A Simulation Approach For The Optimization Of Distributed Energy Supply Systems Based On Energy Demands In Business Area.

Takahiro Ueno1, Kentaro Takahashi1, Daisuke Sumiyoshi2
1Graduate School of Human-Environment Studies, Kyushu University, Fukuoka, Japan
2Faculty of Human-Environment Studies, Kyushu University, Fukuoka, Japan

Abstract
This research aims to optimize configuration, arrangement, and operation of distributed energy supply systems based on energy demands in a business area. We developed a method to estimate the five-minute energy demand of power and heat (heating, cooling and hot water) of non-residential buildings for one year. This method formulated each demand from the standard amount based on statistical and measurement data, by changing it and reproducing the actual fluctuations according to the type of buildings, total floor area, outdoor air temperature and a random number simulation.

Furthermore, we estimated energy demands of dozens of buildings in the business area of Japan. Moreover, we set distributed energy supply systems (photovoltaic power generation system, combined heat and power, storage batteries) on these buildings and studied best configuration and operation of these energy systems. This study confirmed that an energy aggregation by introducing a HIC is more suitable than the optimization in individual buildings depending on the purpose.

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. Fichera et al. (2018) developed a comprehensive tool that combines spatial and energy issues with optimization methods to support urban planners in the decision-making process for urban energy strategies. They applied the method to a neighbourhood of the municipality of Catania in Southern Italy, and showed a network of energy exchanges in optimized urban energy scenarios aimed at reducing CO2 emissions. Gagliano et al. (2017) provided a GIS tool for territorial decision-making to help develop a sustainable energy action plan for the municipality of Randazzo in Sicily, Italy. The proposed tool permits an immediate update of the energy evaluations and offers a clear visualisation of the effects of interventions, giving important support to the involved decision makers. Burdjalov et al. (2017) developed a stock building model approach for the annual, daily, and hourly effect analysis of PV and storage battery from the home and system level to the region-wide population. In addition, they used this approach for the Northwest U.S. to simulate various PV and storage battery deployment scenarios and demonstrate the maximum technical potential of power demand reduction. Azar and Lin (2017) presented an agent-based modelling framework to simulate building energy feedback involving occupants on a community scale. This framework can expand feedback methods from individual to groups of buildings, and it showed significantly higher energy saving effects than the single-building method. Kimura et al. (2017) proposed an urban-scale energy demand model for a Japanese commercial building to consider HVAC system configurations. They applied this model to clarify that the diversity in the HVAC system configurations is important to reproduce a time-series power demand at an urban level. Schumacher et al. (2017) presented the simulation environment for computing the interaction of buildings and the electrical grid in a dynamic and closed-loop manner. They illustrated that the energy simulation of a community scale with 64 buildings takes just a few minutes when using this tool in a single core framework. Schwan and Unger (2017) presented a simulation approach to model the demand and supply grids of heating, cooling and power in city quarter. This approach can evaluate large-scale heating, cooling and power supply systems such as photovoltaic power plants and district heating and cooling. Gavan and Mouky (2017) developed a 3D modelling tool covering the dynamic simulation from the building to the urban scale. This tool can evaluate the thermal and energy behaviour at a city district level based on different thermal characteristics of a building such as envelop heat loss coefficient, and window area for each direction. These studies have confirmed some controversial points, such as the calculation time interval being large, the classification of types for non-residential buildings being few, or that the target scale was small. Therefore, this paper describes the development of the energy-demand estimation method and DESS models for non-residential buildings and analyzes effects of optimization for the DESS capacities in Japanese business areas by using these methods.
Methodology for creating time-series energy demand data

In order to clarify the calculation interval of the demand estimation methodology, we analyzed the influence on the peak value of the difference of the aggregation time interval by using the measurement data from the power demand from an office building. Table 1 shows the peak value for each month and the ratio to the one-minute interval value (value in parentheses). In the measurement period, seven months had fewer 60-minute interval values than 90% of the one-minute interval values (underlined).

Table 2 shows the peak in the aggregation time interval. The peak time of the one-minute interval is all in the morning, but some months changed by one hour or more in over 30 minute intervals (underlined).

These results indicate that the methodology of long calculation interval outputs a value and time of peak demand different from the actual demand, and may cause an error in DESS optimization. It is desirable to estimate the demand in one minute or second intervals according to the fluctuation range of PV power generation. Taking the estimation on a city scale into account, it is also important to extend the calculation interval due to the reduction of the calculation load. Therefore, because the error between the five-minute interval and the one-minute interval was small in tables 2 and 3, we set five-minute interval calculations for this methodology to reproduce the demand fluctuation according to the actual situation and to reduce the calculation load.

This methodology is a program for six non-residential building types (hospital, hotel, office, store, restaurant, and school). This program estimates the individual five-minute energy demand of power and heat (heating, cooling and hot water) of all buildings in the target area. Table 2 shows the FIR of the power demand on weekdays in August as an example.

### Standard demand setting

At first, we made a standard EUI and standard FIR based on Japanese documents (SHASE, 1994; SHASE, 2015) that described the standard energy demand of each of the six building types in Japan. Table 3 shows the EUI. Figure 2 shows the FIR of the power demand on weekdays in August as an example.

#### EUI changing

This step makes the individual EUI of the building from the standard EUI according to a function of the GFA and a random number simulation.

#### EUI changing by GFA

Many factors affect the EUI of buildings, but this paper focused on the GFA which can be considered the most important factor. We made natural logarithms of EUI and GFA based on statistical data (JSBC 2013) on the energy consumption of non-residential buildings in Japan. Figure 3 shows those natural logarithms. We set equations of restaurant and school as a constant because there are few data and most restaurants have little GFA.

### Table 1: Peak power demand in time intervals of Office.

<table>
<thead>
<tr>
<th>Month</th>
<th>1minute</th>
<th>5minute</th>
<th>15minute</th>
<th>30minute</th>
<th>60minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015 Aug.</td>
<td>289</td>
<td>276</td>
<td>274</td>
<td>273</td>
<td>272</td>
</tr>
<tr>
<td>2015 Sep.</td>
<td>267</td>
<td>250</td>
<td>244</td>
<td>232</td>
<td>231</td>
</tr>
<tr>
<td>2015 Oct.</td>
<td>243</td>
<td>231</td>
<td>222</td>
<td>203</td>
<td>192</td>
</tr>
<tr>
<td>2015 Nov.</td>
<td>239</td>
<td>230</td>
<td>222</td>
<td>209</td>
<td>198</td>
</tr>
<tr>
<td>2015 Dec.</td>
<td>255</td>
<td>246</td>
<td>241</td>
<td>240</td>
<td>231</td>
</tr>
<tr>
<td>2016 Jan.</td>
<td>275</td>
<td>262</td>
<td>260</td>
<td>255</td>
<td>255</td>
</tr>
<tr>
<td>2016 Feb.</td>
<td>261</td>
<td>250</td>
<td>243</td>
<td>234</td>
<td>225</td>
</tr>
<tr>
<td>2016 Mar.</td>
<td>288</td>
<td>284</td>
<td>281</td>
<td>274</td>
<td>256</td>
</tr>
<tr>
<td>2016 Apr.</td>
<td>291</td>
<td>275</td>
<td>267</td>
<td>254</td>
<td>240</td>
</tr>
<tr>
<td>2016 May</td>
<td>274</td>
<td>263</td>
<td>258</td>
<td>252</td>
<td>246</td>
</tr>
<tr>
<td>2016 Jun.</td>
<td>276</td>
<td>266</td>
<td>259</td>
<td>259</td>
<td>255</td>
</tr>
<tr>
<td>2016 Jul.</td>
<td>320</td>
<td>304</td>
<td>300</td>
<td>299</td>
<td>295</td>
</tr>
<tr>
<td>2016 Aug.</td>
<td>313</td>
<td>300</td>
<td>296</td>
<td>296</td>
<td>299</td>
</tr>
</tbody>
</table>

### Table 2: Peak time in time intervals of Office.

### Table 3: EUI.

<table>
<thead>
<tr>
<th>Annual demand</th>
<th>Office</th>
<th>Hospital</th>
<th>Store</th>
<th>Hotel</th>
<th>Restaurant</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power[kWh/m²]</td>
<td>115</td>
<td>209</td>
<td>284</td>
<td>183</td>
<td>206</td>
<td>64</td>
</tr>
<tr>
<td>Cooling[MJ/m²]</td>
<td>295</td>
<td>363</td>
<td>627</td>
<td>366</td>
<td>432</td>
<td>246</td>
</tr>
<tr>
<td>Heating[MJ/m²]</td>
<td>55</td>
<td>162</td>
<td>138</td>
<td>200</td>
<td>322</td>
<td>67</td>
</tr>
<tr>
<td>Hot water[MJ/m²]</td>
<td>8</td>
<td>270</td>
<td>172</td>
<td>423</td>
<td>1305</td>
<td>77</td>
</tr>
</tbody>
</table>

Figure 1: Calculation flow and image of each step.

Figure 2: FIR of power demand on weekdays in August.

EUI changing by random number simulation

Even if two buildings have the same building type and the same GFA, their EUI would be different according to age and envelope component performance. Therefore, this paper also changes the EUI by using random number simulation.
simulation with a probability distribution in addition to changing them via the GFA.

We made a frequency distribution for the EUI of each building type from the statistical data, and confirmed that the frequency distribution was in almost the same form as the normal distribution when the number of data was sufficient. Therefore, we calculated the variances of normal distribution based on those data, and used them and the normal distribution to make the equation (Equation (1)) for the EUI, changing it by random number simulation. Table 4 shows the set variance. This step applies the random numbers made for each building to this equation and calculates the multiplication ratio for the standard EUI.

\[ x = \int_{0}^{\infty} \left\{ 1 / \sqrt{2\pi \sigma^2} \cdot e^{-(t-100)^2 / 2\sigma^2} \right\} dt \quad (1) \]

**FIR changing**

This step creates the individual FIR of the building in five-minute intervals. However, the hot water demand uses the standard FIR directly because that demand fluctuation decreases due to the hot water storage tank.

**Power FIR changing by random number simulation**

The behaviour changes of people in a building have a big impact, we thought that this fluctuation is influenced by the number of people, and then divided one day into four time zones by the number of people in the building. Table 5 shows the time zones. We calculated the variance for each time zone from the measured data of one building (Table 6), and used them, the normal distribution, and random number simulation to reproduce the power demand fluctuation in five-minute intervals. Moreover, time zones in one day differ by building type. Therefore, this paper set four time zones for each building type from the standard demand ratio.

**Cooling and heating FIR changing by outside temperature and random number simulation**

Heat demand for cooling and heating is strongly influenced by outside temperatures. In order to reproduce this influence, we made an equation (Equation (2)) of the cooling/heating FIR based on the outside temperature from the measurement data of two buildings. This equation calculates the multiplication ratio of the cooling or heating FIR in five-minute intervals according to the gap between the outside temperature at the target time and the monthly average temperature at the same time. Furthermore, this equation reproduces the actual demand difference in the same gap by the random number simulation with the normal distribution. The variance of this normal distribution is the variance (\( \approx 0.14 \)) calculated from the measured data. The input temperature was made based on the ten-minute intervals measurement data (JMKA 2019) published by the government.

\[ R(\text{temp}) = (k \cdot T(t) + 100) \cdot R / 100 \quad (2) \]

**Demand calculation equations by energy application**

Equations (3) - (5) show a summary of the calculation equations for the energy demands for power, cooling, heating and hot water in this methodology.
generation amount or exhaust heat amount. These setting values are based on the existing program (SHASE, 2013).

\[
E_{pow} = E_{pow, ra} \times \left( \frac{A_{pow} \times L_{chp}^2 + B_{pow} \times L_{chp} + C_{pow}}{100} \right)
\]

\[
E_{tes} = E_{tes, ra} \times \left( \frac{A_{tes} \times L_{chp}^2 + B_{tes} \times L_{chp} + C_{tes}}{100} \right)
\]

CHP preferentially supplies exhaust heat to heating or cooling, and supplies it to heating and hot water through a heat exchanger (exchange efficiency: 1.0 [-]). On the other hand, supply to cooling uses GeneLink: a waste heat driven absorption chiller. The ratio of the limit for the exhaust heat amount of GeneLink for a rated capacity of this system (Table 7) varies according to the GeneLink loading factor (Figure 5).

ACS operation
This step uses ACS to process the air conditioning heat demand remaining after CHP operation, and adds the power consumption amount of ACS to the power demand. The ACS of all of the buildings are the building multi air conditioners, and their efficiency is constant (heating: 3.4 [-], cooling: 3.2 [-]).

PV generation
This step calculates PV generation by the following Equation (8) based on a Japanese Industrial Standard (JIS, 2005), and supplies it to the power demand

\[
P_{pv} = P_{sol} \times E_{sol} \times S_{pv} \times R_{tem} \times R_{con} \times R_{ath}
\]

Battery operation
This step operates the storage battery. The storage battery is a lithium-ion battery, and it has a main body and PCS. PCS converts alternating currents into direct currents to charge and discharge the storage battery. This paper calculates the efficiency of the PCS based on the following equations. In addition, the charge and discharge efficiency of the main body is 0.957[-]. When the storage battery is not full and the generation amount of CHP and PV is larger than the power demand, this battery charges the gap amount between these. On the other hand, when the power demand is larger than the generation amount, this battery discharges the gap amount between these.

\[
E_{cha} = -1.3301L_{pcs}^4 + 3.5788L_{pcs}^3 - 3.52L_{pcs}^2 + 1.5153L_{pcs} + 0.6671
\]

\[
E_{dch} = -0.6323L_{pcs}^4 + 2.0429L_{pcs}^3 - 2.4482L_{pcs}^2 + 1.2972L_{pcs} + 0.6795
\]

HWS operation
This step is performed on a hot water storage tank or a boiler according to the hot water demand. Table 6 shows the capacity per GFA by building type of the hot water storage tank based on the past literature (JSBC, 2001). The effective hot water storage amount of these tanks is 70% of the capacity of these tanks. When this effective amount becomes zero, the boiler uses gas to supply hot water to the tank. The office building type does not have a tank, and uses only a boiler to supply hot water.

Figure 4: Calculation flow of energy supply systems.

Table 7: GeneLink capacity intensity [MJ/m²].

<table>
<thead>
<tr>
<th>Office</th>
<th>Hospital</th>
<th>Store</th>
<th>Hotel</th>
<th>Restaurant</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.99</td>
<td>33.05</td>
<td>35.17</td>
<td>26.57</td>
<td>45.13</td>
<td>26.49</td>
</tr>
</tbody>
</table>

Figure 5: Limit for exhaust heat amount of GeneLink.

Table 8: Capacity intensity of hot water tank [MJ/m²].

<table>
<thead>
<tr>
<th>Office</th>
<th>Hospital</th>
<th>Store</th>
<th>Hotel</th>
<th>Restaurant</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>8.78</td>
<td>3.29</td>
<td>13.26</td>
<td>40.60</td>
<td>3.36</td>
</tr>
</tbody>
</table>

Conversion to primary energy consumption
The last step in each loop converts the instantaneous value ([kWh/h] or [MJ/h]) of the remaining power demand and the gas usage to the integrated value ([kWh] or [MJ]) and calculates the PEC from these values. The PEC coefficient [MJ/kWh] is 9.97 in the daytime (8 o'clock to 22 o'clock) and 9.28 in the nighttime (22 o'clock to 8 o'clock). Furthermore, this model does not calculate energy saving via reverse power flow.

Case study of optimal arrangement for energy supply system in commercial and business areas
This chapter examined two case studies for the optimal arrangement of DESS in some commercial and business areas. It analyzed the optimum capacity and its effect by changing the capacity of each supply facility and introducing HIC.
Outline of target areas

We chose three areas in Fukuoka city for target areas. This city is located in the south west of Japan. Table 9, and Table 10 show the number and total GFA of the buildings in the three areas. A area is the central commercial area of the city. Office and store buildings are concentrated in this area. B area has many office buildings, and there are also many hotel buildings because this area is in front of the station. C area has many store buildings. The proportion of low-rise buildings is large in this area; thus, the sum of the GFA is small for the number of buildings.

Distributing verification and validation

Prior to proceeding with the case studies, we confirmed the influence from random number simulations in the estimation methodology to the potential reliability of the approach. We calculated 100 times in each area and made a box plot of the area total annual energy demand which is most affected factor by the random number simulation (figure6). This figure shows that almost all of the calculation results are in the 10% range from the average. These variances are also shown in Table 11. This table indicates that calculations in the area scale can reduce their variance and converge to the average result.

Table 9: Number of buildings in target areas [-].

<table>
<thead>
<tr>
<th>Office</th>
<th>Hospital</th>
<th>Store</th>
<th>Hotel</th>
<th>Restaurant</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>248</td>
<td>8</td>
<td>280</td>
<td>1</td>
<td>31</td>
</tr>
<tr>
<td>B</td>
<td>255</td>
<td>6</td>
<td>151</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>C</td>
<td>174</td>
<td>1</td>
<td>224</td>
<td>7</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 10: Total value of GFA in target areas [m^2].

<table>
<thead>
<tr>
<th>Office</th>
<th>Hospital</th>
<th>Store</th>
<th>Hotel</th>
<th>Restaurant</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>897826</td>
<td>32359</td>
<td>1211352</td>
<td>10477</td>
<td>7321</td>
</tr>
<tr>
<td>B</td>
<td>572463</td>
<td>13100</td>
<td>602753</td>
<td>210227</td>
<td>6654</td>
</tr>
<tr>
<td>C</td>
<td>187144</td>
<td>7270</td>
<td>337661</td>
<td>89930</td>
<td>9741</td>
</tr>
</tbody>
</table>

Demand analysis

Figures 7(a)-7(d) show the demand in each of the three areas, and the demand of a general office building in A area, as a sample. The energy demand fluctuation of the three areas is less chaotic than that of the sample building in any energy application. The fluctuation trends of power demand in the three areas are similar, these are almost constant after a rise at 9 o’clock (Start time zone), and return to the midnight amount at around 21 o’clock (End time zone). Cooling and heating demand have larger fluctuations than that of the power demand, because of the influence of the outside temperature. Hot-water demand has more peaks than that of other energy usage demands. A and B areas have three peaks at 10, 13 and 18 o’clock, due to the characteristics of the store building type. In addition, B area has a peak in hot-water demand for hotels late at night. Heating and hot water demand in C area are smaller than those of the other two areas, due to the GFA over the area.

Figure 6: box plot of total annual energy demand.

Figure 7: Prediction of weekly energy demand.
of the hospital building. This building type has a large heating and hot water demand.

**Discussion of the most energy saving systems arrangement**

This paper changed the setting of DESS for each building to examine the most energy saving systems of the buildings and total energy saving effect in the area. Table 12 shows cases for the capacity, number and operation mode of DESS. The CHP rated generation capacity case has three kinds, and changes this capacity in each kind according to the GFA of the building. In addition, PV was installed on half of the roof area of all non-residential buildings in all cases. The calculation result has 96 cases for every building in these areas. Moreover, we set the case of the smallest primary annual energy consumption in each building as a BEST case for each area. We calculated a reduction rate of primary annual energy consumption in BEST case by using the following equation as the effect of BEST case.

\[
R_{\text{best}} = \frac{(C_{\text{def}} - C_{\text{best}})}{C_{\text{def}}} \times 100
\]

Figure 8 shows this rate. Optimization of energy supply systems in each building reduced annual PEC by 25% in all three areas. This paper limits optimization to just the annual fixed operation mode, the number, and the capacity of DESS. Therefore, these areas should reduce their energy consumption more by using other methodologies, such as improvement of these systems operation flexibility, introduction of the district heating, and cooling, and permission for reverse power flow.

We calculated the optimal capacity intensities of CHP and storage batteries based on the setting of the BEST case as an indicator of the optimum system configuration. Figure 9 shows their capacity intensities. Total values of the GFA in each area are 600,000 m² to 2,000,000 m². Taking these values into account, the capacities of CHP and storage battery between the areas have large gaps. The cause of this gap is a small difference between building characteristics in each area, such as average value of GFA and major building type in each area.

**Discussion of the effect for HIC**

This discussion aggregated CHP arrangement by making HIC pairs and using CHP of one building in each pair to supply both buildings. According to a Japan HIC promotion manual, these pairs are suitable for neighboring buildings, which have large GFA. Therefore, we set these condition pairs as the buildings whose GFA were more than 5,000 m², and they are located within 100 m. The one with the bigger GFA in each pair has CHP and GeneLink, and use them to supply both buildings. The conveying power demand of HIC was calculated by a following Equation (12) and added to the power demand of the building.

\[
P_{\text{pump}} = P_{\text{loss}} \times D_{\text{buit}} \times Q_{\text{pump}} / 3600
\]

Table 13 shows a summary of the HIC pair. The A and B areas have dozens of these pairs and target more than the half of total GFA. On the other hand, the C area has few pairs because of the large proportion of low-rise buildings.
We compared the calculation result of the BEST cases with HIC and those without HIC. The HIC did not change the optimum capacity of the storage battery, but it affected that of CHP. Table 14 shows a comparison of the calculation result of the BEST cases. In any area, as far as simple energy savings, the results without HIC were higher; however, HIC has a higher reduction efficiency in every area (the bottom value in Table 14).

Figure 10 indicates the cause of that, by showing the comparison of weekly CHP used exhaust heat of buildings with and without HIC. This week has same CHP operation between with and without HIC. Thus, this figure indicates that the HIC improves CHP efficiency by using excess exhaust heat. As a result of improving the efficiency of each CHP in this manner, the HIC reduced the arrangement CHP number in the target area and increased the reduction efficiency.

**Conclusion**

This paper analyzed an effect of an optimization for DESS in Japanese business areas by using the energy-demand estimation method and DESS model for non-residential buildings. This effect reduced 25% of the annual energy consumption in target areas. Furthermore, the simulation result indicated HIC increases the energy saving efficiency of CHP.

These results indicate that the optimum capacity and operation method of energy supply systems in urban scale varies due to the purpose, such as simple energy saving or improvement of these systems efficiency. A more advanced analysis is required to add models of heat energy aggregation systems other than HIC and large-scale storage batteries, such as a thermal storage tanks and a sodium-sulfur batteries. Moreover, in order to develop this research, the area demand data for additional analysis such as accuracy verification must be measured.

**Acknowledgement**

This work was supported by JSPS KAKENHI Grant Number JP17K14773 and 18J12025.

**Nomenclature**

- $A = \text{the GFA [m}^2\text{]}$
- $A_{so} = \text{the second order coefficient of the total efficiency curve (power demand following: } -14.4, \text{heat demand following: } -7.6) [-]$
- $A_{p} = \text{the second order coefficient of the power generation efficiency curve (power demand following: } 7.2, \text{heat demand following: } 11.8) [-]$
- $\text{ACS} = \text{Air conditioning system}$
- $B_{so} = \text{the first order coefficient of the total efficiency curve (power demand following: } 43.6, \text{heat demand following: } 32.4) [-]$
- $B_{p} = \text{the first order coefficient of the power generation efficiency curve (power demand following: } 8.2, \text{heat demand following: } 0.7) [-]$
- $C(A) = \text{the multiplication ratio for the annual energy demand by the GFA} [-]$
- $C_{\text{heat}} = \text{the total value of the annual primary energy consumption under the Best case [MJ]}$
- $C_{\text{det}} = \text{the total value of the annual primary energy consumption in the area without a system [MJ]}$
- $C_{\text{sun}} = \text{the constant term of the total efficiency curve (power demand following: } 70.8, \text{heat demand following: } 75.2) [-]$
- $C_{\text{pow}} = \text{the constant term of the power generation efficiency curve (power demand following: } 84.6, \text{heat demand following: } 87.5) [-]$
- $\text{CHP} = \text{Combined heat and power}$
- $D_{\text{hall}} = \text{the distance between buildings [m]}$
- $\text{DESS} = \text{Distributed energy supply system}$
- $T(t) = \text{the difference between the outside temperature and the monthly average value[°C]}$
- $R = \text{the multiplication ratio using the random number simulation with the normal distribution[%]}$
- $E_{\text{Co,He}}(t) = \text{the five-minute interval cooling or heating demand [MJ/h]}$
- $E_{\text{H}}(t) = \text{the five-minute interval hot water demand [MJ/h]}$
- $E_{\text{P}}(t) = \text{the five-minute interval power demand [kWh/h]}$
- $E_{\text{ch}} = \text{the PCS charging efficiency [-]}$
- $E_{\text{sh}} = \text{the PCS discharge efficiency [-]}$
- $E_{\text{t}} = \text{the CHP total efficiency [-]}$
- $E_{\text{pv}} = \text{the PV conversion efficiency (=0.2)[-]}
- $E_{\text{p}} = \text{the CHP power generation efficiency [-]}
- $E_{\text{rs}} = \text{the CHP rated power generation efficiency (=0.45)[-]}
- $E_{\text{rs}} = \text{the CHP rated total efficiency (=0.85)[-]}
- $E_{\text{rs}} = \text{the standard hot water EUI [MJ/(h*m2)]}
- $E_{\text{rs}} = \text{the standard power EUI [kWh/(h*m2)]}
- $E_{\text{rs}} = \text{the Energy use intensity [MJ/(h*m2)] or [kWh/(l*year*m2)]}$
- $FIR = \text{Five-minute interval ratios for the EUI by month and day of the week [%]}$
- $GFA = \text{Gross floor area [m2]}$
- $\text{GIS} = \text{Geographic information system}$
- $\text{HIC} = \text{Heat interchanging}$
- $\text{HWS} = \text{Hot water supply system}$
- $k = \text{the coefficient(cooling: 0.0647 heating: } -0.0697)[°C^{-1}]$
- $L_{\text{chp}} = \text{the load factor to the rated power generation or the rated exhaust heat [-]}$
- $L_{\text{pcs}} = \text{the PCS charge and discharge load factor [-]}$
- $P_{\text{loss}} = \text{the pressure loss per unit distance [Pa/m] (=400)}$
- $P_{\text{p}} = \text{the conveying power demand of HIC [kWh/h]}$
- $P_{\text{pv}} = \text{the PV power generation[kWh/h]}$
- $P_{\text{sol}} = \text{irradiation [kWh/m2]}$

Proceedings of the 16th IBPSA Conference
Rome, Italy, Sept. 2-4, 2019

3427
PV = Photovoltaics

\( Q_{pump} \) = the of HIC [m³/h]

\( R(\text{temp}) \) = the multiplication ratio for the five-minute cooling or heating demand ratio by the outside temperature and the random number simulation [-]

\( R_{\text{heat}} \) = the reduction rate in BEST cases [%]

\( R_{\text{con}} \) = the PV correction by current conversion loss (=0.95) [-]

\( R_{\text{con},\text{He}}(t) \) = the five-minute interval standard cooling or heating demand ratio [-]

\( R_{\text{con},\text{Hw}}(t) \) = the five-minute interval standard hot water demand ratio [-]

\( R_{\text{con}} \) = the PV correction by other loss (=0.95)[-]

\( R_{\text{con},\text{Hw}}(t) \) = the five-minute interval standard power demand ratio [-]

\( R_{\text{temp}} \) = the PV correction by temperature rise (=Jun.-Sep. are 0.9, Nov.-Feb. are 0.95, other months are 0.92)[-]

\( R_{\text{con},\text{Hw}}(t) \) = the multiplication ratio for the five-minute power demand ratio by the random number simulation [-]

\( R_{\text{con},\text{Hw}}(t) \) = the multiplication ratio for the standard EUI by the random number simulation [-]

\( S_{\text{pv}} \) = the PV area [m²]  

\( x \) = random variable [%]  

\( y \) = probability (multiplication ratio for annual demand) [%]  

\( \pi = P_i \) [-]  

\( \sigma^2 \) = variance [-]  

\( \mu \) = mean(=100) [%]

References


San Francisco (USA), August 7-9, 2017.

Proceedings from the 15th IBPSA Conference

San Francisco (USA), August 7-9, 2017.