Department of Environment Systems
Graduate School of Frontier Sciences
The University of Tokyo

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Master's Thesis

Finding the optimal operation of air conditioners in Tokyo's office districts focusing on total environmental impacts including labor productivity loss

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指導教員：　井原　智彦　准教授

Supervisor: Tomohiko IHARA Associate Professor

薛　雲飛

XUE Yunfei

Content

1. Background

1.1 Global warming

With the progress of global warming, the deviation of the average temperature of the world in the year 2021 (average near-surface temperature and sea surface temperature on the land) was 0.22 ℃, and it was the sixth highest since the start of the statistics in 1891[1]. As shown in Fig.1-1, the annual average temperature in the world has risen 0.73 ℃ for 100 years by repeating various fluctuations, especially after the mid-1990s, the years of high temperature gradually increased [1].

According to the data of the Bureau of Environment, Tokyo Metropolitan Government, the annual average temperature in Tokyo has increased by about 3 ℃ in the past 100 years[2]. For workers in Tokyo's urban areas, the rising temperature will change their working environment, exposing them to high temperatures.

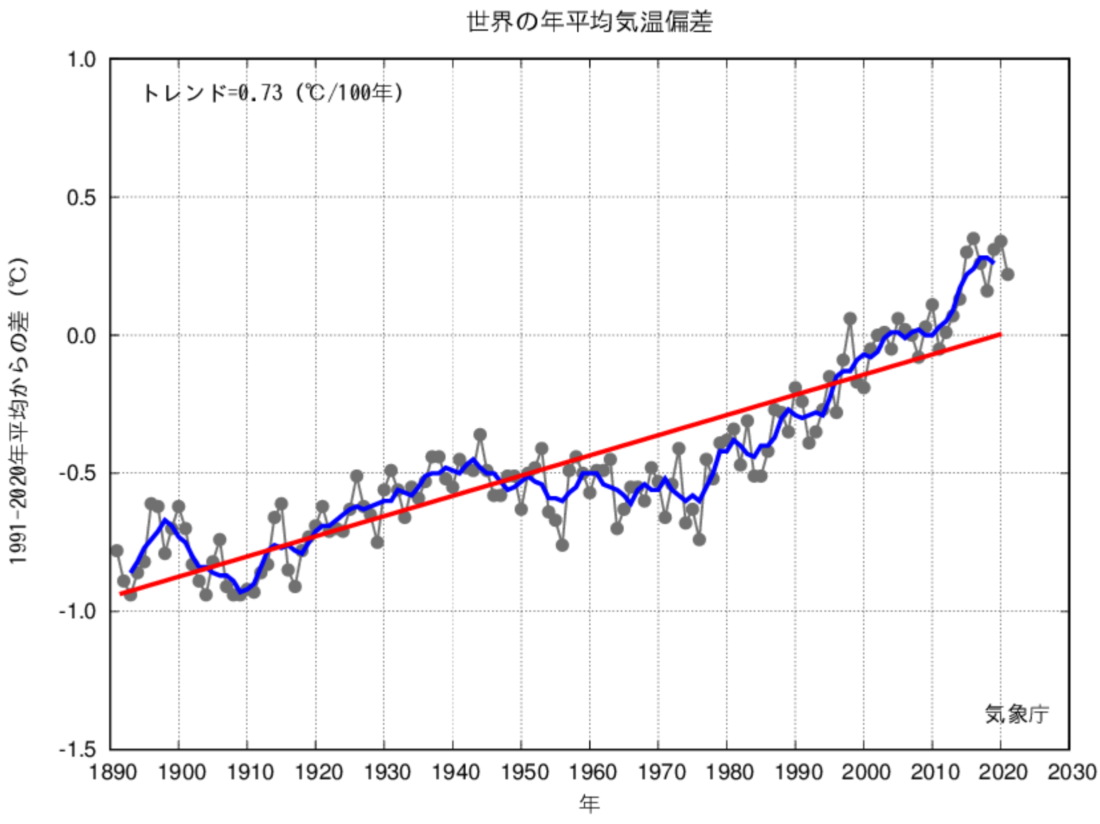


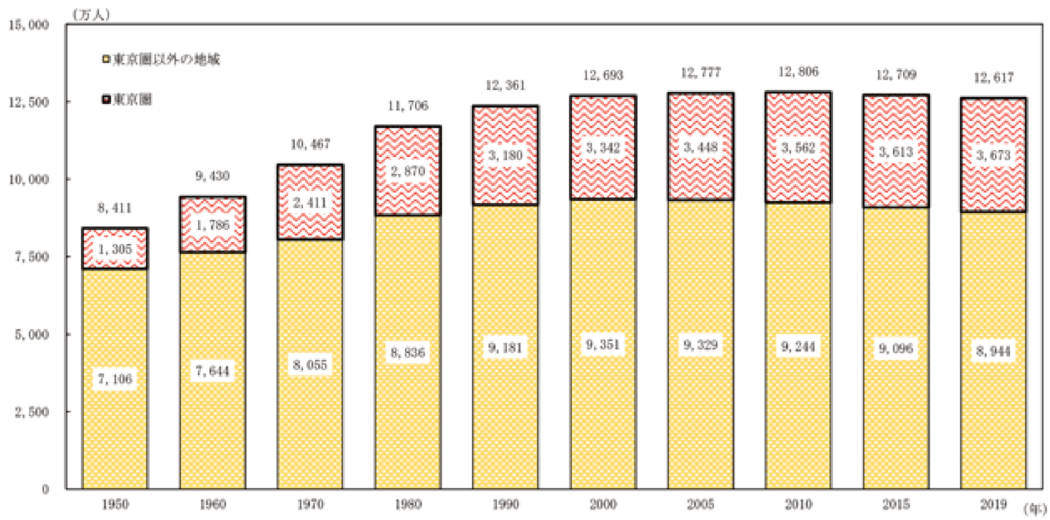
Fig.1-1Deviation of world annual average temperature (1891 ~ 2021)[1]

1.2 Heat Island effect

The heat island effect refers to the phenomenon that the temperature in urban areas is higher than that in suburban areas. In Tokyo, compared with global warming, the temperature rise in urban areas caused by the heat island effect are even more obvious [3]. The heat island effect will be aggravated by the heat from traffic and AC in urban areas, which undoubtedly makes the labor force in urban areas of Tokyo more vulnerable to high-temperature damage.

1.3 Population aggregation in Tokyo

In the past 70 years, the population aggregation in Tokyo has continued. By 2019, the population of Tokyo circle has reached 37million [4]. Many people gather, which means that the high temperature in Tokyo in summer will bring harm to the labor productivity of a large number of workers and cause huge economic losses.



(東京都及び東京圏の人口が総人口に占める割合) (%)

	1950年	1960年	1970年	1980年	1990年	2000年	2005年	2010年	2015年	2019年
東京圏	15. 5	18. 9	23. 0	24. 5	25. 7	26. 3	27. 0	27. 8	28. 4	29. 1
(東京都)	7. 5	10. 3	10. 9	9. 9	9. 6	9. 5	9. 8	10. 3	10. 6	11. 0

(備考) 総務省「国勢調査」(1950～2015 年)、総務省「人口推計」(2019 年) により作成。

Fig.1-2 Population changes in Tokyo [4]

1.4 Office labor in Tokyo

Tokyo has become the largest metropolitan area in Japan and has also gathered the largest number of employed people. As shown in Table.1-1[5], the working population of Tokyo is 8.397 million, accounting for 12.2% of the whole country.

Table.1-1 Employment status, male and female population over 15 years old [5]

表1　就業状態、男女別15歳以上人口

〔単位：東京都(千人)、全国(万人)、%、ポイント〕

就業状態		実数			対前年 増減数			対前年 増減率		
		男女計	男	女	男女計	男	女	男女計	男	女
東京都（千人）	15歳以上人口	12,386	6,046	6,340	−23	−21	−2	−0.2	−0.3	−0.0
	労働力人口	8,397	4,628	3,769	35	−10	45	0.4	−0.2	1.2
	就業者数	8,146	4,471	3,674	42	−14	55	0.5	−0.3	1.5
	完全失業者数	252	157	95	−6	4	−10	−2.3	2.6	−9.5
	非労働力人口	3,979	1,413	2,566	−60	−13	−47	−1.5	−0.9	−1.8
	労働力人口比率	67.8	76.5	59.4	0.4	0.1	0.7	…	…	…
	就業率	65.8	73.9	57.9	0.5	0.0	0.8	…	…	…
	完全失業率	3.0	3.4	2.5	−0.1	0.1	−0.3	…	…	…
全国（万人）	15歳以上人口	11,044	5,332	5,711	−36	−22	−15	−0.3	−0.4	−0.3
	労働力人口	6,860	3,803	3,057	−8	−20	13	−0.1	−0.5	0.4
	就業者数	6,667	3,687	2,980	−9	−22	12	−0.1	−0.6	0.4
	完全失業者数	193	116	77	2	1	1	1.0	0.9	1.3
	非労働力人口	4,175	1,526	2,650	−29	−1	−27	−0.7	−0.1	−1.0
	労働力人口比率	62.1	71.3	53.5	0.1	−0.1	0.3	…	…	…
	就業率	60.4	69.1	52.2	0.1	−0.2	0.4	…	…	…
	完全失業率	2.8	3.1	2.5	0.0	0.1	0.0	…	…	…
全国比	15歳以上人口	11.2	11.3	11.1	0.0	0.0	0.0	…	…	…
	労働力人口	12.2	12.2	12.3	0.0	0.1	0.1	…	…	…
	就業者数	12.2	12.1	12.3	0.1	0.0	0.1	…	…	…
	完全失業者数	13.1	13.5	12.3	−0.4	0.2	−1.5	…	…	…
	非労働力人口	9.5	9.3	9.7	−0.1	0.0	−0.1	…	…	…

注）全国比は全国の数値に対する東京都の割合である。

Among this working population, employees working in the office will account for the majority. As shown in table.1-2, office workers are 2.236 million and specialist/professional workers are 2.035 million. Most of the two occupations mentioned above work in office buildings, and some of the rest, too.

Table.1-2 Main occupations of Tokyo[5]

第 6 表　主な職業別就業者数

（単位：千人）

男女・年			専門的・技術的職業従事者	事務従事者	販売従事者	サービス職業従事者	生産工程従事者	運搬・清掃・包装等従事者	その他(左記以外のもの)
実数	男女計	平成31・令和元年平均	1,911	2,034	1,163	969	521	480	982
		令和 2	1,961	2,213	1,161	893	469	490	917
		3	2,035	2,236	1,155	887	465	454	914
	男	平成31・令和元年平均	1,104	823	695	387	365	279	818
		令和 2	1,140	921	688	340	317	299	781
		3	1,177	911	688	328	315	278	776
	女	平成31・令和元年平均	807	1,211	468	583	156	202	164
		令和 2	821	1,292	473	553	152	191	136
		3	858	1,325	468	559	150	176	139
対前年増減数	男女計	令和 2年平均	50	179	−2	−76	−52	10	−65
		3	74	23	−6	−6	−4	−36	−3
	男	令和 2年平均	36	98	−7	−47	−48	20	−37
		3	37	−10	0	−12	−2	−21	−5
	女	令和 2年平均	14	81	5	−30	−4	−11	−28
		3	37	33	−5	6	−2	−15	3

注）日本標準職業分類（平成21年12月改定）に基づく職業別で、結果表章を行っている。その他(左記以外のもの）には、「管理的職業従
従事者」、「農林漁業従事者」、「輸送・機械運転従事者」、「建設・採掘従事者」及び「分類不能の職業」が含まれている。

1.5 The increase in cooling demand and energy consumption

Due to the above-mentioned global warming and heat island effect, the cooling demand of people gathered in urban areas in summer will continue to increase. This naturally brings greater energy consumption, brings greater pressure on power generation, and increases the risk of power failure in summer.

As shown in Fig.1-3, IEA predicted the AC stock worldwide in the future [6], and there will be a great increase in the total number of AC, especially in China and India. According to the research of Dahl, R et al.2013[7], it is estimated that the electricity consumed by AC in the world has reached 1 trillion kilowatt hours (kWh). In addition, modeling results by Isaac et al. 2009[8], show that world energy demand for AC will increase rapidly in the 21st century, for example, the increase in the median scenario is from close to 300 TWh in 2000, to about 4000 TWh in 2050 and more than 10,000 TWh in 2100.

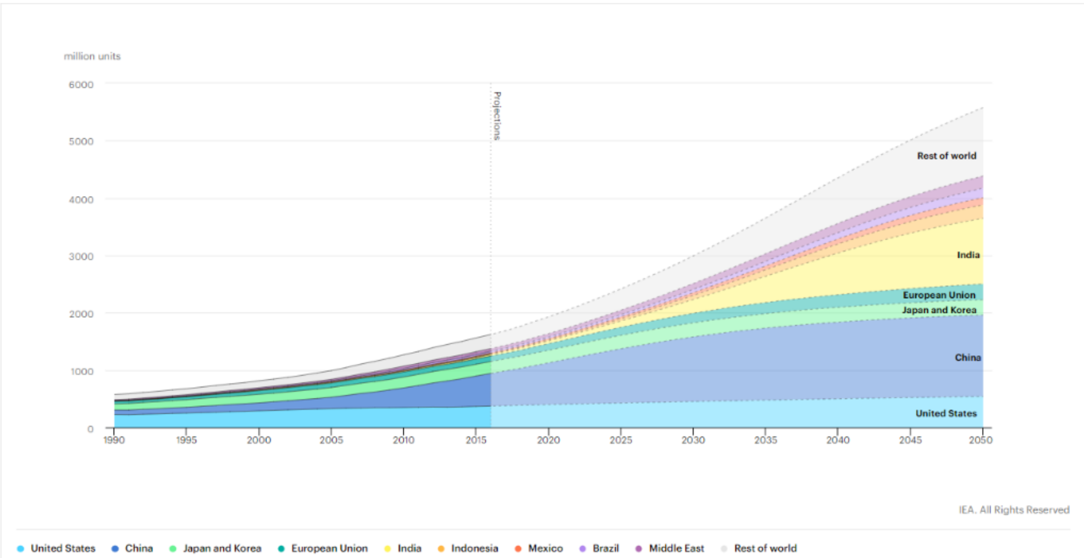


Fig.1-3 Global Air Conditioner Stock, 1990-2050, IEA [5]

1.6 The assessment of air conditioner

AC as a solution to protect urban populations from excessive heat exposure creates the challenge of increasing electricity consumption and greenhouse gas emissions, exacerbating climate change [9]. In addition, the direct heat rejected from the AC unit, adds to street level heat and therefore the urban heat island effect [10]. Obviously, the cost of using air conditioning is significant, especially considering the target to control global warming below 1.5 ℃ in the future[11].

On the other hand, the benefits of air conditioning are also indispensable. AC does protect workers from heat stress providing cooler spaces, thus protecting labor productivity, and bringing economic benefits [12]. The air conditioner also brought benefits like reduction in sleep disturbance[13]. The health benefits brought to people are also environmental impacts, which cannot be ignored when assessing air conditioning.

To sum up, the assessment of the environmental impacts caused by air conditioning is very important, and the cost and benefit of air conditioning should be comprehensively considered.

2. Introduction

2.1 Optimal operation of AC

As mentioned above, with the use of AC and the increase in cooling demand, questions like how to correctly evaluate the role of AC and what is the optimal operation of AC are becoming more and more important.

2.2 The protective effect of AC on labor productivity

First of all, AC protects people’s health and avoids the risk of heatstroke, which is undeniable. What is often ignored is that AC also improves labor productivity by creating a suitable working environment.

Multiple previous studies on IEQ (indoor environmental quantity) factors have pointed out this conclusion. For example, O. Seppänen et al.2006[14] gave the relationship between indoor temperature and office labor productivity through regression analysis. Similarly, Li Lan et al.2011[15] gave the relationship between TSV (thermal sensation vote) and labor productivity through investigating TSV in different temperature and clothing situations and conducting tests neurobehavioral examining different component skills, addition, and typing tasks. These studies show that using AC to maintain indoor temperature in a certain temperature range can maintain labor productivity in an efficient state. Both too high and too low temperature will reduce labor productivity and lead to possible economic losses.

2.3 Research gap

The hot summer in Tokyo and a large number of employed people may cause great labor losses due to the high temperature in Tokyo in summer. However, few studies have quantified the labor productivity protected by the use of AC in office buildings in Tokyo. In addition, the temperature limit of 28 ℃ advocated by the government is also lack of rational basis. Therefore, it is necessary to explore the best setting temperature of the air conditioner in the office district.

On the other hand, many studies on the optimal environment in the office buildings use the salary and electricity fees as the criteria to judge the optimal AC operation, such as Changzhi Dai[16] and Hakpyeong Kim[17]. However, from a social perspective, it is far from enough to only consider salaries and electricity fees. In order to conduct a comprehensive assessment of AC, the best way should consider the total environmental impacts which should include benefits and costs. In the office, the main benefit of using air conditioning is to reduce the loss of labor productivity. Therefore, the economic value of the reduced labor productivity loss is taken as benefits. The energy fees and the environmental impacts caused by the power generation as costs.

2.4 Research objective

This study aims at assessing the cost-benefit analysis of AC focusing on total environmental impacts of AC in the office districts in Tokyo. The economic value of the reduced labor productivity loss is taken as benefits. The energy fees of ACs and the environmental impacts generated during power generation as costs.

Another goal of this study is to find the optimal set-point temperature to address the trade-off problem between the labor productivity enhancing perspective and the energy saving perspective. Based on this, verify whether the temperature limit of 28 ℃ is reasonable.

Eventually, propose the sustainable way of using AC in office buildings districts.

3. WRF-CM-BEM model

3.1 Introduction of CM-BEM model

In order to estimate the labor productivity protected by AC, it is necessary to obtain the indoor thermal index under the conditions of AC on and without AC. On the other hand, in order to estimate the energy cost caused by the use of AC and the environmental impacts caused by power generation.

This study uses CM-BEM to calculate the indoor thermal index and energy consumption of AC. As shown in the Fig3-1, This model is composed of two sub-models which are canopy model (CM) and building energy model (BEM). The model describes the feedback process, which is composed of the impact on a building's air-conditioning energy-demand from the weather inside an urban canopy and the effects of exhaust heat on the external environment [18].

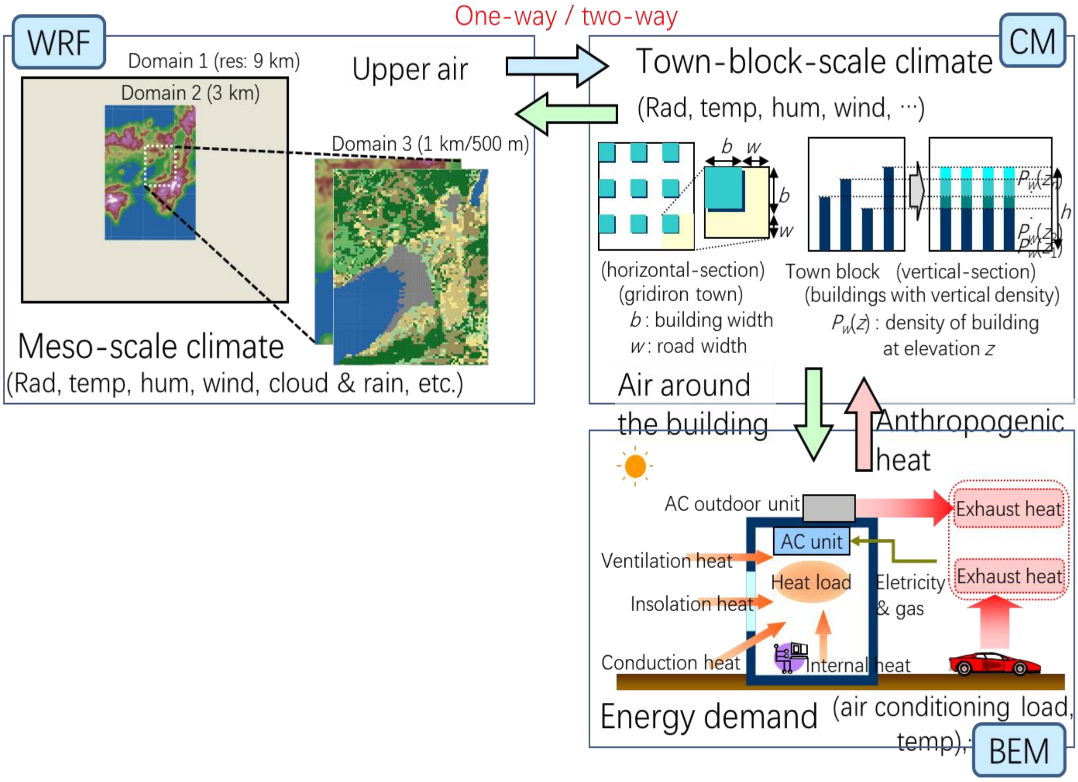


Fig.3-1 Structure of WRF-CM-BEM

In order to perform simulation using CM-BEM, the sky upper limit boundary condition is required. For the upper boundary condition of the sky, the calculation result by the Weather Research and Forecasting Model (WRF) is used.

CM is the Canopy model to simulate the effects from buildings, and then give the temperature results to calculate the thermal environment in buildings. The CM vertically resolves the phenomena occurring inside an urban canopy layer in order to describe the several-hundred-meters-scale weather changes. Same-sized parallelepiped buildings are arranged horizontally, and the existing density of buildings is considered for every altitude in the vertical direction [15].

The BEM calculates the heat budget of a building based on the assumption that it is a single box. In the BEM, the building energy model, both the sensible and latent heat are calculated, according to the AC, hot water generator, vehicles, anthropogenic heat is given to the CM model to recalculate the meteorological data used for BEM.

3.2 District type in the CM-BEM

On dividing Tokyo's 23 wards according to the 4th mesh (the 3rd mesh divided into four meshes), 2457urban districts are generated. The 3rd mesh is an about 1 km · about 1 km square district divided by continuous latitudinal and longitudinal lines, based on the ''Standard local mesh and standard local mesh code'' (No.143 Announcement by the Administrative Management Bureau in Japan, 1971) [15]. These districts are divided into 3 different kinds of building types which are the office type, detached type and apartment type based on the land and building usage. Among them, 429 districts are selected as office-building districts in this simulation. As Fig.3-2 shows, most of these districts are concentrated in the central area of Tokyo's 23 wards, and the rest diverge outward along the traffic lines.

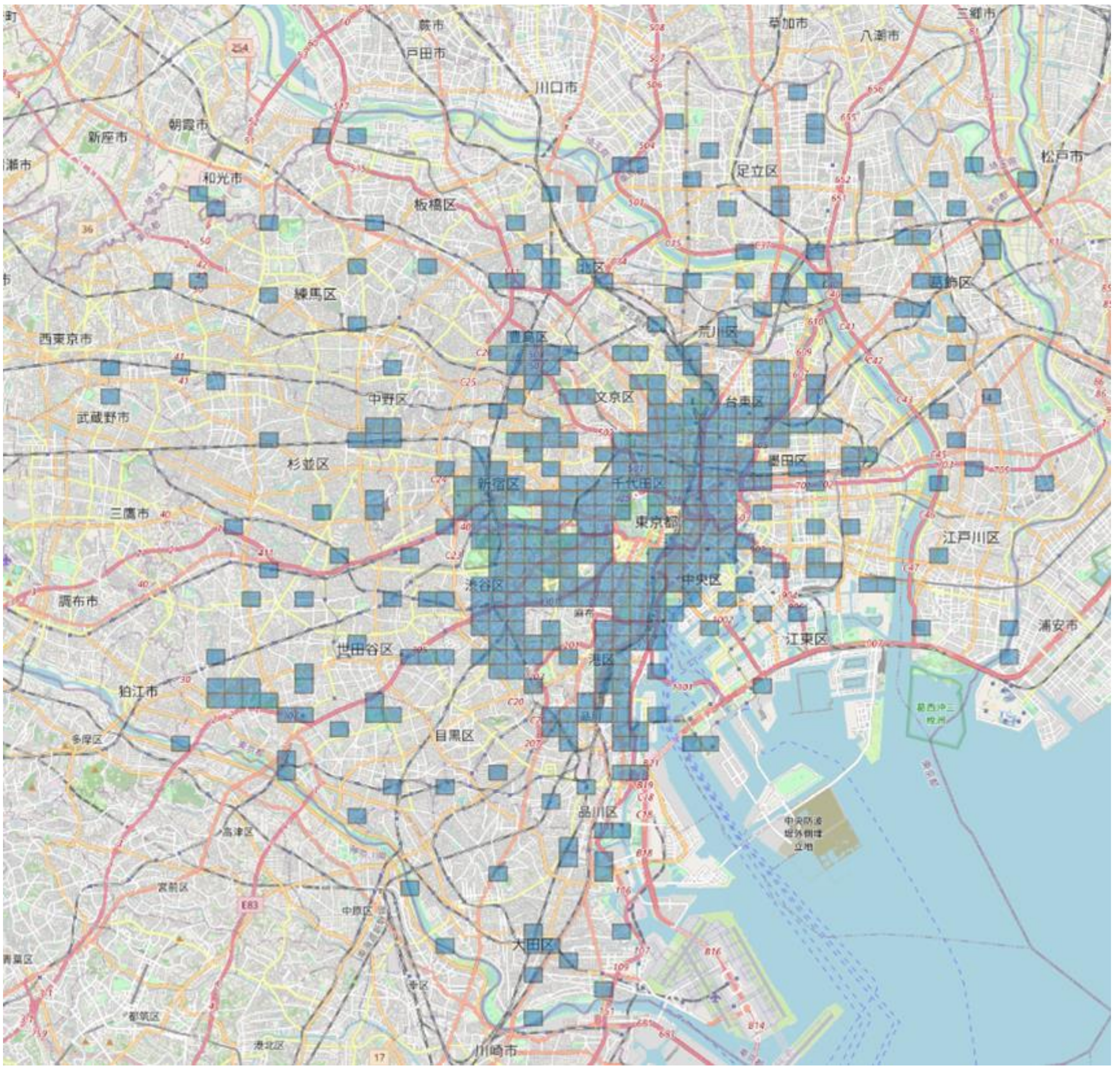


Fig.3-2 Distribution of office districts

Previously, in the CM-BEM, if there are multiple building types in one district, only the property of the dominant building type will be used as the property of the city district, which brought great errors in simulation results compared to the real value. Under the revision of two previous laboratory members [19][20], this model is improved to be able to save properties of multiple building types in one city district, according to the research of Nishimoto [20], the maximum error decreased from 60% to 40%. In this research the version of 3 building type CM-BEM model will be used. In this version of CM-BEM, the energy consumption of AC and indoor thermal index in different building types can be calculated separately, so the calculation result is only the result of office buildings in this district, which makes the protected labor productivity and energy consumption closer to the real situation.

3.3 Simulation period

To ensure that it is necessary to use AC, this simulation only includes the results of July and August. Although the summertime in Tokyo is not only these two months, but there are also many time periods in other months (June and September) when the temperature is low and AC is not required. When the maximum temperature of the day exceeds 30 ℃, it can be considered necessary to turn on the AC. As shown in Fig.3-3, the days when the maximum temperature exceeds 30 ℃ in June and September are basically less than 10 days, while the days when the maximum temperature exceeds 30 ℃ in July and August are basically more than 20 days [21]. The meteorological data used this time are from 2000. The days when the daily maximum temperature exceeds 30 ℃ are 3 days in June, 24 days in July, 29 days in August and 10 days in September. Therefore, the time period of this simulation is July and August. For other years, corresponding adjustments should be made according to the meteorological data, because there will be few days of high temperature in summer in some years.

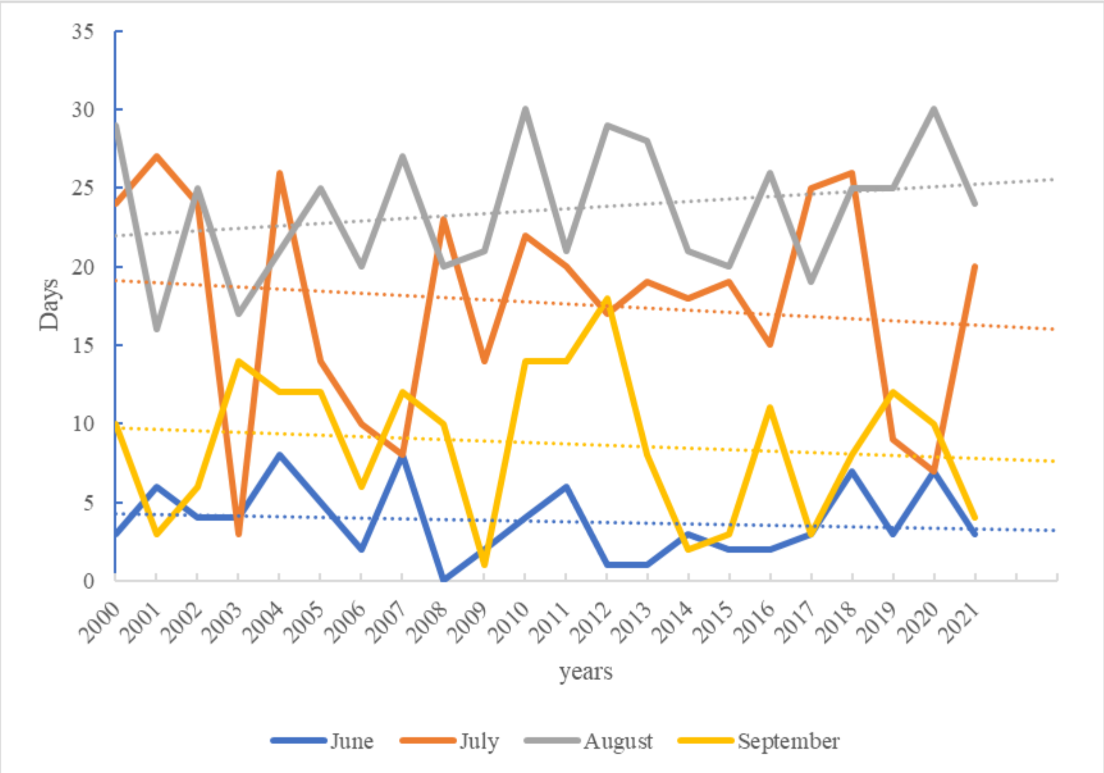


Fig.3-3 Days (months) with daily maximum temperature above 30 ℃ in Tokyo (2000–2021, June–September) [19]

The weather data used in this simulation is from 2000/07/01 to 2000/8/31. Parameters in the weather data include the ambient temperature, wind velocity, specific humidity and intensity of downward short-wave radiation and long wave radiation, accumulated total precipitation.

3.4 Setting of AC parameters

In this simulation, three AC are set, two of which are powered by electricity and the other by gas. The specific settings of the AC are shown in table 3-1. In order to analyze the cost-benefit of AC under different setting temperatures, a total of five AC setting temperatures of 24/25/26/27/28 ℃ are set. Take the labor productivity of protection as the benefit, energy cost and environmental impacts as the cost to determine the optima operation of AC.

Table.3-1 Settings of AC

Items	MEACH1	CEASCH	CAWDCH
Rating COP	2.6	2.73	0.97
Lowest Load Ratio	0.2	0.2	0.2
Exhaust heat location	1	1	1
Equipment allowance	0	5	5
Auxiliary energy ratio	0	0.22	0.22
Composition of heat source	0.53	0.13	0.34

3.5 Calculation of cooling area

Since CM-BEM outputs the power of the AC in each district, in order to calculate the energy consumption of the AC, it is necessary to specify the cooling area of each district. Therefore, the cooling area of each district is calculated by using the urban shape in CM-BEM and GIS data, as shown in Fig.3-4.

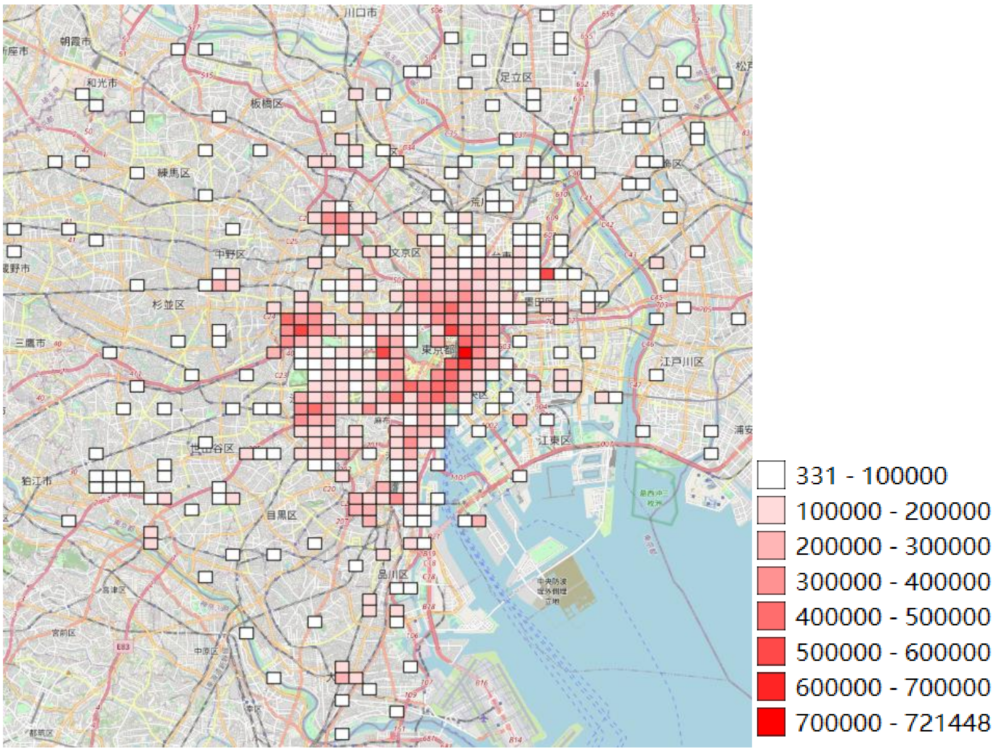


Fig. 3-4 Cooling area of each districts

4. Evaluation of labor productivity

4.1 Choosing important IEQ factors

Previously, a brunch of studies has been done about how IEQ (indoor environment quantity) factors will affect people's work performance, but the conclusions are also very different due to difference in controlled environments, testing projects and regions.

For example, Fisk and Rosenfeld [22] estimated that the improvement of indoor environment can bring a direct increase in labor productivity, ranging between 0.5% and 5%. Proper indoor thermal condition[23][24][25] and indoor air quality [26][27][28][29] have been proved to be of great help to better work performance. However, there are few studies on the combined effects of these factors. Qualitative studies have been conducted by Witterseh et al.[30] on the combined effects of temperature and recorded noise. In conclusion, temperature, noise, air quality, ventilation etc. can all have an impact on work performance. The main purpose of this study is to explore the impact of AC on the indoor environment under the refrigeration mode, and how this impact will ultimately affect labor productivity. Basically, the noise of the AC is not particularly large, and the impact on the air quality is also minimal, so the IEQ factors that need to be focused on are temperature, humidity, and ventilation.

As show in the Table.4-1[33], this is the result of an indoor IEQ factors survey on Tokyo office buildings under naturally ventilated (NV) mode and ran in AC (AC) mode. The results show that mean indoor relative humidity oscillated between 46% and 55% in NV mode, fluctuating little in AC mode and remaining at 50%-52%[33]. It can be seen that the AC has little effect on the indoor humidity in the cooling mode but will make the indoor humidity tend to be stable.

Table.4-1 IEQ factors under air conditioning and natural ventilation

Table 3
Outdoor and indoor environmental data recorded during the survey period.

Variable	NV ($N = 423$)		AC ($N = 1979$)		All data ($N = 2402$)	
	Mean	SD	Mean	SD	Mean	SD
T_o (°C)	27.5	2.8	30.2	2.1	29.7	2.5
RH_o (%)	65.3	10.4	63.2	9.9	63.5	10.0
T_g (°C)	29.4	1.5	27.9	1.2	28.2	1.3
T_a(°C)	29.3	1.4	27.9	1.1	28.2	1.3
RH (%)	52.6	6.4	50.8	4.4	51.2	4.9
AH ($g_{w/kg_{da}}$)	13.4	1.6	11.9	1.2	12.2	1.4
A_v (m/s)	0.2	0.1	0.3	0.2	0.2	0.2
I_{cl_tot} (clo)	0.62	0.07	0.63	0.08	0.63	0.08
Activity (Met)	1.1	0.2	1.1	0.2	1.1	0.2
CO_2 (ppm)	613	167	1149	413	1055	433

N = sample size; T_o: outdoor temperature (°C); RH_o: outdoor relative humidity (%); T_a: indoor air temperature (°C); T_g: indoor globe temperature (°C); RH: indoor relative humidity (%); AH: indoor absolute humidity (g_w/kg_{da}); A_v: indoor air velocity (m/s); I_{cl_tot}: Subjects total clothing insulation (clo); CO_2: carbon-di-oxide concentration (ppm).

In the above study. mean indoor air velocity in NV mode was slightly lower than that of the AC mode, which was around 0.20 m/s and 0.25 m/s in NV and AC modes respectively. The median of air velocity in NV mode was 0.18 m/s while it was 0.21 m/s in AC mode[33]. The ASHRAE suggests an air velocity between 0.18 and 0.25 m/s for three categories of buildings[34]. So, although the AC will slightly increase the air velocity, it still has a limited impact on work performance.

Although AC affects many IEQ factors, the most important factor is temperature, and the influence of other factors is relatively limited. Therefore, this study needs to pay attention to the impact of indoor temperature on work performance.

4.2 Indoor temperature and work performance

There are many studies that give the relationship between temperature and work performance. However, there is no such study in Japan at present. Considering that the local climate conditions may have an impact on the ability of human body to perceive the thermal environment, it needs to be revised when selecting a reference study.

As shown in Fig.4-1, four relatively complete studies on the relationship between indoor temperature and work performance are sorted out[14][16][15][17][27].

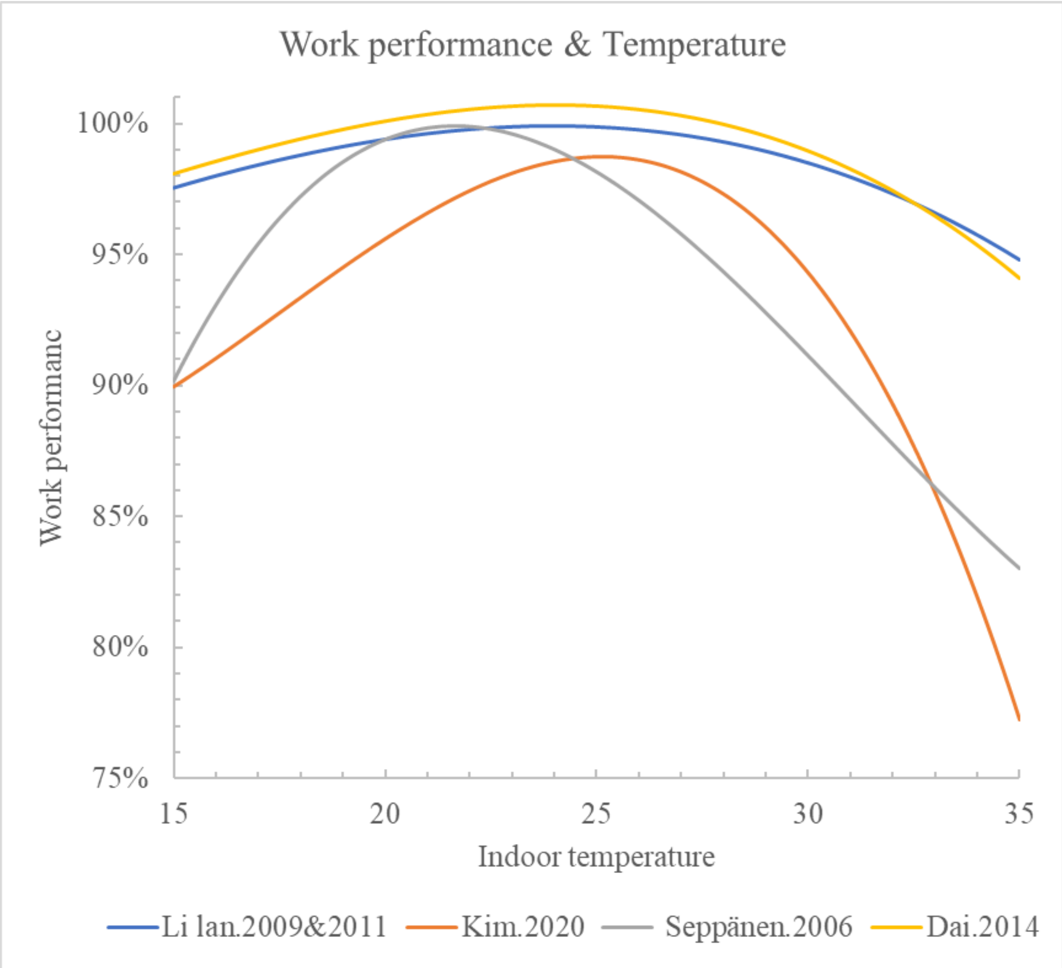


Fig.4-1 Comparison of 4 exisisting studies

In the above four studies, the performance always reaches the maximum value when reaching a certain temperature and will decay when the temperature is lower or higher than that temperature. Li Lan and Dai's research adopted the same relationship between TSV (thermal sensing vote) and work performance, so they both reached the maximum value at 24 ℃. The results of Seppänen and Kim reached the maximum at 21.75 ℃ and 25.15 ℃ respectively.

Li Lan's research also points out that, the relationship developed between thermal sensation and performance can be a useful tool to predict productivity loss due to thermal discomfort in the cost-benefit calculations pertaining to indoor environments[15]. Li Lan and Kim both used the same questionnaire to conduct TSV to find out the most comfortable temperature (thermal neutral), and similar studies have been conducted by Hom. B [35]in Tokyo. The TSV results of Li Lan and Kim are to reach the most comfortable temperature at 24 ℃ and 25 ℃ respectively, which is consistent with the maximum working performance. And Hom. B 's research points out that in office buildings in Tokyo and Kanagawa, the most comfortable temperature in the air-conditioning cooling mode is 25.4 ℃[35]. Therefore, it can be inferred that the temperature of the maximum working efficiency in Tokyo should be close to 25.4 ℃. Therefore, compared with other studies, Kim's conclusion is more suitable for modification and application in Tokyo.

Then how to carry out such modification? As shown in Fig.4-2 and Fig.4-3, in Hom. In the results of Hom. B and Li Lan, the relationship between TSV and temperature is linear[27][35]. Therefore, the temperature can be linearly transformed on the result of Kim. Since the most comfortable temperature in Tokyo is 0.4 ℃ higher than that in Seoul, the amplitude of this linear transformation is 0.4 ℃. In addition, the advantages of Kim's research include compared with Li Lan's experiment, Kim's experiment is better in temperature range and gradient, and compared with Seppänen's conclusion, Kim's experiment is closer to the actual office work. So finally, this study chose to modify Kim's conclusion, and then applied it in Tokyo.

Kim's original formula for calculating temperature and working performance is shown in (1)[17], and the modified formula is shown in (2)

$$P = (-0.0035 \cdot T^3 + 0.1840 \cdot T^2 - 2.6171 \cdot T + 56.264)/51.8 \qquad (1)$$

Where P represents work performance, T represents indoor temperature.

$$P = (-0.0035 \cdot (T - 0.4)^3 + 0.1840 \cdot (T - 0.4)^2 - 2.6171 \cdot (T - 0.4) + 56.264)/51.8 \qquad (2)$$

Where P represents work performance, T represents indoor temperature.

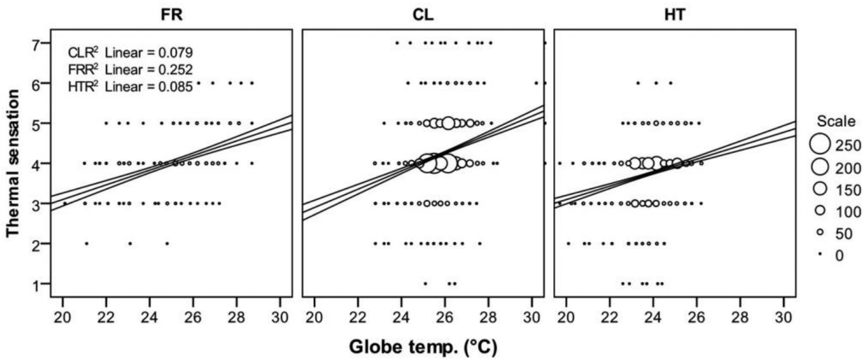


Figure 6. Relation between modified thermal sensation vote (mTSV) and indoor globe temperature.

Fig.4-2 Hom.B results about TSV and Temperature[35]

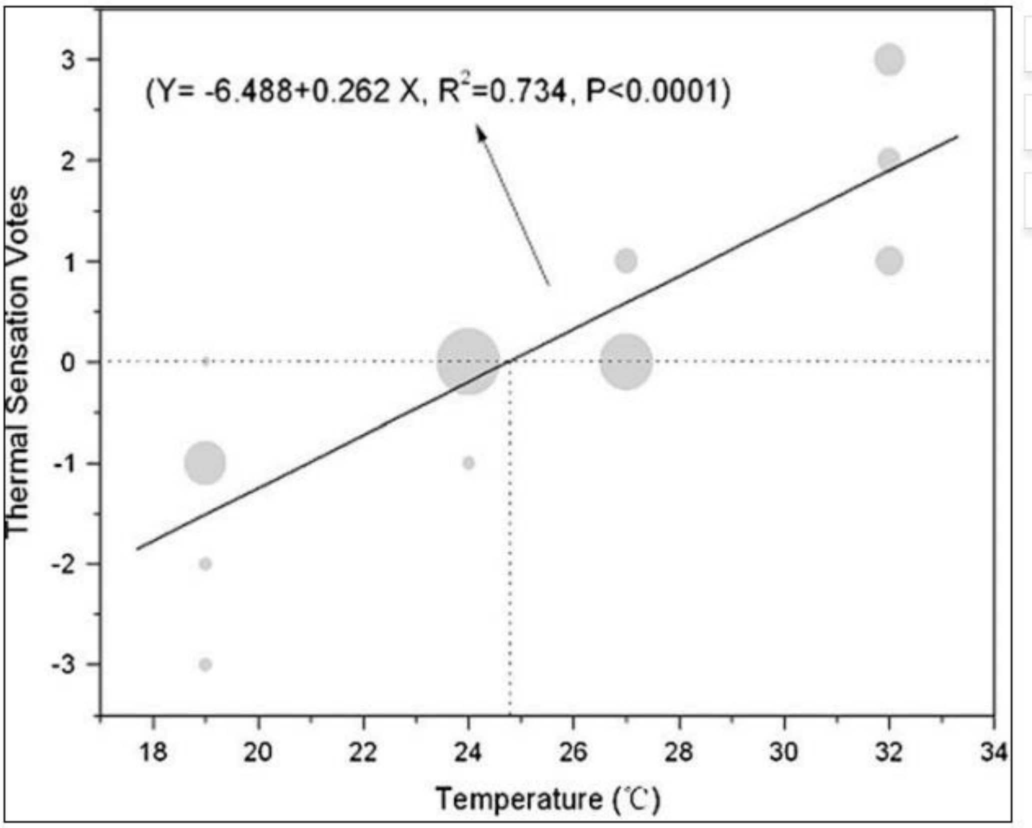


Fig. 3. Correlation of thermal sensation votes versus air temperature.

Fig.4-2 Li Lan results about TSV and Temperature[27]

4.3 Economic value of labor productivity loss

Jun’ya Takakura et al 2017 used constant elasticity substitution (CES) production functions to calculate the economic value of labor productivity[37]. In order to express the labor productivity loss due to reduced worktime, Jun’ya multiplied the labor input by the ratio of the worktime reduction, and their product was used as the effective labor input to the production function[37]. In the industrial production sector, due to the impact of high temperature, it needs time to rest to avoid heatstroke, so the working hours will be reduced. In the industrial production sector, due to the impact of high temperature, it needs time to rest to avoid heatstroke, so the working hours will be reduced. However, for the staff of office buildings, the working hours will not be reduced, so the main impact of not turning on the AC is their work performance. On the other hand, there will be staff from different industries in the office building, so the labor productivity is not classified by industry. So, this study applied Cobb–Douglas production functions as a special case of the CES production function, which is when substitution parameter approaches zero in the limit.

Cobb-Douglas production function is used to represent the conversion relationship between work performance decline and economic loss. The Cobb-Douglas production function is showed as (3), which is widely used to represent the technological relationship between the amounts of two inputs (particularly physical capital and labor) and the amount of output that can be produced by those inputs.

$$Y = AK^{\beta k}L^{\beta l} \tag{3}$$

Where Y represents total production, L represents labor input, K represents capital input, A represents total factor productivity. βk and βl are the output elasticities of capital and labor, respectively.

Due to the decline of work performance caused by high temperature, capital input and current technical level remain unchanged, so the only reduction is labor input, i.e. L. Regard Y as GDP, take the value of βl is 0.75[36]. Therefore, the relationship between work performance and economic loss is as (4).

$$EL = \frac{GDP}{Total\ working\ hours} \times n \times h \times (100\% - P^{0.75}) \tag{4}$$

Where EL represents economic loss, P represents work performance, h represents working hours, n represents number of workers.

The labor productivity per worker of Tokyo’s 23 wards is JPY6,172 per hour[38]. The number of workers in each urban district is from national investigation of Matters concerning the basic aggregates such as aggregate migration and employment status of Japan in 2015[39], and the working hours are from the statistical results of Statistics Division, bureau of general affairs.[40]

The distribution of the workers and working hours is shown in the Fig.4-2 and Fig. 4-3. The red is about dark, which means that the larger the number of workers in the district, the longer the working hours.

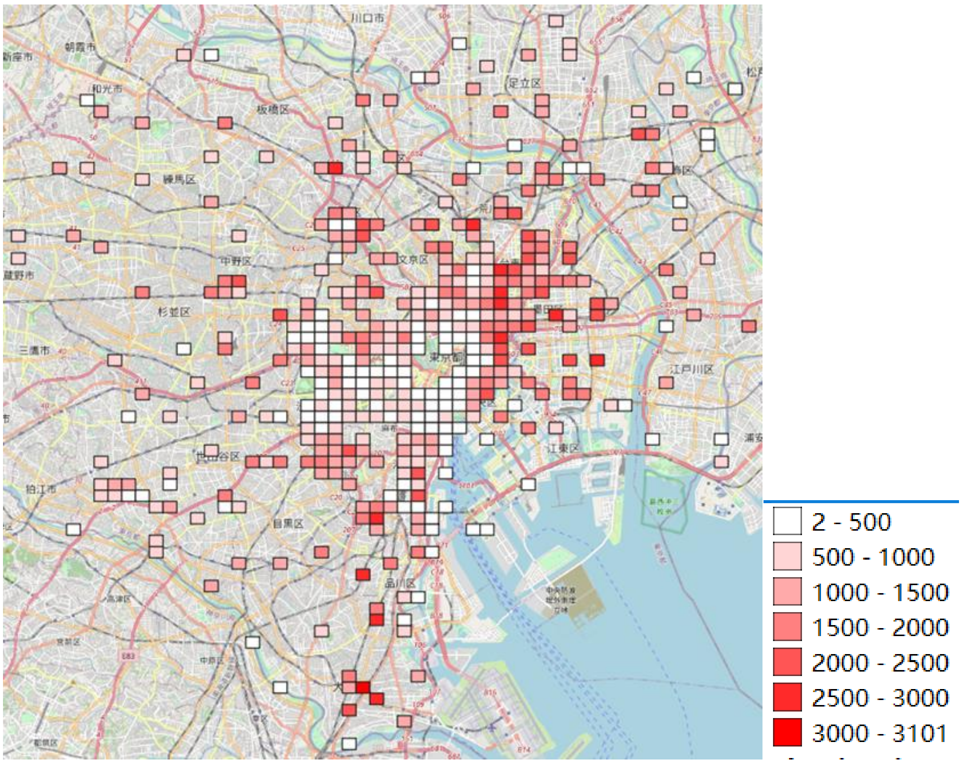


Fig.4-2 distribution of the workers

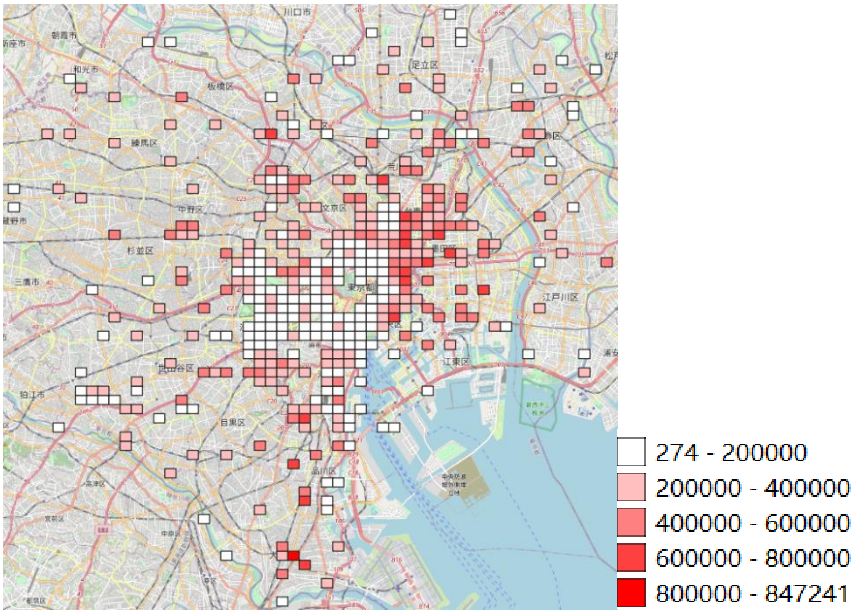


Fig.4-3 distribution of the working hours

5. Evaluation of environmental impacts

5.1 Inventory analysis

As the cost of using AC, in addition to the power cost, the environmental impacts caused by power generation should also be taken into account. In this paper, OpenLCA is used to do the inventory analysis of electricity and gas in Tokyo, Japan. And the economic benefit is analyzed according to G20 population weighted factor of Lime3.

OpenLCA is an open source and free software for sustainability and Life Cycle Assessment. The inventory analysis is based on the IDEA which is a hybrid inventory database features both statistical and process-based data. It comprehensively covers nearly all economic activities in Japan and contains about 3800 processes that are classified based on the Japan Standard Commodity Classification. IDEA v2 is provided as a group of interlinked unit process datasets and very transparent.

The inventory analysis of electricity is based on the process 331122014 electricity, Japan (Tokyo Electric Power Co., Inc), 2014FY. Time period is 2014/04/01-2015/03/31. This Process converts various energies to electric power.

(1) Potential energy of water is converted into electricity in hydroelectric power generation.

(2) Thermal energy by combustion is converted into electricity in thermal power generation.

(3) Thermal energy by nuclear fission is converted into electricity in nuclear power generation.

(4) Thermal energy of underground is converted into electricity in geothermal power generation.

(5) Wind energy is converted into electricity in wind power generation.

(6) Solar energy is converted into electricity in solar power generation.

Product is 1kWh in the receiving end and takes into account station service power and transmission and distribution loss. Numerical value of FY2011 is used for transmission and distribution loss rate of FY2012.Targets 10 general electricity utility companies. There are sources of general electricity other than above general electricity utility companies in Japan, and they do not supply all the public electric power in the country.

The inventory analysis of gas is based on the process 341111000 town gas. Time period is 2010/04/01-2010/12/31. The end date is December 31, 2010, which is the scope end date (not the data collection end date). Japanese domestic data is utilized.

See Appendix (A) (B) (C) (D) for details of inventory analysis of electricity and gas.

5.2 Impact analysis

After obtaining the results of inventory analysis, the next step is to conduct impact analysis according to Lime3. The choice of Lime 3 weighting factors is

(1) [WF]G20 (population weighted),

(2) [IF2] Emissions & production country (interest rate 3%)

Details are showed in the appendix (E)(F)(G)

The value of social assets may be different due to the different interest rate, and other aspects are the same. The G20 was chosen to consider the impact on the whole world. In the Lime3, the monetary unit is 2015$us PPP, according to the data provided by the world bank, the exchange rate is 1 US dollar =123.2755 yen[41].

The economic value of environmental impacts caused by electricity and gas are shown in the Table5-1.

Table5-1. Value of environmental impacts

unit	Electricity/1kWh	Gas/1m^3
2015$US.ppp	0.0205	0.055
円	2.52	6.78

The composition of environmental impacts is shown in the Fig.5-1 & Fig.5-2.

According to the website of TEPCO and Tokyo gas[42][43], give the energy fee of electricity and gas as in Table 5-2.

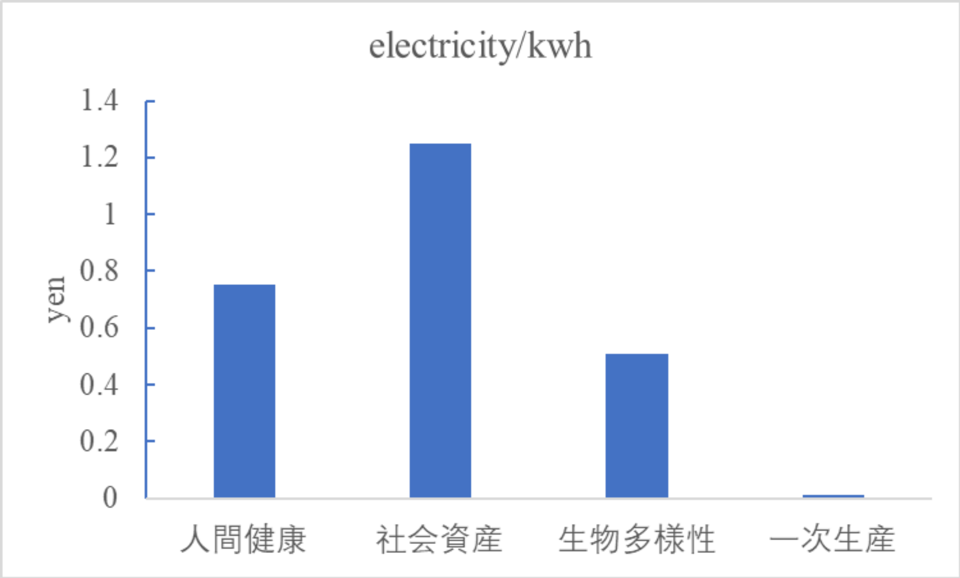


Fig.5-1 The composition of environmental impacts of electricity

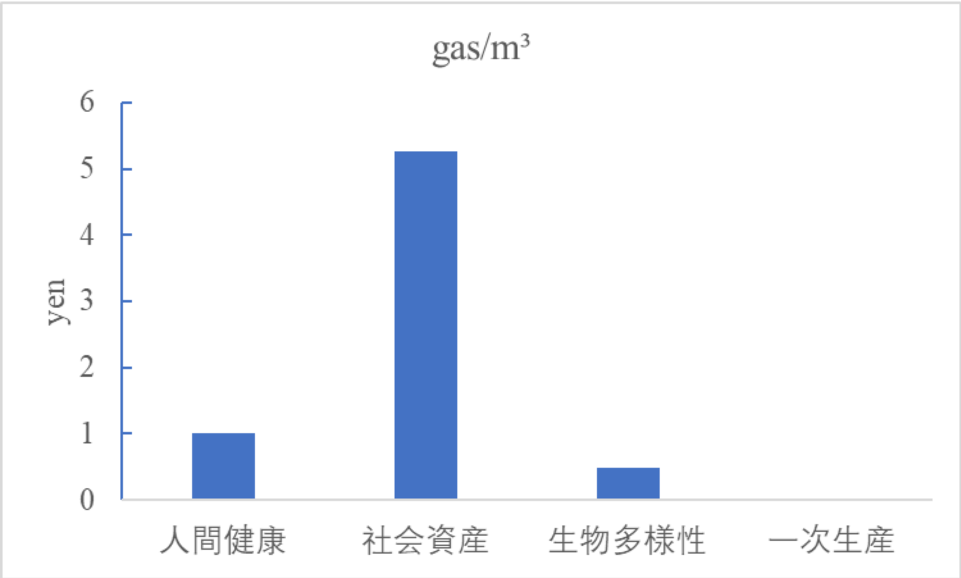


Fig.5-2 The composition of environmental impacts of gas

Table 5-2 energy fee

Low voltage power (summer)electricity	Business AC summer contract gas
17 円 37 銭/kWh	100.57 円/m^3

6.Results

6.1 Performance and air conditioning power

As mentioned in the second subsection of Chapter 4, Kim's conclusion can be adjusted and applied to Tokyo. The relationship between indoor temperature and work performance is shown in the Fig.6-1.

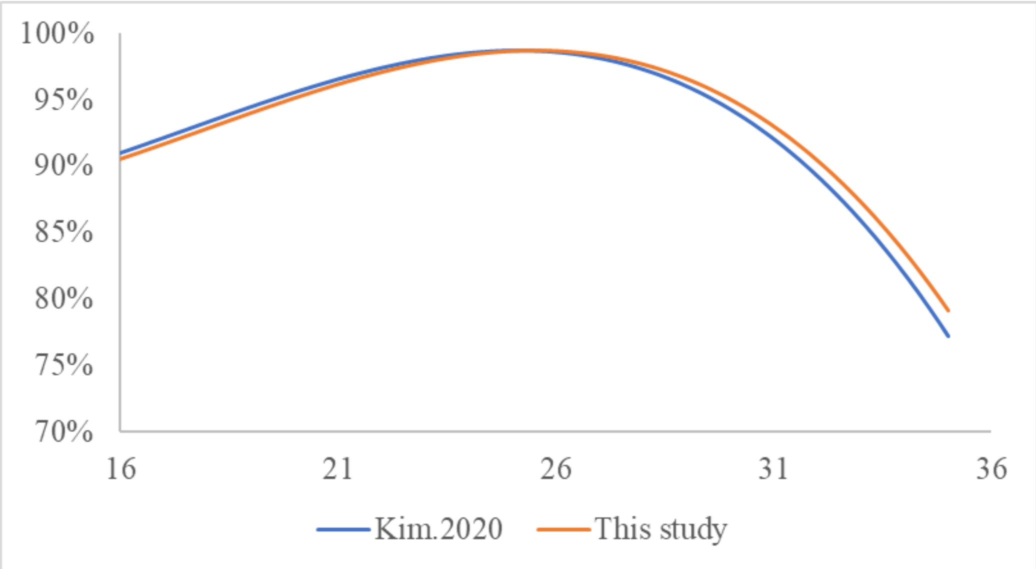


Fig.6-1 Work performance evaluation method in this study

When the indoor temperature reaches 25.55 ℃, the work performance is the highest. As the indoor temperature increased to above or decreased to below 25.55 ℃, it was shown that the work performance relatively decreased. The district 533945471 on July 29th with a setting temperature of is 26℃ is taken as an example.

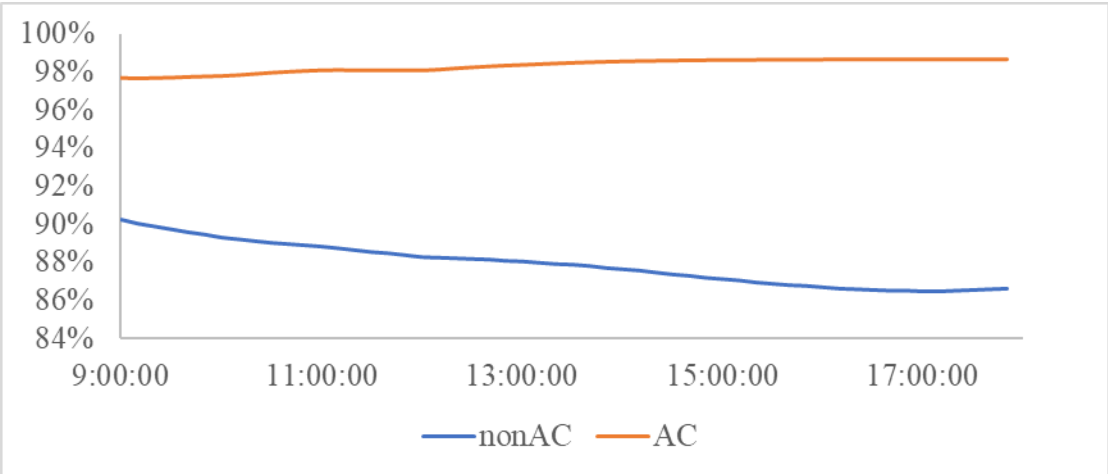


Fig.6-2 Work performance of a day

AC represents the working performance when the air conditioner is turned on, and nonAC represents the working performance when the air conditioner is not turned on. When the air conditioner is on, the work performance can be maintained at a high level all day. When the air conditioner is not on, the work performance will be significantly reduced, and the reduction will be continuously increasing.

After getting the work performance under the conditions of turning on the air conditioner and not turning on the air conditioner, we can calculate the labor productivity protected by the air conditioner. CM-BEM also gives the power of the air conditioner, so it is shown in the Fig.6-3.1.

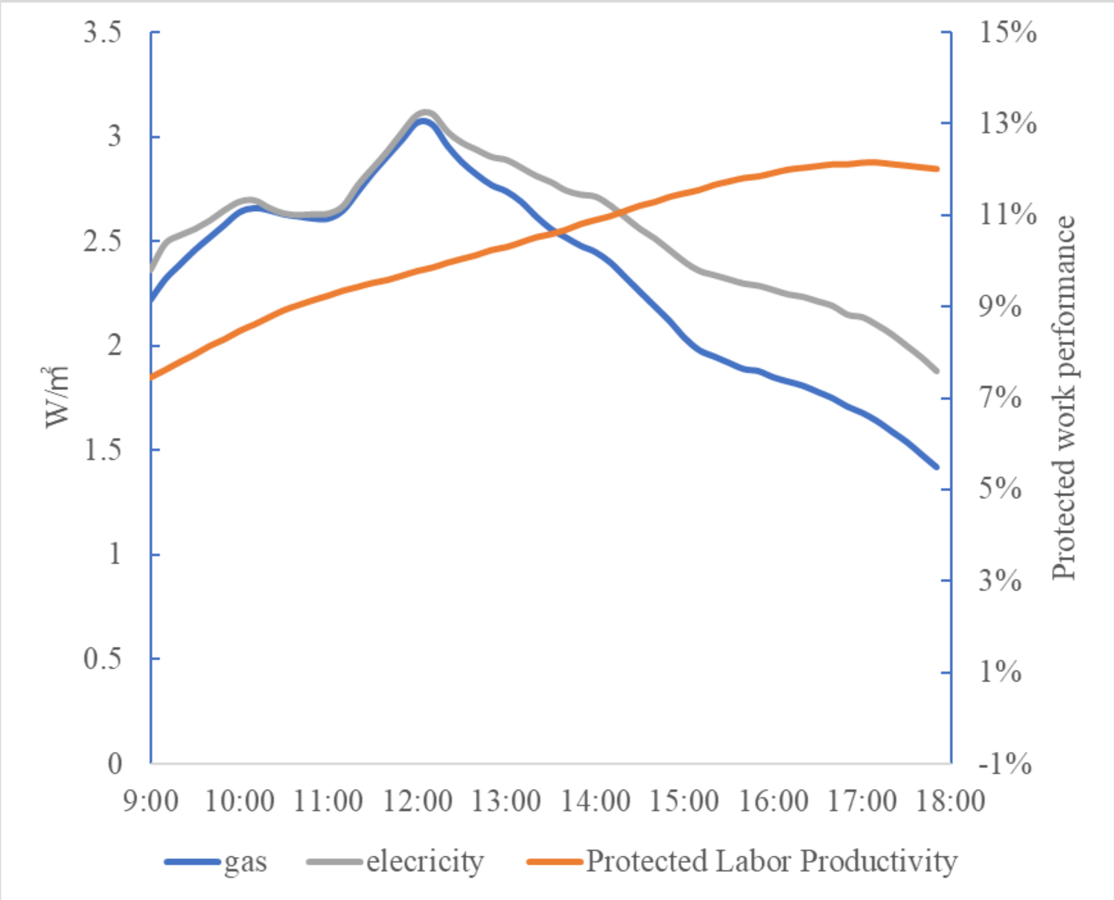


Fig.6-3.1 AC power(gas &electiricity) and protected work performance

It can be seen from the Figure that the power of the air conditioner reaches the maximum at noon, which may be because the solar radiation is the highest at this time, and then the power of the air conditioner begins to decline. It can be seen from the Figure that the power of the air conditioner reaches the maximum at noon, which may be because the solar radiation is the highest at this time, and then the power of the air conditioner begins to decline. The labor productivity protected by air conditioning has been rising. This is because in the afternoon, the indoor temperature with the air conditioner turned on is lower, so the protected labor productivity has been increasing.

The situation in July and August is shown in Fig.6-3.2.

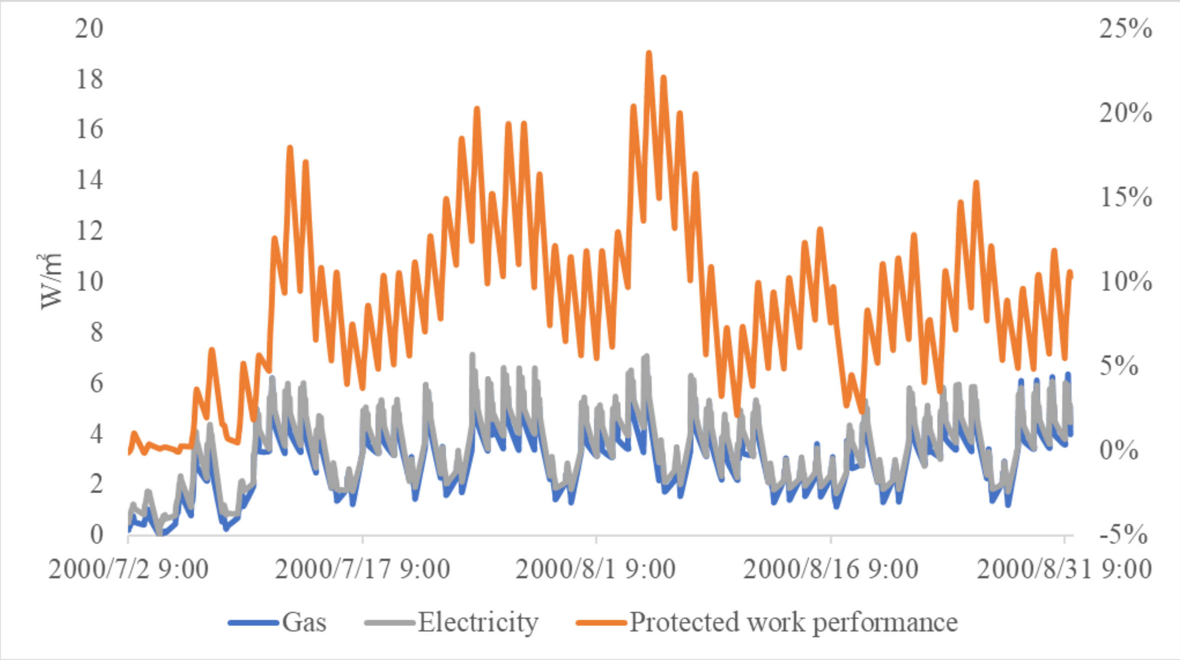


Fig.6-3.2 AC power(gas &electiricity) and protected work performance in July and August

After obtaining the work performance in July and August, the labor productivity protected by air conditioning in summer can be calculated by combining the working hours and the number of workers in each district.

After getting the air conditioning power in July and August, combined with the cooling area data of each district, the energy consumed by air conditioning in summer can be calculated. Therefore, the energy fees and environmental impacts can be obtained.

6.2 Protected labor productivity by AC

The results show that the labor productivity that AC can protect is huge. As shown in Fig.6-4, the labor productivity protected under different AC setting temperatures. The darker the color, the greater the protected labor productivity. Because it is the result of the whole district, this result depends not only on the protected work performance, but also on the workers and working hours in the district. The working hours of each district are set according to the number of full-time workers and part-time workers.

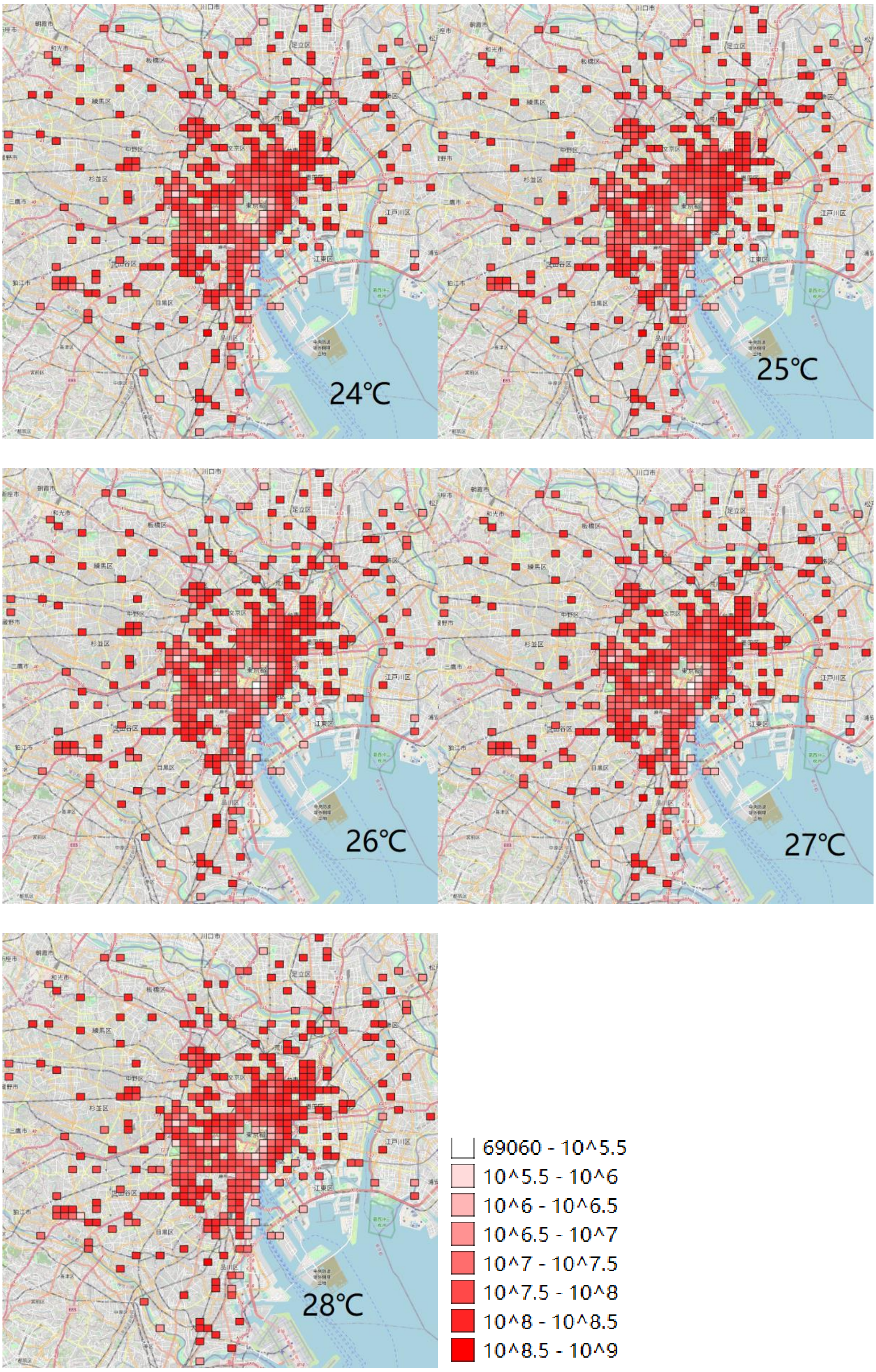


Fig.6-4 Protected labor productivity in 24/25/26/27/28℃

The protected labor productivity of the districts near the imperial palace of Japan is lower. This may be because these districts are mainly shopping malls, theatres and other commercial facilities, rather than office buildings. The results in the northeast part are higher. When the setting temperature of the air conditioner is 26 ℃, the labor productivity of most districts is the largest. As shown in Fig.6-4-2, the setting temperature of the air conditioner when the protected labor productivity of the district is at the maximum.

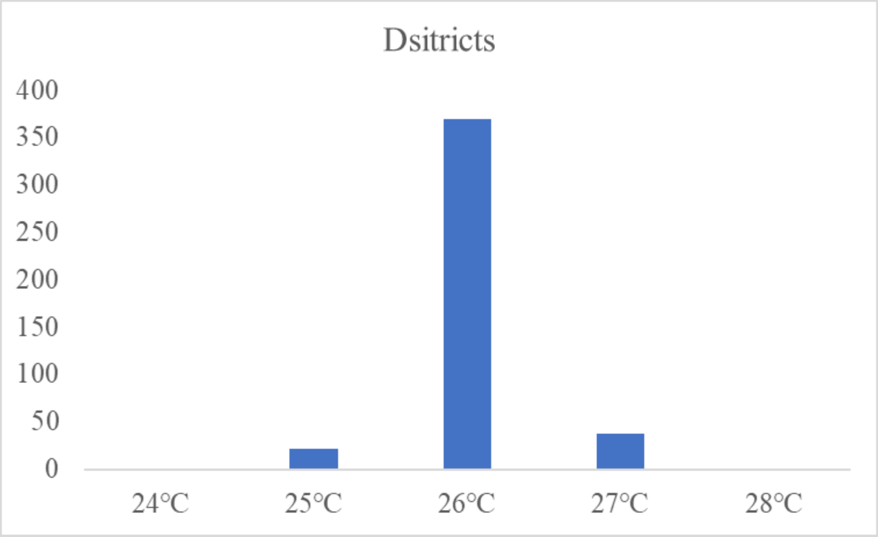


Fig.6-4-2 Districts (max protected labor productivity AC setting temperature)

In the 429 districts, 369 have the highest protected labor productivity when the setting temperature of the air conditioner is at 26 ℃, with 22 districts at 25 ℃ and 38 districts at 27 ℃. The distribution of these districts is shown in Fig.6-4-3(from white to red 25℃/26℃/27℃). The districts which max protected labor productivity AC setting temperature is 25 ℃ basically close to the sea or other water areas. And the districts which max protected labor productivity AC setting temperature is 27℃ basically in the northeast of Tokyo. This result may be due to the cooler weather in the districts near the seaside, while the districts near the northeast of Tokyo are hotter. Because the maximum performance is at 25.55 ℃, too high or too low temperature will lead to poor performance. Another possible reason is the temperature difference during the day. The average indoor temperature without turning on the air conditioner during working hours is shown in the Fig.6-4-4. From white to red represents the temperature from low to high.

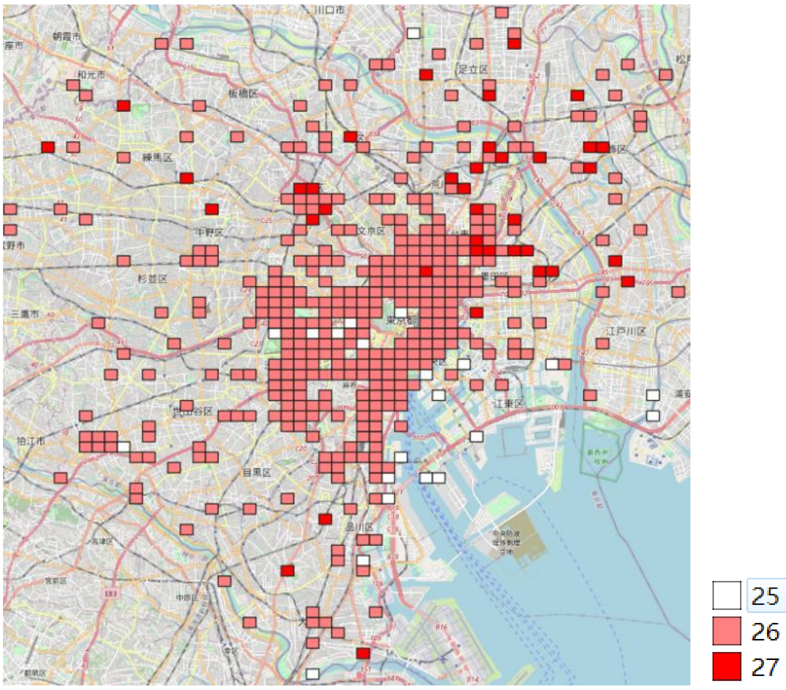


Fig.6-4-3 Districts distribution (max protected labor productivity AC setting temperature)

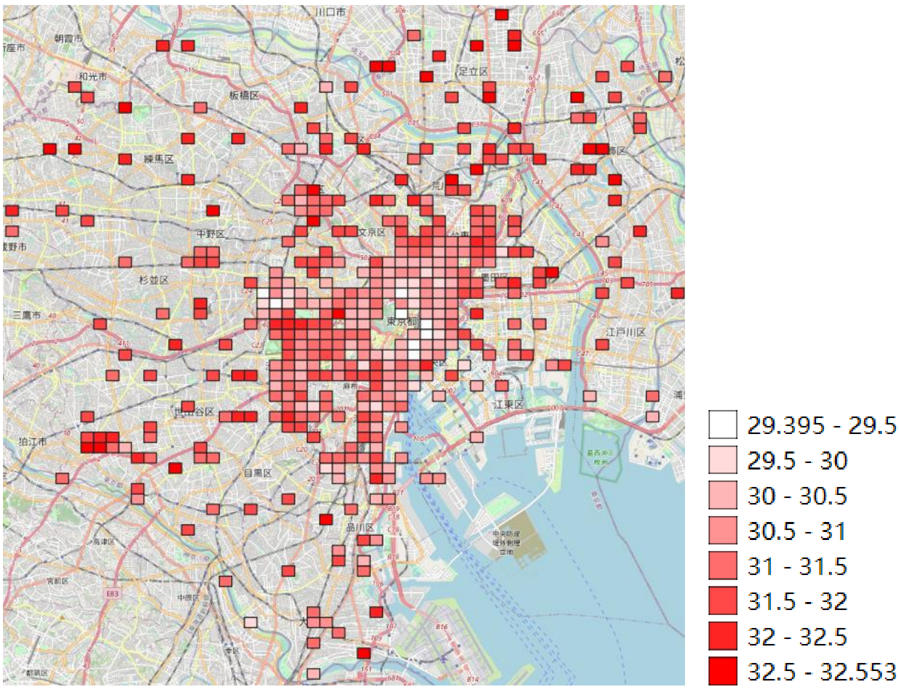


Fig.6-4-4 Average indoor temperature without turning on the air conditioner during working hours

As shown in Fig.6-5, the total labor productivity protected in 429 districts has reached a considerable number.

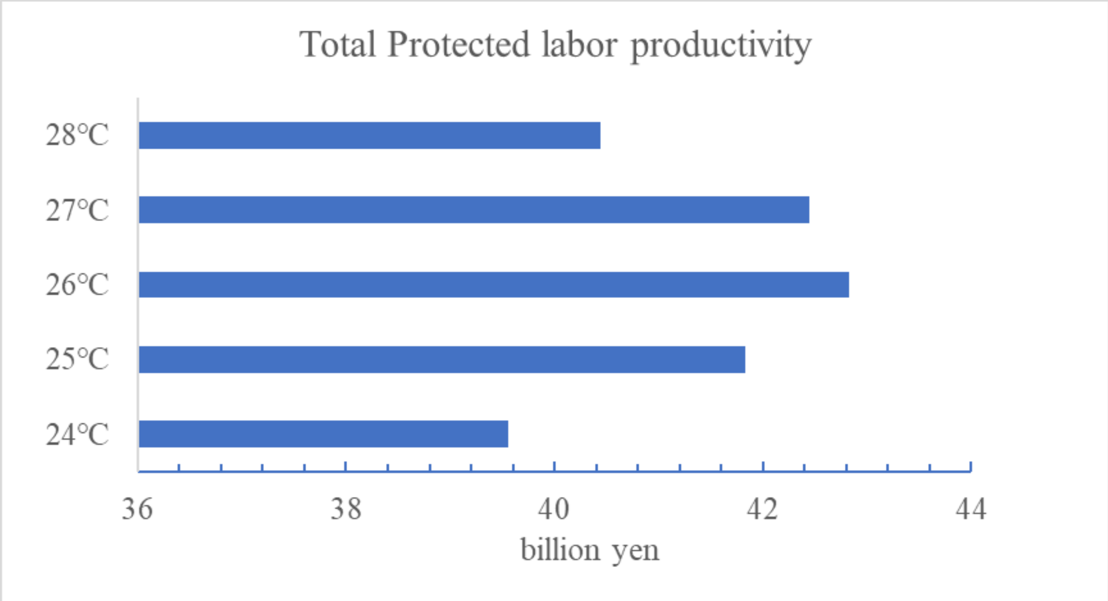


Fig.6-5 Protected labor productivity in all 429 districts

When the AC setting temperature is 26 ℃, it reaches the maximum value, about 43 billion yen. When the setting temperature of the AC is 25 ° C and 27 ° C, the result is not far from 26 ° C. Even at 24 ℃ and 28 ℃, the protected labor productivity reached about 40 billion yen.

Comparing the per capita protected labor productivity with the GDP of Tokyo[38] (because no monthly statistical results are found, the data used here is Tokyo's annual per capita GPD divided by 6), the results are shown in Fig.6-6.

In general, the labor productivity protected by AC exceeded about 5% of GDP in summer and reached a maximum of 5.52% at 26 ℃. Even when the setting temperature of the AC is 24 ℃, the labor productivity of the protection reaches 5.10% when it is the lowest. This result shows that if the air conditioner is not turned on, the economic losses will be huge. And other losses caused by heatstroke have not been considered.

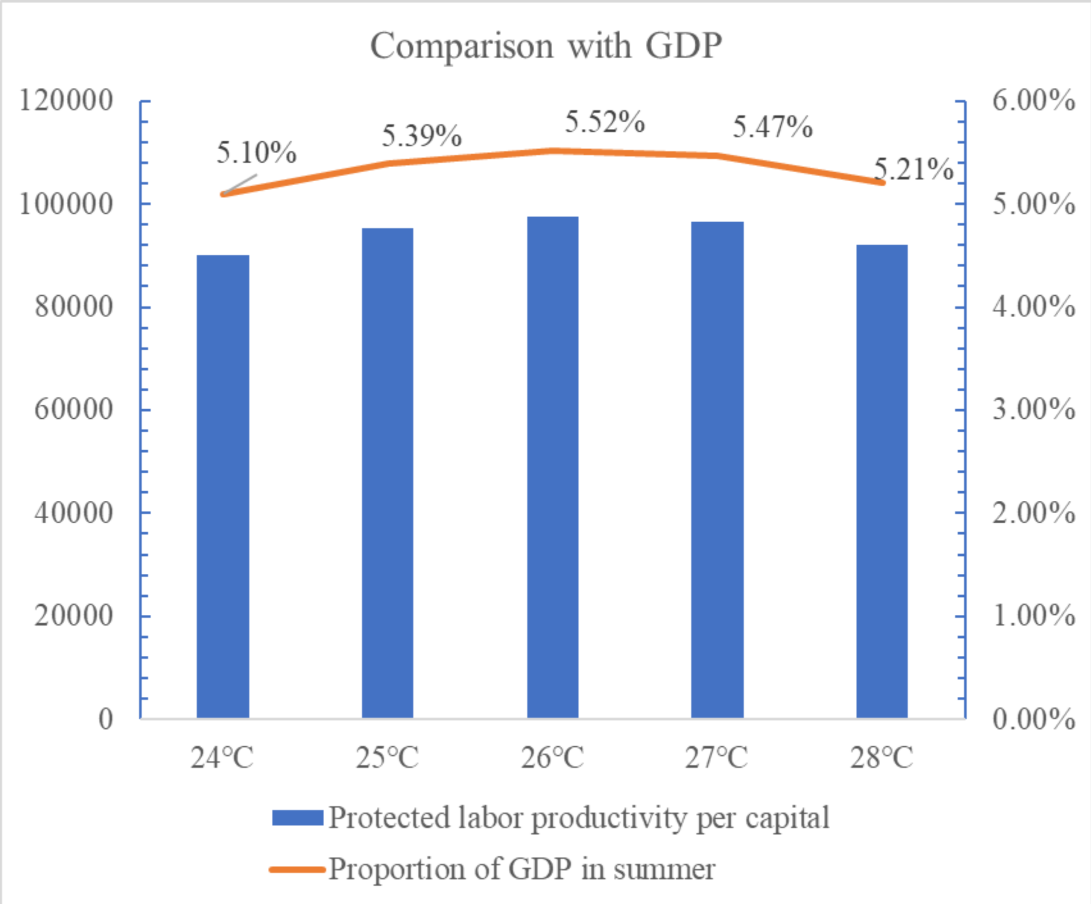


Fig. 6-6 Per capita labor productivity protected by air conditioning

6.3 Energy fee and environmental impacts

The energy cost and environmental impacts consumed by the use of AC are considered to be the total cost of using AC.

As in Fig.6-7, it shows the total cost of each district under different AC setting temperatures. With the deepening of color, the total cost is higher. The total cost is determined by the cooling area of the district and the AC power per unit area. The cooling area is calculated based on GIS data, so there may be some buildings that are not offices but are included. It can be found that with the increase of the setting temperature of the AC, the cost of using AC will gradually decrease.

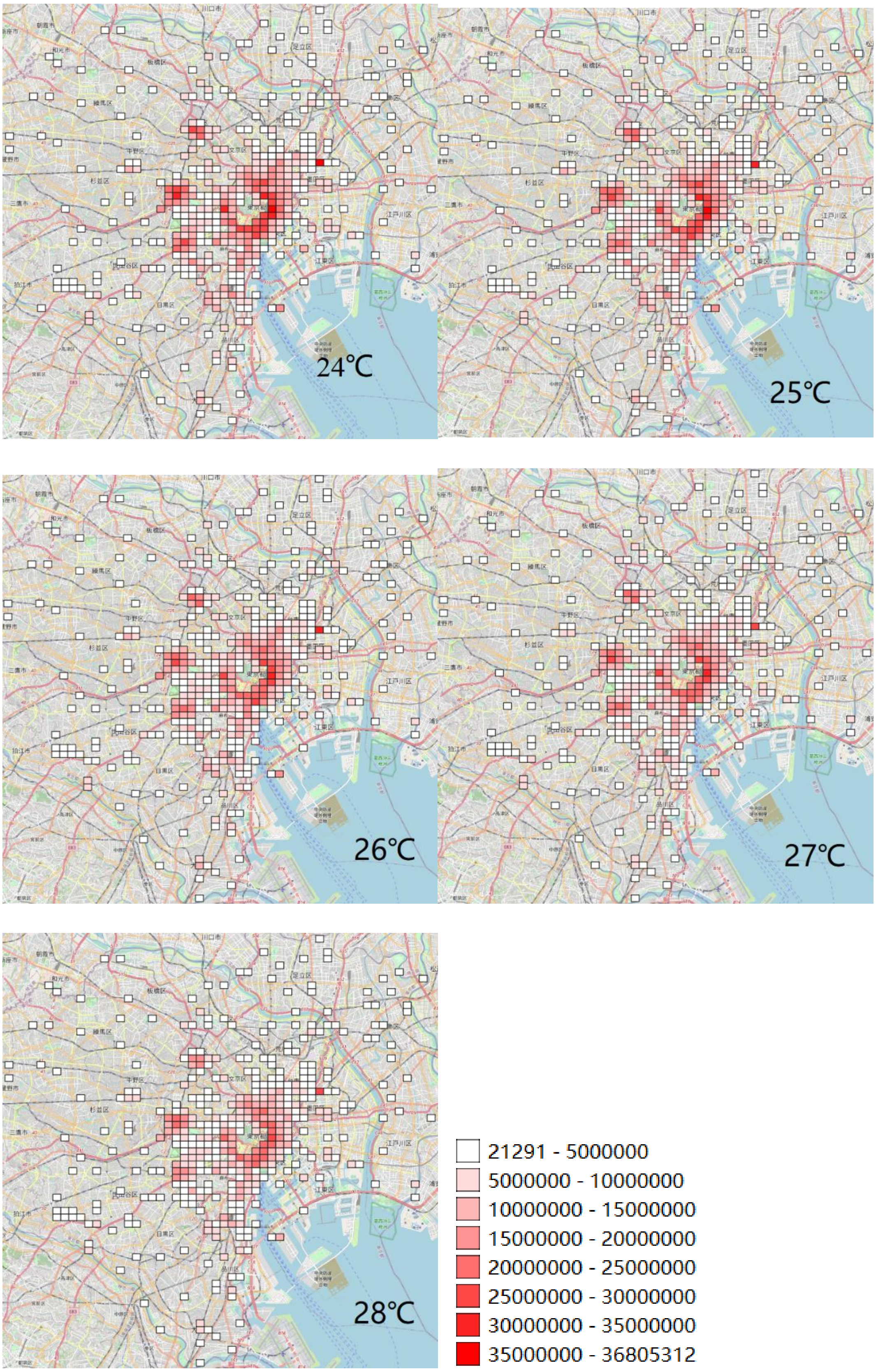


Fig.6-7 Total cost of each setting temperature

Regardless of the setting temperature of the AC, the cost is reduced with the direction away from the center of Tokyo. In addition to the larger cooling area in the central area of Tokyo, the energy consumption required for cooling in the central area of Tokyo will also be higher due to the heat island effect.

As shown in Fig.6-8, the total cost of all 429 districts It decreases with the decrease of the setting temperature of the AC. The downward trend of energy consumption is basically linear.

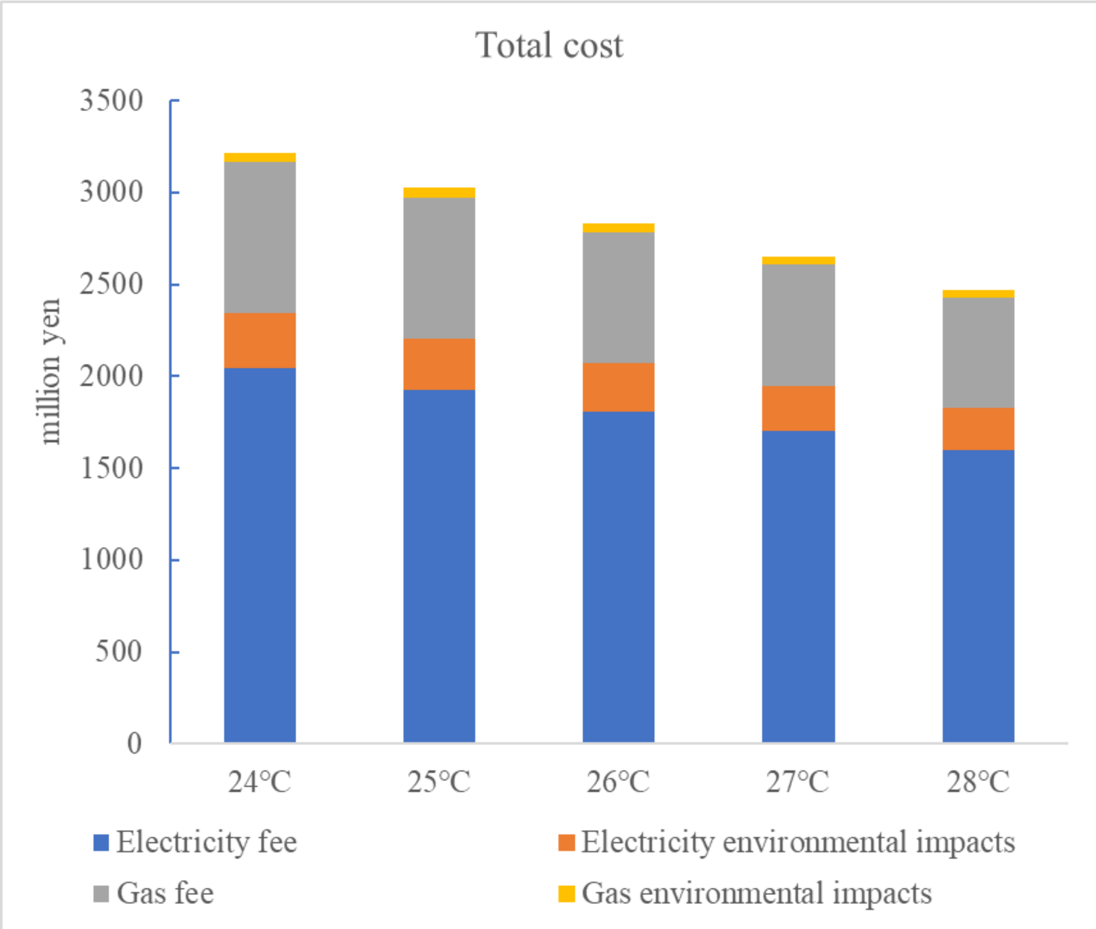


Fig.6-8 Total cost of each setting temperature

On the other hand, in terms of cost composition, the largest part is electricity fee, followed by gas fee, electricity environmental impacts, and gas environmental impacts. And with the increase of the setting temperature of the AC, the proportion of the cost of gas in the total cost will be lower, while the proportion of electricity will rise.

As for the per capita cost of using AC is shown in Fig. 6-9. In summer office buildings, the cost of using AC per capita is about 6,000–7,000 yen, which is still very low compared with GDP, only about 0.3–0.4%.

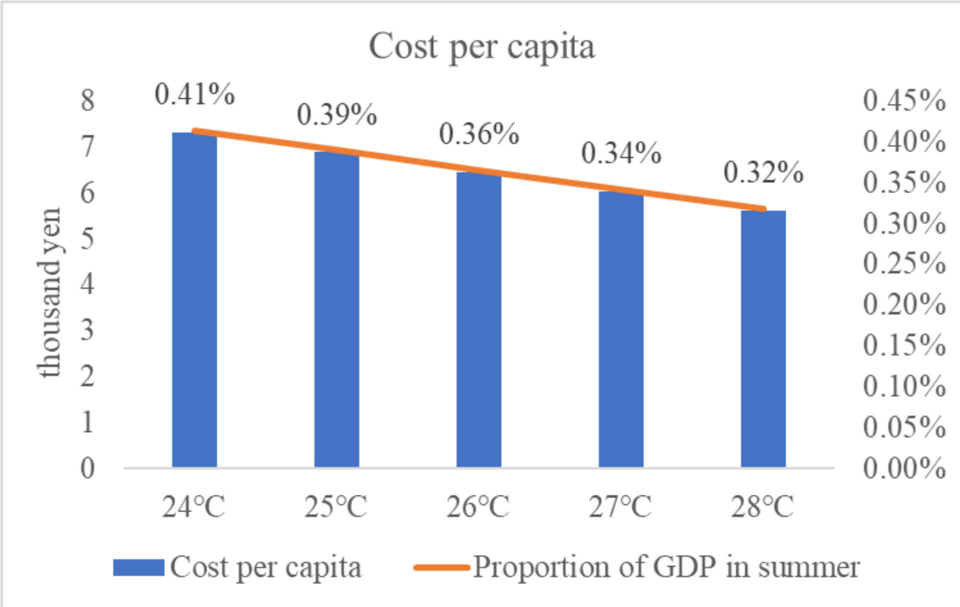
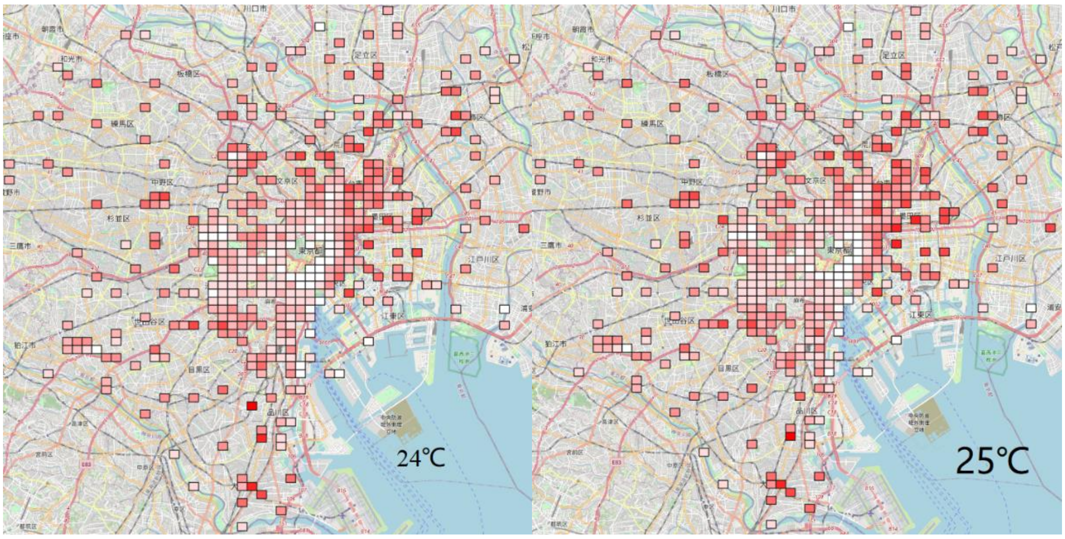


Fig. 6-9 Per capita cost of using air conditioners

6.4 Cost & benefit results

In order to get the most optimal operation of AC, it is necessary to conduct cost-benefit analysis under different setting temperatures. The AC setting temperature with the highest cost-benefit analysis result is called optimal setting temperature.



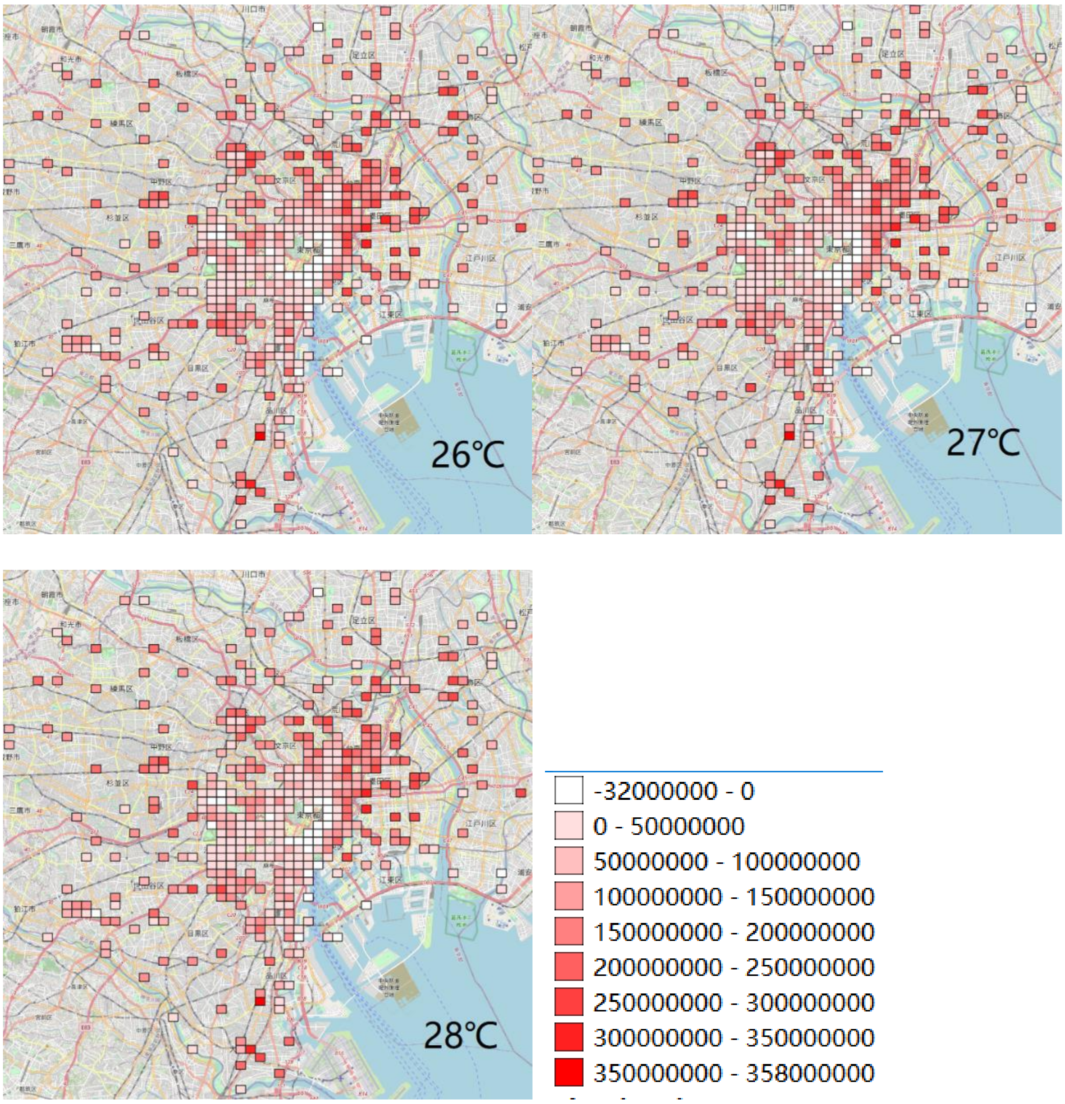


Fig.6-10 Cost-benefit analysis results of each AC setting temperature

The cost-benefit analysis results of each district at each AC setting temperature are shown in Fig.6-10. The cost-benefit analysis takes the labor productivity protected by AC as the benefit, and the energy cost and environmental impacts as the cost. In other words, the results of cost-benefit analysis represent the net economic benefits of AC in this district. In terms of distribution, the result of cost-benefit analysis is the lowest in the central area of Tokyo, the highest in the relatively middle area, and the result will become again lower in the districts far away from the urban center. Taking the emperor’s palace of Japan as the center, the result of cost-benefit analysis of the districts in the northeast will be higher.

The result of cost-benefit analysis in central Tokyo is the lowest. This means that the net economic benefit of using AC in central Tokyo is lower than that in other regions. In other words, the cost performance of AC is lower. Similar to the result of protected labor productivity, the cost-benefit results of northeast Tokyo is higher.

The results of most districts show that when the setting temperature of the AC is 26 ℃, the result of cost-benefit analysis is the highest, followed by 25 ℃ and 27 ℃, and 24 ℃ and 28 ℃ are the lowest.

As shown in Fig.6-11, the cost-benefit analysis results are quite huge reaching about 40 billion yen when the setting temperature is 26℃. The cost-benefit analysis results are the net benefits shown as blues bars, the costs are shown as orange bars. Two bars together are the protected labor productivity.

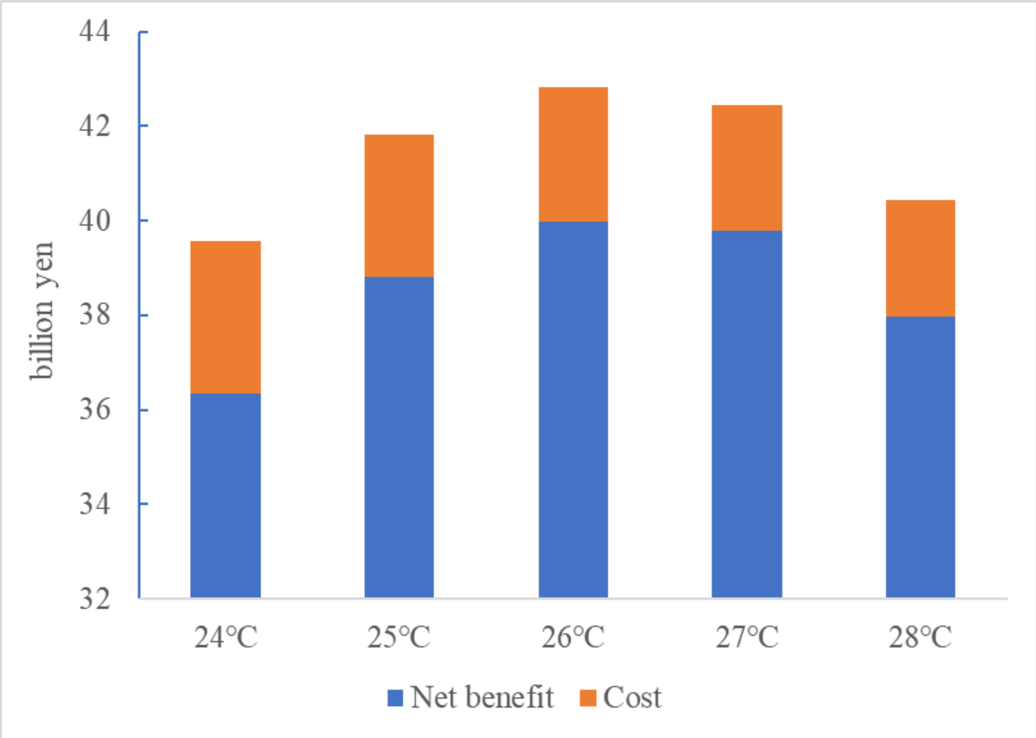


Fig.6-11 Cost & benefit results of each setting temperature

As shown in Fig.6-12, the cost-benefit analysis results per capita reached 91,044 yen, accounting for about 5.15% of the per capita GDP in summer when the setting temperature is 26℃. Even when the setting temperature of the AC is 24 ℃, the cost-benefit analysis is the lowest, reaching 82,739 yen, accounting for about 4.68% of the per capita GDP in summer.

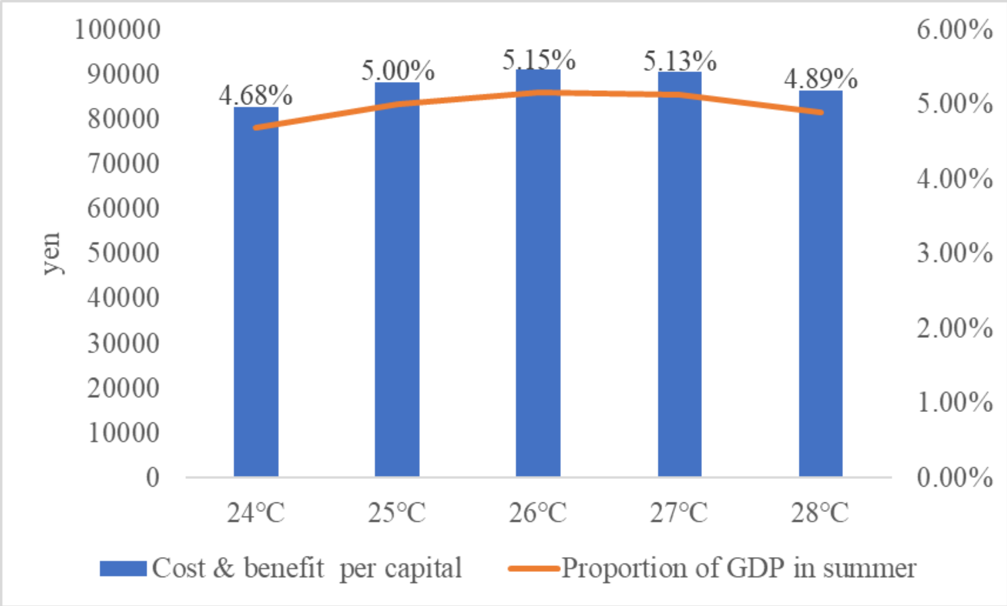


Fig.6-12 Cost & benefit results per capita of each setting temperature

6.5 The optimal setting temperature of AC

By comparing the results of cost-benefit analysis, the optimal setting temperature of AC in each district can be obtained. The optimal AC setting temperature of each district is shown in the Fig.6-13. However, there is no district with the optimal AC setting temperature of 24 ℃. So, the color from white to red represents that the optimal setting temperature of the district is reduced from 25 ℃ to 28 ℃. (25/26/27/28℃.)

The optimal setting temperature of AC in central Tokyo is higher, mostly 27 ℃ or 28 ℃. And slightly away from the center, the optimal setting temperature of the AC is mainly 26 ℃. The optimal setting temperature of the AC in the office district further away from the center and distributed with the rail transit lines is also basically 26 ℃. Only a few districts have the optimal AC temperature of 25 ℃, most of them are located near the water area. The statistical results of the district are shown in the Fig.6-14.

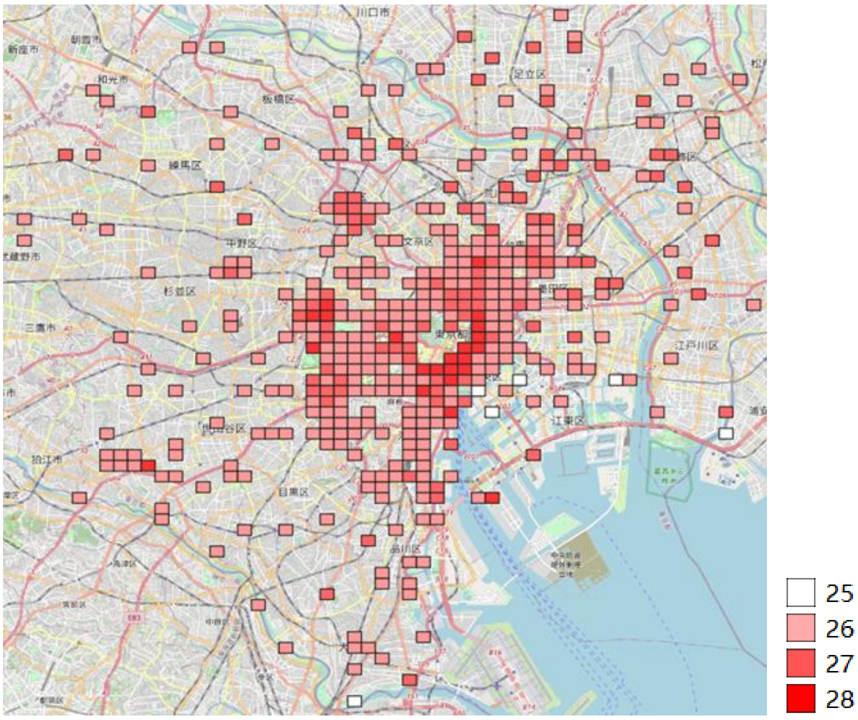


Fig.6-13 Optimal setting temperature of each district

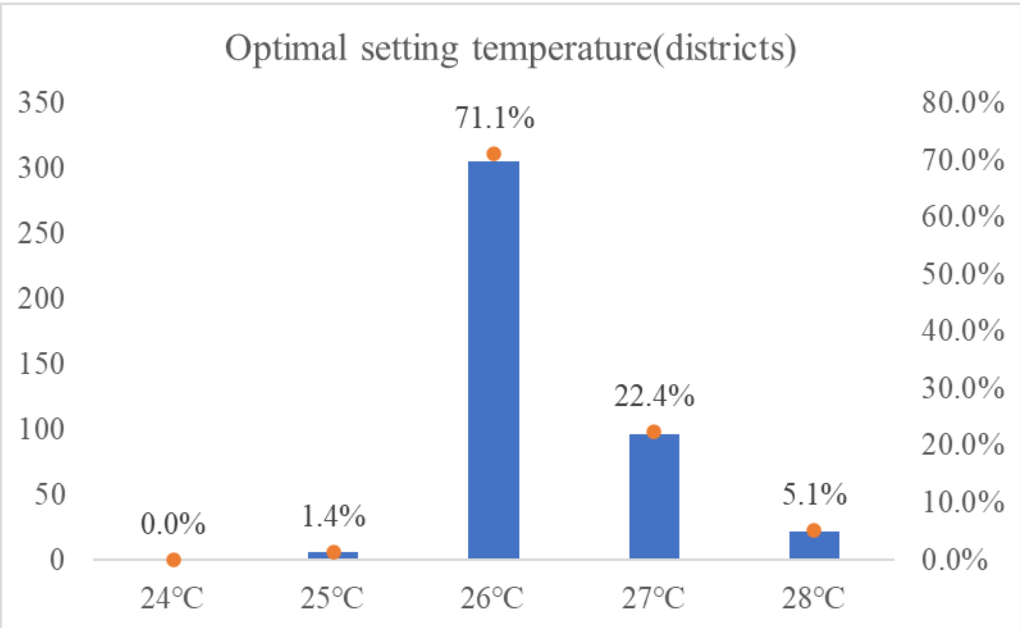


Fig.6-14 Optimal setting temperature by districts

As mentioned above, there is no district with optimal AC setting temperature of 24 °C. There are 6 districts with optimal AC setting temperature of 25 °C, accounting for 1.4%. There are 305 districts with optimal AC setting temperature of 26 °C, accounting for 71.1%. There are 96 districts with optimal AC setting temperature of

27 °C, accounting for 22.4%. There are 22 districts with optimal AC setting temperature of 28 °C, accounting for 5.1%.

The statistical results of the workers are shown in the Fig.6-15. The total number of workers in the district with optimal AC setting temperature of 25 °C is 2,912, accounting for 0.7%. The total number of workers in the district with optimal AC setting temperature of 26 °C is 348,695, accounting for 79.4%. The number of workers in the district with the setting temperature of 27 °C is 85,691, accounting for 19.5%. The number of workers in the district with optimal AC setting temperature of 28 °C is 1,969, accounting for 0.4%.

For the vast majority of Tokyo office buildings, the optimal setting temperature of AC is 26 °C, which is the largest net economic benefit.

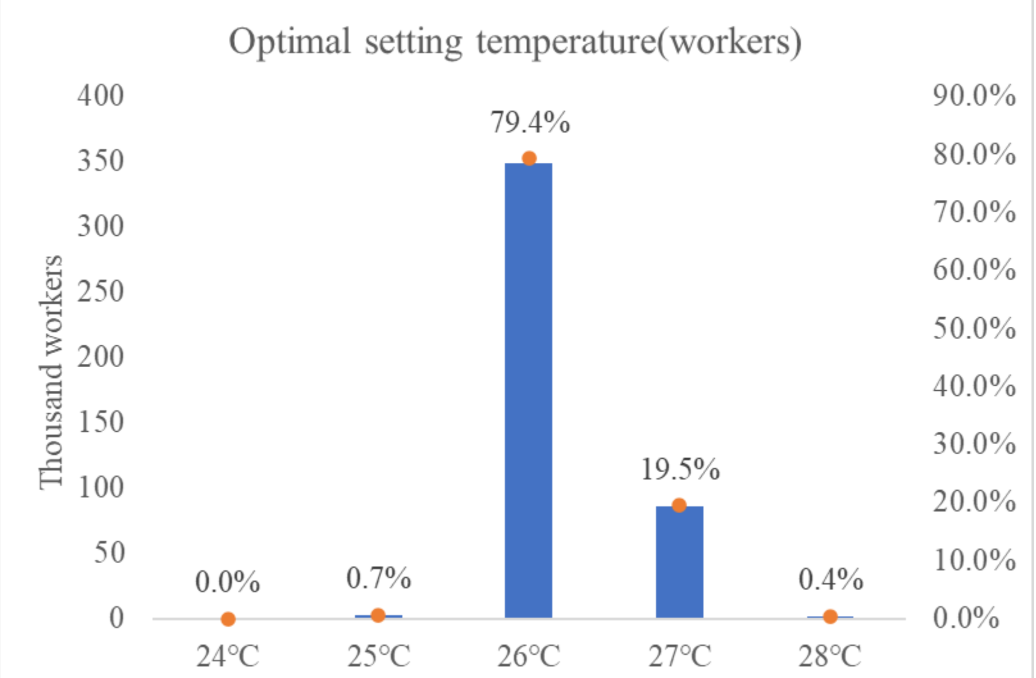


Fig.6-15 Optimal setting temperature by workers

6.6 Comparison of 26 °C and 28 °C

26 °C is the most common optimal AC setting temperature obtained in this study. This is not consistent with the 28 °C recommended by the government, so it is necessary to compare the two situations. As shown in Table 6-1, the protected labor productivity, energy fee and environmental impacts are declining by 5.9%, 14.6% and 13.9% respectively. But the cost-benefit results are also declining by 5.3%.

Table 6-1 Comparison between the 26 ℃ and 28 ℃

Per capita(yen)	26℃	28℃	Decrease range
Protected labor productivity	97,488	92,053	5.9%
Energy fee	5,737	5,005	14.6%
Environmental impacts	707	621	13.9%
Cost & benefit	91,044	86,428	5.3%

In other words, although the 28 ℃ recommended by the government is indeed effective in saving energy and reducing environmental impacts, it cannot make up for the gap in the protected labor productivity.

7.Conclusion

This study derives the labor productivity protected and the energy consumed by air conditioning by simulating 429 office districts in Tokyo's 23 wards.

(1) The per capita value of labor productivity protected by AC reaches 97,488 yen accounting for 5.52% of Tokyo's per capita GDP in summer when the setting temperature is 26 ℃, and 5.15% even after deducting energy fees and environmental impacts. The total number of workers reached about 439,267 in this simulation, and the total protected labor productivity by AC reached 42,446,428,471 yen at the setting temperature of 26 ℃. This result shows that the economic benefits brought by AC are huge, which was often ignored in the past. And the difference in economic benefits caused by different setting temperatures of air conditioners is actually quite considerable. The labor productivity protected by the setting temperature of the air conditioner at 26 ℃ is 2,884,311,645 yen higher than that at 24 ℃. If we consider that there are actually more than 439,267 office workers in Tokyo, the economic benefits of choosing optimal air conditioning setting temperature will be greater.

(2) In terms of optimal setting temperature of air conditioner, the result of 71.1% districts is 26 ℃, and the result of 22.4% districts is 27 ℃. This means that the results of most districts are consistent, that is, 26–27 ℃ is the highest net economic benefit. From the perspective of the number of workers, 98.89% of the workers have the highest net economic benefit at 26-27 ℃. Because there are more staff in those districts. In addition, the setting temperature of optimal air conditioner also depends on the value of labor productivity. If the value of labor productivity increases, the optimal setting temperature of air conditioner in more districts will be 26 ℃.

So, we can draw a conclusion which is that although the optimal setting temperature may be different in each district, in general, the optimal setting temperature of the AC in the Tokyo office districts is 26 ℃.

(3) In terms of energy fees and environmental impacts, the 28 ℃ recommended by the government is 14.6% and 13.9% lower than 26 ℃. But the protected labor productivity also decreased by 5.9%. Because the value of labor productivity is far greater than the energy fees and environmental impacts. Therefore, comparing the results of cost-benefit analysis, 26 ℃ is 5.3% higher than 28 ℃. Therefore, for the office districts, the net economic benefit of 26 ℃ is significantly higher than that of 28 ℃.

The 28 ℃ recommended by the government is indeed effective in saving energy and reducing environmental impacts, but the decline of labor productivity protected by AC is not enough to cover the gap. Therefore, through cost-benefit analysis, the conclusion of this study is that, at least in office districts, lower AC setting temperature should be adopted.

8.Discussion

Limited by some conditions, the results of this study still have shortcomings.

(1) This study only selects the indoor temperature as the variable. In addition to the limited impact of air conditioning on other IEQ factors, it is also because there are few quantitative studies on combine effect of temperature, humidity, air velocity etc. If there is more study about the combine effect, the labor productivity protected by air conditioning will be more accurate.

(2) Limited by the data source, the meteorological data used in this simulation is from 2000, and other data are from 2015–2020 (number of workers, working hours, traffic heat removal, GIS data, etc.)

(3) The cooling area may not match the number of workers. This is also one of the reasons why the optimal air conditioning setting temperature in some districts is 28 ℃.

(4) This study only simulates the situation of office districts. In fact, many districts also have office buildings, but they are not classified as office districts, so the coverage is not comprehensive.

(5) This study adopts the results of previous studies on work performance. Although adjusted, it is still unable to verify whether it is suitable for the situation in Tokyo.

(6) Sensitivity analysis was not performed in this simulation. The index that may have an important impact on this simulation is the per capita cooling area. Because the cooling area and the number of people in the office are from different data sources, the results of some blocks may be very different. While other parameters are consistent for each block.

9.Prospect

There are still many deficiencies in this study, and the aspects that can be improved in the future include:

(1) In this study, the environmental impacts generated by air conditioning is limited to energy consumption. However, the environmental impacts caused by the production and waste treatment of air conditioners should also be included according to the service life of air conditioners.

(2) By changing the elasticities of labor productivity in the Cobb-Douglas production function, we can actually calculate the loss of labor productivity in different industries. However, there is a lack of methods to determine the specific industry of the workers in the districts.

(3) If we analyze the energy consumption data and protected labor productivity data in different time periods, we may be able to give more reasonable suggestions on the opening time of the air conditioner in a day. So as to achieve more energy conservation while protecting labor productivity.

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Appendix

Appendix(A): Inventory analysis of electricity (Input)

Input Flow	Category	Sub-category	Unit	Result
air	natural resource	in air	kg	1.13E-07
carbon dioxide	natural resource	in air	kg	3.43E-10
helium	natural resource	in air	kg	0
primary energy from solar energy	natural resource	in air	MJ	0.006736
primary energy from wind power	natural resource	in air	MJ	4.15E-07
acid clay	natural resource	in ground	kg	2.88E-20
aluminium	natural resource	in ground	kg	1.27E-07
antimony	natural resource	in ground	kg	4.68E-14
barium	natural resource	in ground	kg	7.27E-13
bentonite	natural resource	in ground	kg	0
bismuth	natural resource	in ground	kg	-2.2E-17
borax	natural resource	in ground	kg	6.45E-14
boron	natural resource	in ground	kg	0
brown coal, 17.2MJ/kg	natural resource	in ground	kg	0
calcium carbonate	natural resource	in ground	kg	5.02E-08
carbon	natural resource	in ground	kg	8.11E-10
chromium	natural resource	in ground	kg	-5.8E-15
clay	natural resource	in ground	kg	-2.7E-15
cobalt	natural resource	in ground	kg	3.86E-13
copper	natural resource	in ground	kg	6.87E-14
crude oil, 44.7MJ/kg	natural resource	in ground	kg	0.025215
cryolite	natural resource	in ground	kg	0
diamond	natural resource	in ground	kg	3.1E-15
diatomite	natural resource	in ground	kg	2.13E-14
dolomite	natural resource	in ground	kg	8.13E-14
feldspar	natural resource	in ground	kg	6.66E-14
fluorspar	natural resource	in ground	kg	1.85E-09
gallium	natural resource	in ground	kg	2.13E-19
geothermal energy	natural resource	in ground	MJ	0.000299
gold	natural resource	in ground	kg	2.07E-17
hard coal, 25.7MJ/kg	natural resource	in ground	kg	0.032675
iron	natural resource	in ground	kg	3.07E-12
iron ore	natural resource	in ground	kg	0
kaolin	natural resource	in ground	kg	6.68E-11
lanthanum	natural resource	in ground	kg	0

lead	natural resource	in ground	kg	9.34E-12
lithium	natural resource	in ground	kg	5.7E-17
manganese	natural resource	in ground	kg	6.65E-14
marble	natural resource	in ground	kg	-2.6E-13
metallurgical coal, 29.0MJ/kg	natural resource	in ground	kg	2.23E-08
mineral phosphate	natural resource	in ground	kg	1.93E-10
Mineral resources from the ground of the other	natural resource	in ground	kg	1.05E-10
molybdenum	natural resource	in ground	kg	1.3E-12
Natural Gas Liquids, 46.5MJ/kg	natural resource	in ground	kg	3.61E-09
natural gas, 54.6MJ/kg	natural resource	in ground	kg	0.160332
natural latex	natural resource	in ground	kg	6.25E-13
neodymium	natural resource	in ground	kg	0
nickel	natural resource	in ground	kg	-5.8E-15
niobium	natural resource	in ground	kg	-2E-19
ore (not specific)	natural resource	in ground	kg	1.76E-10
peridotite	natural resource	in ground	kg	0
pit sand	natural resource	in ground	kg	0
platinum	natural resource	in ground	kg	-3E-18
praseodymium	natural resource	in ground	kg	6.79E-19
pyrophyllite	natural resource	in ground	kg	0
quartz sand	natural resource	in ground	kg	3.46E-11
rock, except limestone	natural resource	in ground	kg	0
samarium	natural resource	in ground	kg	0
sand (sea and river)	natural resource	in ground	kg	0
selenium	natural resource	in ground	kg	-3.2E-21
serpentine	natural resource	in ground	kg	8.22E-13
silica stone	natural resource	in ground	kg	1.73E-11
silver	natural resource	in ground	kg	6.96E-14
sodium carbonate	natural resource	in ground	kg	0
sodium chloride	natural resource	in ground	kg	4.9E-14
sulfur	natural resource	in ground	kg	8.15E-09
talc	natural resource	in ground	kg	2.1E-11
tantalum	natural resource	in ground	kg	0
tellurium	natural resource	in ground	kg	-4.2E-18
titanium	natural resource	in ground	kg	5.21E-12
tungsten	natural resource	in ground	kg	-6.3E-17
uranium, U3O8	natural resource	in ground	kg	1.93E-10
vanadium	natural resource	in ground	kg	-7.9E-17

wood, Japan, artificial forest, reforestation	natural resource	in ground	kg	2.09E-10
wood, Japan, artificial forest, without reforestation	natural resource	in ground	kg	2.09E-10
zinc	natural resource	in ground	kg	1.17E-12
zirconium	natural resource	in ground	kg	-8.5E-19
brine water, use	natural resource	in water	m3	1.81E-17
brine water, withdrawal	natural resource	in water	m3	2.06E-17
ground water, consumption	natural resource	in water	m3	7.89E-07
ground water, use	natural resource	in water	m3	5.79E-06
ground water, withdrawal	natural resource	in water	m3	6.58E-06
primary energy from hydro power	natural resource	in water	MJ	0.186156
rain water, use	natural resource	in water	m3	2.3E-09
rain water, withdrawal	natural resource	in water	m3	3.95E-09
sea water, consumption	natural resource	in water	m3	8.82E-05
sea water, use	natural resource	in water	m3	0.191932
sea water, withdrawal	natural resource	in water	m3	0.19202
surface water, consumption	natural resource	in water	m3	1.93E-05
surface water, use	natural resource	in water	m3	0.345459
surface water, withdrawal	natural resource	in water	m3	0.345478
transpiration, ground water, consumption	natural resource	in water	m3	1.96E-12
transpiration, rain water, consumption	natural resource	in water	m3	1.66E-09
transpiration, surface water, consumption	natural resource	in water	m3	3.51E-11
building site	natural resource	land	m2*a	0.000586
field	natural resource	land	m2*a	5.57E-10
forest	natural resource	land	m2*a	1.85E-09
forest to barren land	natural resource	land	m2	2.32E-11
forest to building site	natural resource	land	m2	1.17E-05
forest to field	natural resource	land	m2	1.11E-11
forest to forest	natural resource	land	m2	2.32E-11
forest to miscellaneous plantation	natural resource	land	m2	6.14E-14
forest to orchard	natural resource	land	m2	1.65E-18
forest to other, land use, land transformation	natural resource	land	m2	3.03E-15
forest to rice paddy	natural resource	land	m2	2.86E-14
forest to transport artery	natural resource	land	m2	6.92E-29

mineral extraction site	natural resource	land	m2*a	0.000453
miscellaneous land use type to mineral extraction site	natural resource	land	m2	9.06E-06
miscellaneous plantation	natural resource	land	m2*a	3.07E-12
orchard	natural resource	land	m2*a	8.25E-17
other land use type	natural resource	land	m2*a	1.51E-13
rice paddy	natural resource	land	m2*a	1.43E-12
transport artery	natural resource	land	m2*a	3.46E-27

Appendix(B): Inventory analysis of electricity(Output)

Output Flow	Category	Sub-category	Unit	Result
NOx, non-urban	air	non-urban air or from high stacks	kg	0.000228
NOx, urban high stacks	air	non-urban air or from high stacks	kg	0.000173
Particulates (PM10), non-urban	air	non-urban air or from high stacks	kg	3.26E-06
Particulates (PM10), urban high stacks	air	non-urban air or from high stacks	kg	5.53E-07
SOx, non-urban	air	non-urban air or from high stacks	kg	0
SOx, urban high stacks	air	non-urban air or from high stacks	kg	3.14E-05
sulfur dioxide, non-urban	air	non-urban air or from high stacks	kg	0.000477
sulfur dioxide, urban high stacks	air	non-urban air or from high stacks	kg	1.54E-06
2,3,7,8-tetrachlorodibenzo-p-dioxin	air	unspecified	kg	9.64E-23
ammonia	air	unspecified	kg	-2.1E-18
arsenic	air	unspecified	kg	2.69E-09
cadmium	air	unspecified	kg	2.22E-10
carbon dioxide	air	unspecified	kg	1.13E-11
carbon dioxide (biogenic)	air	unspecified	kg	1.44E-09
carbon dioxide (fossil)	air	unspecified	kg	0.554451
carbon monoxide	air	unspecified	kg	6.14E-05
CFC-11	air	unspecified	kg	0
CFC-12	air	unspecified	kg	0
chlorine	air	unspecified	kg	1.45E-15
chromium	air	unspecified	kg	4.9E-09
cobalt	air	unspecified	kg	-5.1E-29
copper	air	unspecified	kg	-3.2E-22
H2SO4	air	unspecified	kg	-8.4E-23
HCFC-141b	air	unspecified	kg	5.84E-15
HCFC-22	air	unspecified	kg	5.79E-11
HFC-134a	air	unspecified	kg	8.52E-16
hydrocarbons	air	unspecified	kg	7.95E-06

hydrogen chloride	air	unspecified	kg	-4.3E-19
hydrogen fluoride	air	unspecified	kg	-1.4E-18
hydrogen sulfide	air	unspecified	kg	-9.7E-21
lead	air	unspecified	kg	1.29E-08
mercury	air	unspecified	kg	3.25E-09
methane	air	unspecified	kg	6.78E-14
methane (biogenic)	air	unspecified	kg	6.08E-14
methane (fossil)	air	unspecified	kg	0.000134
nickel	air	unspecified	kg	5.5E-09
nitrous oxide	air	unspecified	kg	3.2E-07
non-methane volatile organic compounds	air	unspecified	kg	2.93E-05
PFC-116	air	unspecified	kg	1.07E-18
PFC-14	air	unspecified	kg	1.07E-17
sulfur hexafluoride	air	unspecified	kg	3.05E-08
vanadium	air	unspecified	kg	1.97E-08
volatile organic compound	air	unspecified	kg	-2.6E-17
zinc	air	unspecified	kg	6.88E-08
NOx, urban air close to ground	air	urban air close to ground	kg	1.75E-12
Particulates (PM2.5), urban air close to ground	air	urban air close to ground	kg	0
sulfur dioxide, urban air close to ground	air	urban air close to ground	kg	1.14E-28
treated industrial waste for landfill	soil	industrial	kg	4.18E-10
treated MSW for landfill	soil	industrial	kg	0
acid (as H+)	water	unspecified	kg	-3E-21
ammonium	water	unspecified	kg	5.41E-16
arsenic	water	unspecified	kg	1.56E-18
boron	water	unspecified	kg	5.33E-18
cadmium	water	unspecified	kg	9.77E-21
chemical oxygen demand	water	unspecified	kg	2.47E-13
chromium	water	unspecified	kg	4.86E-20
cobalt	water	unspecified	kg	-1E-21
copper	water	unspecified	kg	-1.3E-21
hydrocarbons	water	unspecified	kg	-2E-17
hydrogen fluoride	water	unspecified	kg	-8.1E-17
lead	water	unspecified	kg	2.3E-19
manganese	water	unspecified	kg	1.12E-18
mercury	water	unspecified	kg	5.59E-21

N total	water	unspecified	kg	1.99E-15
nickel	water	unspecified	kg	-1.6E-20
nickel compounds	water	unspecified	kg	1.08E-18
oil and grease	water	unspecified	kg	1.11E-14
P total	water	unspecified	kg	7.83E-16
sulphuric acid	water	unspecified	kg	-4.8E-19
suspended solids	water	unspecified	kg	3.57E-14
zinc	water	unspecified	kg	3.9E-19

Appendix(C): Inventory analysis of gas (Input)

Input Flow	Category	Sub-category	Unit	Result
air	natural resource	in air	kg	2.9E-07
carbon dioxide	natural resource	in air	kg	7.56E-10
helium	natural resource	in air	kg	0
primary energy from solar energy	natural resource	in air	MJ	8.14E-05
primary energy from wind power	natural resource	in air	MJ	3.16E-05
acid clay	natural resource	in ground	kg	6.68E-22
aluminium	natural resource	in ground	kg	3.45E-07
antimony	natural resource	in ground	kg	8.03E-14
barium	natural resource	in ground	kg	1.4E-12
bentonite	natural resource	in ground	kg	0
bismuth	natural resource	in ground	kg	-3.4E-17
borax	natural resource	in ground	kg	1.4E-13
boron	natural resource	in ground	kg	0
brown coal, 17.2MJ/kg	natural resource	in ground	kg	0
calcium carbonate	natural resource	in ground	kg	1.23E-07
carbon	natural resource	in ground	kg	2.2E-09
chromium	natural resource	in ground	kg	6.57E-15
clay	natural resource	in ground	kg	3.11E-14
cobalt	natural resource	in ground	kg	8.89E-13
copper	natural resource	in ground	kg	1.35E-13
crude oil, 44.7MJ/kg	natural resource	in ground	kg	0.074825
cryolite	natural resource	in ground	kg	0
diamond	natural resource	in ground	kg	-1.7E-14
diatomite	natural resource	in ground	kg	3.97E-14
dolomite	natural resource	in ground	kg	3.7E-13
feldspar	natural resource	in ground	kg	4.36E-14
fluorspar	natural resource	in ground	kg	4.93E-09
gallium	natural resource	in ground	kg	-5.1E-18

geothermal energy	natural resource	in ground	MJ	3.4E-05
gold	natural resource	in ground	kg	3.78E-17
hard coal, 25.7MJ/kg	natural resource	in ground	kg	0.001406
iron	natural resource	in ground	kg	1.47E-11
iron ore	natural resource	in ground	kg	0
kaolin	natural resource	in ground	kg	1.47E-10
lanthanum	natural resource	in ground	kg	0
lead	natural resource	in ground	kg	2.16E-11
lithium	natural resource	in ground	kg	-1.9E-16
manganese	natural resource	in ground	kg	2.04E-13
marble	natural resource	in ground	kg	-2.4E-12
metallurgical coal, 29.0MJ/kg	natural resource	in ground	kg	2.39E-08
mineral phosphate	natural resource	in ground	kg	4.41E-10
Mineral resources from the ground of the other	natural resource	in ground	kg	2.43E-10
molybdenum	natural resource	in ground	kg	3E-12
Natural Gas Liquids, 46.5MJ/kg	natural resource	in ground	kg	1.88E-11
natural gas, 54.6MJ/kg	natural resource	in ground	kg	1.005984
natural latex	natural resource	in ground	kg	1.06E-12
neodymium	natural resource	in ground	kg	0
nickel	natural resource	in ground	kg	-6.9E-15
niobium	natural resource	in ground	kg	-1.1E-18
ore (not specific)	natural resource	in ground	kg	3.91E-10
peridotite	natural resource	in ground	kg	0
pit sand	natural resource	in ground	kg	0
platinum	natural resource	in ground	kg	6.61E-18
praseodymium	natural resource	in ground	kg	1.14E-17
pyrophyllite	natural resource	in ground	kg	0
quartz sand	natural resource	in ground	kg	5.69E-11
rock, except limestone	natural resource	in ground	kg	0
samarium	natural resource	in ground	kg	0
sand (sea and river)	natural resource	in ground	kg	0
selenium	natural resource	in ground	kg	3.74E-18
serpentine	natural resource	in ground	kg	1.71E-12
silica stone	natural resource	in ground	kg	2.93E-11
silver	natural resource	in ground	kg	1.14E-13
sodium carbonate	natural resource	in ground	kg	0
sodium chloride	natural resource	in ground	kg	1.18E-13
sulfur	natural resource	in ground	kg	2.61E-08
talc	natural resource	in ground	kg	4.64E-11

tantalum	natural resource	in ground	kg	0
tellurium	natural resource	in ground	kg	-8.4E-18
titanium	natural resource	in ground	kg	1.21E-11
tungsten	natural resource	in ground	kg	6.86E-17
uranium, U3O8	natural resource	in ground	kg	8.3E-12
vanadium	natural resource	in ground	kg	3.89E-17
wood, Japan, artificial forest, reforestation	natural resource	in ground	kg	4.57E-10
wood, Japan, artificial forest, without reforestation	natural resource	in ground	kg	4.57E-10
zinc	natural resource	in ground	kg	2.6E-12
zirconium	natural resource	in ground	kg	1.29E-17
brine water, use	natural resource	in water	m3	2.88E-17
brine water, withdrawal	natural resource	in water	m3	-2.3E-17
ground water, consumption	natural resource	in water	m3	4.25E-06
ground water, use	natural resource	in water	m3	8.13E-05
ground water, withdrawal	natural resource	in water	m3	8.56E-05
primary energy from hydro power	natural resource	in water	MJ	0.00558
rain water, use	natural resource	in water	m3	4.94E-09
rain water, withdrawal	natural resource	in water	m3	8.45E-09
sea water, consumption	natural resource	in water	m3	0.000263
sea water, use	natural resource	in water	m3	0.003804
sea water, withdrawal	natural resource	in water	m3	0.004067
surface water, consumption	natural resource	in water	m3	1.02E-05
surface water, use	natural resource	in water	m3	0.010545
surface water, withdrawal	natural resource	in water	m3	0.010555
transpiration, ground water, consumption	natural resource	in water	m3	3.53E-12
transpiration, rain water, consumption	natural resource	in water	m3	3.51E-09
transpiration, surface water, consumption	natural resource	in water	m3	6.34E-11
building site	natural resource	land	m2*a	0.00014
field	natural resource	land	m2*a	1E-09
forest	natural resource	land	m2*a	4.05E-09
forest to barren land	natural resource	land	m2	5.07E-11
forest to building site	natural resource	land	m2	2.8E-06
forest to field	natural resource	land	m2	2E-11
forest to forest	natural resource	land	m2	5.07E-11

forest to miscellaneous plantation	natural resource	land	m2	1.04E-13
forest to orchard	natural resource	land	m2	2.99E-18
forest to other, land use, land transformation	natural resource	land	m2	4.96E-15
forest to rice paddy	natural resource	land	m2	4.66E-14
forest to transport artery	natural resource	land	m2	1.13E-28
mineral extraction site	natural resource	land	m2*a	1.95E-05
miscellaneous land use type to mineral extraction site	natural resource	land	m2	3.9E-07
miscellaneous plantation	natural resource	land	m2*a	5.21E-12
orchard	natural resource	land	m2*a	1.5E-16
other land use type	natural resource	land	m2*a	2.48E-13
rice paddy	natural resource	land	m2*a	2.33E-12
transport artery	natural resource	land	m2*a	5.63E-27

Appendix(D): Inventory analysis of gas (output)

Flow	**Category**	**Sub-category**	**Unit**	**Result**
NOx, non-urban	air	non-urban air or from high stacks	kg	0.000465
NOx, urban high stacks	air	non-urban air or from high stacks	kg	0.000406
Particulates (PM10), non-urban	air	non-urban air or from high stacks	kg	3.01E-06
Particulates (PM10), urban high stacks	air	non-urban air or from high stacks	kg	7.55E-09
SOx, non-urban	air	non-urban air or from high stacks	kg	0
SOx, urban high stacks	air	non-urban air or from high stacks	kg	2.17E-05
sulfur dioxide, non-urban	air	non-urban air or from high stacks	kg	0.002216
sulfur dioxide, urban high stacks	air	non-urban air or from high stacks	kg	4.95E-06
2,3,7,8-tetrachlorodibenzo-p-dioxin	air	unspecified	kg	1.79E-22
ammonia	air	unspecified	kg	-2.5E-18
arsenic	air	unspecified	kg	1.16E-10
cadmium	air	unspecified	kg	9.57E-12
carbon dioxide	air	unspecified	kg	2.67E-11
carbon dioxide (biogenic)	air	unspecified	kg	3.13E-09
carbon dioxide (fossil)	air	unspecified	kg	0.5353
carbon monoxide	air	unspecified	kg	4.46E-05
CFC-11	air	unspecified	kg	0
CFC-12	air	unspecified	kg	0
chlorine	air	unspecified	kg	2.63E-15

chromium	air	unspecified	kg	2.11E-10
cobalt	air	unspecified	kg	2.77E-28
copper	air	unspecified	kg	-3.9E-22
H2SO4	air	unspecified	kg	-1E-22
HCFC-141b	air	unspecified	kg	9.53E-15
HCFC-22	air	unspecified	kg	1.56E-10
HFC-134a	air	unspecified	kg	1.39E-15
hydrocarbons	air	unspecified	kg	4.85E-05
hydrogen chloride	air	unspecified	kg	-5.1E-19
hydrogen fluoride	air	unspecified	kg	4.09E-19
hydrogen sulfide	air	unspecified	kg	-1.2E-20
lead	air	unspecified	kg	5.55E-10
mercury	air	unspecified	kg	1.4E-10
methane	air	unspecified	kg	1.1E-13
methane (biogenic)	air	unspecified	kg	1.2E-13
methane (fossil)	air	unspecified	kg	0.000306
nickel	air	unspecified	kg	2.37E-10
nitrous oxide	air	unspecified	kg	9.71E-07
non-methane volatile organic compounds	air	unspecified	kg	4.49E-07
PFC-116	air	unspecified	kg	2.57E-18
PFC-14	air	unspecified	kg	2.57E-17
sulfur hexafluoride	air	unspecified	kg	5.04E-10
vanadium	air	unspecified	kg	6.77E-10
volatile organic compound	air	unspecified	kg	7.77E-18
zinc	air	unspecified	kg	2.17E-09
NOx, urban air close to ground	air	urban air close to ground	kg	2.84E-12
Particulates (PM2.5), urban air close to ground	air	urban air close to ground	kg	0
sulfur dioxide, urban air close to ground	air	urban air close to ground	kg	1.86E-28
treated industrial waste for landfill	soil	industrial	kg	8.94E-10
treated MSW for landfill	soil	industrial	kg	0
acid (as H+)	water	unspecified	kg	-3.6E-21
ammonium	water	unspecified	kg	9.18E-16
arsenic	water	unspecified	kg	2.89E-18
boron	water	unspecified	kg	9.86E-18
cadmium	water	unspecified	kg	1.81E-20
chemical oxygen demand	water	unspecified	kg	6.04E-13

chromium	water	unspecified	kg	9.01E-20
cobalt	water	unspecified	kg	-1.2E-21
copper	water	unspecified	kg	-1.6E-21
hydrocarbons	water	unspecified	kg	6.48E-18
hydrogen fluoride	water	unspecified	kg	4.35E-17
lead	water	unspecified	kg	4.67E-19
manganese	water	unspecified	kg	2.08E-18
mercury	water	unspecified	kg	1.31E-20
N total	water	unspecified	kg	3.95E-15
nickel	water	unspecified	kg	-2E-20
nickel compounds	water	unspecified	kg	1.99E-18
oil and grease	water	unspecified	kg	2.58E-14
P total	water	unspecified	kg	1.67E-15
sulphuric acid	water	unspecified	kg	-5.8E-19
suspended solids	water	unspecified	kg	7.76E-14
zinc	water	unspecified	kg	7.22E-19

Appendix(E): [WF]G20 (population weighted)

Country name	人間健康の損失	資源の損失	生物種の損失	森林の損失	森林の損失
	US$/1DALY	US$WTP/1US$SA	US$/1種	US$/1kg	US$/1億トン
G20	9.58E+03	9.24E-01	6.25E+09	2.99E-02	2.99E+09

Appendix(F): [IF2] Emissions

地球温暖化		大気汚染			光化学オキシダント	
CO2 (B2)		PM2.5			O3	
m1		BCOC (PM2.5)	SO2 (PM2.5)	NOx (PM2.5)	NOx (O3)	NMVOC (O3)
US$/kg	US$/kg	US$/kg	US$/kg	US$/kg	US$/kg	US$/kg
生物多様性	人間健康	人間健康	人間健康	人間健康	人間健康	人間健康
0.007456574	0.009634604	4.051834921	1.236445797	0.330395205	0.192456771	0.011197187

Appendix(G): [IF2] Production country (interest rate 3%)

水	US$/m3	人間健康	IF2

土地利用	方法2②	田	US$/m2	生物多様性	0.011533
		その他農用地	US$/m2	生物多様性	0.033803
		森林	US$/m2	生物多様性	0.177675
		草地	US$/m2	生物多様性	1.276202
		湿地	US$/m2	生物多様性	1.426619
		その他	US$/m2	生物多様性	0.832733
	維持(occupation)	Infrastructure 社会基盤	US$/m2/yr	一次生産	0.041642
		Cropland 農耕地	US$/m2/yr	一次生産	0.005267
		Wilderness 荒地	US$/m2/yr	一次生産	0
		Forestry 森林地	US$/m2/yr	一次生産	0
		Grazingland 放牧地	US$/m2/yr	一次生産	0.003352
	改変(transformation)	Forestry→Infrastructure	US$/m2	一次生産	3.12312
		Forestry→Cropland	US$/m2	一次生産	0.064782
		Forestry→Grazingland	US$/m2	一次生産	0.041227
		Cropland→Infrastructure	US$/m2	一次生産	3.058338
		Cropland→Grazingland	US$/m2	一次生産	-0.02356
		Grazingland→Infrastructure	US$/m2	一次生産	3.081893
	方法2②		US$/kg	一次生産	0.118398

森林資源		(非Plantation)	US$/kg	生物多様性	0.025467
		(不明)	US$/kg	生物多様性	0.015025
資源消費	Ac	生産国	US$/kg	社会資産	
			US$/kg	生物多様性	
			US$/kg	一次生産	
	Ag		US$/kg	社会資産	806.8151
			US$/kg	生物多様性	1.162504
			US$/kg	一次生産	4.711151
	Al		US$/kg	社会資産	0.994715
			US$/kg	生物多様性	0.000756
			US$/kg	一次生産	0.003169
	Au		US$/kg	社会資産	60374.25
			US$/kg	生物多様性	2.8145
			US$/kg	一次生産	10.16952
	B		US$/kg	社会資産	35.31724
			US$/kg	生物多様性	0.000392
			US$/kg	一次生産	0.002956
	Ba		US$/kg	社会資産	0.088093
			US$/kg	生物多様性	0.00024
			US$/kg	一次生産	0.000442
	Ce		US$/kg	社会資産	

			US$/kg	生物多様性	0.001026
			US$/kg	一次生産	0.001408
	Co		US$/kg	社会資産	18.66663
			US$/kg	生物多様性	0.003976
			US$/kg	一次生産	0.031199
	Cr		US$/kg	社会資産	13.424
			US$/kg	生物多様性	0.000567
			US$/kg	一次生産	0.001555
	Cu		US$/kg	社会資産	6.548081
			US$/kg	生物多様性	0.005509
			US$/kg	一次生産	0.015435
	Dy		US$/kg	社会資産	
			US$/kg	生物多様性	0.230901
			US$/kg	一次生産	0.310059
	Er		US$/kg	社会資産	
			US$/kg	生物多様性	0.269209
			US$/kg	一次生産	0.360756
	Eu		US$/kg	社会資産	
			US$/kg	生物多様性	0.055716
			US$/kg	一次生産	0.075839
	F		US$/kg	社会資産	0.19074

			US$/kg	生物多様性	0.000151
			US$/kg	一次生産	0.000354
	Fe		US$/kg	社会資産	0.078318
			US$/kg	生物多様性	0.000152
			US$/kg	一次生産	0.000339
	Gd		US$/kg	社会資産	
			US$/kg	生物多様性	0.195763
			US$/kg	一次生産	0.262539
	Ho		US$/kg	社会資産	
			US$/kg	生物多様性	0.268495
			US$/kg	一次生産	0.359906
	Hg		US$/kg	社会資産	35.73095
			US$/kg	生物多様性	0.339254
			US$/kg	一次生産	0.541902
	La		US$/kg	社会資産	
			US$/kg	生物多様性	0.037951
			US$/kg	一次生産	0.051866
	Li		US$/kg	社会資産	2.771965
			US$/kg	生物多様性	0.016243
			US$/kg	一次生産	0.075728
	Lu		US$/kg	社会資産	

			US$/kg	生物多様性	0.268026
			US$/kg	一次生産	0.358836
	Mg		US$/kg	社会資産	0.000102
			US$/kg	生物多様性	0
			US$/kg	一次生産	0
	Mn		US$/kg	社会資産	2.037253
			US$/kg	生物多様性	0.000541
			US$/kg	一次生産	0.002266
	Mo		US$/kg	社会資産	11.60008
			US$/kg	生物多様性	0.07304
			US$/kg	一次生産	0.151475
	Nb		US$/kg	社会資産	24.44912
			US$/kg	生物多様性	0.07039
			US$/kg	一次生産	0.388197
	Nd		US$/kg	社会資産	
			US$/kg	生物多様性	0.044343
			US$/kg	一次生産	0.060653
	Ni		US$/kg	社会資産	20.40021
			US$/kg	生物多様性	0.010137
			US$/kg	一次生産	0.035791
	P		US$/kg	社会資産	0.020875

			US$/kg	生物多様性	0.000782
			US$/kg	一次生産	0.001953
	Pb		US$/kg	社会資産	3.548609
			US$/kg	生物多様性	0.001466
			US$/kg	一次生産	0.005158
	Pd		US$/kg	社会資産	22007.17
			US$/kg	生物多様性	7.799828
			US$/kg	一次生産	88.0115
	Pr		US$/kg	社会資産	
			US$/kg	生物多様性	0.126068
			US$/kg	一次生産	0.172353
	Pt		US$/kg	社会資産	26261.29
			US$/kg	生物多様性	8.047631
			US$/kg	一次生産	73.6661
	Re		US$/kg	社会資産	1518.142
			US$/kg	生物多様性	0.034213
			US$/kg	一次生産	0.128778
	Sb		US$/kg	社会資産	15.68886
			US$/kg	生物多様性	0.009972
			US$/kg	一次生産	0.01564
	Si		US$/kg	社会資産	

			US$/kg	生物多様性	0.000308
			US$/kg	一次生産	0.000604
	Sm		US$/kg	社会資産	
			US$/kg	生物多様性	0.097528
			US$/kg	一次生産	0.133453
	Sn		US$/kg	社会資産	27.37301
			US$/kg	生物多様性	0.217891
			US$/kg	一次生産	0.468684
	Sr		US$/kg	社会資産	0.125577
			US$/kg	生物多様性	0.126975
			US$/kg	一次生産	0.26082
	Ta		US$/kg	社会資産	17.82883
			US$/kg	生物多様性	0.029866
			US$/kg	一次生産	0.319592
	Tb		US$/kg	社会資産	
			US$/kg	生物多様性	0.516868
			US$/kg	一次生産	0.694677
	Ti		US$/kg	社会資産	5.876009
			US$/kg	生物多様性	0.000375
			US$/kg	一次生産	0.001091
	Tl		US$/kg	社会資産	5268.559

			US$/kg	生物多様性	
			US$/kg	一次生産	
	Tm		US$/kg	社会資産	
			US$/kg	生物多様性	0.27065
			US$/kg	一次生産	0.36235
	U		US$/kg	社会資産	62.30708
			US$/kg	生物多様性	0.0063
			US$/kg	一次生産	0.062142
	V		US$/kg	社会資産	0.065614
			US$/kg	生物多様性	0.010279
			US$/kg	一次生産	0.047223
	W		US$/kg	社会資産	14.03923
			US$/kg	生物多様性	0.007385
			US$/kg	一次生産	0.013009
	Yb		US$/kg	社会資産	
			US$/kg	生物多様性	0.264619
			US$/kg	一次生産	0.354275
	Y		US$/kg	社会資産	101.8337
			US$/kg	生物多様性	0.150649
			US$/kg	一次生産	0.202867
	Zn		US$/kg	社会資産	3.175199

			US$/kg	生物多様性	0.002036
			US$/kg	一次生産	0.005877
	Zr		US$/kg	社会資産	
			US$/kg	生物多様性	0.025376
			US$/kg	一次生産	0.093913
	oil		US$/kg	社会資産	0.249199
			US$/kg	生物多様性	
			US$/kg	一次生産	
	NG		US$/kg	社会資産	0.023947
			US$/kg	生物多様性	
			US$/kg	一次生産	
	coal		US$/kg	社会資産	2.02E-06
			US$/kg	生物多様性	3.12E-05
			US$/kg	一次生産	0.000811
	LS		US$/kg	社会資産	
			US$/kg	生物多様性	1.06E-05
			US$/kg	一次生産	0.000276
	Rock		US$/kg	社会資産	
			US$/kg	生物多様性	8.94E-06
			US$/kg	一次生産	0.000232