AN APPLICATION STUDY ON THE OPTIMIZED MODEL OF DISTRIBUTED LOCAL ENERGY SUPPLY SYSTEMS FOR THE SUSTAINABLE REDEVELOPMENT OF A DENSELY BUILT-UP AREA IN TOKYO

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Summary

Distributed energy systems are expected to rationalize the supply of energy to built-up areas, but up to now very few researches have been done in order to estimate the effect of their application to actual cities. In this research, therefore, the application of distributed energy systems to a densely built-up area typical of Japan where such systems are likely to be effective was simulated, and the decrease in energy consumption, decrease in CO_2 emission and the degree of effect on the heat-island phenomenon were calculated. As a result, it was discovered that the introduction of distributed energy systems would have an enormous effect in a built-up area of this kind where buildings of different uses are crowded together because electrical power and heat would be used more efficiently. In addition, other merits of introducing such systems--for example, improvement of security functions in times of emergency and enhancement of amenities--were also investigated.

1. Research Objective

Distributed energy systems are expected to conserve energy when used as on-site supply systems for electrical power and heat. They have been studied as a method for rationalizing the supply of energy to, not only individual buildings, but built-up areas with accumulations of large buildings mainly for office and commercial use. However, built-up areas typical of Japan are often crowded with small detached houses. At present not much is known of the effect on the conservation of energy of the introduction of distributed energy systems to such areas.

This research, therefore, was intended to verify the conservation of energy, decrease in the emission of CO_2 and the effect on the heat island for the area as a whole, if optimal distributed energy systems for diverse building uses were introduced into a typical Japanese built-up area that includes many houses.

At present, decrepit buildings often exist in such densely built-up areas, and frequent reconstruction of buildings is anticipated in the future. In this research, it was assumed that the introduction of distributed energy systems will take place gradually in conjunction with such renewal of the built-up area, and that the optimal network system will be formed by 2030. In addition, improvement of security in times of emergency and enhancement of amenities through the introduction of distributed energy systems were investigated.

2. Research Method

In this research, the subject of the case study was a built-up area within a 500-meter radius of Sangenjaya Station in Setagaya Ward, Tokyo. In this area, a commercial and business district consisting mainly of offices and stores is situated along major streets. Beyond it is a district of mainly wooden detached houses. The area is typical of built-up areas in Japan in being densely built-up with relatively small buildings.

In the first stage of research, a plan to renew buildings and the built-up area in order to improve the sustainability of the regional environment was devised, based on the present condition of the district and on-going city planning, and an image of the subject area 30 years in the future was drawn. At the same time, the structure of distributed energy systems and a micro-grid system to be introduced into the area was studied. In the second stage, simulations were carried out with respect to the decrease in energy consumption and decrease in the heat island as a result of the introduction of the distributed energy systems, and these effects were verified.

3. Proposed Future Image of the Area

3.1 Configuration of a Future Vision (2030) for the Subject Area

The subject area is surrounded by distinctive commercial centers and built-up residential areas. It is located three kilometers west from JR Shibuya Station. With its accumulation of residential, commercial, service and business functions and advanced educational institutions of various kinds, it serves as a center for living for a wide area.

Figure 1 Present situation of the area

In studying the future image of the subject area, a vision of the future in 2030 (Table 1) was first determined. In this scenario, the area is converted into a low emission-type built-up area adapted to the age of the global environment; the heat-island effect and volume of CO_2 emission are controlled, improvements in disaster prevention (preparedness against earthquakes and fires) are achieved, and amenities for the living environment are provided. Next, the subject area was divided into five blocks, based on characteristics such as building uses, and a renewal plan for prototypical buildings and the built-up area, a distributed energy system and a network plan for that system were devised in accordance with the future vision (*Fig.2*).

Table 1 Outline of the Future Vision (2030) of the Subject Area

Population	The population of the area will be kept at the same level as a result of the continued influx of people of the younger generation. Overall, there will be an aging of the population.
Households	The total number of households will increase. Households consisting of just one person or a couple will increase; family households and multi-generational households will decrease.
Residential district	In the built-up area densely crowded with wooden buildings in the northern part of the area, projects for fireproof acceleration and amelioration of crowding will be concentrated along evacuation routes in order to improve disaster prevention. Strategic centers for disaster prevention and greening will be developed as large public housing projects are rebuilt. In other residential areas, reconstruction will gradually take place as buildings become dilapidated.
Commercial and business district	Demand for business and commercial uses in the area will remain high because of excellent access to the center of the city. Furthermore, demand for new service functions and new forms of business spaces such as SOHO will grow as civil society matures. Diverse forms of multifunctional buildings will increase. Conversions of medium-size buildings will take place.
Green	At present, green areas are extreme scarce. For that reason, open spaces and green areas will be created and the greening of buildings will be promoted. Existing rivers will be improved, and the waterside will be made into a park and reconstructed into a green network linked to a large, nearby park.
Livability	A highly convenient and pleasant built-up area for living will be formed, with a verdant pedestrian-oriented spatial network organized around new commercial centers and large parks. A diverse and distinctive townscape that makes full use of the characteristic of facilities and spaces in the area will be formed.
Thermal environment	"Passageways for air" will be formed by consolidating buildings along major streets and arranging them appropriately. Furthermore, the thermal environment will be improved and growth of a heat island will be controlled through greening of buildings and on the ground.
Energy consumption	On the one hand, floor area will grow, mainly for commercial and business use, and the number of equipment used in houses will increase. On the other hand, efficiency of energy consumption of the equipment will improve. Energy consumption behavior and pattern will diversify as lifestyles become even more diverse.
Energy supply system	Hydrogen tubing will be laid along major streets, and hydrogen will begin to be supplied in places (along with municipal gas and electrical power). Solar power systems and highly efficient distributed energy systems will become more widespread. Along major streets, buildings will begin sharing an energy plant. In addition, a micro-grid system will be constructed in the area.
Disaster prevention	Fireproof acceleration and the development of firebreaks and evacuation routes will proceed as land is consolidated and more buildings are used jointly. The micro-grid system will make possible the transfer of electrical power and the supply of the minimum necessary level of power in times of emergency (i.e. approximately 30 percent of normal level).

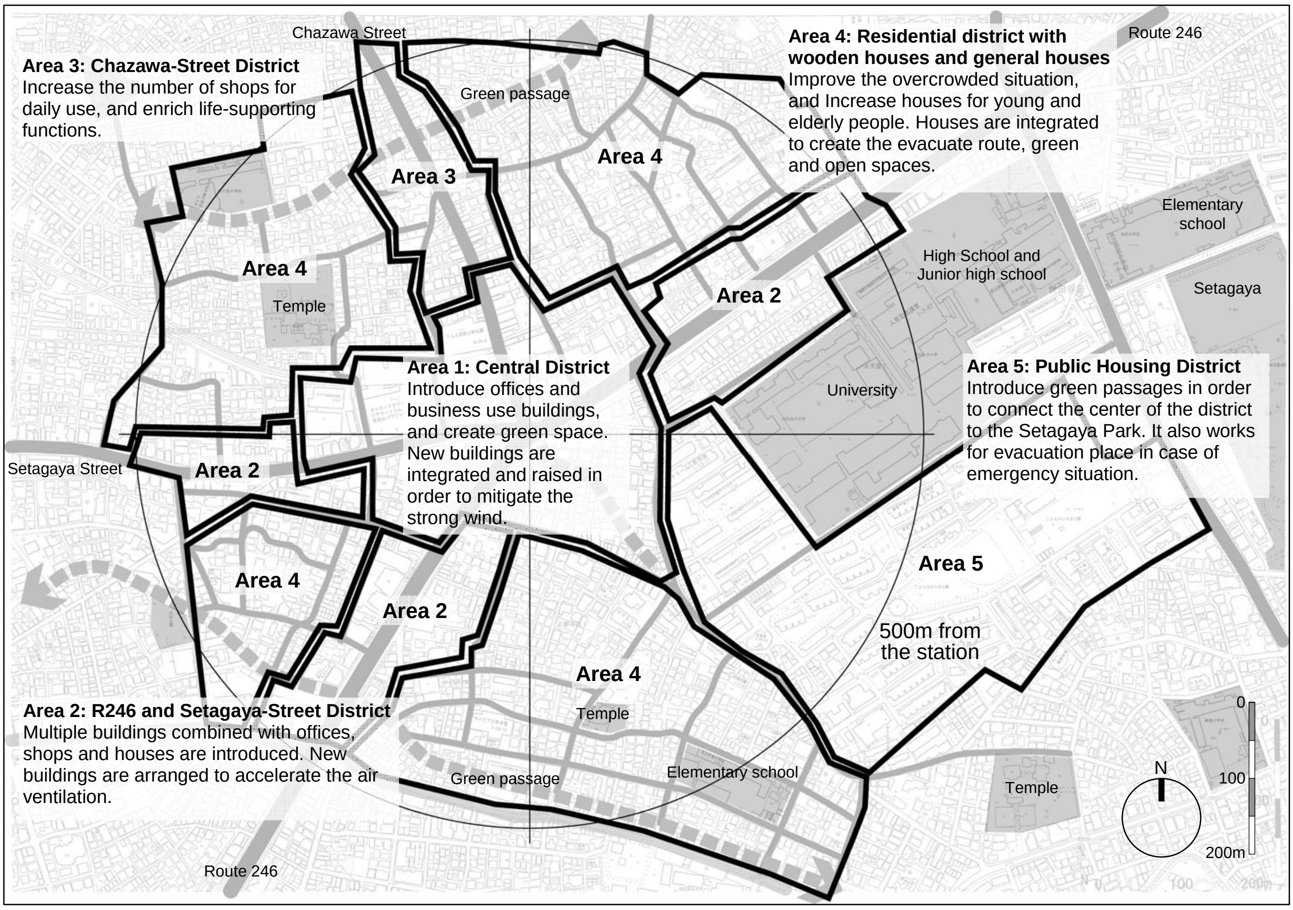


Figure 2 Future vision (2003) of the subject area

3.2 Proposal for Renewal Prototype Unit

In each district, a prototype for building renewal and a distributed energy system adapted to the characteristics of that district were studied. Representative examples (Area 1, Area 4) are indicated below. With respect to the distributed energy system, a micro-grid system for optimizing the energy supply to the area as a whole was introduced.

Area 1: ***Central district***

Concept

- A new symbolic district that combines residential, commercial and professional functions.
- Formation of an energy supply center for the entire area; promotion of energy conservation in the area.
- Utilization of the density transfer system in constructing a redevelopment building.
- Multifunctional buildings combining entertainment, residential and office facilities.
- Offer of open spaces to overcrowded areas.

Energy supply image

- There is an accumulation of buildings, mainly for commercial and office use; demand for energy consumption is also concentrated in this district.
- An energy plant, organized around fuel cells and supplied directly with hydrogen from hydrogen tubing laid along a major street, will be situated in the redevelopment building.
- Electrical power, cooling water, hot water, potable water and grey water will be all managed at this plant and supplied to each building in the district.

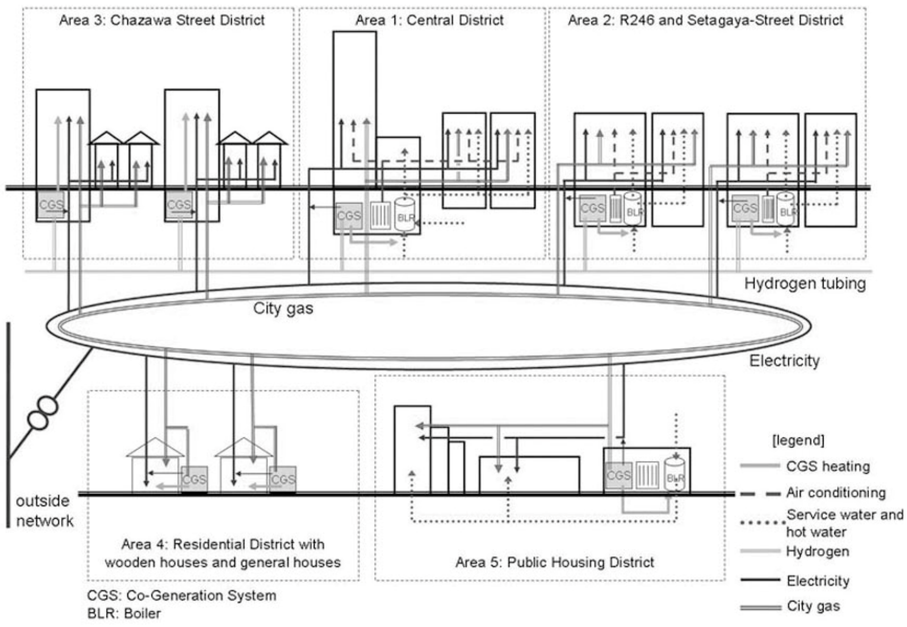
Area 4: ***Residential district with wooden houses and general houses***

Concept

- Energy self-sufficiency and energy-conservation will be promoted by having each house possess a generator facility.
- Infrastructure will be redeveloped, evacuation routes for emergencies will be created and open spaces and a community plaza for disaster-prevention use will be constructed through consolidation of land and the joint use of buildings.
- Fireproof buildings will be constructed along major streets and firebreaks formed.

Energy supply image

- The system for each unit will be a combination of a solar generator and fuel cell for household use. A stable supply of energy will be provided by incorporating the systems into a micro-grid.
- Heat will not be conveyed to other buildings in this district.



The energy facilities introduced in each district are optimized according to the demand of energy for the area.
In Area 3-5, energy generation facilities with fuel cells are introduced. The hydrogen used for fuel cells is supplied from hydrogen-tubing laid under R246 Street. Electricity and heat generated from them are supplied for air-conditioning and heating water.
In Area 4 and 5, residential use fuel cells combined with solar cells are introduced. Regarding apartment buildings, energy generation facilities that control the electricity and create flesh water from the brown water.
Finally, all facilities are linked and they constitute a micro-grid system to optimize the use of electricity.

Figure 3 Energy network system applied to the subject area

3.3 Changes in the number of households and total floor area through renewal of built-up area

Table 2 is a comparison of the number of households and the total floor area of the subject area as a whole in 2030, if renewal prototype units are developed in each block, to those in 2000.

Table 2 Number of households and total floor areas in the subject area

year	The number of households					floor areas (unit: 1000m^2)				Floor area ratio (%)
	Total	detached houses		apartment houses						
		single	family	single	family	Total	Offices	Shops	Houses	
2000	10,546	582	965	5,096	3,902	1,089.3	251.6	154.8	682.9	136
2030	11,992	375	876	6,313	4,428	1,323.6	330.7	188.6	804.2	165
Rate of change (%)	+13.7	-35.6	-9.2	+23.9	+13.5	+21.5	+31.4	+21.8	+17.8	+ 29

4. Calculation of energy consumption volume and effect on Heat Island

4.1 Calculation of energy consumption and CO_2 emission volume

4.1.1 Simulation method

Comparison was made between (1) **present condition** (2000); (2) **BaU case** (Business as Usual case; no measures are taken until 2030, the same system and same efficiency of equipment as exist now); and (3) **countermeasure case**; distributed power sources are introduced and improvements are made in efficiency of equipment (details are as indicated in 3.2). Simulations of energy demand and supply were carried out for the three cases, and annual volume of consumption of primary energy and volume of CO_2 emission were calculated and compared. The bases for the calculations are indicated in Table 3.

Table 3 Bases for Calculating Volume of Energy Consumption and Volume of CO_2 Emission

Assumed energy consumption:	for office building, from The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan data; for residential building [1]
primary energy conversion value:	electrical power (all day) 9.83MJ/kWh, electrical power (nighttime) 9.31MJ/kWh, gas 46.1MJ/m3N [2]
CO2 emission conversion value:	electrical power (all day) 0.69kg-CO_2/kWh, gas 2.36kg-CO_2/m^{3}N [3]

4.1.2 Energy consumption and CO_2 emission Decrease

In this simulation, the spread of distributed energy systems 30 years from now was taken into consideration. The rate of introduction of distributed energy systems into each district was set at 40 to 100% (100% being the maximum introduction of the optimum system for a district). If all districts experienced a 100%

introduction, consumption of primary energy would decrease 37% compared with the **Bau case** and 26% compared with the **present condition**. (CO_2 emission would decrease 45% and 35% respectively.)

With respect to the total annual primary energy consumption volume (Table 4) for the area as a whole, taking into consideration the rates of introduction of distributed energy systems, a comparison of the **present condition** and the **BaU case** shows an approximately 18% increase (18% increase in CO_2 emission volume). By contrast, the **countermeasure case** results in an approximately 29% decrease (33% decrease in CO_2 emission volume) compared with the **BaU case** and an approximately 16% decrease (20% decrease in CO_2 emission volume) compared with the **present condition**.

If this is examined by area, the **BaU case** results in an approximately 39% increase in primary energy compared with the present condition in the central district, which has the biggest energy load. This is the result of an increase in the volume of energy consumption produced by growth in total floor area (46%). However, the **countermeasure case** (with a rate of introduction of 40%) has a notable effect, resulting in an approximately 26% decrease (4% increase compared to the present) compared with the **BaU case**. In the wooden residential district, occupied mainly by detached houses, primary energy remains at virtually the same level even in the **BaU case** because it is assumed the total floor area will not change in the future. However, in the **countermeasure case** (with a rate of introduction of 40%), an energy supply system operated 24 hours a day, combining fuel cells and solar cells, produced a large decrease of approximately 28%.

Thus, there are two possible factors contributing to the decrease in primary energy consumption and concomitant large decrease in CO_2 emission. One is that the systems introduced into each district are adapted to the actual state of energy consumption in each district and make possible the efficient use of electrical power and heat. The second is the construction of a micro-grid for supplying electrical power and the optimization of that supply for the entire area.

Table 4 Primary energy consumption and CO_2 emission (**Present**, **BaU**, **Countermeasure case**)

		Total			Area 1 Central District			Area4 Residential District		
		(1)Present	(2)BaU (2030)	(3)Counter measure (2030)	(1)Present	(2)BaU (2030)	(3)Counter measure (2030) *Introd. rate: 40%*	(1)Present	(2)BaU (2030)	(3)Counter measure (2030) *Introd. rate: 40%*
Primary Energy (GJ)	Total	2,214231	2,606,857	1,860,338	732,567	1,020,384	758,160	337,179	321,562	233,122
	Deference to (1) (Num, %)	0 **0%**	392,626 **17.7%**	-353,892 **-16.0%**	0 **0%**	287,817 **39.3%**	25,593 **3.5%**	0 **0%**	-15,617 **-4.6%**	-104,057 **-30.8%**
	Deference to (2) (Num, %)	–	0 **0%**	-746,519 **-28.6%**	–	0 **0%**	-262,224 **-25.7%**	–	0 **0%**	-88,440 **-27.5%**
CO_2 Emission (ton)	Total	148,171	175,015	118,393	49,191	69,080	49,482	22,682	21,598	14,660
	Deference to (1) (Num, %)	0 **0%**	26,844 **18.1%**	-29,778 **-20.1%**	0 **0%**	19,889 **40.4%**	291 **0.6%**	0 **0%**	-1,084 **-4.8%**	-8,022 **-35.4%**
	Deference to (2) (Num, %)	–	0 **0%**	-56,622 **-32.3%**	–	0 **0%**	-19,598 **-28.4%**	–	0 **0%**	-6,938 **-32.1%**

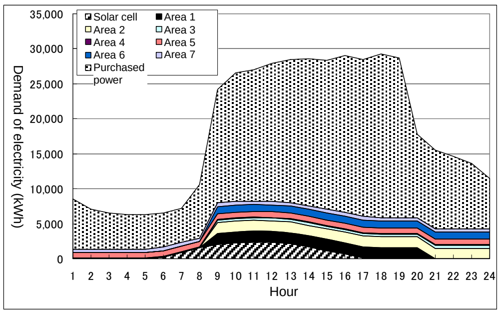


Figure 4 The change of the area's energy consumption in one day (countermeasure case in August)

With respect to the abovementioned result, the rate of introduction of new systems in the **countermeasure case** was assumed to be 0.4-1.0 of the optimum/maximum volume of introduction for each area in order to make the simulation realistic. The primary energy for the area if optimum/maximum introduction of the measures is carried out will undergo a decrease of 37% (45% decrease of CO2 emission volume) compared with the **BaU case** and a decrease of 26% (35% decrease of CO_2 emission volume) compared with the **present condition**.

4.2 Outdoor Thermal Environment Simulation

To study the thermal effect of waste heat on the outdoor environment in case that distributed energy supply facilities were installed in a densely built-up area, a simulation of thermal diffusion conditions and ground level temperature was carried out by three-dimensional Computational Fluid Dynamics (CFD) analysis [4]. Here, simulation is carried out for the district around the energy center (central district) where the thermal effect is expected to be especially great, as explained in 4.1.2. Comparison of computational results will be made of two cases, the **present condition** (2000) and the **countermeasure case** (2030).

4.2.1 Outline of Calculation Area

Analysis Area

The analysis area for this simulation was the central district indicated in 3.2. This area is descretized into 133,555 grids (present) and 138,404 grids (countermeasure case) respectively with unconstructed grid system. In the **countermeasure case**, the effect of the outdoor thermal environment on the area for which electricity and heat are supplied by the energy plant was analyzed (*Figs. 5, 6*).

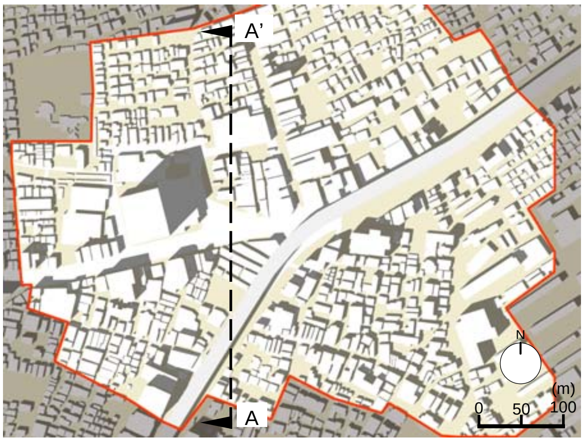


Figure 5 Analysis area (present)

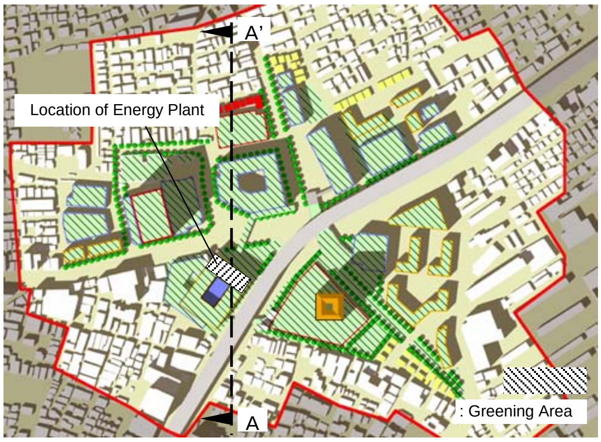


Figure 6 Analysis area (Countermeasure case)

Building Conditions

Extremely small buildings such as detached houses were consolidated into a number of buildings in an attempt to simplify computational conditions and thereby facilitate calculations. Data required for radiation analysis such as data on conduction rate are indicated in Tables 5, 6. In the **countermeasure case**, greening measures such as greening of rooftops and ground areas have been taken.

Configured Date and Time

August 6th is targeted as the day for analysis. The radiation and conduction analysis and the CFD analysis are performed at 14:00 on August 6th. The CFD analysis is performed using the surface temperature of the ground and building that are used as boundary conditions at 14:00 on August 6th.

Weather Conditions

Weather conditions are taken from the AMeDAS (Automated Meteorological Data Acquisition System) data on August 6th 2002. Moreover, in the CFD analysis (14:00 August 6th), the wind direction is south, the wind velocity is 3.1m/s at a height of 76m, and the air temperature and relative humidity are set at 34.9°C and 45%.

Waste Heat Conditions

Table 7 shows the sum of the waste heat volume from the area under present conditions and in the **countermeasure case**. Under **present conditions**, it was assumed emission of waste heat takes place near the center of the roof of each building. In the **countermeasure case**, it was assumed emission of waste heat takes place only from the roof over the energy plant. The waste heat volume from each air conditioner used in the calculations is indicated in Table 8.

Table 5 conditions of materials

	Thermal conductivity [W/mK]	Volumetric specific heat [kJ/m^{3}K]
mortar	1.5	1600
concrete	1.4	1931
Plaster board	0.17	1028
rock wool board	0.06	2508
Insulation board	0.04	4.0
asphalt	0.73	1950
gravel	0.62	1500
soil	1.5	3100

Table 6 conditions of wall surfaces

	Albedo	Longwave emittance
Mortal	0.2	0.90
concrete	0.2	0.90
asphalt	0.1	0.95
External walls of very high building	0.4	0.90

Table 7 Heat waste from air conditioning system (Total)

Present condition			**Countermeasure case**（Energy Center）		
Electric air conditioner (outdoor unit)	Sensible heat (kW)	18,243	Gas Cogeneration System for air conditioning (cooling tower)	Sensible heat (kW)	4,410
	Exhaust volume (m^3)	4,378,316		Latent heat (m^3)	39,686
Gas air conditioner (cooling tower)	Sensible heat (kW)	961		Exhaust volume (m^3)	6,184,229
	Latent heat (kW)	8652	Gas Cogeneration System (chimney)	Sensible heat (kW)	3,910
	Exhaust volume (m^3)	1,281,820		Latent heat (kW)	434
Gas air conditioner (chimney)	Sensible heat (kW)	961		Exhaust volume (m^3)	20,377
	Latent heat (kW)	107	Fuel Cell	Sensible heat (kW)	1,440
	Exhaust volume (m^3)	5011		Latent heat (kW)	160
				Exhaust volume (m^3)	21,200

Table 8 Heat waste and temperature from air conditioning machines

Present		Exhaust temperature	Exhaust volume (for cooling)	**Countermeasure case** (Energy plant)		Exhaust temperature	Exhaust volume (for cooling)	Blowoff velocity
Electric air conditioner	Heat dissipation (outdoor unit)	Outdoor temp.+10°C	320 m^3/kW	Fuel Cell	Exhaust gas	48°C	5.3 m^3/kW	Depending on exhaust volume
Gas absorption chiller and heater	Heat dissipation (cooling tower)	Outdoor temp. +1°C	240 m^3/kW	Gas absorption chiller and heater	Heat dissipation (cooling tower)	Outdoor temp. ＋1°C	240 m^3/kW	25 m/s
	Exhaust gas (chimney)	200°C	1 m^3/kW		Exhaust gas (chimney)	150°C	1 m^3/kW	Depending on exhaust volume

4.2.2 Improvement of Outdoor Thermal Environment

The following shows the results of analysis of the thermal environment. A look at the temperature distribution at 1.5 meters above ground level (*Figs. 7, 8*) shows that in the **countermeasure case**, concentrating the waste heat from buildings in the energy plant has a major effect, significantly reducing the area where the temperature is 36°C or higher. Whereas the average temperature in the analysis area is 35.84°C at present, in the **countermeasure case**, it becomes 35.63°C or 0.21°C lower, although the total floor area of the countermeasure case is larger than that of the present case. This is because most of waste heat is emitted into the upper air and the configuration and the arrangement of large buildings increase the ventilation inside the city block. A look at the wind speed at ground level (*Figs. 9, 10*) shows that consolidating buildings in the **countermeasure case** has a major effect on ventilation; the average wind speed, which is 1.09 m/s at **present**, becomes a greatly improved 1.29 m/s in the future. A look at the vertical distribution of wind speed and temperature (*Figs. 11-14*) shows that in the **countermeasure case**, waste heat from the energy plant, emitted at a speed of 25 m/s, rises high into the air and has virtually no effect at ground level.

Figure 7 Ground temperature (present)

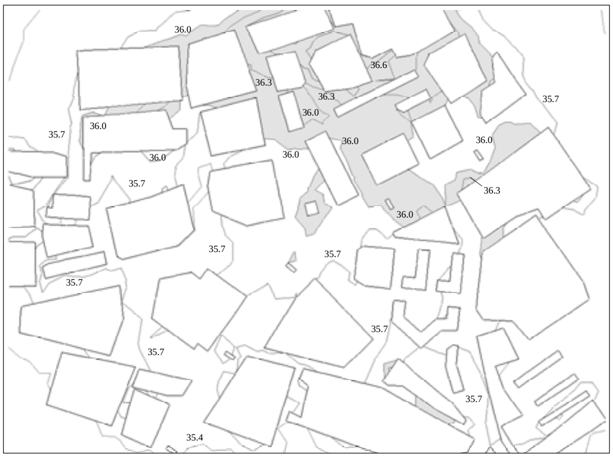


Figure 8 Ground temperature (countermeasure case)

(height 1.5m, Gray area represents temperature over 36°C)

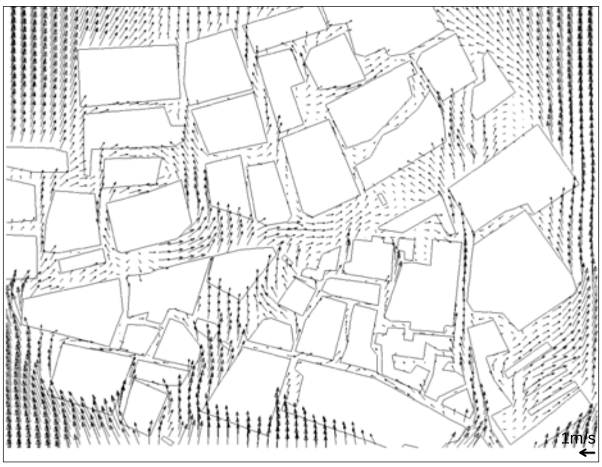


Figure 9 Wind direction and velocity (present)

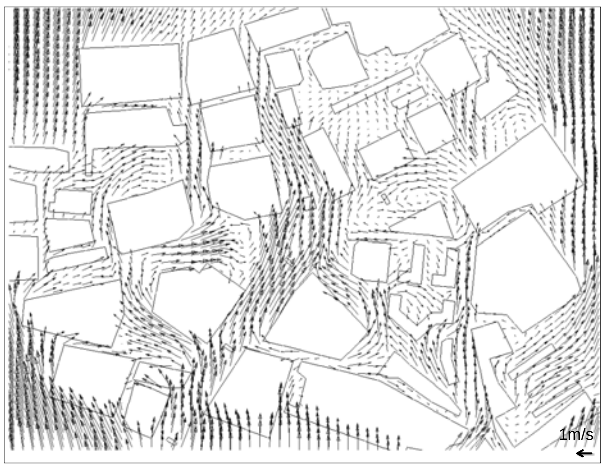


Figure 10 Wind direction and velocity (countermeasure case)

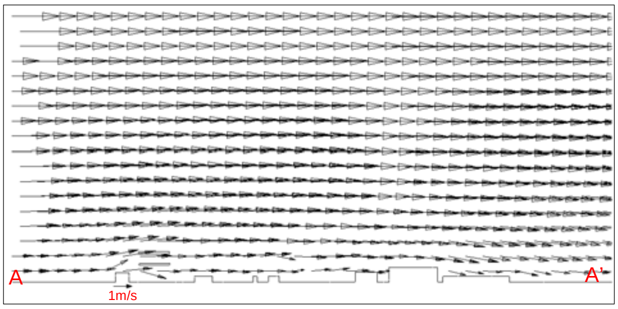


Figure 11 Wind direction and velocity (A-A' Section, present)

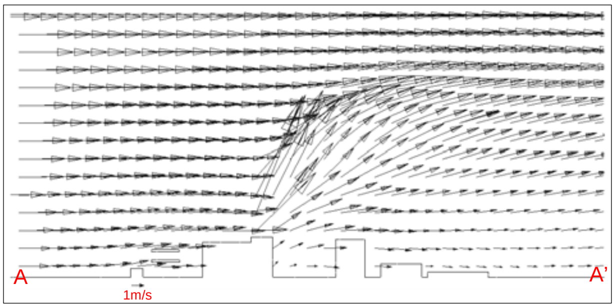


Figure 12 Wind direction and velocity (A-A' Section, countermeasure case)

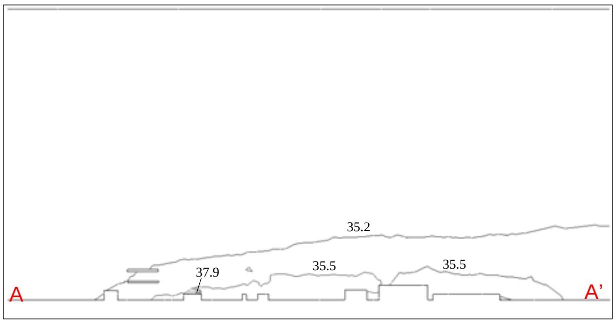


Figure 13 Air temperature (Celsius) (A-A' Section, present)

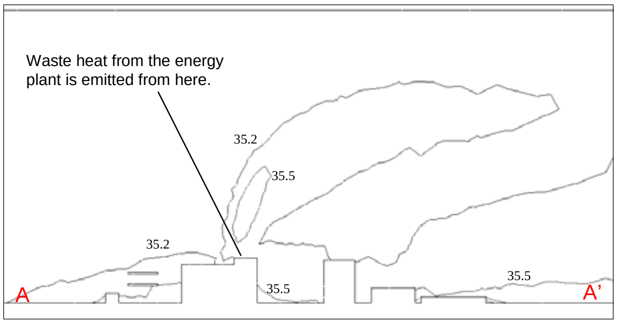


Figure 14 Air temperature (Celsius) (A-A' Section, countermeasure case)

5. Conclusion

The present research demonstrates that the introduction of distributed energy systems in a densely built-up area in Japan has an enormous effect; the **countermeasure case** results in a 29% decrease in primary energy and a 33% decrease in CO_2 compared with the **BaU case**. Moreover, the waste heat from the distributed energy systems has virtually no effect on the heat island phenomenon because it is emitted high into the upper air. Rather, changes in the configuration and arrangement of large buildings increase comfort by improving ventilation at ground level and controlling the rise in air temperature in summer.

The results of this simulation demonstrate not only that distributed energy systems can be introduced into buildings or multiple buildings but that organizing such systems into a network can contribute to the rationalization of the energy supply to a built-up area. They showed, furthermore, that if buildings are arranged in certain ways and measures such as greening are also taken, such systems can contribute to an improvement in the security of the energy supply and the enhancement of amenities in a built-up area as a whole.

Though, Many issues must still be dealt with before implementation; e.g. the problem of improving the infrastructure to make it possible to introduce new systems, and the question of how building renewal in densely built-up areas should be promoted. In the future, studies will be carried out, not only on the effect of introducing distributed energy systems, but on actual implementation measures.

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