Basic study on thermal environment of condominium dwelling units, Part 2—Database creation and analysis example of relationship between dwelling units and cooling load

Shimon Nihei1, Shinya Satoh, Shinichi Hirao2 and Atsushi Tasaki3

1Department of Architecture, College of Science & Technology, Nihon University, Tokyo, Japan; 2Mec Eco Life CO., LTD., Tokyo, Japan; 3Bau Physik Design Lab CO., LTD., Tokyo, Japan

Correspondence
Shimon Nihei, Department of Architecture, College of Science & Technology, Nihon University, 3-11-2, Kanda Surugadai, Chiyoda-ku, Tokyo 101-8308, Japan.
Email: nihei.shimon@nihon-u.ac.jp

Funding Information
Mitsubishi Estate Residence Co., Ltd; MEC eco LIFE CO., LTD.

The Japanese version of this paper was published in Volume 83 Number 747, pages 821-831, https://doi.org/10.3130/aija.83.821 of Journal of Architecture and Planning (Transactions of AIJ). The authors have obtained permission for secondary publication of the English version in another journal from the Editor of Journal of Architecture and Planning (Transactions of AIJ). This paper is based on the translation of the Japanese version with some slight modifications.

Received October 9, 2019; Accepted December 15, 2019
doi: 10.1002/2475-8876.12139

1. Introduction

The Japanese government has created a global warming countermeasure plan based on COP21 [Note 1] and is targeting an approximate 40% reduction in CO2 emissions in the home department by FY 2030 in comparison with the levels in 2013. To achieve these lofty objectives, practical approaches and novel conceptualizations with a systematic focus, not only on design and supply components but also the resident, are required. For example, Class 4 residences with regard to insulation performance as a standard for saving energy, are not yet widespread [Note 2]. Additionally, even in the case of certified low-carbon residences that achieve an even higher performance, only approximately 8300 residences have been constructed [Note 3]. Class 4 and certified low-carbon objectives can be used as performance standards, and though they have not yet become widespread, researchers and practitioners have begun to advocate a concept that combines living standards with high sufficiency, such as smart wellness [Note 4] and clima design [Note 5], with achievement of performance standards. However, the possibility of improving the thermal environment that incorporates performance standards, based on dwelling unit design [Note 6] building elements that replace frontage ratios (ie, frontage and ratios), has not yet been clarified.

On the other hand, it has been mentioned in a previous report1 that in the case of dwelling unit design for condominiums, the dwelling unit plan is stylized as an nLDK [Note 7]. Therefore, while the achievement of performance standards is becoming mandatory, it may be possible to review the dwelling unit design itself by considering the thermal environment from the dwelling unit design side, in addition to insulation and glass specifications. For example, from a previous report, it was clarified that the mode of a frontage was 6.2 m, but once the dimensions that take the thermal environment into consideration were clarified, it become evident that more than 50,000 [Note 8] dwelling units are created annually, and
promising inroads to a large-scale general reduction in CO₂ emissions can be expected. Previous reports have focused on the indices of “\( q \)” and “period heating load” (hereafter “heating load”) to potentially contribute to the improvement of the thermal environment despite increasing variation in dwelling unit design, and showed the relationship between dwelling unit design and heating load by handling large amounts of provided dwelling unit data. Building on this existing report, this study adds “cooling load per unit area [Note 9]” (hereafter “cooling load”), “heat loss amount per temperature difference [Note 10]” (hereafter, \( q \)), and “solar heat gain amount during cooling period [Note 11]” (hereafter \( m_c \)) as indices of the thermal environment when cooling, to complete a database that can be evaluated from both heating and cooling loads. In this study, the dwelling unit design building element for evaluating design indicators [Note 12] related to each form of insulation and the cooling load for each building envelope element, and the effectiveness of design indicators associated with each form of insulation and the cooling load were used for each element of the building envelope.

Based on the above, this study has the following two aims.  

1. We will compare the cooling load that reflects the design indicator and dwelling unit design associated with each form of insulation. We will also clarify the trends and relationships between the design indicators associated with each form of insulation and the cooling load for each building envelope element, and the effectiveness of the design indicators.  

2. Henceforth, we shall create a database in line with external conditions to perform factor analysis. On the basis of this, we shall show sample analyses of design indicators associated with a cooling load and effective insulation, and the building envelope building element.

The fraction of cooling load that comprises the annual consumed energy in a residence is reported to be small [Note 14]; however, by improving the thermal environment, many composite advantages can be obtained, such as the inhibition of overheating within a room, downsizing of installed air conditioning equipment, peak cuts in power, and contributions to medium-term expansion that do not rely on cooling. Additionally, although it cannot be denied that comfort in the summer months may be compromised by prioritizing the winter months when planning, we believe that there is value in creating a database for both cooling and heating load and showing examples of analyses.

### Table 1. Main elements of the dwelling unit design to extract

| Elements | Overview |
|----------|----------|
| Heating/cooling loads | Dwellling unit area (m²) | Area of dedicated dwelling unit. |
| Building envelope | Building envelope area (m²) | Building envelope area in dwelling. |
| \( U_A \)q | Plan shape complexity | Value of dwelling circumferential length divided by square root of dwelling dedicated area. |
| Orientation | Frontage (m) | Width of dwelling as seen from front. |
| Number of open sides | Unit depth/frontage | Ratio of unit depth divided by frontage. |
| Neighboring buildings | Opening ratio (%) | Ratio of opening area divided by floor area [Note 20]. |
| \( m_c \) | Eaves depth/opening height | Ratio of eaves depth of living room main opening window area (balcony protruding dimensions) divided by length from eaves to opening edge. |
| [Note 19] | [Note 19] | |

### 2. Method and Subjects of Study

The subject of the study was the 2229 dwelling units in 22 residence buildings in the metropolitan area [Note 15] presented in the existing report. However, to minimize regional differences based on climate conditions, the survey targeted six regions [Note 16] in the revised energy-saving standard region category. From this, the 1603 3LDK dwelling units (2014), the most commonly provided unit, was used as the sample, and a sample analysis is shown. To perform the analysis, we extracted the various elements of the building envelope that we assumed the architectural designer had in mind at the time of design, as shown in Table 1, and the external conditions data, from the surveyed target. In particular, reconstructed [Note 17] dimensions and ratios based on the net quantity [Note 18] at the time of calculation of design indicators associated with cooling load and insulation were used for each element of the building envelope. “Eaves depth/opening height [Note 19]” was added to the building envelope building elements in the existing report. Following this chapter, we compare in Chapter 3 the design indicators associated with cooling load and insulation for each element of the building envelope using a layered scatter plot for each number of open sides, to show the trends and relationships of design indicators associated with cooling load for each building envelope element, as well as the effectiveness of design indicators related to insulation. In Chapter 4, we create an additional database in line with the external conditions to show the dimensions and ratios for improving the thermal environment using a factor analysis. We create a layered scatter plot for each orientation by building envelope element as a sample analysis of this database. On the basis of this, we show an analysis of the design indicators associated with cooling load and effective insulation, as well as building.
envelope building elements, and clarify the possibility of improving the thermal environment using dwelling unit design.

3. Trends in 3LDK as Seen from the Perspective of Design Indicators Associated with Cooling Load and Various Types of Insulation

3.1 Overview of the samples used in this chapter
The sample in this chapter was taken from a performance evaluation document in the residence performance display system and conforms to the energy-saving standard specification (Class 4). The sample is composed of 1603 3LDK dwelling units (2014) with different directional orientations as shown in Table 2. The units vary in number of open sides, as shown in Table 3. Additionally, the total includes 770 dwelling units (48.0%) with adjacent buildings, and approximately half are thought to be somewhat impacted by solar heat acquisition. All samples meet the standard values ($\eta_A < 2.8$) for the solar heat acquisition coefficient during the cooling period in the revised energy-saving standards.

3.2 Method of calculating cooling load and design indicators associated with each form of insulation
Cooling load is calculated using a simulation tool [Note 21]. The settings for the building energy simulation are as shown in Table 4. We can obtain $q$ and $m_C$ based on the revised energy-saving standard calculation standards.

3.3 Relationship between cooling load and design indicators associated with each form of insulation
Using a scatter plot, we can see the relationship between the design indicators associated with each form of insulation and cooling load (Figure 1). For $U_A$, the correlation coefficient is 0.15, for $q$, the correlation coefficient is 0.49, and for $m_C$, the correlation coefficient is 0.74. From here, we can see that the correlation with cooling load is strongest in the order of $m_C > q > U_A$.

3.4 Comparison of the cooling load and design indicators associated with insulation as seen from each building envelope element
Using a scatter plot, we compare the correlation between the cooling load and design parameters associated with insulation for each building envelope element. A differential analysis is performed for each of the four open sides, which is one of the external conditions, and these are shown in Figures 2–8. Additionally, if we judge the correlation coefficient within a confidence interval range of 95%, based on a significance test, no correlation is observed if $|r| > 0.12$. In the diagram, one side is expressed as ($\times$), two sides at both ends as ($\bullet$), two continuous as ($\Delta$), and three sides or four sides as ($\bigcirc$).

3.4.1 Relationship with the dwelling unit area
No strong correlation can be seen between the cooling load and dwelling unit area regardless of the number of open sides (Figure 2). Therefore, it is possible that the cooling load cannot be controlled depending on the dwelling unit area. Note that a strong positive correlation can be seen in some of the number of open sides, such as in the $m_C$ and $q$ values.

3.4.2 Relationship with the building envelope area
No strong correlation can also be seen between the cooling load and building envelope area, regardless of the number of open sides (Figure 3). Therefore, it may not be possible to control the cooling load depending on the building envelope area. Note that a strong correlation can be seen in some of the number of open sides, such as in the $m_C$ and $q$ values.

3.4.3 Relationship with dwelling unit plan shape complexity criteria
A strong positive correlation can be seen between the cooling load and dwelling unit plan shape complexity indicators for one open side ($\times$), and it is possible that the cooling load can be controlled (Figure 4). A strong correlation can also be seen in some of the number of open sides, such as in $m_C$.

3.4.4 Relationship with frontage
A strong positive correlation can be seen between the cooling load and frontage for the two continuous ($\Delta$) open sides, and it is possible that the cooling load can be controlled (Figure 5). A strong positive correlation can also be seen in the $m_C$, $q$, and some of the $U_A$ in number of open sides. A particularly strong positive correlation can be seen in cooling load as well as $m_C$ and $q$ in two continuous ($\Delta$) open sides.

3.4.5 Relationship with depth frontage ratio
A strong negative correlation can be seen between the cooling load and depth frontage ratio for the two continuous ($\Delta$) open sides, and it is possible that cooling load can be controlled (Figure 6). A strong correlation can be seen even for the $m_C$ and $q$, and $U_A$ in number of open sides. A particularly strong negative correlation can be seen in cooling load, as well as $m_C$ in two continuous ($\Delta$) sides.

3.4.6 Relationship with opening ratio
A strong correlation can be seen between cooling load and opening ratio for one ($\times$) or two continuous ($\Delta$) open sides, and it is possible that cooling load can be controlled (Figure 7). A strong correlation can be seen for $m_C$, $q$, and some of $U_A$ in number of open sides. A particularly strong positive correlation can be seen in the cooling load and design indicators associated with each form of insulation for one ($\times$) and two continuous ($\Delta$) open sides.

3.4.7 Relationship with eaves depth/opening height
A strong negative correlation can be seen between cooling load and eaves depth/opening height for one ($\times$) and two continuous ($\Delta$) open sides, and it is possible that cooling load can be controlled (Figure 8). A strong correlation can also be seen for $U_A$, $q$, and some of $m_C$ in number of open sides. A particularly strong negative correlation is observed in cooling load for $m_C$ in one ($\times$) and two continuous ($\Delta$) open sides.

3.5 Summary
The correlations between cooling load and various design indicators associated with insulation in Figures 2–8 are shown in list form in Table 5. We can see that the various elements of building envelopes other than the dwelling unit area (Figure 2) and building envelope area (Figure 3) can be controlled with regard to the cooling load. Therefore, if we look mainly at Figures 4–8, omitting...
dwelling unit area and building envelope area, we can see that \( m_C \) is the design indicator associated with insulation that is closely correlated with the cooling load. This trend is the same as that seen in Figure 1. In Chapter 4, we proceed with an analysis focusing on cooling load and \( m_C \). From these, we could confirm that the design indicators associated with insulation are effective depending on the building envelope building element. However, factor analysis should be conducted in accordance with the external conditions because it cannot be stated that there is no correlation when \( |r| > 0.12 \) based on the significance test. Therefore, in Chapter 4, we create an additional database in line with external conditions. We show a sample analysis and confirm the possibility of improving the thermal environment based on the dwelling unit design.

### 4. Trends When in Line with External Conditions

#### 4.1 Overview of sample in this chapter

In this chapter, to line up the external conditions, we take 711 dwelling units [Note 29] from intermediate floors (excluding the top floor and bottom floor) from adjacent buildings that impact the acquisition of solar heat, and perform a differential analysis by orientation. North-facing dwelling units and the two dwelling unit areas that were particularly large were excluded from the investigation [Note 30]. As a result, there were 702 dwelling units, and a classification by orientation is shown in Table 6. The correlation coefficient was calculated within a 95% confidence interval range, and the strength of the correlations is shown in Tables 7–13. “Number of open sides and orientation as a single type (hereafter, Dwelling Unit type)” without correlation based on the significance test have the cells set to a white background. For items where trends conflict with those seen in the cooling load and \( m_C \) of the previous chapter despite an observed correlation, an under-bar is added to the character.

#### 4.2 Cooling load and \( m_C \) trends as seen from each building envelope element

**4.2.1 Relationship with dwelling unit area by orientation**

No strong positive correlations were seen between the cooling load and dwelling unit area for any number of open sides (Figure 9; Table 7). A strong positive correlation was seen for the three dwelling unit types in this chapter. This was broken down between the...
Figure 2. Relationship with dwelling unit area

Figure 3. Relationship with building envelope area

Figure 4. Relationship with plan shape complexity

Figure 5. Relationship with frontage
south-facing dwelling units with two continuous (Δ) open sides, and east-facing and west-facing dwelling units with three sides or four sides (○). The same trend was seen for $m_C$ and dwelling unit area.

4.2.2 Relationship with the building envelope area by orientation
A strong positive correlation was not seen between the cooling load and building envelope area for any number of open sides in the previous chapter (Figure 10; Table 8). A strong positive correlation was seen for the three dwelling unit types in this chapter. This was broken down between the south-facing dwelling units with two continuous (Δ) open sides, and west-facing and east-facing dwelling units with three sides or four sides (○). The same trend was seen for $m_C$ and building envelope area. The strong positive correlation trend was the same for the dwelling unit area.

4.2.3 Relationship with dwelling unit plan shape complexity criteria by orientation
A strong positive correlation was seen between the cooling load and dwelling unit plan shape complexity criteria in the previous chapter for one (×) open side (Figure 11; Table 9). In this chapter, a strong positive correlation was seen for the three dwelling unit types. This was broken down between south-facing and west-facing dwelling units with one (×) open side, and west-facing dwelling units with three sides or four sides (○). Only one dwelling unit type showed the same strong correlation with cooling load with regard to $m_C$ and dwelling unit plan shape complexity criteria, which was the west-facing dwelling unit with three sides or four sides (○). From this, we can see that the two dwelling unit types and the south-facing and west-facing dwelling units with one (×) open side have small dwelling unit plan shape complexity, and can control cooling load regardless of $m_C$.

4.2.4 Relationship with frontage by orientation
A strong positive correlation was seen between the cooling load and frontage in the previous chapter for two continuous (Δ) open sides (Figure 12; Table 10). In this chapter, a strong positive correlation was seen for the three dwelling unit types and the south-facing and west-facing dwelling units with one (×) open side, and west-facing dwelling units with three sides or four sides (○).
unit types. This was broken down between south-facing dwelling units with two continuous (Δ) open sides, and west-facing and east-facing dwelling units with three sides or four sides (○). The same trend was seen for mC value

### Table 5. List of correlation coefficients from the viewpoint of “cooling load” and “design criteria related to insulation”

| Figure | × | ● | △ | ○ |
|--------|---|---|---|---|
| 2      | −0.03 | −0.16 | −0.11 | −0.03 |
| 3      | 0.19 | −0.12 | −0.08 | −0.06 |
| 4      | 0.29 | 0.01 | 0.14 | 0.07 |
| 5      | 0.55 | 0.10 | −0.03 | −0.15 |
| 6      | 0.55 | −0.13 | −0.05 | 0.16 |
| 7      | 0.93 | 0.48 | 0.44 | 0.20 |
| 8      | −0.60 | −0.14 | −0.27 | 0.17 |

| Figure | × | ● | △ | ○ |
|--------|---|---|---|---|
| 2      | −0.19 | −0.26 | 0.29 | 0.08 |
| 3      | 0.07 | −0.25 | 0.30 | 0.16 |
| 4      | 0.41 | −0.23 | −0.09 | 0.09 |
| 5      | 0.02 | −0.09 | 0.48 | 0.36 |
| 6      | −0.21 | −0.15 | −0.47 | −0.40 |
| 7      | 0.45 | −0.22 | 0.48 | 0.30 |
| 8      | −0.55 | −0.12 | −0.53 | −0.35 |

### Table 6. Composition ratio for number of open sides for each orientation (%:units)

| 1 side (●) | 2 sides at both ends (●) | 2 continuous (Δ) | 3 sides | 4 sides (○) |
|------------|--------------------------|-----------------|--------|------------|
| S          | 6.8%:48                  | 15%:106         | 3.4%:24 | 6.9%:49    |
| W          | 17.6%:125                | 1.4%:10         | 10.3%:73 | 4.4%:31    |
| E          | 15.5%:110                | 5.4%:38         | 6.1%:43 | 6.3%:45    |

### Table 7. List of correlation coefficients for each direction in the dwelling-unit area

| S | Cooling load (MJ/m²) | mₑ (W/Wm²) |
|---|----------------------|------------|
| W | Cooling load (MJ/m²) | mₑ (W/Wm²) |
| E | Cooling load (MJ/m²) | mₑ (W/Wm²) |

### Table 8. List of correlation coefficients for each direction in the building envelope area

| S | Cooling load (MJ/m²) | mₑ (W/Wm²) |
|---|----------------------|------------|
| W | Cooling load (MJ/m²) | mₑ (W/Wm²) |
| E | Cooling load (MJ/m²) | mₑ (W/Wm²) |

### Table 9. List of correlation coefficients for each direction in the plan shape complexity

| S | Cooling load (MJ/m²) | mₑ (W/Wm²) |
|---|----------------------|------------|
| W | Cooling load (MJ/m²) | mₑ (W/Wm²) |
| E | Cooling load (MJ/m²) | mₑ (W/Wm²) |

### Table 10. List of correlation coefficients for each direction in the unit frontage

| S | Cooling load (MJ/m²) | mₑ (W/Wm²) |
|---|----------------------|------------|
| W | Cooling load (MJ/m²) | mₑ (W/Wm²) |
| E | Cooling load (MJ/m²) | mₑ (W/Wm²) |

### Table 11. List of correlation coefficients for each direction in the unit depth/frontage

| S | Cooling load (MJ/m²) | mₑ (W/Wm²) |
|---|----------------------|------------|
| W | Cooling load (MJ/m²) | mₑ (W/Wm²) |
| E | Cooling load (MJ/m²) | mₑ (W/Wm²) |
and frontage as well. The strong positive correlation trend was the same for the dwelling unit area and building envelope.

### 4.2.5 Relationship with unit depth/frontage by orientation

A strong negative correlation was seen between the cooling load and unit depth/frontage ratio in the previous chapter for two continuous (Δ) open sides (Figure 13; Table 11). In this chapter, a strong negative correlation was seen for six of the dwelling unit types. This was broken down between the east-facing dwelling units with one (×) open side, south-facing and west-facing dwelling units with two continuous (Δ) open sides, and east-facing and west-facing dwelling units with three sides or four sides. From this, we can see that the cooling load can be controlled regardless of $m_c$ by increasing the unit depth/frontage ratio for the east-facing and west-facing dwelling units with two sides at both ends (●).

### 4.2.6 Relationship with opening ratio by orientation

A strong positive correlation was seen between the cooling load and opening ratio in the previous chapter for the one (×) and two continuous (Δ) open sides (Figure 14; Table 12). In this chapter, a strong positive correlation was seen for six of the dwelling unit types. This is broken down between the east-facing and west-facing dwelling units with one (×) open side, south-facing and west-facing dwelling units with two continuous (Δ) open sides, and west-facing and east-facing dwelling units with three sides or four sides (○). The same trend was seen for $m_c$ and opening ratio.

### 4.2.7 Relationship with eaves depth/opening height by orientation

A strong negative correlation was seen between the cooling load and eaves depth/opening height in the previous chapter for one (×) and two continuous (Δ) open sides (Figure 15; Table 13). In this chapter, a strong negative correlation was seen for ten of the dwelling unit types. This was broken down between the dwelling units with one (×) open side in all orientations, south-facing and west-facing dwelling units with two sides at both ends (●), dwelling units with two continuous (Δ) open sides in all orientations, and west-facing and east-facing dwelling units with three sides or four sides (○).

Only six types of dwelling units showed the same strong negative correlation with the cooling load with regard to $m_c$ and eaves depth/opening height. This was broken down...
between east-facing and west-facing dwelling units with one (×) open side, south-facing and west-facing dwelling units with two continuous (△) open sides, and west-facing and east-facing dwelling units with three sides or four sides (○). However, even though a strong negative correlation was seen between the west-facing and east-facing dwelling units, as the solar elevation was low, it cannot be asserted that solar shading from the eaves (balcony) in the main opening was occurring, and verification of the impact of complex solar shading materials, including wing walls and handrails, will be an issue moving forward. We can see that for the south-facing dwelling units with one (×) open side and south-facing dwelling units with two open sides at both ends (●), cooling load can be controlled regardless of $m_C$ by increasing the eaves depth/opening height.

4.3 Summary
We have learned the following from this chapter.

1. The characteristics of one open side (×) dwelling unit types. The types of dwelling units that can control the cooling load were as follows: “dwelling unit plan shape complexity criteria” (hereafter “complexity”) and “eaves depth/opening height” (hereafter “eaves”) of south-facing dwelling units, the “complexity” and “opening ratio” of west-facing dwelling units, and the “unit depth frontage ratio” and “opening ratio” of east-facing dwelling units. Among these were three dwelling unit types that could control cooling load regardless of $m_C$. We can see that these were the “complexity” and “eaves” of south-facing dwelling units, and the “complexity” of west-facing dwelling units.
The characteristics of two open sides at both ends (●) dwelling unit types. The types of dwelling units that can control the cooling load were as follows: the “unit depth frontage ratio” and “eaves” of the south-facing dwelling units, and the “unit depth frontage ratio” of east-facing dwelling units. Additionally, these three dwelling unit types could control cooling load regardless of $m_C$.

There were several types of dwelling units with two continuous (△) open sides and three sides or four sides (□) that could control the cooling load by using building envelope building elements. On the other hand, no dwelling units that could control cooling load regardless of $m_C$ were seen.

The highest number of orientations in which strong correlations were seen between cooling load and $m_C$ was in west-facing dwelling units with nine total, followed by east-facing dwelling units with seven total, and south-facing dwelling units with five total.

The highest number of orientations in which a strong correlation was seen only with cooling load was in south-facing dwelling units ("complexity" and "eaves" of one [×] open side, and the “unit depth frontage ratio” and “eaves” of two open sides at both ends [●]), followed by east-facing dwelling units ("unit depth frontage ratio" of two open sides at both ends [●]), and west-facing dwelling units ("Complexity" of one [×] open side), each with one total. We can see that cooling load in each of these can be controlled from the dwelling unit design side regardless of $m_C$.

When looking by building envelope element, “eaves” and “opening ratio” had the lowest number of dwelling unit types...
that were uncorrelated, thus we can surmise that the impact of “eaves” and “opening ratio” on cooling load is high.

5. Discussion and Future Challenges

As it can be assumed that condominiums will be one type of stock in the near future, we believe that we can address not only reductions in energy consumption, but the dwelling unit design itself by handling large quantities of condominium dwelling unit data, creating a database to reproduce in detail the building elements of the building envelope and external conditions, and deriving a method of improving the thermal environment through dwelling unit design. Continuing from the previous report which had the same objectives and methods, this study has focused on the cooling load and demonstrated sample analyses. We created a database to which we added “cooling load”, design criteria “q” and “mc” associated with each form of insulation, and “eaves”, a building envelope building element.

In Chapter 3, we performed a comparison of cooling load and design indicators associated with each form of insulation by building envelope building element using a differential analysis scatter plot sorted by the number of open sides to clarify the trends and relationships to the cooling load, and the effectiveness of design indicators associated with each form of insulation. As a result, we can see that $m_c$ is the design indicator associated with insulation that is correlated with the cooling load. From this, we confirmed that design indicators
associated with insulation are effective depending on the building envelope element. However, we can see that it may be necessary to further align external conditions using factor analysis based on significance tests.

In Chapter 4, we created a database further aligning the building elements of external conditions to make possible a dwelling unit design that incorporates a thermal environment based on quantitative criteria such as dimensions and ratios, and which does not require carrying out a building energy simulation. From this, we know that there are building envelope building elements that can control cooling load depending on the number of open sides in the dwelling unit and orientation (dwelling unit type). In particular, it is surmised that the building envelope building elements “eaves” and “opening ratio” have high impacts on the cooling load. Additionally, it may be possible to control the cooling load from the dwelling unit design side since we now know that there is a specific type of dwelling unit that can control cooling load regardless of $m_c$.

In this way, we have shown the potential of sample analyses and a database for the various elements in the building envelope. Individual dwelling units are a small target with regard to improving the thermal environment based on the dwelling unit design, but the effect of reducing energy consumption is significant if we consider the high supply of condominiums, and this may become the trigger for changing the dwelling unit design of apartment complexes. Moving forward, we would like to perform a factor analysis to clarify the building envelope building elements that have a major impact on improving the thermal environment. Additionally, we would like to add building elements, such as room layout and solar shading materials etc., and derive the dimensions and ratios required to improve the thermal environment using dwelling unit design.

Acknowledgments

This study was supported by Mitsubishi Estate Residence Co., Ltd and MEC eco LIFE CO., LTD. The authors express special thanks for providing drawings.

Disclosure

The authors have no conflicts of interest to declare.

Notes

Note 1) The 21st United Nations Framework Convention on Climate Change (COP21) was held in Paris in 2015. The Paris treaty was adopted as a new international framework to reduce greenhouse gas emissions from 2020. The Japanese government submitted the “Intended Nationally Determined Contribution” (INDC) based on the Paris Treaty, and drew up a global warming measure plan to achieve medium-term objectives.

Note 2) According to p.137 of the Housing/Architecture WG (June 2012) in a report (Ministry of the Environment) on measures and policies since 2013 (https://funetshare.env.go.jp/roadmap/from2013.html), the fraction of Class 4 residential stock was shown to be 5% in 2010.

Note 3) Number of dwelling units, such as joint housing, in certification plans, such as for low-carbon architecture, at the end of September 2016 (http://www.mlit.go.jp/report/press/house04_hh_000698.html [see 2016.10.31]). Additionally, certified low-carbon architecture is a system certifying the fact that the amount of primary energy consumed has been reduced by 10% when compared to standard values determined in energy-saving methods. Dwelling units with performance of certified low-carbon architecture comprising the 6.01 million condominium stock (2013) are no more than 0.12%.

Note 4) According to 2, smart wellness is said to be an integrated future vision that, going beyond just energy saving, also provides health improvement, support for the elderly, improved resilience, and achieves a low-load, highly efficient lifestyle. Additionally, the Smart Wellness R&D Commission has been established within the Japan Sustainable Building Consortium, and the aim is to spread a postmaterialist culture while presenting a design method, residential industry activities, and policies.

Note 5) According to 3, clima design is said to be an architectural planning and design method that achieves both load reduction and quality improvements. Additionally, clima refers to climate but has a wider meaning beyond just the natural environment, including indoor climate in a historical, cultural, and natural sense, and is a concept not restricted to reducing load.

Note 6) The dwelling unit design includes a flat plan (area, shape, floor, and depth), cross-sectional plan (shape and floors etc.), room layout and equipment plan. Therefore, the flat plan and cross-sectional plan are called the dwelling unit design.

Note 7) “n” is a variable and represents the number of private rooms. LDK represents living room and dining kitchen.

Note 8) According to the Ministry of Land, Infrastructure, Transport and Tourism, residential housing statistics (2016), the number of supplied residential apartments for sale was 114,560, of which 64,769 were in the metropolitan area.

Note 9) Cooling load (MJ/year per residence) is the energy that needs to be removed to maintain the set indoor temperature. Additionally, it is possible to estimate cooling load by taking the sum of the product of indoor/outdoor temperature differential and heat loss amount (W/K) and the product of solar radiation intensity (W/m²) and solar heat gain amount (W/W/m²). In practice, this is related to heat generation items, such as building envelope and loss between rooms, solar radiation gain (building envelope and infiltration section), nocturnal radiation, accumulated heat load, and loss due to ventilation, lighting and equipment for raising cooling load, and human bodies. Cooling load in this study uses simulation software for the calculation and reflects all the items listed above.

Note 10) $q$ (W/K) is the total after calculating building envelope area × thermal transmittance × temperature difference coefficient = thermal loss for each periphery structure, such as exterior wall, roof, and opening section, and totaling the thermal loss amounts.

Note 11) $m_c$ (W/W/m²), during the cooling period, refers to the total solar radiation heat that is absorbed by walls and glass etc., and transmitted between rooms, divided by the total solar radiation heat that enters. This is a value that considers awning and glass characteristics, such as orientation and eaves.

Note 12) Design criteria related to various forms of insulation are indicated by “$q$”, “$m_c$”, and “$U_l$” in this study.

Note 13) Building envelope is the side connected to the thermal boundary. Specifically, this is the peripheral area structure in a dwelling unit, including the exterior wall, roof, floor connected to the outside air (piloti), windows, adjoining dwelling unit, or common areas of a building, solar heat gain and eaves.

Note 14) According to 4, there was a difference of cooler (1 GJ):heater (7.2 GJ) = 1:7.2 for the annual mean value and cooler (0.6 GJ):heater (2 GJ) = 1:3.3 for the mode of energy consumption per household throughout the country (compared to the heater, the cooler consumes one digit). There was a difference of cooler: heater = 1:1.7 for the mean value and cooler: heater = 1:1.9 for the mode of the samples in this study. This difference is also likely because the samples in 2 included cold locations and residences.

Note 15) The metropolitan area is defined by the residential market trend survey of the Housing Administration of the Ministry of Land, Infrastructure, Transport, and Tourism, and the HASEKO RESEARCH INSTITUTE, Inc. “CRI” etc. It includes Tokyo, Kanagawa Prefecture, Saitama Prefecture, and Chiba Prefecture.

Note 16) The revised energy-saving standards refer to the energy-saving standards enacted in 2013. Five regional categories (Saitama City etc.) included in the Metropolitan area were excluded to reduce regional differences in climate conditions.

Note 17) Items related to the building envelope in this study were extracted as “building envelope” building elements, using as a reference the “dwelling unit framework” in Table 1.5 Table 3.6 “Items related to
the flat plan” in Table 5.7 and the “flat plan” in Table 1.4. A conceptualized dwelling unit is shown in Table S1.

Note 18) Net quantity refers to the area of roofs, exterior walls, opening sections, ceilings and floors, the length of thermal bridges, and the depth and height of eaves, wing walls, and handrails. Cooling load and design criteria related to various types of insulation are calculated based on this net quantity.

Note 19) The “Eaves depth/opening height” added as building envelope building elements are the only solar shading materials connected to frames around the opening section in the revised energy-saving standard building envelope that can be evaluated. From this, it is judged that it has a major impact on cooling load and has been added to enrich the database.

Note 20) All the samples in this study had the same performance with regard to the opening section related to the opening ratio. The actual specification is a combination of aluminum joinery and two single-plate glass panes, and the thickness of the hollow layer is 6 mm.

Note 21) The simulation software used was the same as in the previous report, and the general energy simulation tool for architecture “BEST (Building Energy Simulation Tool)” was used. Not only the exterior wall, dwelling unit, window area, and eaves depth, but also the wing wall, balcony handrail, and a simple description of the adjacent buildings can be inputted with this tool. For example, the method of calculating the exterior wall area, in the case of the plane diagram in Figure S1, is (2X + 2Y)× story height, and the exterior wall is input based on the cranked shape. Additionally, with regard to the window as well, the area, glass characteristics, orientation, and rooms they belong to are inputs for all windows. For others, in consideration of the differences in temperatures between rooms, the net quantity is calculated separately for LDK, the various bedrooms, and non-air-conditioning equipment (corridors painted in gray, water-related equipment), with consideration given to the movement of heat between partitioned walls.

Note 22) Building energy simulations conditions were set with reference to 10.

Note 23) Against the background of the reduction in number of residences in [Note 28] in the previous report, the calculation of cooling load, in the same way as for heating load, is interpreted as using Bedroom 3 as a low frequency room, such as a storeroom. In concrete terms, the bedroom in Table 3.3.13 for 10 is Bedroom 3 in this study, children’s room 1 is Bedroom 1 in this study, and children’s room 2 is Bedroom 2 in this study.

Note 24) We referred to Table 3.2.5 in 11. In concrete terms, this is calculated as (thermal transmittance × surface area) × 0.15.

Note 25) Non-conditioned space has the same significance as a “non-residential room,” based on the standards of the revised energy-saving standards. In concrete terms, these are the bathroom, toilet, powder room, corridors, entrances, partitions, and storage such as closets separated by doors.

Note 26) The lighting burden assumes the lighting time other than bedtime for air conditioning operating time in Table 4, and the LDK has a zone floor area × 10 W/m2, and for others (Bedroom and Non-conditioned space), this is set to zone floor area × 5 W/m2. Human body-generated heat uses the air conditioning operating time as the time in the room in Table 4, and for LDK this is set to three people, and for Bedroom to one person, with 1.2 Met/person. Equipment-generated heat and cooking-generated heat for all zones is set to consecutive zone floor area × 5 W/m2, with the time in the room for LDK only calculated as 5 W/m2.

Note 27) A value of 0.6 times/h is used to approach the actual shape by adding the open window ventilation to the reference value of 0.5 times/h.

Note 28) The surveyed subjects in this study are a total of six regions from the regional classifications in the revised energy-saving standards used when calculating the design indicators associated with insulation, but to reflect the actual form of the plan, the selected point when calculating cooling load uses the weather data close to the building site. This specifically refers to Tokyo, Nerima, Fuchu, Funabashi, and Yokohama.

Note 29) A different standard was used for the middle of the central floors excluding the top and bottom floor despite being the same dwelling unit plan because we observed differences in specification, such as story height, opening area, handrail specification (concrete or glass), and slab.

Note 30) The number of north-facing dwelling unit samples is seven, but of these six dwelling units have exactly the same room layout and building envelope building elements, and as the effective number of samples is two, the north-facing dwelling units are excluded from the samples. Next, the dwelling unit area with particularly large dwelling units had an area of 156.99 m2. This was broken down between the west-facing and east-facing dwelling units with two continuous (Δ) open sides, with one of each. These two dwelling units are special floor specifications in a tower apartment, and are not general dwelling unit designs, so due to this special nature, were removed from the samples.

References

1. Nihei S, Satoh S, Hirao S. Basic study on thermal environment of condominium dwelling units: database creation and analysis example of heating load and envelope average U-value. J Architect Plann (Transactions of AJJ). 2015;80:2429–2437. (in Japanese)

2. Murakami S, et al. Creation of new value and associated support for new society as part of residential life: report on investigation progress conducted by Smart Wellness Housing R&D Committee, IEBC No. 206. Institute for Building Environment and Energy Conservation (IBEC). 2015:2–7. (in Japanese)

3. Murakami S, Koizumi M. Climate Design: Shape of New Environmental Culture. Tokyo: Kajima Institute Publishing; 2016:10–16. (in Japanese)

4. Mizutani S, Inoue T, Oguma T. Energy consumption for different uses in housing and energy usage: analysis based on national scale questionnaire. J Environ Eng (Transactions of AJJ). 2006;71:117–124. (in Japanese)

5. Sasaki M, Hanazato T. Analyses of plans of typical dwelling units of newly-built condominiums for multi-family housing in Japan. J Architect Plann Environ Eng (Transactions of AJJ). 2000;65:59–66. (in Japanese)

6. Hanazato T, Sasaki M, Otake T, Hirano Y. Planning characteristics of large-size condominium units supplied in the Tokyo metropolitan area. J Architect Plann (Transactions of AJJ).2003;68:9–15. (in Japanese)

7. Kadowaki F, Fukao S. Relationships among building design parameters of dwelling unit in multi-unit residential building. J Architect Plann (Transactions of AJJ).2005;70:63–69. (in Japanese)

8. Kadowaki F, Fukao S. Comparative analyses of design characteristics of dwelling units between super-high-rise and mid-to high-rise residential building. J Architect Plann (Transactions of AJJ).2006;601:73–80. (in Japanese)

9. Kadowaki F. Structure of influence among building design parameters of dwelling unit in multi-unit residential building. J Architect Plann (Transactions of AJJ).2010;75:1103–1110. (in Japanese)

10. Nishizawa S, et al. Explanation of energy consumption calculation method in criteria of housing business, Institute for Building Environment and Energy Conservation (IBEC). 2009:35–47. (in Japanese)

11. Sawachi T, et al. Method and explanation of calculation and judgment based on act on the rational use of energy in 2013 (II housing), Institute for Building Environment and Energy Conservation (IBEC). 2013:178–242. (in Japanese)

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure S1. Example for dwelling unit

Table S1. Main elements of dwelling unit design in building envelope

How to cite this article: Nihei S, Satoh S, Hirao S, Tasaki A. Basic study on thermal environment of condominium dwelling units, Part 2—Database creation and analysis example of relationship between dwelling units and cooling load. Jpn Archit Rev. 2020;00:1–13. https://doi.org/10.1002/2475-8876.12139