Academic Article

Estimation of the Energy Consumption and the Exhaust Heat from Buildings

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ABSTRACT

Grasping the local energy consumption and the artificial exhaust heat is an effective response to the global warming and heat island phenomenon of recent years. In particular, the data ascribed to buildings is significant.

The aim of this study is to create distribution maps by calculating building energy consumption and the amount of exhaust heat caused by air conditioning in Fukuoka City, based on the building data from the Fukuoka City Housing & Urban Planning Bureau.

223 city blocks also have an exhaust sensible heat of more than 10.0GJ/ (ha･day), making up 19.8% of the total. It is correspondence between the areas of exhaust sensible heat with highest levels with the high air temperature ones, for example, the Tenjin district and the Hakata Station district.

Key Words : Distribution map, Energy consumption, Exhaust heat, GIS, Fukuoka City

1. Introduction

Grasping the local energy consumption and the artificial exhaust heat is an effective response to the global warming and heat island phenomenon of recent years. In particular, the data ascribed to buildings is significant.

From a point of view to the alleviation of the heat island phenomenon, it is necessary to calculate the amount of artificial exhaust heat drained from building facilities to the atmosphere, and the amount of exhaust sensible heat affecting the air temperature rise directly. Particularly, it is important that how much exhaust by sensible heat, quality of the exhaust heat grasped.

The aim of this study is to create distribution maps by calculating building energy consumption and the amount of exhaust heat caused by air conditioning in Fukuoka City, based on the building data from the Fukuoka City Housing & Urban Planning Bureau.

Fukuoka City faces Hakata Bay, it was developed as the largest commercial city on Kyushu Island, Japan.

According to the Fukuoka Meteorological Observatory in Japan, the annual mean temperature of the latest 10 years rises at 1.1 ℃ compared with 30 years ago in Fukuoka City.

The temperature distribution map when heat island phenomenon is typically observed is shown in Figure 1 [(1)].

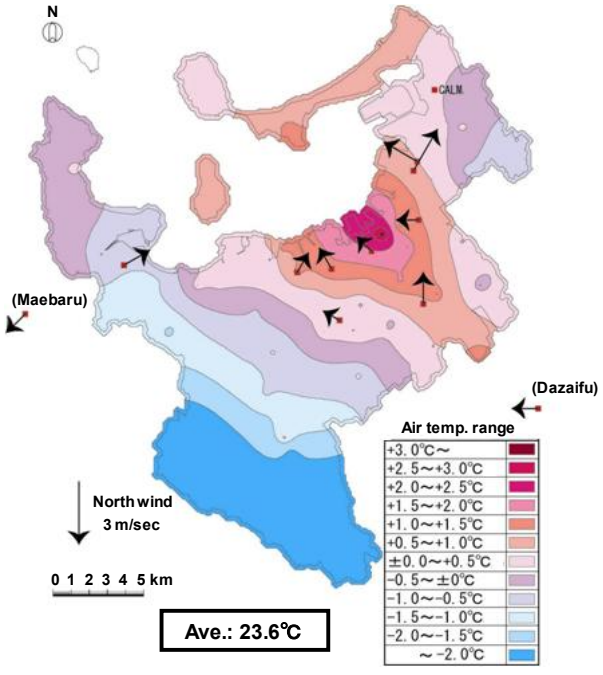
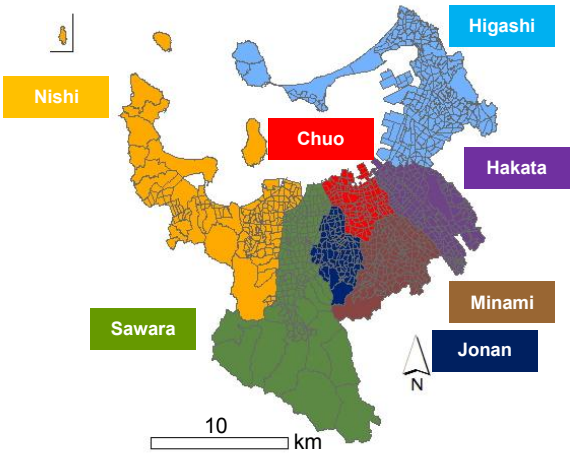


Fig. 1 Temperature distribution map when heat island phenomenon is typically observed

(05:00 a.m., 5th Sep., 2003)

Fugure 2 shows the area and population at seven wards in Fukuoka City as of 30th April, 2014 [(2)].



Ward	Area	Population	Num. of city block
Chuo	15.16 km^2	178,890	123
Hakata	31.47 km^2	213,416	209
Higashi	67.98 km^2	295,943	226
Minami	30.98 km^2	253,253	161
Jonan	16.02 km^2	122,850	95
Sawara	95.88 km^2	214,831	170
Nishi	83.83 km^2	200,065	140
Total	341.32 km^2	1,479,248	1,124

Fig. 2 The wards in Fukuoka City

2. Basic surveys concerning city planning

The 'Basic Surveys Concerning City Planning' is carried out by the Fukuoka City Housing & Urban Planning Bureau. Data on the present conditions of buildings for analysis were provided by the Bureau. The building activity codes within the Basic Surveys Concerning City Planning and the building activity corresponding to their base units are shown in Table 1.

3. Base units

3.1 Primary energy consumption per unit area by building activity

In order to calculate the energy consumption of each building, the amount of primary energy consumption per unit area by building activity code was sought. As the basic data, the results from a questionnaire carried out in Fukuoka City that targeted 416 business and others were used [(3)]. Furthermore, because residences were not included in the previously mentioned questionnaire, survey results from another study on Fukuoka City were used.

Table 1 The building activity codes within the Basic Surveys Concerning City Planning and the building activity corresponding to their base units

Building activity		Building activity of primary energy consumption made to correspond	Building activity of exhaust heat made to correspond
1	Business facilities	Office	Office
2	Commercial facilities	Commercial	Commercial
3	Accommodations	Hotel	Hotel
4	Recreational facilities	Commercial	Commercial
5	Amusement facilities	Commercial	Commercial
6	Commercial use compound facilities	Commercial	Commercial
7	Dwelling houses	Residence	Dwelling house
8	Apartment houses	Residence	Apartment house
9	Dwelling houses combined with store	Residence	Dwelling house
10	Apartment houses combined with store	Residence	Apartment house
11	Work place combination apartment houses	Residence	Apartment house
12	Government and public office facilities	Government and public office	Government and public office
13	Education welfare facilities (A)	Health care	Health care
14	Education welfare facilities (B)	Education	Education
15	Transportation warehouse facilities	Others	Total average
16	Heavy industries facilities	Others	Total average
17	Light industries facilities	Others	Total average
18	Service industry facilities	Others	Total average
19	Household industry facilities	Others	Total average
20	Dangerous materials storage, processing facilities	Others	Total average
21	Agriculture, forestry, and fishery facilities	Others	Total average
22	Others	Others	Total average

Table 2 Primary energy consumption per unit area

Building activity	Fukuoka City	Japan (reference) [(4)]	Unit
Office	2.328	2.303	GJ/ (m^2·year)
Commercial	2.362	3.266	GJ/ (m^2·year)
Hotel	3.125	3.167	GJ/ (m^2·year)
Health care	2.876	3.371	GJ/ (m^2·year)
Education	0.965	1.494	GJ/ (m^2·year)
Government and public office	1.649	1.489	GJ/ (m^2·year)
Residence	66.0	—	GJ/ (house·year)
Others	2.191	2.080	GJ/ (m^2·year)

As shown in Table 2, Making a comparison primary energy consumption per unit area in Fukuoka City with the national average, the big difference is not permitted[4].

Primary energy consumption in August due to air conditioning, which was used to calculate building exhaust heat in August, is also shown in Table 3 by building activity code. For each building, primary energy consumption from March to May was subtracted from primary energy consumption in August as shown in Figure 3. These values were then divided by the total floor area, totaled by building activity and then averaged.

Table 3 Primary energy consumption per unit area in August due to air conditioning

Building activity	Energy consumption per unit area [GJ/ (m^2·month)]	Energy consumption per unit area due to air conditioning [GJ /(m^2·month)]	Source
Office	0.248	0.072	(3)
Commercial	0.292	0.114	
Hotel	0.295	0.051	
Health care	0.258	0.090	
Education	0.127	0.039	
Government and public office	0.169	0.063	
Residence	0.800	0.039	(6)
Others	0.620	0.063	
Total average	0.351	0.066	

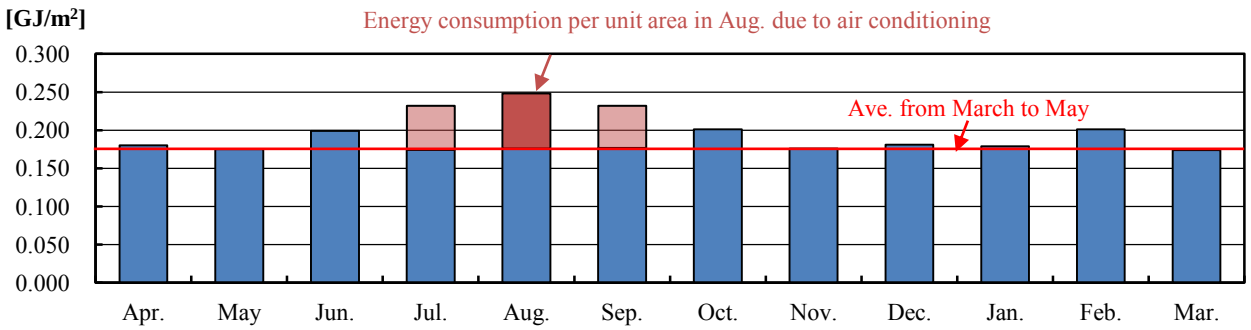


Fig. 3 The estimation way of the primary energy consumption per unit area in August due to air conditioning

3.2 Exhaust heat per unit area caused by air Conditioning

The exhaust heat per unit area caused by air conditioning was found based on the amount of primary energy consumption by air conditioning. The process used is as follows:

1) The amount of primary energy consumption per unit area by air conditioning was proportionally divided by the component ratio of the heat source device.
2) Using the Coefficient of Performance, COP, for each heat source device, the amount of primary energy consumption per unit area for each heat source device was converted to the exhaust heat per unit area.
3) Using the sensible heat to latent heat ratio of exhaust heat for each heat source device, the exhaust heat per unit area was allocated to the exhaust sensible heat per unit area and the exhaust latent heat per unit area.
4) The exhaust heat per unit area, the sensible heat per unit area, and the latent heat per unit area for each building activity were found by calculating the sum of total exhaust heat, the exhaust sensible heat, and the exhaust latent heat for each heat soruce device.

The heat source device COP was established based on pre-existing references as shown in Table 5.

The sensible heat to latent heat ratio of the exhaust heat from heat source devices was established as shown in Table 6 via reference [7].

Calculation results for the exhaust heat per unit area caused by air conditioning for each building activity are as shown in Table 7.

Furthermore, as residences were not the subject of the Fukuoka City survey [4] and are difficult to estimate in the same manner as other data, the calculation results for the exhaust heat per unit area found in reference [6] were used as shown in Table 8. In this case, all air conditioning systems were treated as household use room air conditioners and all exhaust heat was treated as sensible heat emission.

Table 4 Heat source equipments by building activities

Building activity	Absorption chiller and heater	Absorption refrigerator + Steam boiler	Air cooled chiller	Water cooled chiller
Office (N=153)	375,920 (16.3%)	60,314 (2.6%)	368,741 (16.0%)	135,461 (5.9%)
Commerce (N= 61)	389,983 (34.9%)	0 (0.0%)	62,869 (5.6%)	64,308 (5.8%)
Hotel (N= 8)	56,306 (13.8%)	85,964 (21.1%)	0 (0.0%)	14,971 (3.7%)
Health care (N= 8)	62,169 (18.7%)	17,118 (5.1%)	66,175 (19.9%)	53,765 (16.2%)
Education (N= 6)	276,522 (22.9%)	0 (0.0%)	0 (0.0%)	266,577 (22.1%)
Research institute (N= 4)	7,826 (33.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Government and public office (N= 32)	133,875 (49.1%)	25,812 (9.5%)	9,843 (3.6%)	0 (0.0%)
Total (N=272)	1,302,601 (23.0%)	189,208 (3.3%)	507,628 (9.0%)	535,082 (9.5%)

Building activity	Turbo refrigerating machine	Gas heat pump	Multiple-air conditioner for building	Heat storage type air conditioning
Office (N=153)	205,175 (8.9%)	47,840 (2.1%)	888,533 (38.6%)	217,292 (9.5%)
Commerce (N= 61)	108,446 (9.7%)	3,400 (0.3%)	370,238 (33.2%)	117,007 (10.5%)
Hotel (N= 8)	0 (0.0%)	0 (0.0%)	249,397 (61.3%)	0 (0.0%)
Health care (N= 8)	38,730 (11.6%)	23,439 (7.1%)	56,028 (16.9%)	15,036 (4.5%)
Education (N= 6)	0 (0.0%)	322,498 (26.7%)	340,174 (28.2%)	0 (0.0%)
Research institute (N= 4)	0 (0.0%)	7,826 (33.3%)	0 (0.0%)	7,826 (33.3%)
Government and public office (N= 32)	0 (0.0%)	24,731 (9.1%)	50,739 (18.6%)	27,733 (10.2%)
Total (N=272)	352,350 (6.2%)	429,735 (7.6%)	1,955,110 (34.6%)	384,893 (6.8%)

Table 5 COP of heat source equipment

Heat source equipment	COP	Source
Absorption chiller and heater	0.83	(6)
Absorption refrigerator + Steam boiler	0.83	(6)
Air cooled chiller	3	(6)
Water cooled chiller	4	(6)
Turbo refrigerating machine	4	(6)
Gas heat pump	1.3	(7)
Multiple-air conditioner for building	3.5	(6)
Heat storage type air conditioning	2.2	(8)

Table 6 Sensible-latent heat ratio of exhaust heat from heat source equipment

Heat source equipment	Sensible-latent heat ratio		Conditions of data
	Sensible heat	Latent heat	
Absorption chiller and heater	0.13	0.87	Gas boiler + Steam absorption refrigerator
Absorption refrigerator + Steam boiler	0.13	0.87	Gas boiler + Steam absorption refrigerator
Air cooled chiller	1.00	0.00	Air heat source heat pump
Water cooled chiller + Boiler	0.10	0.90	Motor-driven turbo refrigerator
Turbo refrigerating machine + Boiler	0.10	0.90	Motor-driven turbo refrigerator
Gas heat pump	0.95	0.05	Gas heat pump multiple-air conditioner for building
Electric heat pump (Multiple-air conditioner for building)	1.00	0.00	Motor-driven multiple-air conditioner for building
Heat storage type air conditioning	0.50	0.50	Because diffusion rate of water cooling and air cooling were unidentified, we assumed LH and RH the same ratio.

Table 7 Exhaust heat per unit area in August due to air conditioning

Building activity	Exhaust sensible heat per unit area [MJ/ (m^2·day)]	Exhaust latent heat per unit area [MJ/ (m^2·day)]
Office	2.058	1.399
Commerce	2.573	3.396
Hotel	1.465	1.178
Health care	2.136	2.353
Education	1.140	0.895
Government and public office	1.375	2.459
Total average	1.939	1.719

Table 8 Exhaust heat per unit area of dwelling house and apartment house

Building activity	Exhaust heat per unit area [MJ/ (m^2·day)]
Dwelling house	0.704
Apartment house	0.896

4. Calculated results

4.1 Total floor area of each building activity

Table9 shows the total floor area of each building activity.

Fukuoka City is a total of 100.6×10^6 m^2. Of all building activities, 'apartment houses' are the most prevalent and make up 41.8% (42.0×10^6 m^2). 'dwelling houses' are 22.5% (22.6×10^6 m^2) and 'offices' are 9.8% (9.9×10^6 m^2).

Table 9 Total floor area of each building activity

	Office		Commerce		Hotel		Health care		Education	
Chuo	2,744,824	16.4%	1,570,642	9.4%	630,140	3.8%	478,201	2.9%	752,675	4.5%
123	27.8%		25.2%		47.1%		13.1%		13.1%	
Hakata	4,390,712	21.9%	1,634,073	8.1%	568,397	2.8%	408,001	2.0%	901,282	4.5%
209	44.5%		26.2%		42.5%		11.2%		15.7%	
Higashi	1,298,650	6.4%	995,913	4.9%	64,998	0.3%	1,193,293	5.9%	1,057,127	5.2%
226	13.2%		16.0%		4.9%		32.7%		18.5%	
Minami	437,316	3.3%	433,021	3.2%	9,619	0.1%	476,586	3.5%	852,197	6.3%
161	4.4%		7.0%		0.7%		13.1%		14.9%	
Jonan	128,822	1.9%	256,401	3.7%	3,614	0.1%	483,919	7.0%	425,691	6.2%
95	1.3%		4.1%		0.3%		13.3%		7.4%	
Sawara	541,556	4.6%	543,058	4.6%	3,308	0.0%	383,941	3.2%	949,503	8.0%
170	5.5%		8.7%		0.2%		10.5%		16.6%	
Nishi	314,420	2.7%	792,368	6.9%	58,161	0.5%	224,319	2.0%	787,884	6.9%
140	3.2%		12.7%		4.3%		6.1%		13.8%	
Total(1,124)	9,856,300	9.8%	6,225,476	6.2%	1,338,237	1.3%	3,648,260	3.6%	5,726,359	5.7%

	Government and public office		Apartment house		Dwelling house		Others		Total
Chuo	333,717	2.0%	7,987,388	47.8%	1,384,819	8.3%	824,718	4.9%	16,707,124
123	27.5%		19.0%		6.1%		10.4%		16.6%
Hakata	386,025	1.9%	7,642,335	38.1%	1,932,132	9.6%	2,206,719	11.0%	20,069,676
209	31.8%		18.2%		8.5%		27.9%		20.0%
Higashi	166,244	0.8%	7,367,260	36.5%	4,589,060	22.8%	3,438,305	17.0%	20,170,850
226	13.7%		17.5%		20.3%		43.4%		20.1%
Minami	83,835	0.6%	6,563,869	48.9%	4,233,639	31.5%	336,392	2.5%	13,426,474
161	6.9%		15.6%		18.7%		4.2%		13.4%
Jonan	21,752	0.3%	3,280,992	47.5%	2,239,864	32.4%	67,358	1.0%	6,908,413
95	1.8%		7.8%		9.9%		0.9%		6.9%
Sawara	152,736	1.3%	5,145,457	43.4%	3,898,912	32.9%	234,858	2.0%	11,853,329
170	12.6%		12.2%		17.2%		3.0%		11.8%
Nishi	70,639	0.6%	4,039,259	35.3%	4,337,469	37.9%	812,115	7.1%	11,436,634
140	5.8%		9.6%		19.2%		10.3%		11.4%
Total(1,124)	1,214,948	1.2%	42,026,560	41.8%	22,615,895	22.5%	7,920,465	7.9%	100,572,500

Ward	Unit area	Ratio for the whole ward
Num. of city block	Ratio for the whole city	

4.2 Primary energy consumption

Figure 3 shows the annual primary energy consumption for each ward in Fukuoka City by multiplying the primary energy consumption per unit area shown in Table 2 by the total floor area for each building activity.

The result is 120258.1 TJ/year (102905.0 TJ/year when excluding 'others') for Fukuoka City as a whole. Hakata Ward makes up 25.1% (30240.4 TJ/year), Higashi Ward makes up 21.6% (25974.0 TJ/year) and Chuo Ward makes up 18.8% (22561.6 TJ/year).

The annual primary energy consumption calculated from a real energy consumption of residential sector is 42641.4 TJ/year, and one of commercial and others sector is 56747.7 TJ/year. They make a little difference with the result mentioned above (Note 1).

Figure 4 shows the annual primary energy consumption per 1 ha of land area for each city block in descending order.

Fukuoka City as a whole has an average of 5.5 TJ/ (ha･year). The ward with the highest consumption is Chuo Ward with 14.8 TJ/ (ha･year), then Hakata Ward with 9.6 TJ/ (ha･year), then Minami Ward with 4.0 TJ/ (ha ･ year). Yakuinifuku-machi, Chuo Ward has the largest amount with 108.1 TJ/ (ha･year), then Tenjin 1-chome with 98.0 TJ/ (ha･year), and Tenjin 2-chome with 90.6 TJ/ (ha･year).

4.3 Amount of exhaust heat caused by air conditioning

Figure 5 shows the daily amount of exhaust heat caused by air conditioning in August for each ward. For Fukuoka City as a whole, this is 19009 GJ/day (sensible heat: 123189 GJ/day; latent heat: 66819 GJ/day). Hakata Ward makes up 25.2%, Higashi Ward makes up 21.7% (41160 GJ/day) and Chuo Ward makes up 19.3% (36636 GJ/day).

Figure 6 shows the daily amount of exhaust sensible heat in August caused by air conditioning in August per 1 ha of land area for each city block in descending order.

Fukuoka City as a whole has an average of 3.6 GJ/ (ha･day). The ward with the highest level is Chuo Ward with 14.8 GJ/ (ha･day), then Hakata Ward with 9.2 GJ/ (ha･day), and Jonan Ward with 4.4 GJ/ (ha･day). A ratio of exhaust sensible heat from residences is high in Minami Ward and Jonan Ward. Because Higashi Ward has a harbor district, the ratio from 'others' is high. The highest levels are found at Tenjin 1-chome, Hakata Ward with 90.9 GJ/ (ha･day), then Tenjin 2-chome, Hakata Ward with 86.6 GJ/ (ha･day), and Nakasu 3-chome, Chuo Ward with 75.1 GJ/ (ha･day).

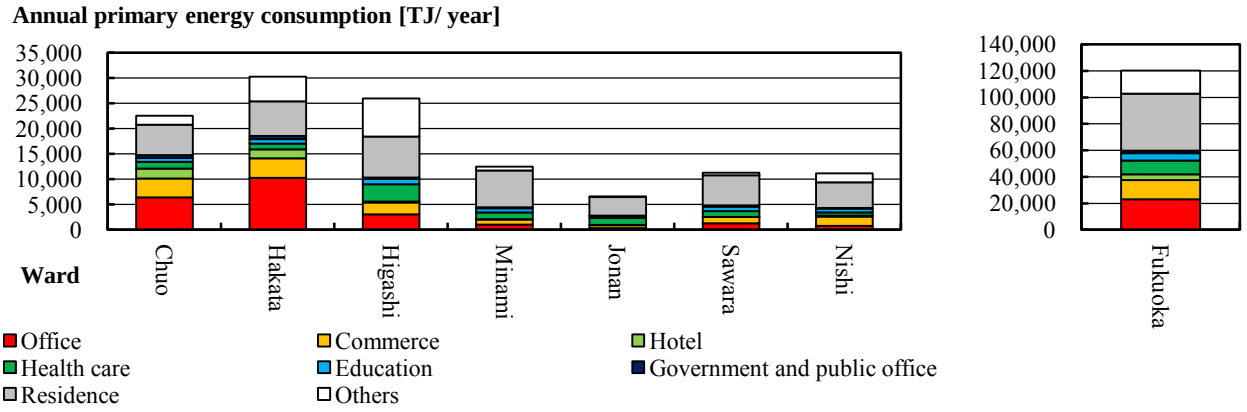


Fig. 3 Annual primary energy consumption for each ward in Fukuoka City

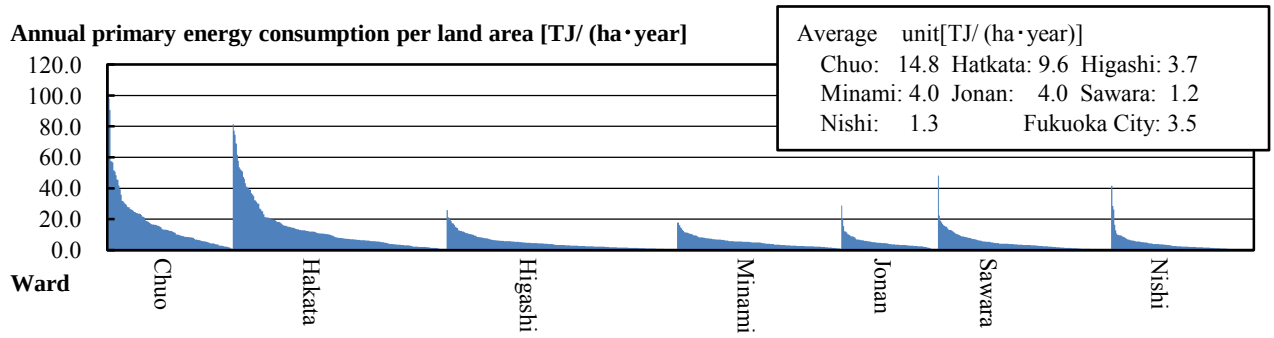


Fig. 4 Annual primary energy consumption per land area for each city block

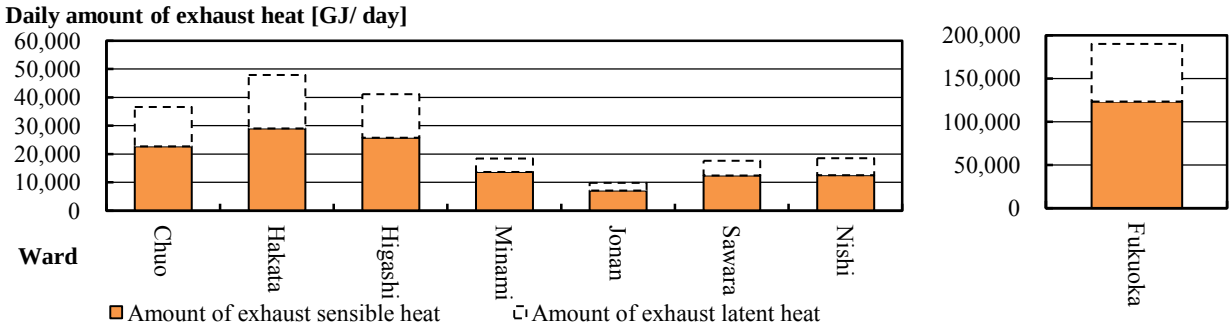


Fig. 5 Daily amount of exhaust heat caused by air conditioning for each ward

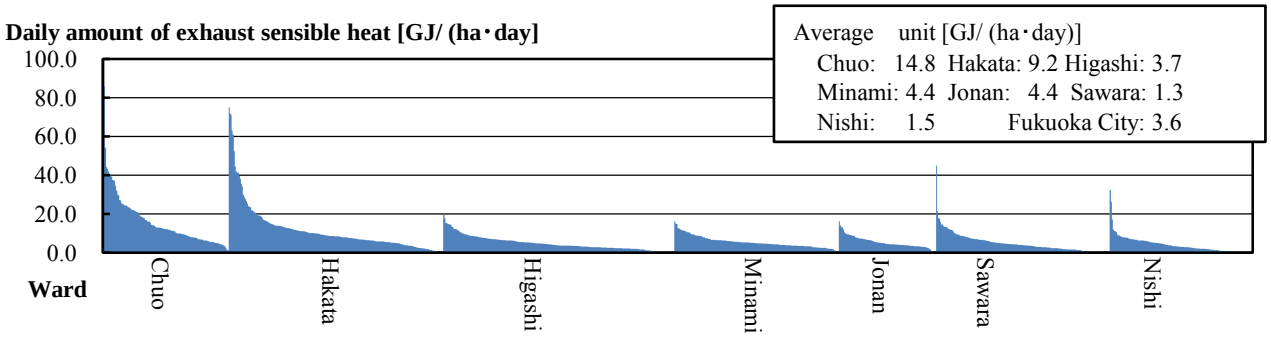


Fig. 6 Daily amount of exhaust sensible heat in August caused by air conditioning per land area for each city block

5. Distribution maps for total floor area of each building activity, primary energy consumption and exhaust heat

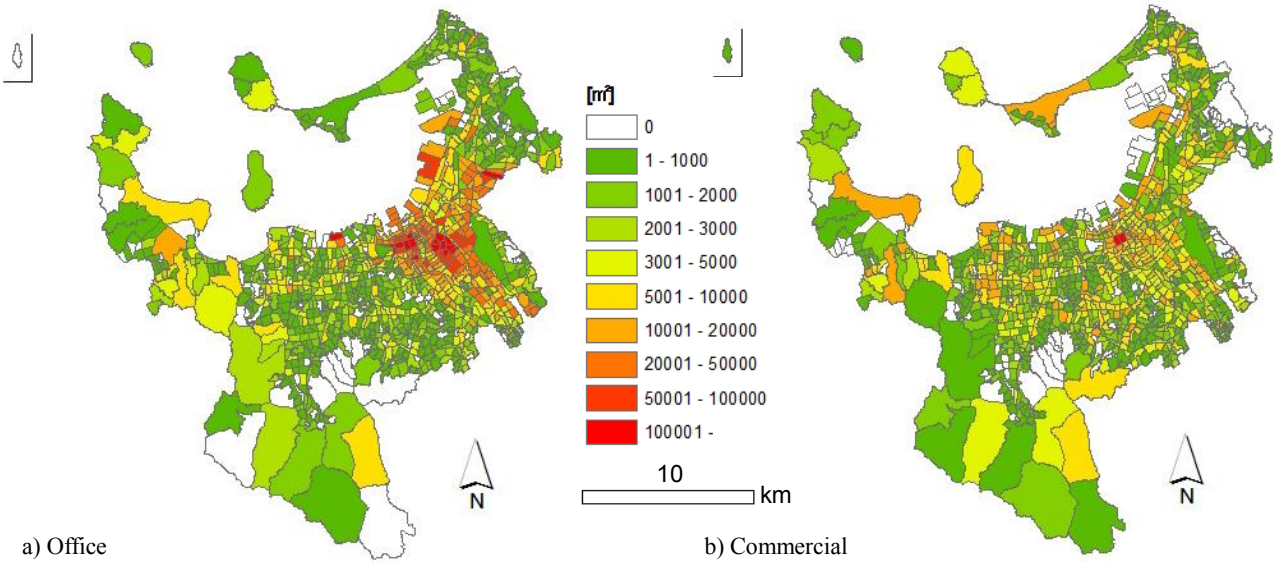
Figure 7 are distribution maps for total floor area of each building activity.

Figures 8 is distribution map for primary energy consumption per land-use area calculated in Chapter 4. For primary energy consumption, 609 city blocks have more than 4TJ/ (ha・year) and are viewed as likely to have district of heating and cooling, making up 54.2% of the total.

Figures 9, Figure 10 and Figure 11 are distribution maps for exhaust heat caused by air conditioning in August per land-use area calculated in Chapter 4.

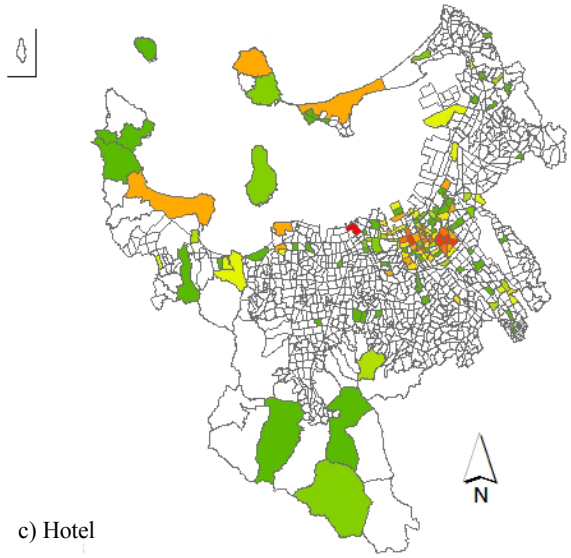
It is 223 city blocks also have an exhaust sensible heat of more than 10.0GJ/ (ha・day), making up 19.8% of the total. correspondence between the areas of exhaust sensible heat with highest levels with the high air temperature ones, for example, the Tenjin district and the Hakata Station district.

91 city blocks also have an exhaust latent heat of more than 10.0GJ/ (ha・day), making up 8.1% of the total.

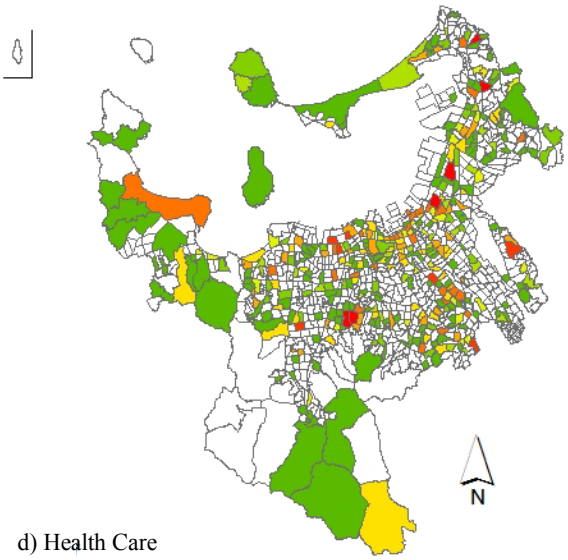


a) Office b) Commercial

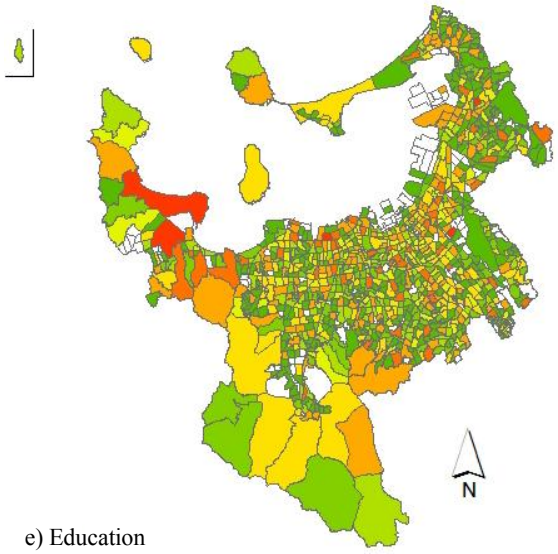
Fig. 7 Distribution maps for total floor area of each building activity



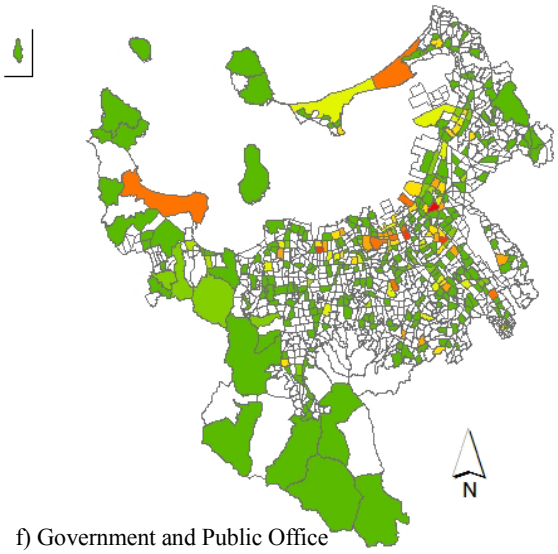
c) Hotel



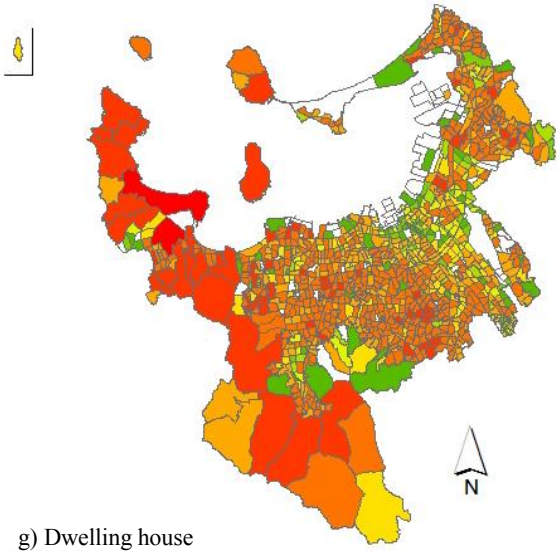
d) Health Care



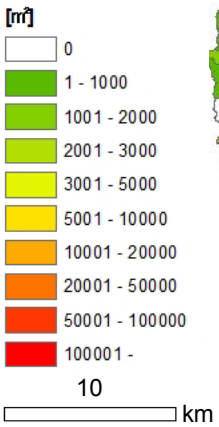
e) Education

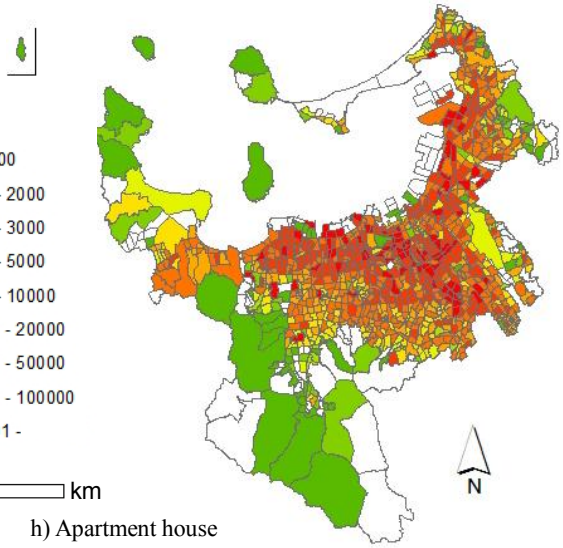


f) Government and Public Office



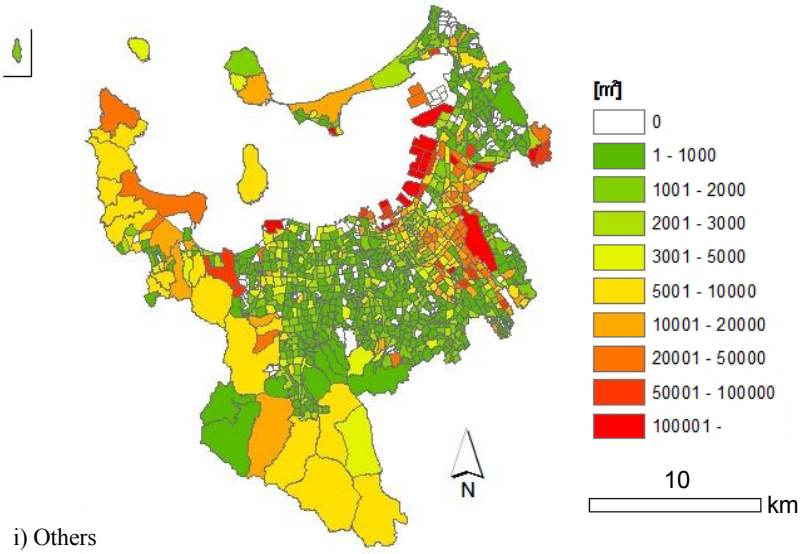
g) Dwelling house





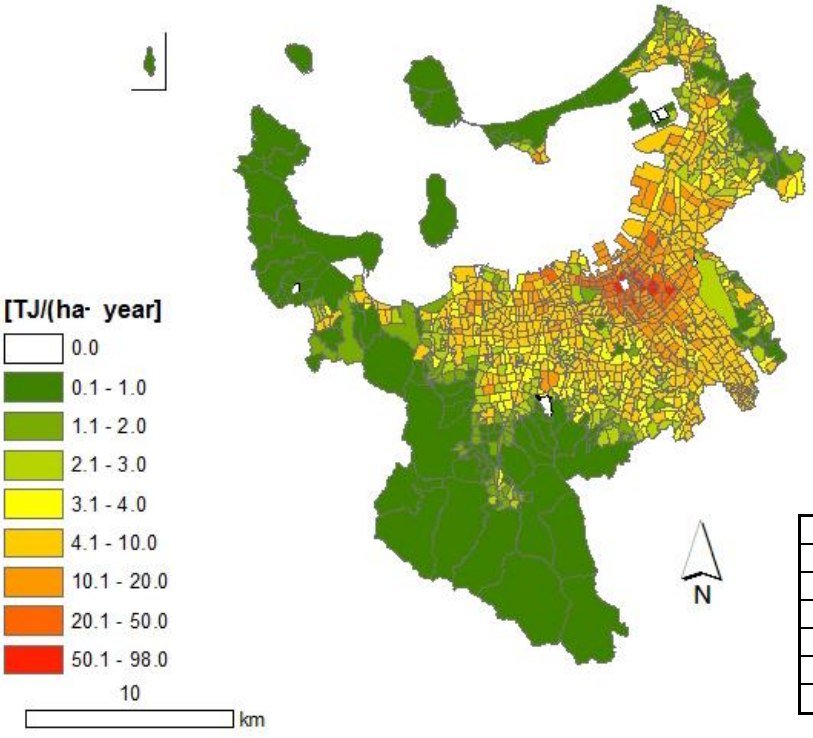
h) Apartment house

Fig. 7 Distribution maps for total floor area of each building activity (continued)



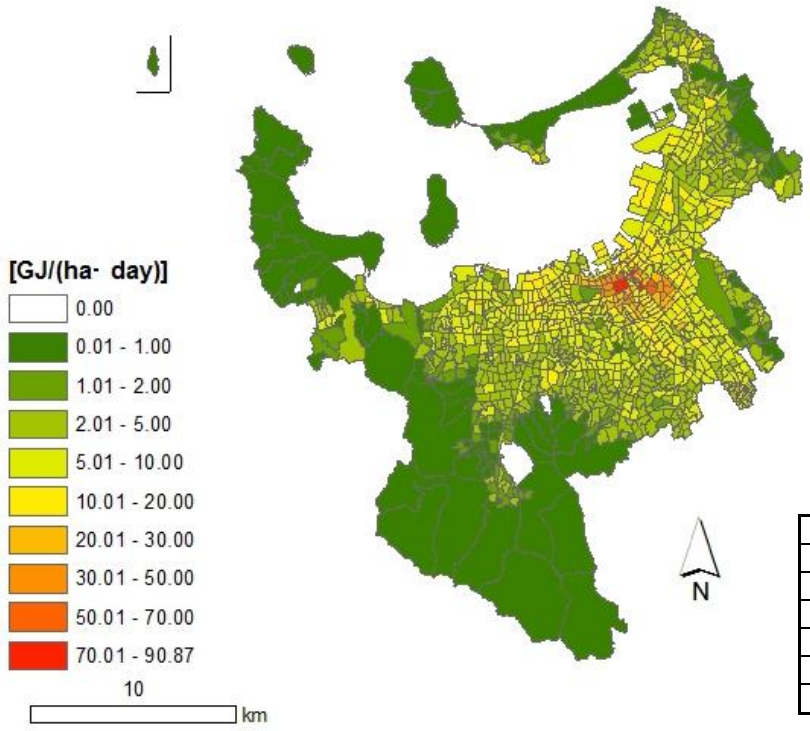
i) Others

Fig. 7 Distribution maps for total floor area of each building activity (continued)



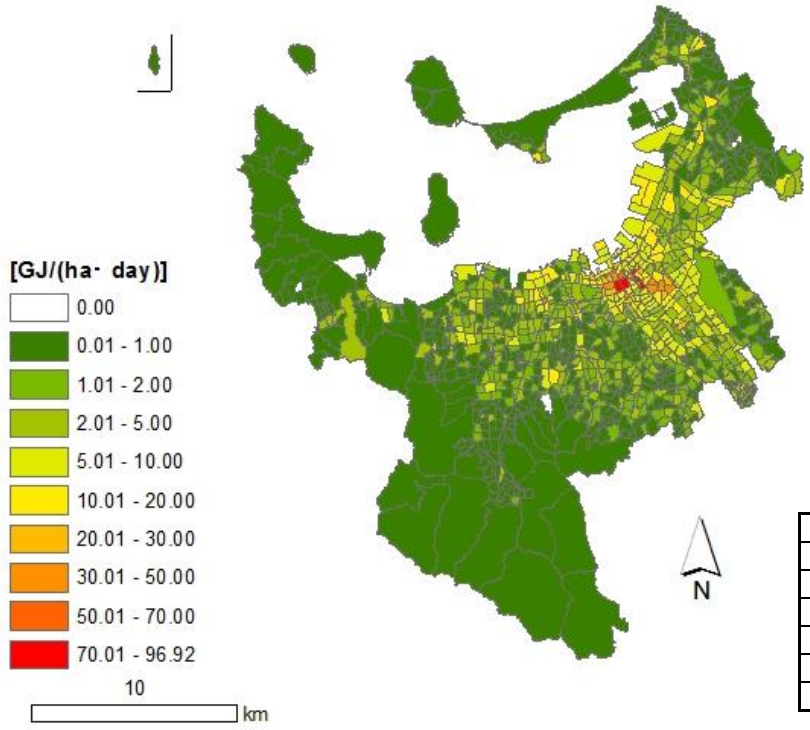
Number of data	1,124
Minimum	0.00 TJ/(ha･year)
Maximum	98.0 TJ/(ha･year)
Total	8055.6 TJ/(ha･year)
Average	7.2 TJ/(ha･year)
Median	4.6 TJ/(ha･year)
Standard deviation	9.5 TJ/(ha･year)

Fig. 8 Distribution map for primary energy consumption per land area



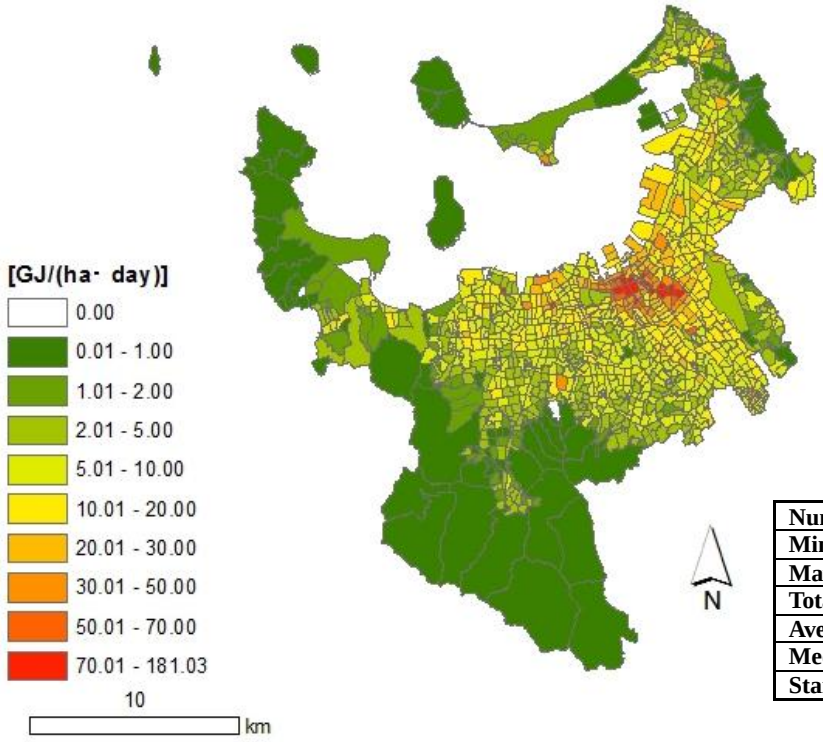
Number of data	1,124
Minimum	0.00 GJ/(ha·day)
Maximum	90.87 GJ/(ha·day)
Total	8352.64 GJ/(ha·day)
Average	7.43 GJ/(ha·day)
Median	5.16 GJ/(ha·day)
Standard deviation	8.88 GJ/(ha·day)

Fig. 9 Distribution map for exhaust sensible heat caused by air conditioning in August



Number of data	1,124
Minimum	0.00 GJ/(ha·day)
Maximum	96.92 GJ/(ha·day)
Total	4346.12 GJ/(ha·day)
Average	3.86 GJ/(ha·day)
Median	1.40 GJ/(ha·day)
Standard deviation	8.40 GJ/(ha·day)

Fig. 10 Distribution map for exhaust latent heat caused by air conditioning in August



Number of data	1,124
Minimum	0.00 GJ/(ha·day)
Maximum	181.03 GJ/(ha·day)
Total	12698.75 GJ/(ha·day)
Average	11.30 GJ/(ha·day)
Median	6.73 GJ/(ha·day)
Standard deviation	16.96 GJ/(ha·day)

Fig. 11 Distribution map for exhaust total heat caused by air conditioning in August

6. Conclusion

In this paper, based on the building data from the Fukuoka City Housing & Urban Planning Bureau, building energy consumption and exhaust heat caused by air conditioning were calculated for Fukuoka City and shown on distribution maps. In the future, we will use this building data to understand the precise details of actual energy consumption, exhaust heat, and other issues.

Notes

1) The real energy consumption in Fukuoka City in FY2007

Table 10. The energy consumption in Fukuoka City in FY2007

(a) Residential sector

	Energy consumption		Energy Unit		Energy consumption [TJ]
Electricity	3466.5	10^6 kWh	9.97	MJ/kWh	34560.5
City gas	12736.0	10^3 m^3	40.046	MJ/m^3	5100.9
LPG	9015.7	10^3 m^3	100.5	MJ/m^3	906.1
Kerosine	56.4	10^3 kL	36.74	MJ/L	2073.8
Total					42641.4

(b) Commercial and others sector

	Energy consumption		Energy Unit		Energy consumption [TJ]
Electricity	4433.2	10^6 kWh	9.97	MJ/kWh	44199.2
City gas	98127.0	10^3 m^3	40.046	MJ/m^3	3929.6
Heavy oil	130.5	10^3 kL	39.1	MJ/L	5103.1
Kerosine	95.7	10^3 kL	36.74	MJ/L	3515.8
Total					56747.7

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