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Development of Area Energy Management System for Business District of Small and Medium Enterprises#

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ABSTRACT

To achieve carbon neutrality in the building sector, advanced low-carbon designs such as Zero Energy Buildings (ZEBs) are increasingly being adopted globally. However, ZEBs often requires significantly higher investment compared to general low-carbon methodologies in buildings. In urban settings, these advanced solutions tend to be implemented primarily by large corporations with sufficient capital, technical expertise, and human resources. In Japan, over 98% of enterprises are classified as small and medium-sized enterprises (SMEs), SMEs often face significant challenges in adopting similar approaches.

Aiming whole carbon neutrality, there is a growing need to develop cost-effective and operationally feasible low-carbon methodologies tailored specifically for SMEs. Such strategies must accommodate both limited financial and ease of daily operation, especially in urban business districts predominantly occupied by SMEs.

This study explores the feasibility of developing an Area Energy Management System (AEMS) to support carbon neutral transitions among SMEs in a test site of "Kanda and Nihonbashi" area in central Tokyo where is known business district for its traditional character and concentration of long-established SMEs.

The methodology includes the following steps;1) Characterization of the Urban Context by GIS, 2) Estimation of Energy Consumption, 3) Development of tailored low-carbon strategies.

This research demonstrates the potential for a localized, collaborative approach to carbon neutrality, emphasizing the development of pragmatic and scalable solutions for SMEs.

Keywords: Carbon neutral, Urban business district, Small and medium enterprises, Area energy management

NONMENCLATURE

Abbreviations	
ZEB	Zero Energy Building
SMEs	Small and Medium Enterprises
GIS	Geographic Information System

1. INTRODUCTION

To achieve carbon neutrality in the building sector, advanced low-carbon building designs such as Zero Energy Buildings (ZEBs) are increasingly being adopted globally [1]. However, the implementation of ZEBs often requires significantly higher investment for new constructions or major renovations compared to general low-carbon methodologies in buildings. In urban settings, these advanced solutions tend to be implemented primarily by large corporations with sufficient capital, technical expertise, and human resources, while small and medium-sized enterprises (SMEs) often face significant challenges in adopting similar approaches [2].

In Japan, small and medium enterprises (SMEs) account for over 98% of all businesses. Despite their significant presence, limited research has been conducted on the feasibility and practical implementation of low-carbon measures tailored to this sector. Many SMEs face barriers such as insufficient knowledge, limited operational experience, and a lack of human resources, which hinder their ability to adopt sustainable practices.

In the context of Japan's national commitment to achieving carbon neutrality, there is an increasing

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demand for cost-effective and operationally feasible low-carbon strategies specifically designed for SMEs. These strategies must consider the financial constraints and operational simplicity required by SMEs, particularly those located in dense urban business districts where such enterprises are highly concentrated.

This study examines the feasibility of implementing an Area Energy Management System (AEMS) as a support framework to facilitate the transition to carbon neutrality among SMEs. The pilot site is located in the Kanda and Nihonbashi districts of central Tokyo, areas distinguished by a high concentration of long-established SMEs and a unique combination of historical and commercial functions. Building characteristics within the area are systematically identified and assessed using GIS data [3][4].

2. STUDY PROCESS

2.1 *Target Site of Business District for SMEs*

To estimate the feasibility of area-based low-carbon initiatives and methodologies that are practically applicable to small and medium enterprises (SMEs), a commercial district in Chuo Ward, Tokyo, was selected as a pilot study site(Figure 1). This district-comprising Ginza, Nihonbashi, and Kanda- is internationally recognized for its history and culture, with a legacy spanning over 350 years.

One of the critical factors influencing energy consumption in this district is the age of its buildings, which has a direct impact on their energy performance. Figure 2 presents the distribution of total floor area categorized by building foundation year, in ten-year increments, based on data from the national land registry. This analysis provides essential insight into the structural characteristics of the built environment, which must be considered when developing and implementing effective low-carbon strategies for SMEs in such urban contexts.

Non-residential buildings constructed between 1981 and 1990 account for the largest share in both total floor area and number of buildings. Additionally, more than 20% of the buildings were constructed before 2011. Buildings constructed between 2011 and 2020 tend to be smaller in size compared to those built in earlier periods(Figure2).

Figures 3, 4, 5, and 6 illustrate the distribution of total floor area and the number of buildings by building use. Buildings with a total floor area under 10,000 m² represent 72% of the total floor area for SMEs, and they account for 98.5% of the total number of buildings.

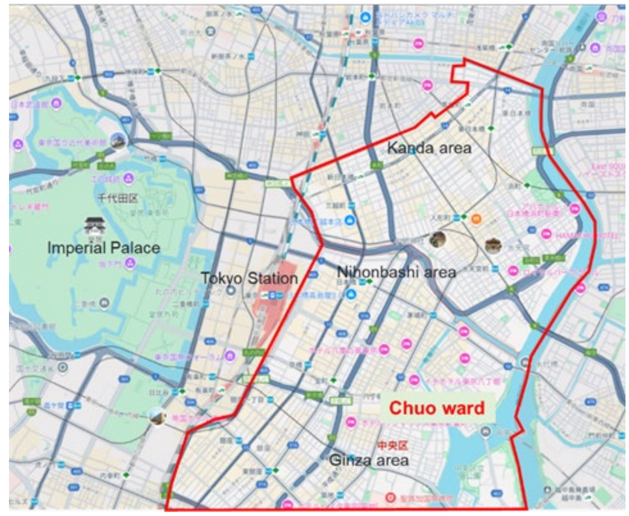


Fig. 1 Site map of "Chuo-ward", Tokyo, Japan (https://www.google.co.jp/maps)

※The building use are classified as follows;
-Non-residence：Building type not including the Residence and Apartment
-Residence：Residence and Apartment
-Residence&Non-residence：Different building type from above 2 classify

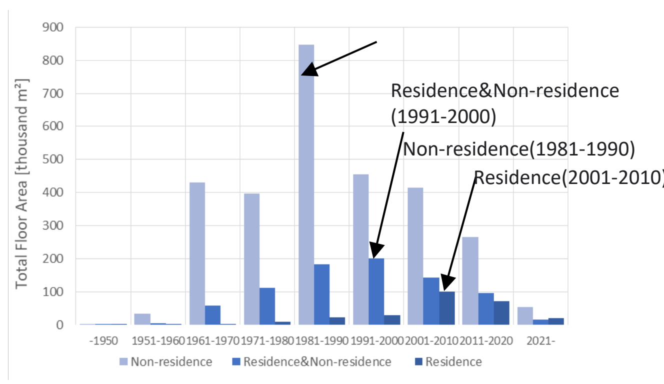


Fig. 2 Total floor area by each foundation year

Notably, buildings under 2,000 m² make up more than 83% of the total number. Offices and office-complex facilities account for approximately 54% of these buildings. Apartments follow at around 27%, and commercial buildings contribute the next largest share at about 7%.

The majority of non-residential buildings were constructed before the amendment of the Energy Conservation Law in 2009. This trend highlights the importance of promoting low-carbon initiatives among SMEs.

2.2 *Estimation of Primary Energy Consumption in Target area*

To estimate the annual primary energy consumption, unit primary energy consumption values for each building type were derived from statistical sources such as data from the Department of Energy and

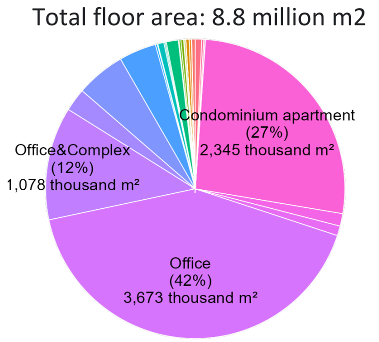


Fig. 3 Portion of total floor area by each building use

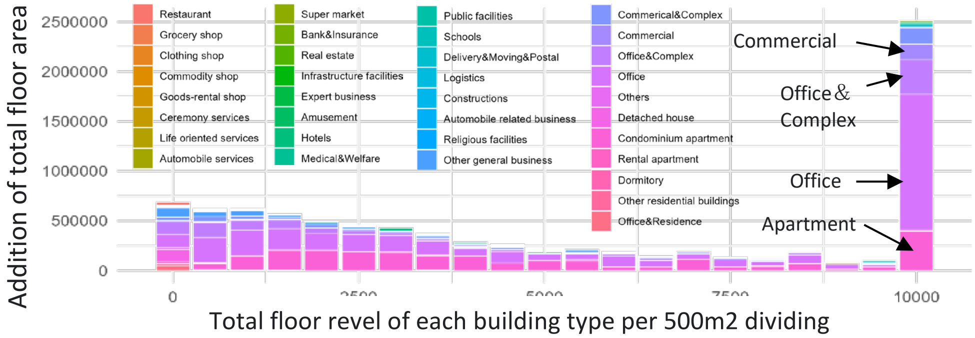


Fig. 5 Addition value of total floor revel of each building type per 500m2 dividing

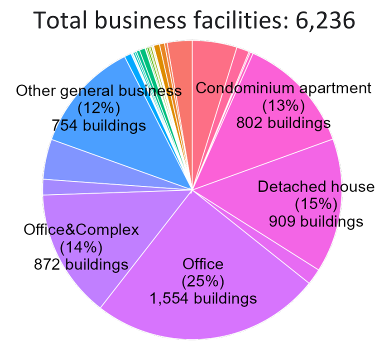


Fig. 4 Portion of building number by each building use

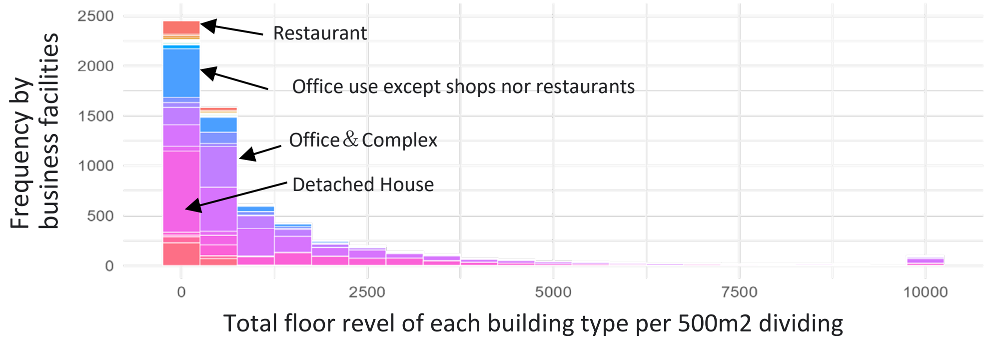


Fig. 6 Frequency by business facilities (building type) by total floor area size per 500m2 dividing

Source: All data have been evaluated with using Zenrin Building Point Data, 2024

Climate Change (DECC) [5] and current research on CO_2 emissions from residential buildings [6].

The median values of primary energy consumption were used as unit consumption data [MJ/(m^2·year)], categorized by building use and total floor area level, based on DECC data from 2007 to 2018 ※1), ※2).

Figure7 and 8 shows CO_2 emissions by building use, while Figure 9 presents the cumulative CO_2 emissions by total floor area (in 500 m² increments). Office buildings account for approximately 55% of the total CO_2 emissions in this area. Commercial buildings contribute around 18%, and condominium apartments account for about 12%.

For small and medium-sized buildings under 500 m², restaurants represent the highest unit CO_2 emissions, exceeding 43%. In total, approximately 64% of primary energy consumption comes from buildings with a floor area of less than 10,000 m².

2.3 Possible effect of Low Energy Management and Low energy behavior

As a high-priority step for SME buildings, feasible and low-cost carbon reduction measures should be

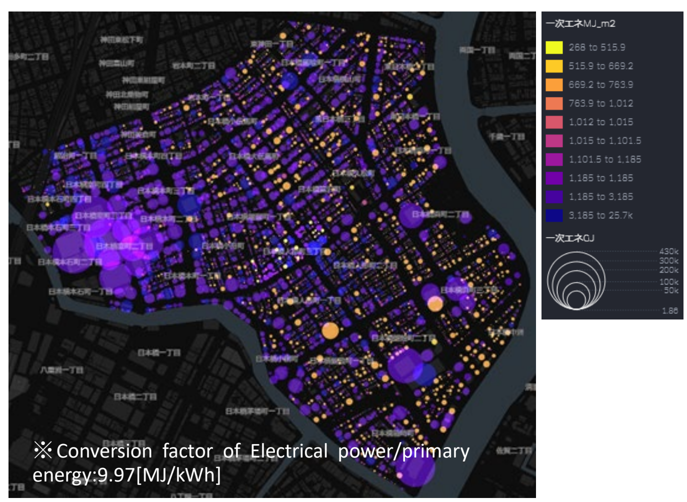
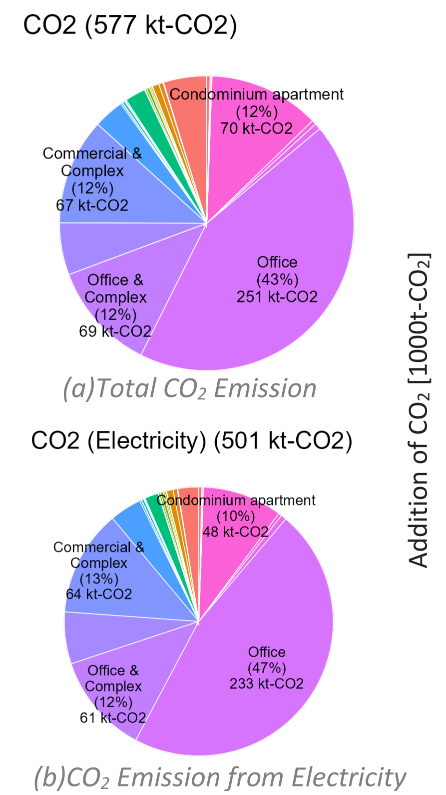


Fig. 7 Distribution of primary energy consumption per business facilities (visualized by Kepler.gl, GIS）

implemented through daily equipment adjustments and behavioral changes, since SMEs often lack sufficient budgets for full-scale low-energy renovations.

The Ministry of the Environment (MOE), Japan, has evaluated the effectiveness of low-carbon measures - referred to as "Eco-Tuning"- in existing buildings, including both large-scale facilities and those operated by SMEs※4), ※5) (Table 1) [7]. On average, Eco-Tuning



(a)Total CO_2 Emission

(b)CO_2 Emission from Electricity

Fig. 8 CO_2 emission by Building use

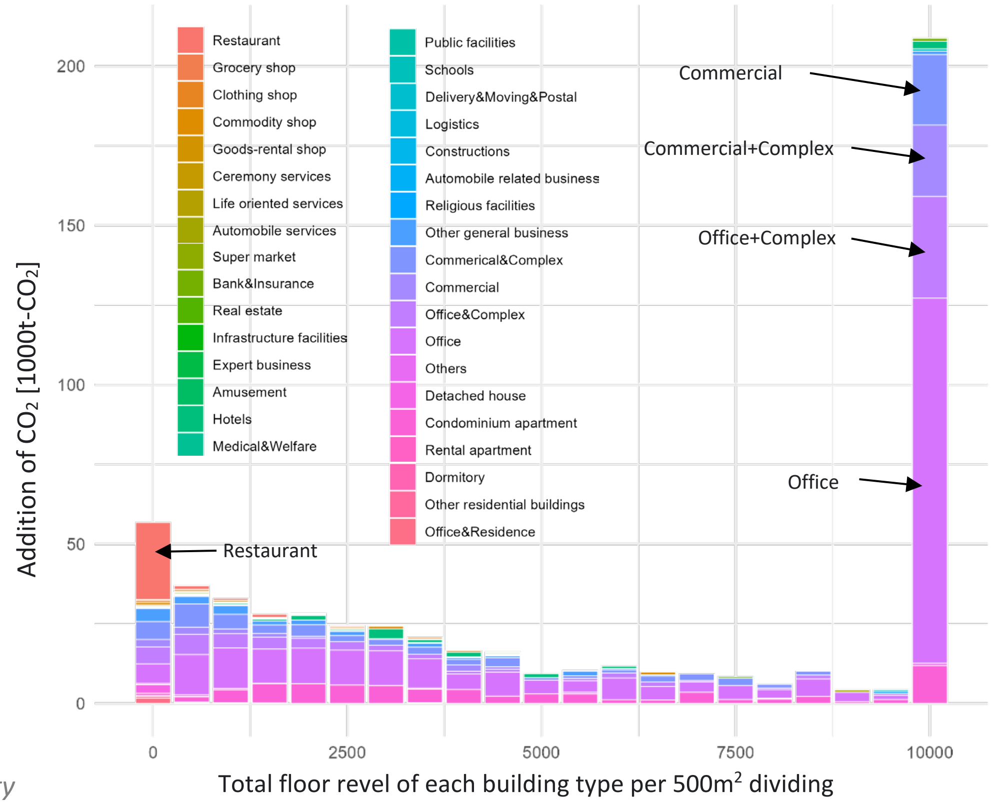


Fig. 9 Addition value of CO_2 by each total floor revel

※1) DECC data：Static data of building energy consumption for all of non-residence building type in Japan that has been investigated by Japan Sustainable Building Consortium(JSBC), Japan
※2) Conversion factor of Electrical power/CO2 emission:0.000422[t-CO_2/kWh], published by MLIT, Japan, 2025
https://ghg-santeikohyo.env.go.jp/calc
※3) Urban Gas except Electrical power; Co-efficiency of CO2 emission:0.0140[t-C/GJ], Conversion factor of Primary energy/CO_2 : 0.05133[t-CO_2/GJ]

has achieved a carbon reduction efficiency of approximately 7.5% across various types of business facilities. Specifically, office buildings and office-complex buildings have shown potential CO_2 reductions of around 9.9%, while commercial and commercial-complex buildings have achieved reductions of about 7.8%.

We conducted interviews with 30 SME companies within the target area to assess the feasibility of Eco-Tuning. Most respondents indicated that these measures are acceptable, and several companies have already implemented actions such as replacing conventional lighting with LED systems. Based on these responses, we identified additional feasible measures, excluding those already undertaken.

In terms of the impact of low-carbon behaviors, related research conducted in the same target area [8] has shown that eco-conscious work practices promoting energy and resource conservation can contribute an additional 2.5% reduction in energy consumption. This applies to office buildings, commercial facilities, mixed-use complexes, and hotels.

Table. 1 Result of low carbon efficiency by Eco-tuning on existing 135 buildings, MOE, 2014[7]

Building type	Number of Buildings	Emission of 2025 (t/7 months)	CO2 reduction rate from 2025 (%)	Averaged CO2 emission in current 3 years(t/7months)	CO2 reduction rate from current 3 years(t/7months)(%)
Office	57	33,107	6.4	34,292	9.9
Commercial	6	10,686	5.1	10,897	7.8
Hotel	9	9,482	4.1	9,527	4.5
Hospital	11	24,743	4	24,838	4.3
School	4	3,678	6	3,759	8
Others	48	24,890	6.3	25,299	8.1
Total	135	106,586	Average : 5.5	108,612	Average: 7.5

※4) Development project to form the business model of Eco-tuning for low carbonization in buildings, 2014"
※5) Eco-tuning : Adjustment followings ; Air supply volume, Cool&Hot water supply volume, Outdoor air intake, Air temperature, Lighting, and other daily operation of Building's equipment

3. RESULTS OF LOW CARBON ESTIMATION

3.1 The effect of Eco-tuning, Low carbon behavior and Renewable energy installation

The total CO_2 reduction rate from both Eco-Tuning and low-carbon behavioral changes is approximately 5% for SME buildings under 10,000 m². When including large companies alongside SMEs in the area, the overall CO_2 reduction rate increases to around 9%.

Additionally, one SME in the area has adopted a rooftop rental solar PV scheme, allowing a third party to install photovoltaic panels on the roof of its facility. This initiative has led to a CO_2 reduction equivalent to 15% of the building's annual electricity consumption. According to our interviews in the target area, this rental PV business model is considered feasible for various building types, including offices, office complexes, commercial buildings, and commercial complexes.

Implementing this PV scheme could increase the CO_2 reduction rate from 5% to 9% for SME buildings under 10,000 m², and from 9% to 11% when including all buildings, both SMEs and large companies.

Figure 10 shows the CO_2 reduction rate by building type, including hotels. Figure 11 illustrates the distribution of CO_2 reduction amounts across the target area.

3.2 *The comprehensive effect of CO_2 reduction from whole types of SMEs buildings*

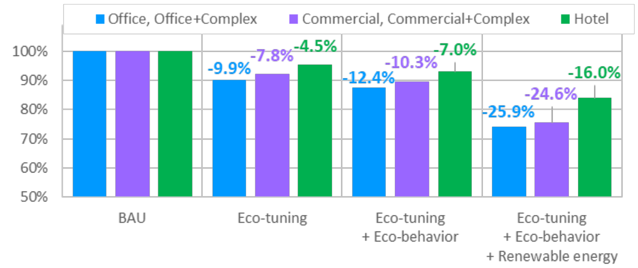
To assess the potential for CO_2 emission reductions among various small and medium-sized enterprises (SMEs) in the target area, this study evaluated the combined impact of Eco-Tuning practices, low-carbon behavioral changes, and the integration of renewable energy (specifically solar power).

The analysis indicates that, when these measures are applied to office buildings, commercial facilities, and hotels, SME buildings with a total floor area of less than 10,000 m² can achieve up to a 12% reduction in CO_2 emissions. Furthermore, when all buildings—including those operated by large enterprises—are taken into account, the overall CO_2 reduction potential increases to approximately 20% (Figure 12).

4. DISCUSSION&CONCLUTION

To advance the practical implementation of low-carbon measures among small and medium-sized enterprises (SMEs) at the regional scale, this study focused on a business district in Tokyo characterized by a high concentration of SMEs. Within the target area, the specifications of building facilities and the distribution of construction years were analyzed using GIS data to clarify factors influencing energy consumption patterns by building type.

Drawing on existing low-carbon case studies, potential reduction measures suitable for SMEs were identified. Their feasibility and acceptability were examined through interviews with SME representatives,



※Electrification rate　Office, Office + Complex : 90%,Commercial, Commercial+Complex : 95%,Hotel : 60%

Fig. 10 CO_2 reduction rate of each building type

Fig. 11 Distribution of CO_2 reduction by Eco-tuning, Low carbon behavior and Renewable energy

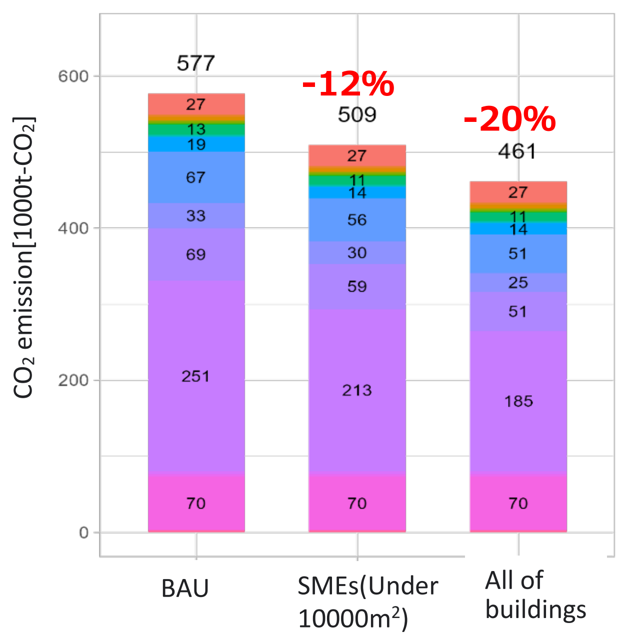


Fig. 12 Estimation of CO_2 reduction [1000t-CO_2]

taking into account deployment priorities. The analysis revealed that optimizing the operation of building equipment (Eco-Tuning), promoting low-carbon behavioral practices in daily operations, and adopting renewable energy technologies can provide cost-effective strategies that require limited financial and human resources. These approaches are broadly applicable across SMEs.

Regarding implementation priorities, office and commercial buildings should be targeted first, followed by hotels, while restaurants may need to be addressed in later stages due to their distinctive operational constraints.

Although the expected reduction efficiencies do not reach the performance level of Zero Energy Buildings (ZEBs), and restaurants—particularly those occupying floor areas below 500 m^2—remain challenging to decarbonize, ongoing research is directed toward identifying more effective and widely acceptable strategies for SMEs as a whole.

Finally, the study suggests that information sharing and behavioral nudging, facilitated through an Area Energy Management System (AEMS) tailored to SMEs, could accelerate area-wide low-carbon transitions in urban districts.

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