A simulation approach for the optimization of distributed energy supply systems based on multiple energy indicators in commercial districts.

Takahiro Ueno
1Building Research Institute, Tsukuba, Japan

Abstract
Urban energy supply systems are changing to distributed energy supply systems (DESS) due to the spread of renewable energy. This paper discusses a simulation study for the optimal layout of DESS in commercial districts based on three annual energy indicators: the primary energy consumption (PEC), the life cycle CO₂ emissions (LCE), and the standard deviation of power supply and demand (SDP). We evaluated the DESS performance in four commercial districts with different characteristics of located buildings, and confirmed that the DESS with settings specific to each energy index reduced PEC by more than 25% and SDP by more than 90%. On the other hand, some simulation results increased LCE by several percent to several tens of percent. The examination for breakdowns of the CO₂ emissions DESS clarified that gas from CHP accounted for more than half of the CO₂ emissions in DESS. Further investigations also indicated that CHP in fine weather during the cooling season could not reduce LCE unless the power generation and exhaust heat matched exactly the power and heat demands of the target buildings.

Key Innovations
- Calculate energy demands and supplies at five-minute intervals
- Use many static equipment models such as absorption chiller, air heat-source heat pump, combined heat and power, storage battery, water heat storage tank
- Change the value of energy demand in each building according to the type of buildings (office, hospital, hotel, store, restaurant and school), total floor area, outdoor air temperature and so on
- Evaluate distributed energy supply systems performance based on three energy indicators

Practical Implications
This white paper confirms the influence of the differences in the optimal target index and the target area’s characteristics on the suitable equipment configuration to be introduced and to gain knowledge on the DESS system’s utilization in commercial districts.

Introduction
Urban energy supply systems are changing to DESS due to the spread of renewable energy. In order to effectively arrange and operate DESS in the city, it is necessary to (1) estimate energy demand for use in each building, (2) consider operation technology such as interchange or storage, and (3) study on a city scale rather than a building scale. Therefore, we aim to construct a method to optimize DESS based on GIS data.

Over the past few years, many researchers have shown an interest in DESS optimization on an urban scale. Hering et al. (2021) showed a design optimization model of a district heating network by mixed integer quadratically constrained program. They presented the case study to the optimization of the integration of low temperature waste heat and indicated the influence of design decisions on the optimal operation. Ferrando et al. (2020) provided a practical overview of the main bottom-up physics-based urban building energy modelling tools. The proposed overview highlighted major differences between UBEM tools that must be considered to choose the proper one for an application. Wetter et al. (2019) developed and demonstrated a BIM/GIS and Modelica framework for building and community energy system design and operation. These activities include a framework for testing district energy system simulations. Nageler et al. (2019) provided a simulation framework for large-scale simulations of district energy systems. They applied this method on the effect estimation of a malfunction at the heat generation plant and found that the reaction rate of the temperature progression was different between the heating network and inside well-insulated buildings. Laitinen et al. (2019) developed an energy-matching assessment tool to demonstrate carbon free energy concepts based on renewable energy sources on a district level. They demonstrated the utilization of the matching tool with a case study on a large district with total building floor area of about 1.6 million m². Dermontzis et al. (2019) presented a simulation approach for a new building district to minimize primary energy consumption of DESS. This approach evaluated a new building district in Innsbruck by means of building and HVAC simulation with respect to final and primary energy for various distribution and heating supply system combinations, installed either in each flat (decentral), building, block (semi-central) or district (central) level. Blacha et al. (2019) developed an integral dynamic simulation model of bidirectional low-temperature networks by heating and cooling using decentralized heat pumps and chillers in an existing district to investigate their complex hydraulic behavior and various system configurations. This
simulation model revealed that the energy efficiency of bidirectional low-temperature networks strongly depends on the composition of the energy demands and the temperatures required by end users.

Most of these studies have measurement and estimated time intervals spanning one hour to one year. However, because the demand for non-residential buildings and the composition of power supplied by the grid fluctuate from moment to moment, a detailed analysis of the effects of introducing DESS need to be conducted using data at finer time intervals and making a comparison with the case where demand is met by the building unit. This includes the analysis of the effect of leveling energy demand fluctuations by consolidating energy demand and stabilizing the operation of the DESS to demand. It is also necessary to consider the energy-saving potential of introducing the DESS that uses both large-capacity power heat source facility and CHP because there is insufficient knowledge on the detailed introduction effect, including the geographical condition of actual buildings, the optimal settings, and the influence of the difference in the characteristics of commercial areas on the introduction effects.

Therefore, this study reproduces in detail the operational stabilization of supply infrastructure via demand consolidation on the basis of the energy demand at 5-minute intervals in all non-residential buildings in commercial and business areas in each region with varying characteristics. Furthermore, the energy-saving effect of introducing a DESS system that uses CHP, power heat source systems, and energy storage systems is shown by comparing a case in which demand is met for each building on the basis of multiple energy indicators while considering the transfer power and heat loss from supplying heat. Moreover, the case study allows us to clarify the suitable equipment configuration and operational settings of the DESS, with each energy index having the highest evaluation and its energy-saving effect estimated; in this manner, it is possible to confirm the influence of the differences in the optimal target index and the target area’s characteristics on the suitable equipment configuration to be introduced and to gain knowledge on the DESS system’s utilization in commercial districts.

**DESS model**

Figure 1 shows the energy supply flow of the DESS model, utilising Visual Basic.NET within Visual Studio 2019 (Microsoft, 2019). The model is divided into CHP and power heat source models, and the researcher can select which one will be operated first. In addition, the model also incorporates a submodel that reproduces the heat transfer from the DESS to consumer buildings (hereinafter, the district heat transfer model). This system only supplies the power generated by means of CHP to the specified target area and meets the total air-conditioning and heat demand therein.

**CHP model**

We used a model comprised an arbitrary number of CHP, two RHAs, and one HEX and reproduces the operation of the CHP at five-minute intervals. Figure 2 shows the performance curve of the CHP. The CHP operates

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**Diagram**: Figure 1: Energy flow of DESS.
according to the demand five minutes prior, and it is operated when the target demand exceeds 50% of the rated capacity per unit (rated power generation amount for the power follow-up and rated exhaust heat amount for the heat follow-up) and increases the number of vehicles in operation by one every time the demand exceeds 50% of the rated capacity. The exhaust heat from the CHP process is used for warm water, which is supplied via RHA and HEX in the order of cooling followed by heating. The efficiencies of the RHA and HEX were set to constant values (Table 1). For the RHA, the ratio of exhaust heat available for the rated capacity was also set (Fig. 3). In addition, the power consumption of CHP auxiliary infrastructure, such as the cooling towers, was set to 5% of the total power generation.

**Power heat source model**

We built a model that reproduces the operation of power heat source equipment at five-minute intervals. Moreover, the set values of the web program were used to determine the equipment characteristics, such as the outside air temperature and chilled water characteristics. The equipment configuration was set using two TRs, one ITR, and two EHPs. During cooling, the TR, ITR, and EHP were operated in that order and, during heating, only the EHP was operated. The performance curve of each of these is shown in Figure 4. The water supply temperatures were (cold: 5°C, hot: 50°C). The power consumption of the chiller auxiliary infrastructure, such as the cooling tower, was set to 5% of the chiller’s total power consumption. Additionally, with respect to the power consumption of the power heat source equipment, it could use CHP generation power if it was set to operate prior to the CHP model.

**Energy storage model**

We used a storage battery model and one TST model. The TST model was a thermal stratification type (thermal efficiency [-]: 0.95). For simplification, the water temperature was kept constant (cold: average 8°C, hot: average 62°C). Furthermore, since the cooling and heating periods for the non-residential buildings are fixed in this study (April-November for cooling and December-March for heating), the cooling and hot water of the TST was also switched during the same period.

The storage battery consisted of a storage battery and a power conditioner. Figure 5 shows the charging and discharging efficiency curve. Table 2 indicates other specifications. The C rate in the table refers to the ratio of the rated charge/discharge power to the capacity, and 1/3 C means that it takes three hours to fully charge or discharge the storage battery by rated charge/discharge.

**District heat transfer model**

We used a model constructed in a previous study to supply heat from the building containing the heat source to the customer’s building via a heat exchanger (exchange efficiency [-]: 1.0) and heat supply piping for both cold and hot water. As it is rare for pipes to be installed directly between buildings, the one-way length was set as the total distance based on the longitude and latitude differences between the DESS and the customer’s building. The heat transfer power was calculated as the power consumption in 1 m of the heat supply pipe. The heat loss from the heat supply pipe was set to the same value in 1 m of piping (cold water: -0.004[MJ/m], hot water: 0.015[MJ/m]) for any pipe diameter.

**Energy index**

When evaluating the energy-saving effect of the energy supply infrastructure, it is necessary to set the evaluation range and period. Furthermore, there are multiple evaluation indexes for energy-saving effects, such as those pertaining to primary energy consumption and CO₂ emissions. Therefore, we evaluated the energy-saving effect of the DESS from multiple perspectives, using three energy indexes.
Primary energy consumption

Given the global trend toward energy efficiency and decarbonization, decarbonizing the power grid has become an important issue in Japan. Therefore, to reduce the amount of thermal power generated and promote the general decarbonization of the grid, we devised an index to minimize annual primary energy consumption for thermal power generation. In this index, power consumption over five-minute intervals in the target area is multiplied by the primary energy conversion coefficient of grid power for each time period. The concomitant amount of gas consumed is added to this as a percentage of primary energy consumption and the annual total value evaluated for the region (Eq. (1)).

\[ E_{PEC} = \sum_{m=1}^{365} \sum_{t=12}^{24} \left( E_{p,m} \times f_{PEC,p,m} \right) + \sum_{m=1}^{365} \sum_{t=12}^{24} \left( E_{g,m} \times f_{PEC,g} \right) \]  

(1)

As the power generation efficiency of thermal power generation differs depending on the fuel used, the primary energy consumption would be effectively reduced if we could operate the DESS while generating power using the least efficient fuel for thermal power generation. To incorporate this into the evaluation, we estimated a time-based primary energy conversion coefficient \( f_{PEC,p,m} \) in Eq. (1) for grid power from the following data:

- hourly thermal power data of the target power system available from the website of the power supply company (Kyushu Electric Power Transmission and Distribution, 2018).
- five-minute thermal power data from hourly data by using a simple moving average method
- capacity and generation priority of thermal power generation such as coal, liquefied natural gas (conventional), liquefied natural gas (combined), and oil.
- primary energy conversion coefficient in each type of thermal power generation

On the other hand, the primary energy conversion coefficient by gas \( f_{PEC,g} \) in Eq. (1) was fixed throughout the year.

Figure 6 shows the transition of the time-based primary energy conversion coefficient of the representative week. It was almost constant at around 9 MJ/kWh throughout the year. The lowest annual value was 8.471 MJ/kWh (power generation efficiency: 42.5%) at 02:30 on May 9. The highest value was 9.601 MJ/kWh (power generation efficiency: 37.5%) at 14:30 on May 13, but high values were recorded on other dates and times as well, totaling 68 hours (0.78%) out of 8,760 hours in a year. At 02:30 on May 9, the power transmission and distribution loss was small because it was during night, while the ratio of power generation of the most efficient combined-type LNG among thermal power generation sources was large. On the contrary, at 14:30 on May 13, only coal-fired power generation (wherein the power generation cost is low) was operated at the rated operating power supply voltage because it could not be flexibly operated; only the highest voltage values were recorded at the dates and times in the daytime when the coal-fired power plants were in operation.

Lifecycle CO₂ emissions

Given that the Japanese government has mandated that each city formulate a reduction plan for the greenhouse gases emitted by its activities, it seems conceivable that the general decarbonization of all commercial and business areas will be required in the future. When promoting the decarbonization of only a given target area, it is effective to actively make use of the power generated by renewable power sources introduced outside the target area via the grid. Furthermore, when assessing the energy-saving effects of DESS, it is important to consider energy consumption during operation as well as throughout the lifecycle, including its manufacturing and dismantling. Therefore, to pursue decarbonization only within a given target area, we devised an index that minimizes the annual value of lifecycle CO₂ (LCCO₂) emissions. In this index, we evaluate the total value for one year by multiplying the power and gas consumption at five-minute intervals in the target area by the LCCO₂ emission coefficient for each of these, as well as the value for one year of LCCO₂ emissions due to the introduction of the DESS (Eq. (2)).

\[ E_{LCE} = \sum_{m=1}^{365} \sum_{t=12}^{24} \left( E_{p,m} \times f_{LCE,p,m} \right) + \sum_{m=1}^{365} \sum_{t=12}^{24} \left( E_{g,m} \times f_{LCE,g} \right) \]  

(2)

Figure 6 shows the boundary conditions for the index’s creation. Considering the collectability of the data and its impact on the results, the evaluation range of this index is limited to processes with a large environmental impact.

First, in almost the same way as the estimation method of time-based primary energy conversion coefficient, the LCCO₂ emission factor for five-minute interval of grid power on the demand side \( f_{LCE,p,m} \) in Eq. (2)) were estimated from the power data and CO₂ emission coefficient data of each power source, such as coal-fired, wind, and solar power generation methods. Throughout the year, the LCCO₂ emission factor due to the gas consumption \( f_{LCE,g} \) in Eq. (2)) was assumed to be 0.062 kg-CO₂/MJ (Tamura, 1999).

Figure 7 shows the transition of the LCCO₂ emission factors with respect to time of the representative week.
Unlike the transition of the primary energy conversion coefficient by time (Figure 6), it fluctuates substantially. This is because the LCCO2 emission factor relates to thermal power generation as well as all power sources and is therefore affected more strongly by solar and wind power generation, with its output power fluctuating from moment to moment depending on the weather conditions. The lowest annual value was 0.272 kg-CO2/kWh at 13:25 on May 14, while the highest was 0.670 kg-CO2/kWh at 22:30 on January 25, which was more than double the lowest value. At 13:25 on May 14, the LCCO2 emission factor decreased because the power generation ratio of the thermal power generation was 23%, while the total power generation ratio of renewable energy power sources such as solar power was approximately 60%. On the contrary, at 22:30 on January 25, the ratio of the thermal power generation was 90% within the year because there was no supply from solar power generation as it was nighttime, on the basis of which the thermal power generation became as large as 90% in the winter (the highest date and time of the year). As a result, the LCCO2 emission factor increased.

Then, we created the annual value per capacity of LCCO2 emissions from non-operational activities such as manufacturing, maintenance, and dismantlement of major facilities in the DESS. Additionally, for the secondary side of consumer buildings, assuming that CO2 emissions from operations other than those of air handling units (AHUs) and fan coil units (FCUs) are calculated as the main equipment, we also calculated the LCCO2 annual emission intensity. Table 3 shows some of these annual costs. In addition to this, the annual cost of DHC heat supply piping was calculated based on the thickness and length of the piping.

**Standard deviation of the power supply and demand**

An increase in the ratio of unstable power, including from solar and wind sources, for grid application could create an imbalance between supply and demand in the near future. Therefore, we formulated an index to reduce the annual standard deviation of the power supply and demand between the target area and grid power, with the aim of contributing to grid power stability. This index aggregates the power demand in the entire target area at five-minute intervals and evaluates their annual standard deviation (Eq. (3)).

\[
S = \sqrt{\frac{1}{365 \times 24 \times 12} \sum_{t=1}^{365 \times 24 \times 12} (E_{p,m} - E_{p,ave})^2}
\]

**Case study**

The target area was set as Fukuoka City in Japan, which is located in Japan’s Kyushu region. This region became difficult to increase renewable energy due to the output suppression of solar power plant, and there was an even greater demand for supply and demand adjustment by promoting power saving and generation in urban areas. Therefore, we estimated the energy-saving effect of introducing the DESS into the commercial district of Fukuoka City, which features the largest population in the Kyushu region and the fifth largest population in Japan.

**Setting of the target area**

As the high heat demand density per hectare is listed as one of the conditions for establishing a district heating and cooling business, it is assumed that the heat demand density has a significant influence on the effect of introducing the DESS. Therefore, targeting all 1,154 subregions of Fukuoka City, based on the city’s ranking of the floor area ratio of non-residential buildings as a measure related to heat demand density, we selected four subregional groups designated as commercial areas, resulting in an area of ~350,000 m2. These were designated areas A to D for the calculations conducted herein (Table 4). Table 5 displays a summary of the characteristics of each region, and Figure 8 shows the ratio of floor areas by building use. Area A has the highest floor area among the four areas, and the percentage of total floor area of office and commercial facilities is large. As Area B lies in front of the station, the percentage of accommodation is larger than in other areas. Given that there are many low-rise buildings in Area C, the floor area ratio is not high given the large number of buildings. As the floor area ratio of Area D is smaller than that of the other areas, it is assumed that the effect of consolidating the energy demand will be small.

### Table 3: Annual LCCO2 emission factor of main DESS.

<table>
<thead>
<tr>
<th>Unit [☆]</th>
<th>Variable</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>kW</td>
<td>70.634</td>
<td>-</td>
</tr>
<tr>
<td>MJ/h</td>
<td>1.717</td>
<td>1436.8</td>
</tr>
<tr>
<td>kW</td>
<td>0.134</td>
<td>43.8</td>
</tr>
<tr>
<td>MJ/h</td>
<td>1.057</td>
<td>2166.6</td>
</tr>
<tr>
<td>MJ/h</td>
<td>1.057</td>
<td>2166.6</td>
</tr>
<tr>
<td>MJ/h</td>
<td>2.715</td>
<td>181.7</td>
</tr>
<tr>
<td>MJ/h</td>
<td>3.030</td>
<td>53.7</td>
</tr>
<tr>
<td>kWh</td>
<td>98.412</td>
<td>-</td>
</tr>
<tr>
<td>MJ</td>
<td>0.260</td>
<td>279.2</td>
</tr>
<tr>
<td>MJ/h</td>
<td>2.241</td>
<td>183.5</td>
</tr>
</tbody>
</table>

### Table 4: Area ratio and rank of small areas in target districts.

<table>
<thead>
<tr>
<th>Area</th>
<th>Small area</th>
<th>Floor area ratio (%)</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>1 : 2</td>
<td>171 : 239 : 31 : 49</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>1 : 2</td>
<td>20 : 204 : 114 : 122</td>
<td>5</td>
</tr>
</tbody>
</table>

### Table 5: Characteristics of target districts.

<table>
<thead>
<tr>
<th>Area</th>
<th>Number of business building [-]</th>
<th>Total gross floor area [㎡]</th>
<th>Floor area ratio [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>303151</td>
<td>671154</td>
<td>423</td>
</tr>
<tr>
<td>B</td>
<td>305166</td>
<td>252</td>
<td>877941</td>
</tr>
<tr>
<td>C</td>
<td>311525</td>
<td>440</td>
<td>641048</td>
</tr>
<tr>
<td>D</td>
<td>299570</td>
<td>121</td>
<td>132606</td>
</tr>
</tbody>
</table>

![Figure 8: Gross floor area ratio of business building.](https://doi.org/10.26868/25222708.2021.30249)
Energy demand of non-residential buildings

Using the demand estimation method developed in our previous report, we calculated five-minute interval power demand and five-minute interval heat demand for heating and cooling of non-residential buildings in each area. Table 6 lists the peak energy demand density and annual energy demand density per hour for each region. Areas A to C meet the peak demand for cooling of 8GJ/ha-h or higher, which is expected to enable the establishment of a heat supply business, but Area A is the only one that meets the 6 GJ/ha-h or higher threshold expected for establishing a heat supply business. On the contrary, in Area D, both cooling and heating values are less than 2 GJ/ha-h, which is assumed to be insufficient for heat supply business purposes. With respect to the annual energy demand density, the value of Area C is about the same as that of Area B, which has a floor area ratio of 1.5, but Area C contains many small-scale commercial facilities where the ratio of the average U-values and facility areas grew over the total floor area where there was increased local electricity and air-conditioning heat demand.

Case description

Table 7 shows the setting cases. CHP had seven cases of major capacities referring to the Japanese CHP catalog collection (Kurin enerugi henshubu: 2018). Furthermore, we set the rated capacity of the RHA, TR, and ITR by multiplying the cooling capacity (Table 10) created from the peak demand in each region by the ratio in 25% increments. We established the heating capacity of the EHP by multiplying the heating capacity in Table 10 with the ratio; the cooling capacity was set to the same value as the heating capacity. To derive the rated capacity of the two TRs and an ITR, the set value was further divided in the ratio of 0.35:0.35:0.3; for that of the two EHP units, the set value was then divided in half. The storage battery and the thermal storage tank each had two capacity cases and the following two operation settings.

Priority on other: Always prioritize other equipment operation with making up for surpluses and shortages of other equipment supply.

Demand response: Prioritize energy storage/energy supply from energy storage systems when demand is low / high during the day.

From a total of 256,000 cases, we calculated the cases with cooling and heating capacity that satisfied the values in Table 10.

The energy-saving effects of each study case according to the energy indexes were obtained by comparing the calculated value with the result of a variable refrigerant flow (VRF) case (Table 11). The VRF case installed a VRF in each building with the capacity to meet peak demand. In addition, the performance curve (Figure 9), annual LCCO2 emission intensity (Table 12) and other characteristics such as the outside air temperature were set to the VRF.

Among the study cases, the case where each energy index became the smallest from the VRF cases was considered the optimal case, and the annual reduction rate of each index in these instances was calculated from Eq. (4).

\[ R_{best} = \frac{(C_{vrf} - C_{best})}{C_{vrf}} \cdot 100 \]  

Results and discussion

Table 11 lists the best case settings and annual reduction rates. The case studies showed that the optimization index and district characteristics change the best case settings. All best cases for the annual primary energy consumption in the target districts operate the CHP to follow the heat demand. In addition, because RHA reduces the amount of acceptable exhaust heat according to the load factor, they introduce large-capacity RHA, operate the TR and ITR

Table 7: Setting cases s.

![Table 7: Setting cases s.](https://doi.org/10.26868/25222708.2021.30249)
prior to the CHP, and supply the stored heat from TST so that the RHA can be operated with only exhaust heat as much as possible. The best cases of LCCO₂ emissions, compared to them of the primary energy consumption, set the smaller capacity of CHP and RHA and the larger capacity of TR and ITR to use more grid power. All best cases for the annual standard deviation of power supply and demand operate the CHP to follow the power demand and use the RHA with 100% capacity. In addition, they introduce the storage battery in districts A and B which have large fluctuations in power demand.

Annual reduction rates in Table 11 indicate that DESS has more energy saving effect than VRF to reduce primary energy consumption and standard deviation of electricity supply and demand. They also show that the DESS with settings specific to each energy index reduced the primary energy consumption by more than 25% and the standard deviation of power supply and demand by more than 90%. On the other hand, the best cases for districts C and D increased LCCO₂ emissions from the VRF case.

In relation to the reason, Figure 10 shows a breakdown of the annual LCCO₂ emissions in the best case for LCO₂ emissions in districts A and D (underline values in Table 11). Gas from CHP accounted about 15% of the CO₂ emissions in DESS. In addition, DESS in district D caused CO₂ emission due to the construction and dismantling of heat supply piping larger than the energy saving effect by the reduction of grid power consumption, and it could not reduce LCCO₂ emissions.

As the cause analysis, wherein the active use of the grid power could further reduce the annual LCCO₂ emissions when compared with the CHP operation, we compared the LCCO₂ emission factor per supply power of the CHP and the LCCO₂ emission factor per grid power on a sunny day (Figure 11). Taking into account the power generation, the coefficient of CHP was larger than the grid power during the daytime in the winter (January 18th), and grid power saved more CO₂ than CHP all day in the mid (May 4th) and summer (August 8th). However, in the case of including the exhaust heat supply for heating, the coefficient of CHP was smaller than the grid power in winter. On the other hand, the efficiency of using exhaust heat for cooling was small, and the proportion of PV power generation in the grid was larger than that in winter, so the CHP coefficient including the exhaust heat supply for cooling was larger than the grid power in the spring and summer. In addition, CO₂ emissions from RHA heating and cooling were larger than those of general air-cooled heat pumps. In these respects, CHP could not reduce LCCO₂ emissions unless the power generation and exhaust heat exactly match the power demand and heat demand of the target building.

**Conclusion**

In this paper, we evaluated the DESS performance in commercial districts based on three indicators. This study built a model to calculate the response of CHP, power heat source equipment, energy storage systems at five-minute intervals. Moreover, a DESS model incorporating factors such as the heat supply pipe length, transfer power, and pipe heat loss was constructed based on these references. Furthermore, we selected several Japanese commercial districts and created some cases on the settings of energy supply systems. The simulation study calculated energy consumption at five-minute intervals in target commercial...
districts, and then evaluated the calculation results of each case according to three indicators. This study showed that the capacity and operation settings of the DESS vary depending on the index to be optimized.

In this study, the effect of introducing the DESS was evaluated from the perspective of energy-saving and reducing CO₂ emissions, but the system is also expected to serve as a local, self-sustaining power supply in the event of disasters. In future research, we will evaluate the DESS performance of improved resilience on the district, such as by extending the duration of local activities when the grid power is cut off due to disasters.

Acknowledgement
This work was supported by JSPS KAKENHI Grant Number JP20K22455.

Nomenclature
- C_Best = E_LCE or E_PEC or S of the Best case [MJ or kg-CO₂ or kWh]
- C_CHP = Combined heat and power
- C_VRF = E_LCE or E_PEC or S of the VRF case [MJ or kg-CO₂ or kWh]
- DESS = Distributed energy supply system
- E_LCE = Annual Lifecycle CO₂ emissions [kg-CO₂]
- E_R, T = Total regional gas consumption at time t [MJ]
- E_PEC = Annual primary energy consumption [MJ]
- E_p,ave = Annual average of total regional power consumption [kWh]
- E_p, T = Total regional power consumption at time t [kWh]
- E_H = Electric heat pump
- f_LCE, g = the LCCO₂ emission factor due to the gas consumption [kg-CO₂/MJ]
- f_PEC, g = the primary energy conversion coefficient by gas [-]
- f_PEC, p,m = the time-based primary energy conversion coefficient [MJ/kWh]
- HEX = Heat exchanger
- ITR = Inverter turbo refrigerator
- R_Sens = the reduction rate in Best cases [%]
- RHA = Rapid-heating apparatuses
- S = Standard deviation of the power supply and demand [kWh]
- TR = Turbo refrigerator
- TST = Thermal storage tank

References


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