A Design Methodology for Perimeter Block Housing Considering Day-lit Environments and Energy Performance

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Abstract

Perimeter block housing was introduced from the 2000s as an alternative means of urban construction that has been polarized between the large-scale development of high-density high-rise buildings and the development of small plots of land. The results of this paper allow the possibility of forming building types that satisfy the standard of two consecutive daylight hours for all households by using the properties and principles of shadows in perimeter block housing. It also provides the possibility of the combination of building forms without daylight interference from the south mass by manipulating the distances between adjacent buildings at different azimuth angles. Furthermore, comparing the energy load of residential buildings as suggested from the results of the study, it was possible to confirm whether residential buildings optimized for the day-lit environment have an effect in terms of energy usage performance, and further suggested planning directions through the analysis of daylight, sunray, and energy load. The study suggests a rational methodology for the layout of residential buildings that is optimized for the day-lit environment and also considers the issue of energy performance.

Keywords: perimeter block housing; urban block; energy performance; day-lit; azimuth angle; distance between buildings

1. Introduction

1.1 Objectives and Significance

Perimeter block housing refers to multiple dwellings formed by erecting perimeter blocks laid out along a grid of streets. The morphological characteristics of perimeter block housing may result in unfavorable orientations for living units and create an imbalance in the day-lit environments of households due to self-shadows on the interior faces. Apartment buildings are in actuality designed on the basis of minimum distances between buildings regulated by The National Building Codes irrespective of the orientations and forms of the buildings. This design method is limited in terms of upholding the right to light for every household and it is quite unreasonable to apply the standards for distances between buildings as prescribed in the existing Building Codes to perimeter block housing closely linked to street geometry. This study analyzed the features of the day-lit environment in perimeter block housing and examined a methodology for designing forms and layouts that meet the requirement of ensuring at least two hours of continuous access to daylight on the winter solstice. Moreover, comparing the heating and cooling load of residential buildings, it was possible to confirm whether residential buildings optimized for the day-lit environment have an effect in terms of energy usage performance, and further suggested planning directions through the analysis of daylight and energy load. This study aims to suggest a rational methodology for the layout of residential buildings that is optimized for the day-lit environment and also considers the issue of energy performance.

1.2 Study Scope and Method

In the first phase of this study, basic models for perimeter block housing were set and the characteristics of their shadows were identified. In the second phase, the housing day-lit environment was optimized based on the principle of shadow characteristics and on the minimum distances between buildings, thereby presenting a methodology for designing building block layouts that satisfy the condition of ensuring two hours of continuous daylight for every household. In the third phase, energy performance was assessed by calculating the heating and cooling load. Furthermore, planning directions were proposed with the aim of optimizing each form of residential building in terms of energy performance.

2. Perimeter Block Housing Day-lit Environment and Shadow Characteristics with Basic Model

2.1 Basic Model and Conditions of Simulation

Basic models for ascertaining the day-lit environment of a courtyard residential building are set
as described in Fig.1., reflecting the system of nearby streets and the distances between adjacent buildings in the Eunpyeong Newtown. The residential building of Eunpyeong Newtown is demonstrative of the typical European-style courtyard-type housing; four external sides each adjacent to a street, a central courtyard within the block, and ratio of 1:1 between the street width to building height. Each seven-story apartment building is 100 m in width, 65 m in length, 20 m in height and 11 m in depth. Each building includes 168 households. Changes in the day-lit environment and the number of households satisfying the legal standards for daylit hours were analyzed by rotating the azimuth angle by 15 degrees in a clockwise direction from 0° to 90° and in a counterclockwise direction from 0° to -90°. Since the orientation of a living room differs depending on the azimuth angle, in the model where plus azimuth angles are used, the living rooms are oriented south and east (Basic Model 1), and in the model where minus azimuth angles are used, the living rooms are oriented south and west (Basic Model 2).

The daylight hours of a living room balcony window were calculated by analyzing the incident solar radiation graph of the single day hourly exposure on the winter solstice in Seoul (Fig.1.a) using the Ecotect Analysis program. In Ecotect, overshadowing is determined by the sun-path diagram of weather data. Ecotect enables accurate and physically valid lighting and daylighting design. (Yan-Yung, 2001; Ali, 2015)

As outlined by court precedents, the right to light is recognized for cases in which the shadow from the main daylighting window is at 50 percent or less, and the same standard was applied. Standard 1 was set as the duration of continuous daylight between 9 a.m. and 3 p.m. (blue line) on the winter solstice, while Standard 2 was set as the accumulated daylight hours from 8 a.m. to 4 p.m. (green line).

2.2 Day-lit Environment on the Exterior Faces
The two bottom floors of the Bo facade are deprived of daylight at an azimuth angle of 0°. The hours of continuous daylight on the first floor increase to two hours or more and 2.6 hours or more at azimuth angles of 30° and -30°, respectively, meeting standard 1. The first floor receives daylight continuously for 2.7 hours or more at an azimuth angle of 45° and is exposed to continuous daylight for 3.4 hours or more at an azimuth angle of -45°. At azimuth angles of 60°, -60°, 75° and -75°, it is possible for all households on the Bo facade to receive natural illumination for three consecutive hours or longer.

The Do facade is oriented due east at an azimuth angle of 0°, and all households exclusive of the five in the lower part of the facade are ensured 2.5 hours of continuous daylight and 3.5 hours of accumulated daylight. At azimuth angles of 15° and -15°, the hours of continuous daylight are confirmed to reach 3.5 hours for most households. At azimuth angles of -30°, 45°, -45° and 60°, it is confirmed that every household excepting the three on the first floor receive four or more hours of accumulated daylight. A daylight pattern equal to that of a due south orientation starts to appear at an azimuth of -60° among the minus azimuths and at an azimuth of 75° among the plus azimuths and, therefore, eight households situated on the two bottom floors fall short of the requirement of receiving four hours of accumulated daylight.

| Table 1. Number of Households Met Standard 1 and 2 |
|-----------------------------------------------|
| Face | STD 1 | STD 2 | STD 1 | STD 2 | STD 1 | STD 2 |
| No. | %     | No. | %     | No. | %     | No. | %     |
| 0°[0°/-90°] | 42 | 100 | 49 | 95 | 42 | 100 | 38 | 90 |
| 15°[15°/-75°] | 30 | 71 | 30 | 71 | 30 | 71 | 42 | 100 |
| 30°[30°/-60°] | 28 | 100 | 0 | 0 | 16 | 57 | 16 | 57 |
| 45°[45°/-45°] | 114 | 81 | 70 | 50 | 116 | 83 | 100 | 71 |
| 60°[60°/-30°] | 45°[45°/-45°] | 75°[75°/-15°] |
| 30°[30°/-60°] | 140 | 112 | 80 | 127 | 90 | 111 | 79 | 126 |
| 45°[45°/-45°] | 30 | 100 | 22 | 78 | 22 | 78 | 25 | 71 |
| 60°[60°/-30°] | 140 | 129 | 92 | 112 | 80 | 127 | 90 | 111 |
| 75°[75°/-15°] | 30 | 100 | 22 | 78 | 22 | 78 | 25 | 71 |

2.3 Day-lit Environment on the Interior Faces
Every household along the Ai facade meets the standard of at least two hours of continuous daylight at an azimuth angle of 0°, as described in Table 1., and 95 percent of the total households satisfy the standard of at least four hours of accumulated daylight. On the east-facing Ci facade, daylight is blocked along a
diagonal from the corner of the relevant interior face due to a self-shadow from the B wing situated to the south. Only 14 households out of the 28 located along the Ci facade satisfy the standard of two guaranteed hours of continuous daylight. Changes in the locations and dispersion of self-shadows begin to clearly show at an azimuth angle of 30° or -30°, while at negative azimuths the C and B wings prevent daylight from reaching households in the adjacent corner of the Ai facade and households in the adjoining corner of the Di facade, respectively. As described in Table 1., the number of households suffering from a self-shadow changes according to reductions in the azimuth angle: 14 households at a 0° azimuth, 12 at -30° azimuth, 10 at -45° azimuth, 7 at -60° azimuth, and 9 at -75° azimuth. On the other hand, at plus azimuth angles, the B and D wings cast a shadow over the Ci facade and the corner of the Ai facade, respectively. The number of households suffering from a self-shadow is 13 at 30° azimuth, 11 at a 45° azimuth, 13 at 60° azimuth, and 8 at 75° azimuth.

3. Understanding of Shadow Characteristics by Azimuth Angle and Related Basic Principles

3.1 Calculation of the Minimum Distances between Buildings by Azimuth Angle

The use of the distances between buildings for meeting the legal standards for daylight hours according to azimuth angles allows the computation of the optimal number of floors satisfying these criteria based on specific street geometry, as well as the forecast of whether households located along the exterior peripheral surfaces facing the streets meet the standards. A simulation was performed for a seven-story apartment building 100 m in width and 20 m in height and with housing units 11 m in depth. The distances between buildings for satisfying the standards for both continuous and accumulated daylight hours per azimuth angle are described in Table 2. When the azimuth angle is set to due south, the distance between buildings should be 1.8 times the height (1.8 h), and as the azimuth angle approaches due east or due west, the distance between buildings for satisfying the standard of two hours of continuous daylight plunges to 0.7 h. There is little difference in the distances between buildings by azimuth angle in terms of meeting the standard for four hours of accumulated daylight, and when the azimuth angle is close to due west or due east, it is impossible to provide four hours of accumulated daylight. At azimuth angles of 0°, 15°, and -15°, there is little disparity between the minimum distances between buildings for meeting the criteria of daylight hours, and even similar shadow characteristics appear. At azimuth angles of 30°, -30°, 45°, -45°, 60° and -60°, there is considerable difference between the separation distances between buildings for satisfying the standards of two hours of continuous daylight and four hours of accumulated daylight. In a mass in the form of a courtyard apartment building, two wings have plus azimuth angles and the two other wings extending at right angles to the above two have minus azimuths. If the two angles consist of 45°/45° or -30°/60°, the distance between buildings for meeting the standards for daylight hours can be at a minimum, and there is a high consequence possibility that a plan with a more ideal day-lit environment and a higher floor area ratio can be actualized.

3.2 Elimination of Self-shadows

Self-shadows are cast on the Bi facade located to the east of the west wing at an azimuth angle of 0°, on the left portion of the Ai façade and the right corner of the Di façade at an azimuth angle of -30°, and on the left portion of the Ci façade and the right of the Ai façade at 45°. At an azimuth angle of 0° it thus becomes necessary to open parts of the B wing, of the C and B wings at -30°, and of the B and D wings at 45° in order to allow incoming sunlight, as shown in Fig.2. The exact ranges of the partial opening at the corners depend on the azimuth angle. The self-shadowed area can be removed, if north-south distance between adjacent buildings of 1.8 h is maintained at the corner.

4. Design Methodology with Optimization of Day-lit Environment

4.1 Courtyard-type Mass: Forms with N-S=1.8h

4.1.1 Example at Azimuth Angle of 0°

At azimuth angle of 0°, the height for the mass can be relatively easily assigned by using the north-south distance between the adjacent buildings as 1.8 h and the east-west distance between the adjacent buildings as 0.75 h. As a result, the A, B, C and D wings can be built up to 5, 8, 11 and 34 stories, respectively. After the overall planning for the mass is determined, the first column of the B wing is reduced to a single story, and the upper floors of the second column are deleted to eliminate the self-shadowing area.

4.1.2 Examples at Other Azimuth Angles

If a north-south distance between adjacent buildings of 1.8 h is used, daylight interference can be eliminated...
in the direction of due north. This method forms the southern mass when a straight line is drawn from a specific point on each adjoining road or each courtyard and the length of the straight line is calculated by using the north-south distance between adjacent buildings of 1.8 h. Based on these varying forms, daylight analysis was conducted at azimuth angles of -30°, 45° and 60° (Refer to Table 4.). With the exception of the A1 households failing to receive two consecutive daylight hours at an azimuth angle of -30°, the proportions of households satisfying the standard for four accumulated daylight hours at the azimuth angles of -30°, 45° and 60° were respectively 77%, 84% and 74%. Given that the basic courtyard-type model referred to in Section 2 has seven stories and 168 households, the form of the relevant mass include 166 households at an azimuth angle of 45°; 184 at an azimuth angle of 60°; and 166 at an azimuth angle of -30°. These results show that the form of the relevant mass can secure a floor area ratio similar to or higher than that of the basic model and improve the day-lit environment.

### 4.2 Methodology for Combining a U-Shaped Building Block and a 15-story Tower

The D wing at an azimuth angle of -30° and the C wing at an azimuth angle of 45° had no effect on the daylight environment of the Ai façade. Therefore, it is reasonable to place a tower on the right-side D wing at minus azimuth angles or on the left-side C wing at plus azimuth angles. For the mass of the A wing as established according to the width of the north street, the number of stories can be calculated by using the distances between adjacent buildings which could satisfy the standard for two consecutive daylight hours. For the B wing and the C wing, or the B wing and the D wing, the number of stories can be determined by applying the distances between adjacent buildings, which are necessary to meet the standard for four hours of accumulated daylight. This is intended to leave room for the possibility of planning to include a tower by securing the extra space required to satisfy the standards for daylight hours. Minimization of the loss of households was achieved by opening the south corner at an azimuth angle of 0° and through the deletion of self-shadowed portions at azimuth angles of -30° and 45°.

This study also performed an additional simulation to verify the locations able to minimize the impact on the daylight environment. The results of daylight analysis show that when the location of the tower was at the bottommost within the relevant block, the effect on the surrounding day-lit environment, particularly the effect on the exterior peripheral faces of the two blocks north of the relevant block, could be minimized. The mass forms proposed for the azimuth angles of 0°, -30° and 45° have 180, 153 and 161 households, respectively. This shows that in this formation of the combination of a U-shaped mass and a tower, every household satisfies the standard for two consecutive daylight hours and it is also possible to ensure development density.
4.3 Combination of Different Building Types

4.3.1 Examples at an Azimuth Angle of 0°

First of all, it requires a north-south distance of 1.8 h and an east-west distance of 0.75 h between adjacent buildings as a foremost priority. Then, to ensure that no household was deprived of daylight by self-shadowing, it became necessary to partially redesign the B wing in the shape of steps, or downsize the wing’s corner by 16 meters to allow incoming sunlight. According to calculations, as the C and D wings can be built up to 12 and 34 stories respectively, to satisfy the standard for at least two consecutive daylight hours for every household. The number of stories was determined as a means to secure the proper floor area ratio, and the mass of residential buildings was built in order to create diversity and change in the landscape. The result of checking the daylight hours at the first story in the worst day-light environment demonstrated that the standard of two consecutive daylight hours was satisfied for every household.

4.3.2 Examples at an Azimuth Angle of -30°

Setting the azimuth angle at an angle other than 0° entails the merit of reducing the distance between adjacent buildings for each azimuth angle, while incurring the demerit of higher daylight interference between residential buildings due to the increase in the stand area of buildings vertically oriented to due north when projected on the horizontal plane. Therefore, two building masses facing each other should in principle satisfy the distances between buildings per azimuth angle, and separately to this issue, a 1.8 h distance in the direction of due north should be secured so as to remove daylight interference of residential buildings caused by mass located towards the south. As the result of assigning a residential building optimized for the daylight environment to each perimeter block housing and verifying daylight hours at the first story of the worst daylight location, it was possible to conclude that every household met the requirement of two hours of continuous daylight.

5. Analysis of Energy Performance and Planning Directions for Optimization

5.1 Climatic Conditions of Seoul

Seoul has a humid continental climate with severe, dry winters, hot summers and strong seasonality. The annual average temperature is 12.5°C, the coldest month is January with the annual average temperature of -2.4°C, and the warmest month is August with the monthly average temperature of 25.7°C. The annual average wind velocity is 2.3 m/s, while the annual average relative humidity is 64 percent. The major climate conditions calculated using the Ecotect weather tool are shown in Table 5a. High levels of solar radiation during the wintertime indicate high potential for passive solar heating and therefore window sizing and thermal mass should be taken into account.

| Seoul, Korea | Best Orientation | 157° |
|-------------|------------------|------|
| Solar Radiation (Total Annual Collection) | E | 36290KWh/m² |
| S | 5909KWh/m² |
| N | 21711KWh/m² |
| W | 9369KWh/m² |
| Climate Type | 4 (ASHRAE) |
| Max. Direct solar | 649.42 W/m² |
| Wind Direction | winter: NW / W summer: N / NE / NW |
| Ave. Wind Speed | 2.3 m/s (Max. Wind 9.3 m/s) |
| Ave. Temperature | 12.5°C |
| Ave. Relative Humidity | 64% |

5.2 Basic Model and Conditions of Simulation

In order to calculate the energy load, modeling was conducted on not only the living room windows in Basic Models 1 and 2, but also the windows in each room as shown in Figure 6. The size of the window applied the generic size of two-bedroom apartment windows according to the three plan types.

Fig.6. Window Type Index and Dimension (Above)
Front (South) and Rear (North) Elevation (Below, Typ.)

The assembly of the exterior walls including the wall surface ratio and the U-value of the building materials were made to satisfy the conditions outlined in Seoul's eco-friendly construction design guidelines, while the summary of building material performances is outlined in Table 5.
The simulation was conducted with the number of residents per household set to four; relative humidity to 60 percent; heating system to underfloor water heating; internal room temperature at 21°C (Heating was activated when under 18°C and cooling was activated when over 26°C, with each system running for 24 hours); and the climate set based on data from Seoul. Calculation of the energy load was based on the results of the simulations conducted through Monthly Heating/ Cooling Loads as provided by the Thermal Analysis function in Ecotect. Ecotect calculates heating/cooling loads based on the guidelines from CIBSE, England, and while Ecotect's energy load calculation is limited by its initial design stage to estimate the actual energy usage rate of buildings, it is capable of producing meaningful results in terms of relative comparisons between different schemes.

Table 5. U-value of Building Assembly

| U-value (W/m²·K) | Exterior Wall | Window | Slab on Grade | Floor Slab | Roof |
|-----------------|---------------|--------|---------------|------------|------|
|                 | 0.27          | 0.117  | 0.25          | 0.08       | 0.18 |

Table 6. Energy Loads at 0°, -30°, and 45° (Basic Model)

| Unit: kWh | Wing | Heating | Cooling | Total Loads |
|-----------|------|---------|---------|-------------|
|           | A    | 523,766 | 37,079  | 560,845     |
|           | B    | 695,208 | 48,188  | 743,396     |
|           | C    | 363,477 | 25,689  | 389,166     |
|           | D    | 363,117 | 25,490  | 388,607     |
|           | Total| 1,945,568 | 136,446 | 2,082,014  |
| Per m²    | 88.3 | 6.2     | 94.5    |
|           | A    | 524,339 | 36,997  | 561,335     |
|           | B    | 676,648 | 47,974  | 724,622     |
|           | C    | 362,278 | 26,030  | 388,308     |
|           | D    | 359,197 | 25,717  | 384,914     |
|           | Total| 1,922,462 | 139,756 | 2,063,218  |
| Per m²    | 87.2 | 6.3     | 93.6    |
|           | A    | 528,911 | 38,459  | 567,371     |
|           | B    | 689,326 | 50,268  | 739,595     |
|           | C    | 354,021 | 25,177  | 379,198     |
|           | D    | 351,765 | 25,852  | 377,618     |
|           | Total| 1,924,023 | 139,756 | 2,063,780  |
| Per m²/m² | 87.3 | 6.3     | 93.6    |

5.3 Energy Performance Comparison for Basic Model at Azimuth Angles of 0°, -30°, and 45°

Regarding the aggregate sum of heating/cooling loads, the lowest loads were produced in the order of -30°, 45°, and 0°, while Table 6. shows that azimuth -30° is the most advantageous. The difference in load per unit of surface area between -30° and 0°, can be estimated at 1.03 kWh. Considering that the insulation for the outer walls and windows were designed conservatively in order to satisfy environmental standards, it is evident that considerable differences in load can result from differences in azimuths alone.

Examining the heating/cooling loads in wings A, B, C, and D showed a considerable decrease in the heating load of the B wing due to the change from azimuth 0° to -30°, caused by the rise in direct heat gain through the living room window as the main source of sunlight in the winter as lower-floor units in the B wing received longer periods of sunlight. In azimuth 45°, the living rooms face south-west in the A and B wings as the long side, while those in the C and D wings as the short side face south-east, and therefore the increase in the extra solar radiation during the summer through the sides Ai and Bo, whose windows are larger in surface area, cause a corresponding increase in the cooling load.

5.4 Energy Performance Comparison for Rectangular-shaped Courtyard-type

A heating and cooling load simulation was conducted for a building with high daylight performance presented in Section 4.2. According to the results shown in Table 7., if a building was formed using the north-south distance of 1.8 h between adjacent buildings, it had the lowest loads for each unit area at an azimuth angle of -30°. The comparison of the building to the seven-story basic model with both at the azimuth angle of -30° showed a decrease in the heating and cooling loads per unit area by a margin of 8.9 kWh per unit area. Along with a change in the azimuth angle for the basic model, the above-mentioned 1.8 h building model revealed an increase in the cooling load at the azimuth angle of 45°, and sharp rises were observed in both the heating and cooling loads at the azimuth angle of 60°, with a particularly noticeable rise in the cooling load.

5.5 Systematic Approach for the Optimization of Energy Performance

The simulation results shown in Section 5.3 indicate that a building with an advantageous azimuth angle for daylighting on the winter solstice and the daylight optimized design does not necessarily create an advantage in terms of energy load. Therefore, adjustment of the windows and the installation of shading devices are vital in structuring the building to minimize energy load.

5.5.1 Window Size Adjustment on Main Façade

In order to reduce heating/cooling loads, the size of windows on the exterior must be changed. First of all, taking into account the issue of securing visibility...
and reducing the surface area of windows that were front-facing windows in the living room and the main bedroom by 750 mm above the floor. The extent of the decrease was greater in the heating load, which fell to around 94 percent, while the cooling load fell to around 96 percent at all azimuth angles. Although identifying an appropriate size of windows in consideration of indoor luminosity requires a separate analysis of indoor luminosity, this study focuses on the issue of energy load and comparing approximate relative values instead.

5.5.2 Installation of Shading Device

In the subsequent phase, the cooling load was sought to be further reduced in the model with window surface areas reduced from the base model, by additionally installing a shading device to outside windows and examining the change in the cooling load. For each azimuth angle, the final modeling process designed louvers of appropriate horizontal and vertical dimensions as in Table 9, with the most ideal design to block sunlight in the summer and to draw sunlight in the winter, and conducted simulations on heating/cooling loads, whereby the cooling load

Table 7. Energy Loads at -30°, 45° and 60°(Courtyard)

| Unit: kWh | Wing | Heating | Cooling | Total Loads |
|----------|------|---------|---------|-------------|
| -30° [-30°/60°] | A | 449,967 | 31,151 | 481,118 |
|           | B | 722,029 | 49,775 | 771,804 |
|           | C | 226,201 | 14,766 | 240,968 |
|           | D | 305,907 | 21,659 | 327,567 |
| Total Floor Area: 21538m² | Total | 1,704,104 | 117,351 | 1,821,459 |
| Per m² | 79.1 | 5.4 | 84.5 |
| 45° [45°/-45°] | A | 560,233 | 40,043 | 600,276 |
|           | B | 737,218 | 52,913 | 790,131 |
|           | C | 384,747 | 31,670 | 416,417 |
|           | D | 246,145 | 17,438 | 263,583 |
| Total Floor Area: 21897m² | Total | 1,928,343 | 142,064 | 2070,407 |
| Per m² | 88.1 | 6.4 | 94.5 |
| 60° [60°/-30°] | A | 767,014 | 55,184 | 822,198 |
|           | B | 738,123 | 51,277 | 789,400 |
|           | C | 430,485 | 72,733 | 503,218 |
|           | D | 364,025 | 23,623 | 387,648 |
| Total Floor Area: 24354m² | Total | 2,299,647 | 202,817 | 2,502,464 |
| Per m² | 94.4 | 83.2 | 102.7 |
in each azimuth angle was found to have decreased by 5-10 percent. The Total Monthly Solar Exposure on the sample side before and after the installation of the shading device demonstrates that the subsequent decrease in the extra solar radiation during the summer allowed a corresponding decline in the cooling load incurred by overheat. In particular, the heating/cooling load in azimuth angle 60° decreased by a significant extent compared to -30° and 0°, which is caused by the reduction in overheating due to the main direction facing south-west. As a result, a model optimized for daylighting through detailed design adjustment confirmed the potential for energy performance optimization.

6. Conclusion

For perimeter block housing, an azimuth angle determines the required distances between adjacent building blocks and the properties of the day-lit environment for ensuring satisfactory daylight levels. According to the result of daylight analysis based on the basic seven-story models, the positive azimuth angles of 45° and 60° and the negative azimuth angles of -30° and -45° were favorable to the daylight environment compared to other azimuth angles, showing that a change in an azimuth angle is able to improve the daylight environment even under identical physical conditions.

The results of this paper allow the possibility of forming building types that satisfy the standard of two consecutive daylight hours for all households by using the properties and principles of shadows in perimeter block housing. Examples are provided of a combination of courtyard and tower types, and the feasibility of the modeled masses is verified through daylight simulations. It also provides the possibility of the combination of building forms without daylight interference from the south mass by manipulating the distances between adjacent buildings at different azimuth angles.

In terms of energy performance, the simulations based on the basic model indicated that the lowest total loads for heating and cooling were produced in the order of –30°, 45° and 0°. Among courtyard-type building masses using the 1.8 h distance optimized for the daylight environment between adjacent buildings, it was not necessarily the case that a mass, at an azimuth angle with a higher ratio of households satisfying the daylight standard to the total households demonstrated better energy performance than other azimuth angles. For the reduction of energy loads, it is necessary to optimize the window sizes by azimuth angle and by orientation, as well as to block summer sunray and reduce cooling loads by installing shading devices for example. Ultimately, to optimize the daylight environment and energy performance at the same time, establishing the long side at an azimuth angle of -30° provides the greatest advantage, and therefore it is desirable to set the said angle as the main azimuth angle when designing a residential district.

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