Strategic schematic design process for realization of ultra-low-carbon buildings

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Abstract. The goal of the present research is to support decision-making in the schematic design phase for the realization of ultra-low-carbon buildings by improving the design procedures. Therefore, this research attempts to build an energy model that allows the designer to determine the equipment and specifications based on energy performance at the schematic design stage. Based on the schematic design outline, the present paper investigates whether the numerical targets that represent the energy performance of the building and the evaluation indexes that can be used at the schematic design stage are examined. In addition, recent system trends, decision specifications, and functions are investigated at the schematic design stage for each equipment item, thereby clarifying the decision level.

1 Introduction

More than 60% of the performance and cost of a building are determined at the schematic design stage [1]. However, it is not easy to clearly indicate the energy performance of the building at this stage. With the recent spread of Sustainable Development Goals (SDGs) and Environmental, Social, and Governance (ESG) investment concepts, environmentally friendly activities, which have been emphasized from an ethical point of view, are changing into a society that is also evaluated from an economic point of view [2]. In addition, while maintaining sufficient communication with the building owner, the designer reduces lifecycle CO_2 ($LCCO_2$) and improves energy efficiency while ensuring service performance for occupants by maintaining a high-quality indoor environment. Furthermore, it is also necessary to respond to the social background and needs described above. A performance-oriented design process [3], which is based on the energy performance of buildings, is effective in addressing this issue, and means of confirming energy performance in the early stages of design are essential for its realization.

Previous research [4] has developed a method for evaluating the environmental performance of buildings at the schematic design stage, but this method is not specific to energy performance. In addition, there are several energy consumption performance calculation tools [5,6] for judging compliance with energy conservation standards. Still, there are relatively many tentative and unclear design parameters at the schematic design stage, and it is somewhat difficult to input data into these tools. Furthermore, at the schematic design stage, there are many tasks, such as comparative examination of various systems and coordination with architects and structure designers. Therefore, in order to confirm the energy performance at the schematic design stage, a simple and relatively accurate calculation tool is required, and it is necessary to use parameters based on reliable evidence, such as quantitatively verified data and literature.

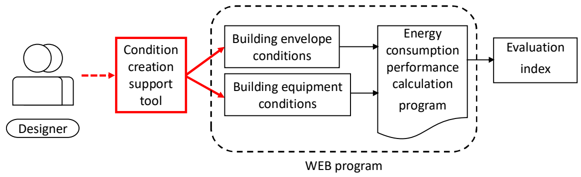

Fig. 1. Outline of condition creation support tool.

Therefore, the present study focuses on the energy consumption performance calculation program (WEB program) among the energy consumption performance calculation tools corresponding to the energy conservation standards, and creates an input condition creation support tool (hereinafter referred to as the support tool) to use with the WEB program. The project uses support tools to establish a comprehensive schematic design process based on energy performance. This schematic design process allows designers to determine equipment and specifications based on energy performance assumptions, improve design quality, and improve design productivity. In addition, building owners can quickly make capital investment decisions for realizing high-performance buildings.

The present paper identifies problems with the general schematic design process and proposes a strategic design process to address these problems. In addition, the existence of numerical targets that represent building energy performance will be investigated for the schematic design outline, and the energy performance evaluation indicators that can be used at the schematic design stage will be studied.

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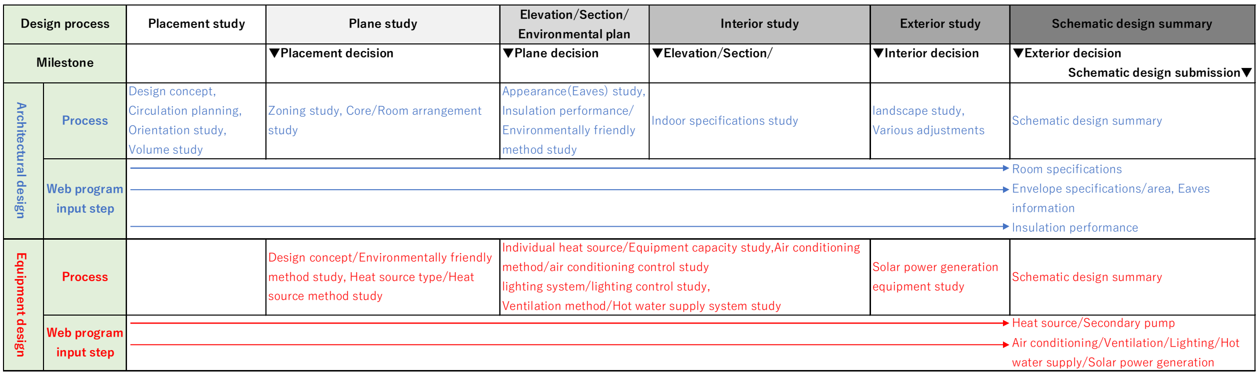

Fig. 2. General schematic design process (example).

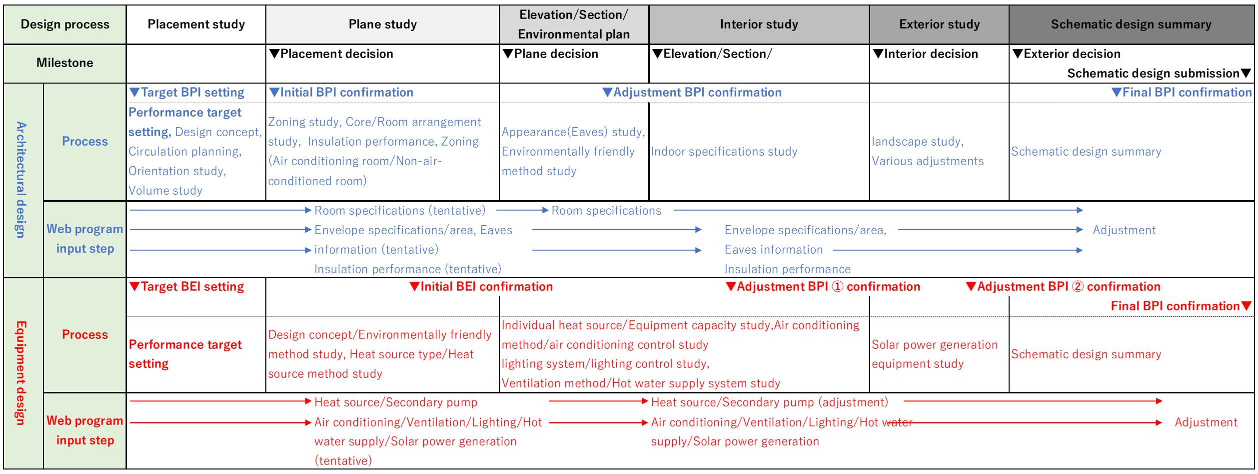

Fig. 3. Strategic schematic design process.

Furthermore, recent system trends will be discussed, and a survey of specifications and functions determined at the schematic design stage for each building facility will clarify the determination level.

2 Outline of condition creation support tool

An outline of the support tool is shown in Figure 1. The "building envelope conditions" and "building equipment conditions" to be input into the WEB program are simplified through a support tool, which also provides highly accurate input support by providing appropriate parameters. In the conventional method, architects and engineers often input their conditions, but with the support tool, designers can share information with each other by sharing the tool, and the degree of impact on energy performance can be checked on a case-by-case basis.

3 Proposing strategic basic design process

3.1 General basic design process

An example of a typical schematic design process is shown in Figure 2. First, the architect arranges the given conditions presented by the owner of the building, and then proceeds with a series of esquisses based on drawings, and examines the layout plans, floor plans, elevation and section plans, environmental plans, interior plans, and exterior plans, in that order. The engineer examines the outline capacity of the heat facilities when the scale, layout, and volume, of the building have been determined and compares various facility methods when the floor plan has been terminated. This is the general schematic design process. The engineer is always involved in studying the building forms while coordinating with the architect and structural designers. The issues here are listed below.

1. Depending on the progress of architectural design, consideration of facility design may be postponed.
2. When changes occur in architectural design, the changes that affect the facility design need to be reviewed, and the workload can be much larger than expected in order to complete the work within the limited design timeframe.
3. In order to realize high-performance buildings, the ideal policy would be to control the thermal load through building planning methods (passive methods) and then maximize the use of passive energy-saving measures and consider the introduction of highly efficient facility systems and unused energy and renewable energy sources.

However, the current schematic design process forces the consideration of facility systems before the consideration of thermal load control.

4. When data are input into the WEB program to check energy performance, all systems and specifications are in the process of being determined. If the target energy performance is not achieved at this stage, it is expected that the systems and specifications will need to be reconsidered.

These four problems can be improved by using an integrated design process [7] in addition to the performance-oriented design process described above.

3.2 Strategic schematic design process

The proposed schematic design process is shown in Figure 3. It begins with establishing building palstar index (BPI) and building energy index (BEI) targets (target BPI and BEI) as a given condition for the building owner, and the building owner and designer share the target values with each other. Designers check BPI/BEI by confirming the results of the WEB program at each design milestone assisted by the support tool, and maintain performance while advancing the design. This improves the problem with regard to issue (4).

After the building layout is determined, the architect confirms the initial BPI by examining the building envelope performance, such as the envelope area and envelope specifications, which are significantly related to the building performance, and further confirms the adjusted BPI reflecting the floor plan after the floor plan is made concrete. Since the BPI values can be quickly confirmed using the support tool, the architect can consider these thermal load control measures ahead of time, and problem with regard to issue (3) can be improved. This can support decision-making concerning the design policy and is expected to reduce design rework.

The engineer obtains the initial BPI and then reviews the heat-source equipment to confirm the initial BEI and ensures the adjusted BEI ① reflecting the various equipment methods after the floor plan has been determined. If any changes affect the thermal load characteristics, information can be shared through the support tools, thereby improving the problem with regard to issue (2).

Then, if there are photovoltaic facilities, their specifications are considered and BEI ② is adjusted. The support tool can ensure the sensitivity of equipment methods to the BEI, thereby assisting building owners in making facility investment decisions through quantitative evaluation of energy performance.

Finally, the BPI/BEI can be calculated at the end of schematic design to determine deviations from the target value and proceed to the design implementation stage. Thus, consistent management of BPI and BEI is expected to improve the problem with regard to issue (1) because it will encourage designers to consider building performance-related issues at an early design stage. Furthermore, decision-making support for building owners can be provided at an early stage.

Table 1. Survey target buildings.

No.	Name	Regional classification	Total floor area [m²]	Scale	Completion
1	bldg.1	6region	40,500	11F, B1F, PH1F	June-12
2	bldg.2	6region	9,100	5F	April-18
3	bldg.3	5region	32,700	7F, B1F, PH1F	June-18
4	bldg.4	6region	10,400	4F	March-18
5	bldg.5	6region	10,400	3F, PH1F	May-19
6	bldg.6	7region	4,000	2F	May-19
7	bldg.7	6region	20,900	6F	May-19
8	bldg.8	3region	8,000	4F	June-19
9	bldg.9	5region	4,100	3F	July-20
10	bldg.10	6region	30,000	7F, B1F, PH1F	July-20
11	bldg.11	1region	4,200	3F	January-21
12	bldg.12	2region	3,800	3F	February-21
13	bldg.13	2region	4,500	3F, B1F	February-21
14	bldg.14	6region	10,400	4F	March-21
15	bldg.15	4region	10,500	4F, B1F, PH1F	May-21
16	bldg.16	6region	10,200	5F	August-21
17	bldg.17	5region	5,000	4F	September-21
18	bldg.18	6region	8,900	5F	March-22
19	bldg.19	1region	8,800	4F	May-22
20	bldg.20	2region	5,800	4F, B1F	October-22
21	bldg.21	6region	6,900	4F	2022
22	bldg.22	6region	11,500	7F, PH1F	January-23
23	bldg.23	2region	6,400	4F	May-23
24	bldg.24	5region	11,700	5F, B1F	June-23
25	bldg.25	2region	10,700	4F, B1F	November-23
26	bldg.26	2region	2,700	2F	May-24
27	bldg.27	7region	6,700	5F	October-24
28	bldg.28	6region	21,100	6F, B1F	March-25
29	bldg.29	6region	21,800	5F, B1F	July-25
30	bldg.30	2region	6,600	4F, PH1F	2025
31	bldg.31	4region	13,700	7F	2025
32	bldg.32	6region	56,300	17F, B2F	2026
33	bldg.33	2region	7,000	4F, B1F, PH1F	2026
34	bldg.34	5region	62,000	15F, B1F	2030
35	bldg.35	6region	17,900	5F	2027

4 Subject of survey

In order to examine the conditions and parameters required by the WEB program that can be input even in the schematic design stage, a survey was conducted in order to determine these practical conditions and parameters. The buildings surveyed are shown in Table 1. Based on the schematic design outline released on municipality websites, a survey was conducted on energy-saving methods, equipment specifications, and functions to be determined at the schematic design stage, as well as the target building energy performance. The investigated buildings were 35 government buildings (offices) that were recently completed or scheduled to be completed. The schematic design outline consists of basic policy, plan outline (such as architecture, structure, facilities, exterior), construction process, cost estimate, etc., and summarizes the business continuity plan (BCP), and environmental consideration plan, as necessary. The energy-saving measures and equipment specifications were only those described in the schematic design outline. Even if such measures and specifications were adopted, those not described in the schematic design outline were excluded from this survey.

A regional classification of buildings and their sizes are shown in Figure 4. The most common category was region 6 (43%). This was followed by region 2 (23%) and region 5 (14%). Approximately 70% of the buildings had sizes between 5,000 and 30,000 m^2.

5 Setting Energy Performance Targets

Among the investigated buildings, 18 buildings had specific numerical targets for energy performance. A list of buildings that had set target values is shown in Table 2. There were 11 buildings with CASBEE rank targets and 12 buildings with zero-energy building (ZEB) rank (including primary energy reduction) targets. Japan aims to achieve an average of ZEB for new buildings by 2030 [8] and in the building stock by 2050 [9]. According to the roadmap for the realization and spread of ZEB [10], initiatives are to be implemented in new public buildings on a priority basis. Therefore, it is believed that setting specific numerical values for ZEB rank and primary energy reductions when planning the construction of government buildings is becoming more widespread. In order to set quantitative target values at the schematic design stage, it is necessary to confirm the energy performance with relatively high accuracy. This encourages the use of the WEB program.

In addition, among the buildings for which target values were set, five buildings had targets listed in the basic policy of the schematic design outline. The basic policy is a statement of the basic approach to realize the construction of a building and reflects the philosophy of the building owner. The designer must report to the building owner the extent to which goals are being met at each stage of the design process. If the WEB program can be used consistently throughout the design process, this would be expected to improve the quality of design and the work efficiency of designers.

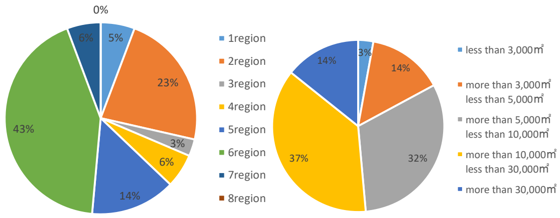

Fig. 4. Regional classification of buildings their sizes

Table 2. List of target buildings for which target values have been set.

No.	Target setting	Description in the basic policy
2	CO_2 : 60t/y reduction Air conditioning : Annual power consumption 42.2% reduction (CO_2 42.2% reduction) Lighting : Annual power consumption 5.9% reduction (CO_2 5.9% reduction) CASBEE AICHI : S rank	-
3	CASBEE : S rank	○
7	Primary energy consumption : 37% reduction CO_2 : 19% reduction	-
10	CASBEE : A rank LCC : 16% reduction LCCO$_2$: 27% reduction Utility costs : 21% reduction	-
12	ZEB Ready (Primary energy consumption 600MJ/㎡・year)	-
13	ZEB Ready (Primary energy consumption 57% reduction) BPI : 0.65 BEI : 0.43	○
16	ZEB Ready (Primary energy consumption 50% reduction)	-
20	Primary energy consumption : 35 ~ 40% reduction	-
22	CASBEE : A rank	-
23	ZEB Ready	-
26	CASBEE : A rank	-
29	CASBEE-NC : S rank CASBEE-WO : S rank ZEB Ready	○
30	CASBEE : S rank ZEB Ready (Primary energy consumption 50% reduction)	○
31	BEI : 0.6 CASBEE : over 1.5 (A rank)	-
32	ZEB Ready	-
33	CASBEE : A rank ZEB Ready	○
34	CASBEE : S rank ZEB Ready (Aiming for Nearly ZEB in the future)	-
35	CASBEE : S rank	-

6 Survey of trends in energy-saving technologies

6.1 Passive energy-saving methods

In order to realize high-performance buildings, it is first necessary to control the thermal load of the building. Moreover, passive design measures that actively use and successfully control natural energy, such as daylight utilization and natural ventilation, are required. The passive energy-saving methods adopted are shown in Figure 5. Daylight utilization and natural ventilation are used in approximately 90% of the investigated buildings, and although the methods of introducing such lighting and ventilation vary, it is believed that some measures are compulsory in public buildings. However, since this method is affected by weather and seasonal conditions, it is difficult to expect it to be effective in reducing thermal load in a stable manner. This is followed by a high rate of adoption of high-efficiency thermal insulation, greening, and sun shading of the envelopes (outer walls, window glass, etc.) because such measures are expected to reduce heat load and improve the thermal environment.

6.2 Active energy-saving and renewable energy sources

As a design process following the previous section, introduction of high-efficiency equipment systems to minimize energy consumption, followed by the introduction of renewable energy sources, will be considered. The active energy-saving and renewable energy sources adopted are shown in Figure 6. Regarding air-conditioning equipment, the adoption rate for variable fresh-air volume control by CO_2 concentration and high-efficiency equipment is approximately 40%, followed by the adoption rate for outdoor air cooling, at approximately 30%. Variable fresh-air volume control by CO_2 concentration is considered to be a method that will be increasingly adopted in the future due to the importance of ventilation and lower occupancy rates in recent years. In addition, the adoption rate for solar panels is approximately 60%, making solar panels the most widespread renewable energy source.

7 Survey of trends in equipment systems and controls

In this section, trends in the adoption of systems and controls for heat-source equipment, air-conditioning equipment, and lighting equipment, which account for more than half of the energy consumption of a typical office, are discussed [11].

7.1 Heat-source equipment

The ratio of fuel types is shown in Figure 7 and the ratio of heat-source system is shown in Figure 8. The ratio of building size according to heat-source system are shown

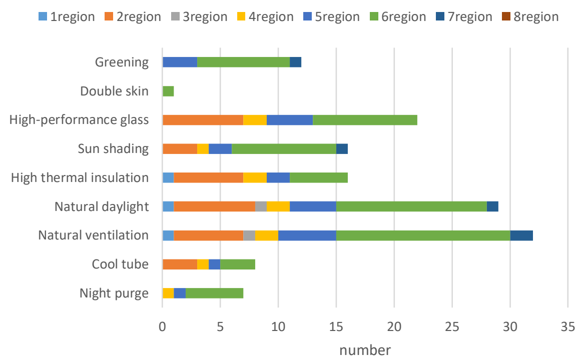

Fig. 5. Passive energy-saving methods adopted.

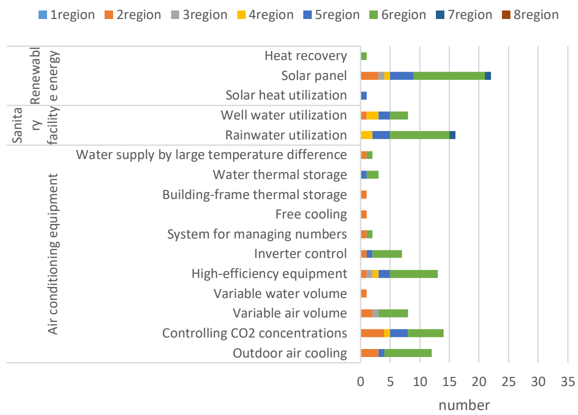

Fig. 6. Active energy-saving and energy-creating methods adopted.

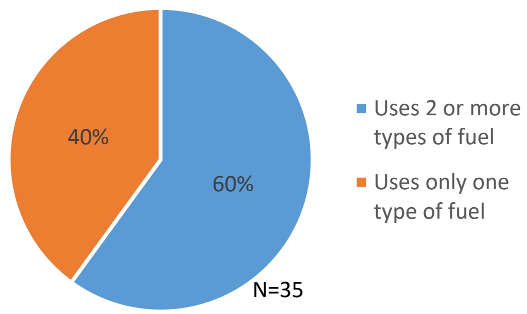

Fig. 7. Fuel types adopted.

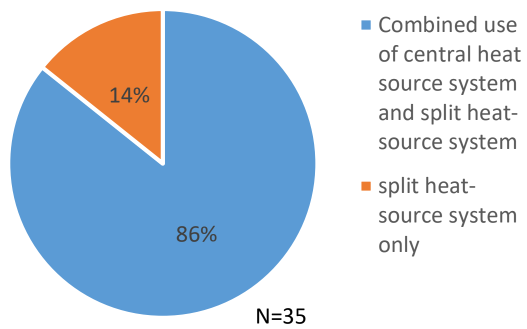

Fig. 8. Heat-source systems adopted.

in Figure 9 and 10. Figure 7 and 8 show that approximately 90% of the buildings use both central heat-source systems and split heat-source systems, and that more than half of the buildings use more than one type of fuel. Figure 9 and 10 show that, except for buildings with sizes of less than 3,000 m^2, only the split heat-source systems is used evenly. Therefore, split heat-source systems are adopted regardless of building size.

The heat-source equipment adopted is shown in Figure 11. Following the gas absorption chiller and air-cooled heat pump chiller, the number of ground-source heat pump chillers adopted is the second largest, indicating a high awareness of the use of renewable energy. As heat-source equipment becomes more sophisticated and complex, it is necessary to consider the optimal scale and rationale for the use of renewable energy sources and their implementation. For this purpose, simple input to the WEB program in the initial design stage would be effective.

7.2 Air-conditioning equipment

The major classifications of air-conditioning systems adopted in offices are shown in Figure 12, and the subcategories are shown in Figure 13. Figure 12 shows that all-air systems accounted for approximately 40%, combined air and water/refrigerant systems accounted for approximately 50%, and radiant air-conditioning systems accounted for approximately 20%. Although convection air-conditioning systems, such as all-air or air and water/refrigerant systems, dominate, the adoption of radiation air-conditioning systems is also notable. Figure 13 shows that, in addition to conventional air-conditioning systems, such as single-duct systems and dedicated outdoor air-handling units and indoor-unit systems, underfloor air-conditioning systems, radiant air-conditioning systems, and task ambient air-conditioning systems have been adopted, indicating that air-conditioning systems are diversifying. The air-conditioning system is determined not only by evaluation based on energy but also based on indoor thermal comfort and intellectual productivity. Therefore, there is a demand for proposals for various air-conditioning systems to suit the air-conditioned space.

7.3 Lighting equipment

The lighting control methods adopted are shown in Figure 14. Brightness detection control and room presence detection control are adopted in nearly 90% of the investigated buildings. In addition, time schedule control and initial illuminance correction can be evaluated by, e.g., multiplying the conventional energy-savings effect rate by the rate determined by the actual measurement survey. In adopting these control methods, it is necessary to consider the scope of their introduction.

In addition, a small amount of task ambient lighting can be seen. Working from home has become more common in recent years, and its adoption may increase as the number of people working in person in the office decreases.

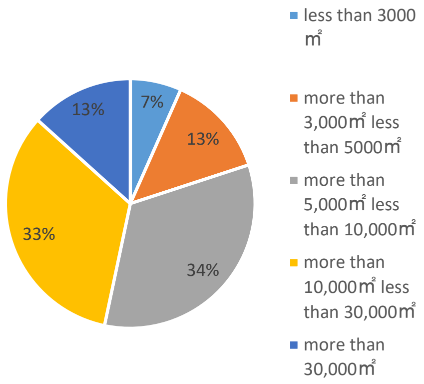

Fig. 9. Ratio of scale by heat-source systems adopted. (Combined use of central heat source system and split heat-source system).

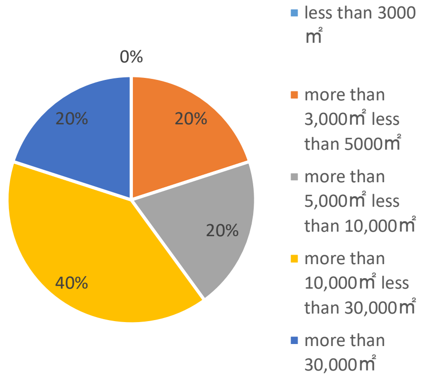

Fig. 10. Ratio of scale by heat-source systems adopted. (Split heat-source system only).

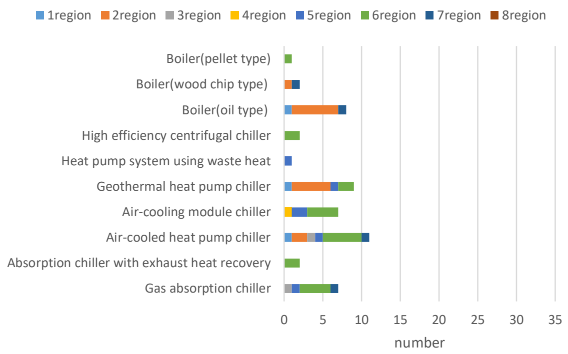

Fig. 11. Heat-source equipment adopted.

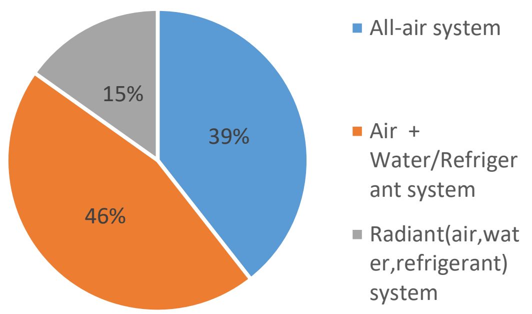

Fig. 12. Major classifications of air-conditioning systems adopted in offices.

8 Trend survey for energy-saving technologies

For each of the 14 facilities, the decisions listed in the schematic design outline were extracted. The results are shown in Table 3.

Regarding heat-source equipment, the energy type and equipment method was clearly specified for most buildings. This is thought to have been determined in terms of energy savings, reliability, and whether BCP support is available. Regarding air-conditioning equipment, there was a description of the air-conditioning system for each subject room. Some of the proposals were clearly described in terms of energy-saving measures. This is thought to have been determined based on, e.g., thermal comfort, indoor temperature and humidity conditions, and duration of use. Regarding ventilation equipment, there was a description of the ventilation system for each use of a subject room. Although the number of air changes was not specified, it is considered to be based on the number of air changes in accordance with the design standards. Regarding hot-water supply equipment, there was a description that is thought to have been determined based on the use and usability of the building. All of the buildings in the present study adopted local hot-water heating using electric heaters. Regarding lighting equipment, fixture types and control methods were described, and light-emitting diodes (LEDs) were used in all of the buildings. These are thought to have been determined with an emphasis on comfort and energy efficiency.

9 Summary and Future Issues

The present paper identified problems with the general schematic design process and proposed a strategic method to address these problems. The existence of numerical targets representing building energy performance at the schematic design stage was investigated for the proposed design outline, and energy-performance evaluation indices that can be used at the schematic design stage were examined. In addition, recent system trends were considered, and the factors determining the specifications and functions at the schematic design stage were clarified by investigating the outline of each system.

In the future, input items for the support tool will be organized, and a draft of the support tool will be prepared. In addition, the accuracy of the input to the support tool will be validated for a model building, and a proposal will be made on how to use the tool in the basic design process while conducting a trial at a practical site.

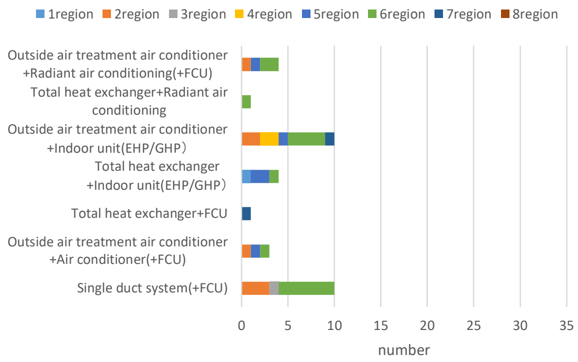

Fig. 13. Subcategories of air-conditioning systems adopted in offices.

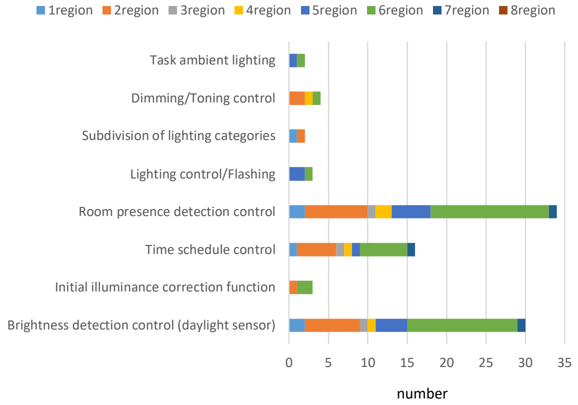

Fig. 14. Lighting control methods adopted.

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Table 3. Significant decisions and determinants during schematic design stage.

Element	Major decisions during the schematic design stage	Major determinants							
		Energy use efficiency		Other than energy use efficiency					
		Energy saving	Resource saving	Reliability	BCP	Economy	Maintainability	Standard/Law	Others
Heat source equipment	energy type, heat source method (central or individual), target area, heat source capacity (central heat source)	○	-	○	○	○	○	-	controllability, etc.
Air-conditioning systems	air conditioning system by application	○	-	-	-	○	○	-	comfortableness, indoor temperature and humidity, Usage time/conditions, operability, etc.
Ventilation equipment	ventilation system by application	○	-	-	-	○	-	○	air conditioning system, etc.
Smoke exhaust equipment	smoke exhaust system	-	-	-	-	-	-	○	
Automatic control equipment	presence/absence of centralized monitoring/BEMS	-	-	-	-	○	○	-	scale etc.
Water supply equipment	water source, water supply system, water supply method, BCP support (presence/absence of water storage, number of days)	-	○	-	○	○	○	-	building size, Site conditions, amount used, etc.
Hot water supply equipment	heat source type/hot water supply system	○	-	-	-	○	○	-	ease of use, application, amount used, etc.
Sanitary equipment	equipment type, cleaning method, presence/absence of water-saving equipment	-	○	-	-	○	○	-	how it is used, etc.
Drainage ventilation equipment	drainage system, drainage method, BCP support (presence/absence of water storage, number of days)	-	-	-	○	○	○	○	site conditions, etc.
City gas equipment	city gas supply status and types	-	-	○	○	○	○	-	site conditions, etc.
Fire extinguishing equipment	Firefighting equipment to be installed	-	-	-	-	-	-	○	
Lighting equipment	type of lighting equipment, control method	○	-	-	-	○	-	○	comfortableness, etc.
Outlet equipment	socket capacity, presence/absence of electric vehicle chargers	-	-	○	-	○	-	○	
Energy use efficient equipment (Solar power generation equipment)	presence/absence of solar power generation facilities, capacity, type, location	○	-	-	○	○	-	-	environmental appeal

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