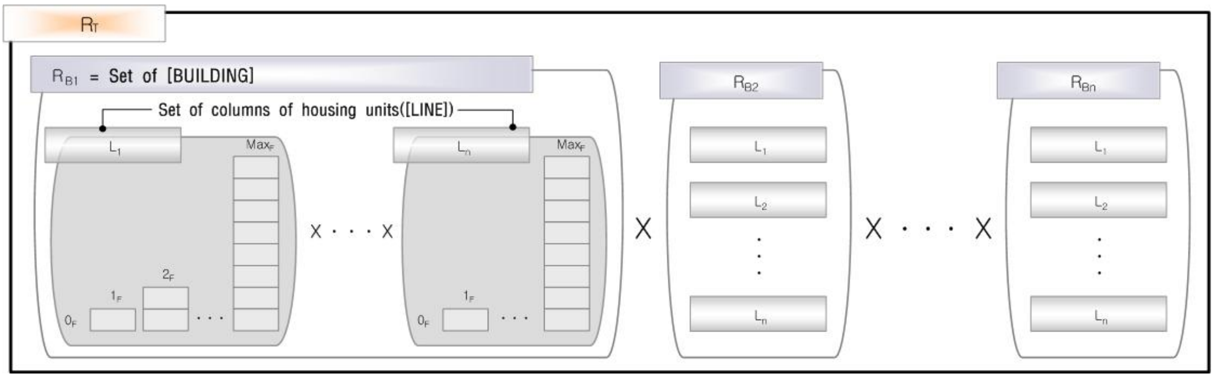

Figure 4. ***L*** **set([LINE[set],** $\boldsymbol{R}_{\mathbf{B}}$ **set([BUILDING] set) and** $\boldsymbol{R}_{\mathbf{T}}$ **set**

(4) Problems in Method for Vertical Layout by General Automation

Based on equation (4) which is the method of vertical layout by general automation above-mentioned, a total of 85,766,121 alternatives for vertical layout of obstruction Bldg.103 are derived by Cartesian-product of several $\boldsymbol{R}_{\mathbf{B}}$. Considering the processing time of solar analysis system which is available to analyze average 10 cases per a second, it will take a total of 2.4E+03 hours to analyze all vertical layouts. The computers can be inefficient and irrational by simple computerization, and it is necessary to optimize this algorithm setting such as intuition experts can have.

3.3. Method for the Optimum Vertical Layout

In this chapter, the method of vertical layout by automation is optimized in a way to set intuition of expert knowledge about the standard sunshine duration and sun-path in the winter solstice.

A) Based on the present standard range, it is necessary to determine whether vertical layout is needed or not about each **[LINE]** to estimate sunshine duration (from 8 to 16). That is, as shown in figure 5, from 8 to 16 o'clock it should be divided into section A(range that vertical layout is necessary) which affects the calculation of sunshine duration and section B and C(range that vertical layout is unnecessary) which does not affect the calculation of sunshine duration. Also, a certain **[LINE]** which is needed vertical layout is necessary to derive information about by what floor has to be proceeded, and a certain **[LINE]** will be how many stories should be designed. Therefore, we defined a factor of "minimum allowable story", that is the minimum story number that is unnecessary vertical layout.

B) In case of section A that may affect the estimation of sunshine duration, it is separated into section A-1(vertical layout is necessary) and section A-2(vertical layout is not necessary) in a boundary of sun-path in winter solstice at *WALDRAM* diagram. Proceeding the vertical layout from the story of original design condition to 0 story in each **[LINE]**s, when all geometrical figure of the **[LINE]** is located blower than sun-path in winter solstice, that is, the story of **[LINE]** which is all geometrical figure of **[LINE]** included in section A-2 is appeared. At this point, the story of **[LINE]** does not affect estimation of sunshine duration at all, and thus it is not necessary to make a vertical layout.

C) On the other hand, a story of certain **[LINE]** in original design condition can be "Minimum allowable story", because **[LINE]** in section B and section C has no effect on estimation of sunshine duration (continuous sunshine duration, accumulative sunshine duration).

D) As mentioned above, the optimization of vertical layout automation is achieved on the basis of above theory. With this in mind, a **[LINE]** set which is defined in equation (2), ***L***, must be redefined as follows. If a certain **[LINE]** is located in section A, a **[LINE]** set, ***L***, is defined as formula (5), and if a certain **[LINE]** is located in section B or C, a **[LINE]** set, ***L***, is defined as formula (6). $\boldsymbol{R}_T$ (equation (4)) that is the set of possible alternatives of all layer-adjustment is able to be deduced from this set ***L*** that can be redefined using equation (3) and equation (4)

L = {x|x ∈ all expected housing unit elements between the original story and the maximum allowable stories, where, the minimum allowable story ≥ 0} (5)

$= \{u_{min}, u_{min+1}, \cdots, u_{Max-1}, u_{max}\}$

L = {x|x ∈ an expected housing unit element is the original story} = $\{u_{max}\}$ (6)

Where,

L: set of housing unit line([LINE]) in the apartment building

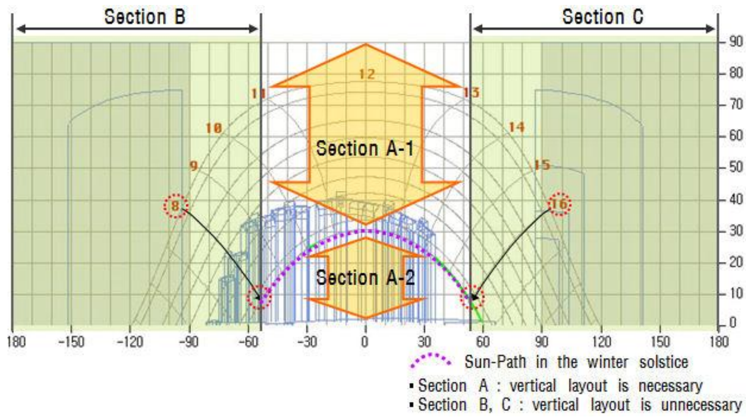

Figure 5. Classification of sections for vertical layout in WALDRAM diagram

4. VERIFICATION

In order to verify the objectivity of the method for the optimum vertical layout suggested in this study, we compared the results by optimum vertical layout with the results by manual process. We were able to confirm that both methods provided the same results. Also, the comparison of solar rights assessment results (continuous sunshine duration, accumulative sunshine duration and satisfaction of the solar rights) against alternatives between manual process and optimum process for vertical layout verified the accuracy of the method for the optimum vertical layout.

The ultimate goal was to suggest the optimal vertical layout of the obstruction buildings (T apartment Bldg.103 and Bldg.105) in order to assure the solar rights at all survey housing units in survey building (C apartment Bldg.202). With respect to this, however, Bldg.105 was excluded in vertical layout because Bldg.105 was determined to be unhelpful in improving the solar rights or to increase sunshine duration. In original design condition, the obstruction Bldg.103 is 20-storied building that has six [LINE]s. On this condition, the method of general automation generated 85,766,121(=21×21×21×21×21×21) alternatives. Meanwhile, the method of the optimum vertical layout generated 2,665,872(=9×9×11×11 ×16×17) alternatives. In this process, some of them were selected for the comparison in terms of analysis of solar access. The results from those layouts were compared with the results by manual process; in the result, the comparison of cases show the same result.(see Table 2) .

Table 2. Comparison of manual process and optimum process for vertical layout

Alternatives	Loss*	Analysis results by manual design process				Analysis results by optimum vertical layout			
		Survey unit.#101 in Bldg.202		Survey unit.#105 in Bldg.202		Survey unit.#101 in Bldg.202		Survey unit.#105 in Bldg.202	
		CSD**	ASD***	CSD	ASD	CSD	ASD	CSD	ASD
Alt 1	14	239	299	54	162	239	299	54	162
Alt 2	16	239	299	99	175	239	299	99	175
Alt 3	20	239	299	99	175	239	299	99	175
Alt 4	22	255	315	125	201	255	315	125	201

* Loss of stories compared with the original design condition
** CSD : continuous sunshine duration (min)
*** ASD : accumulative sunshine duration (min)

5. CONCLUSION

The objective of this paper was to develop the method for the optimum vertical layout of the apartment buildings that can provide proper design alternatives and useful information to ultimately improve indoor comfort. In this study, we suggested an automatic optimum model for vertical layout in high-rise apartment buildings as well as to verify the efficiency and the validity of the objective method. To this end, we compared the methods for the vertical layout to protect solar rights through application in cases. The major results of the study are as follows.

(1) The method of vertical layout by manual process entail iteratively a complicated process of analyzing and investigating numerous possible alternatives to find out the best alternative for improving solar rights in survey units. This method considerably needs lots of time and experts. Not only that, it lowers the productivity and efficiency of work and may possibly mistakes in decision and needs some automatic process using computer.

(2) For the automation of vertical layout of high-rise apartment building, the set of alternatives, $\boldsymbol{R}_{\mathrm{T}}$, for vertical layout by automation is defined through the Cartesian product of the defined set $\boldsymbol{B}$(set of **[BUILDING]**) and set $\boldsymbol{L}$(set of **[LINE]**) and is shown in equation (4).

(3) For the improvement of inefficiency and absurdity that can arise from simple automation, we have attempted to optimize the method of vertical layout by automation in such a way to set intuition of expert knowledge about the standard sunshine duration and sun-path in the winter solstice.

(4) In the verification of the automatic method for the optimum vertical layout, first, it is expected to reduce in processing time and workforce in comparison with manual method; second, faster processing is expected in comparison with the method of general automation.

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