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Energy Intensity Reduction in the APEC Regions' Urbanised Cities

APEC Energy Working Group

November 2022

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FINAL STUDY REPORT

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The APEC workshop on Energy Intensity Reduction (EIR) in the APEC Regions' Urbanised Cities was held on 23 March 2021 in Hong Kong, China. The workshop shared the result of the energy intensity reduction performance analysis in developed APEC member economies' urbanised cities and identified key drivers for accelerating aggregated energy intensity reduction for new and existing buildings, in addition to regulations. 16 speakers and 88 participants of regulators, experts, international organisations, designers and operators across 12 APEC economies and 7 international organisations attended the workshops to obtain, share and strengthen the knowledge, abilities, skills and technical know-how to improve their EE&C policies and regulations in the building sector.

Contents

1 Introduction

The Asia-Pacific Economic Cooperation (APEC) member economies account for around 60% of the world's energy consumption. In light of the rapid development and increasing urbanisation rate, APEC member economies will continue to play a significant role in reducing greenhouse gas emissions and combating climate change. In response to that, in 2011, APEC Leaders set a target to reduce aggregate energy intensity by at least 45% by 2035, with 2005 as the baseline year. Various energy policies and strategies have been implemented in different APEC member economies to achieve this energy intensity reduction target.

This project aimed to identify the strategies that allow the selected APEC member economies' cities to perform outstandingly in energy intensity reduction and identify key drivers for enhancing building energy efficiency in contribution to accelerating aggregated energy intensity reduction. By disseminating effective building energy policies and successful approaches, as well as emerging energy efficiency and conservation (EE&C) technology application opportunities identified in these selected cities, the conclusions of this project will guide the policymakers of APEC member economies to make proactive decisions and stimulate positive moves towards enhancing building energy efficiency in their cities. All of these will achieve accelerated aggregated energy intensity reduction in their economies.

2 Definitions and Terminology

2.1 Definition of Urbanised City

There is no standard international definition of city or urbanisation. According to the United Nations [1], the definition of urbanisation varies among different locations, subject to its distinctive, administrative, economic, population size, density and urban characteristics.

In this study, "urban density" and "population" were the two major parameters considered for defining and selecting an "urbanised city". Regarding APEC's publication [2], the urban density threshold for defining a "city" ranges from 150 per km^2 to 1,500 per km^2 in different economies. The population threshold for defining a "city" ranges from 200 to 50,000. Among various definitions, 2,000 inhabitants are the most frequently used threshold value and will be adopted in this study.

2.2 Definition of Final Energy Demand

Final energy demand was adopted as the basis for evaluating progress toward the energy intensity goals in this study, referring to APERC's Outlook [3]. Final energy demand was categorised into four sectors - Buildings, Industry, Transport and Agriculture/Others. The final energy demand in each sector was calculated with corresponding data collected from each city.

Buildings Sector includes energy consumed in both residential and service buildings. Energy demand for residential buildings is the energy end-use at the household level. Energy demand for service buildings consists of the energy end-use in office and non-office buildings such as hospitals, warehouses and educational institutions.

Industry Sector includes the final energy demand of iron and steel, non-metallic mineral, chemical and petrochemical, paper and pulp, aluminium, mining, non-specified and others.

Transport Sector includes the final energy demand of aviation, shipping, road, rail, pipelines and others.

Agriculture/Other Sectors includes the final energy demand of machinery and activity for agriculture and other non-specific energy consumptions.

As in urbanised cities, the increasing population will affect the energy end-use. Hence, the energy end-uses per capita will be used as the parameter to normalise the impact due to population growth.

2.3 Definition of Energy Intensity

Energy Intensity is defined as the final energy demand divided by nominal Gross Domestic Product (GDP):

$$Energy\ Intensity = \frac{Final\ Energy\ Demand}{GDP} \text{ [3]}$$

The aggregate energy intensity reduction of 45% set by APEC Leaders, 2005 is adopted as the baseline year for comparison in this study.

2.4 Reduction Target Projection

The reduction target projection was a preliminary gap analysis for each city with a hypothetical energy end-use in 2035. Assuming each of the cities would achieve the APEC Leader's goal of energy intensity reduction by 45% in 2035 using 2005 as a baseline, the energy intensity for each city in 2035 will be:

$$Energy\ Intensity_{2035} = Energy\ Intensity_{2005} \times (1 - 45\%) \qquad \text{Eq. (1)}$$

$Energy\ Intensity_{2035}$ is defined as:

$$Energy\ Intensity_{2035} = \frac{Energy\ end - use_{2035}}{Projected\ GDP_{2035}} \qquad \text{Eq. (2)}$$

By referencing the projected GDP from OECD [4] and APERC [3], the energy end-use in 2035 was calculated based on the following equation.

$$Energy\ end - use_{2035} = Energy\ Intensity_{2005} \times (1 - 45\%) \times Projected\ GDP_{2035} \qquad \text{Eq. (3)}$$

3 Methodology

This project was carried out by selecting seven cities among outperformed APEC member economies in terms of energy intensity reduction when comparing the result of the year 2016 to 2005.

Seven cities are shortlisted for carrying out the Study based on the following criteria:

- Leading performance in energy intensity reduction among APEC member economies;
- Availability of GDP data and energy end-use data of different sectors, in particular the Buildings sector, at the city level;
- With the Buildings sector accounting for a significant amount of energy end-use; and
- Highly urbanised city.

The representative cities from these economies selected for this study are Beijing; Singapore; Hong Kong, China; the City of Sydney; Tokyo; New York City and Seoul, details were summarised in Appendix A.

The historical events, policies, GDP and energy end-use data of the shortlisted cities from 2005 to 2017 were reviewed. The energy intensity reduction trend was analysed against the building-related policies to provide a preliminary gap analysis with the APEC Leader's goal of achieving an energy intensity reduction of 45% from the 2005 baseline. The key drivers for these cities to outperform in energy intensity reductions were explored. The potential innovation and technology (I&T) application opportunities that drive the success of aggregated energy intensity reduction were analysed.

Hong Kong, China organised an online APEC Workshop on 23 March 2021 to intensify collaboration between APEC economies and capacity building on the policy frameworks, good practices and applicable I&T for energy efficiency and conservation (EE&C). The Workshop Summary was attached in Appendix B.

4 Detailed Study on Shortlist Cities

4.1 People's Republic of China – Beijing

Beijing is the capital city of the People's Republic of China (China). The area of Beijing was 16,411km2 [5], with a population of 21.7million [5] in 2017. The urban density of 1,323 persons/km^2, fulfils the definition of an urbanised city.

In 2017, China was the largest energy consumption economy in the APEC region. According to the APERC's Outlook [3], China achieved a 36.2% energy intensity[1] reduction in 2016 due to rapid economic development and soaring GDP.

According to the Beijing Statistical Yearbook 2019 (the Yearbook) [5], the city achieved a 73.5% energy intensity[2] reduction from 2005 to 2017, which aligned with the APEC Leaders' goal of energy intensity reduction. Beijing's final energy demand per capita in 2017 remained similar to the 2005 baseline, and it is expected to be contributed by the positive result of implementing EE&C policies.

4.1.1 Final Energy Demand Overview

According to the Yearbook [5], the total energy consumption in Beijing was estimated to be 2,090,410 TJ in 2017. The building sector, including residential and service sub-sectors, was the major consuming sector (52.9%), followed by the industry sector (25.8%) and the transport sector (19.4%) (Figure 1).

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[1] Energy intensity is calculated based on final energy demand (toe)/ GDP (constant 2010 USD)

[2] Energy intensity calculated based on final energy demand (TJ)/nominal GDP (million USD)

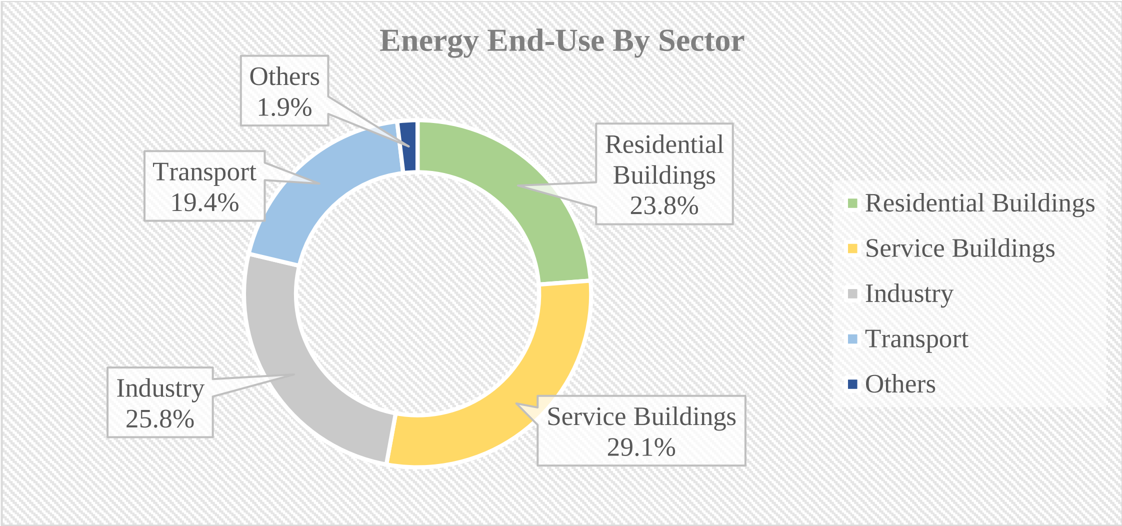


Figure 1 Energy end-use by sector of Beijing in 2017

In the study period of this project, Beijing was still intensifying its land use with an increasing urbanisation rate and improving living standards. The construction industry is booming with the development of new buildings; the newly constructed building floor area has doubled since 2005. With the rapid growth of the building industry in Beijing as per the trend of new construction works since 2005, the building sector energy demand increased as anticipated.

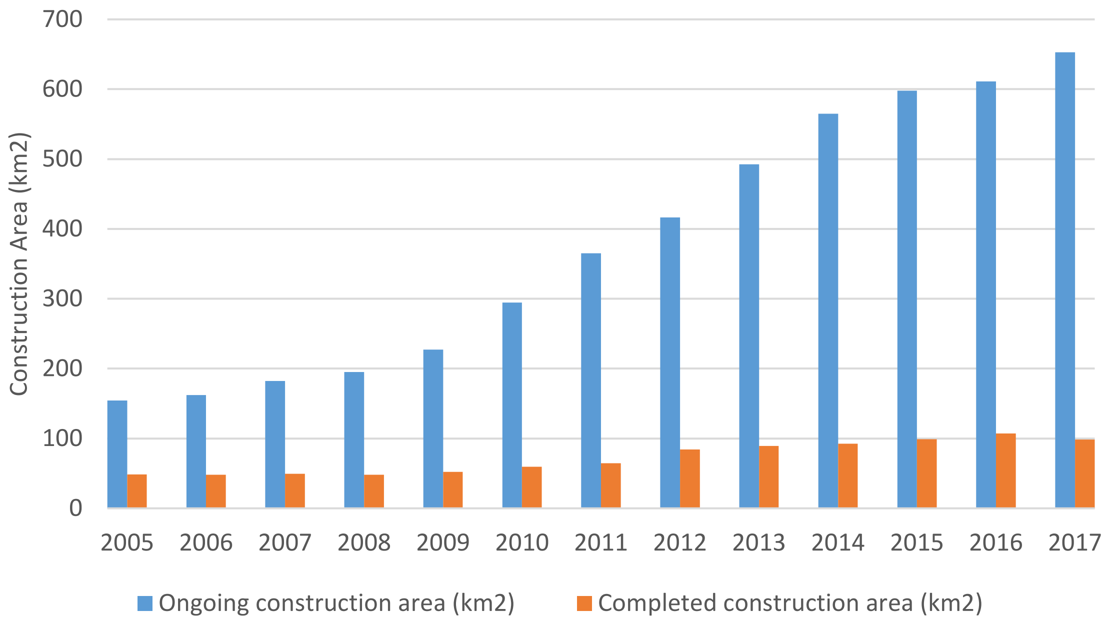


Figure 2 Ongoing construction area and completed construction area of Beijing from 2005 to 2017 [6]

4.1.2 Building Sector Energy Consumption

The building sector accounted for about half of the total energy consumption in 2017. Compared with 2005 as the baseline year, the total energy consumption in the building sector had increased by 75.7% by 2017. The energy end-use in both the service and residential buildings sectors demonstrated an increasing trend due to the ongoing rapid urbanisation of Beijing, as shown in Figure 3. The weighting of energy end-use from residential buildings had been increasing since 2005.

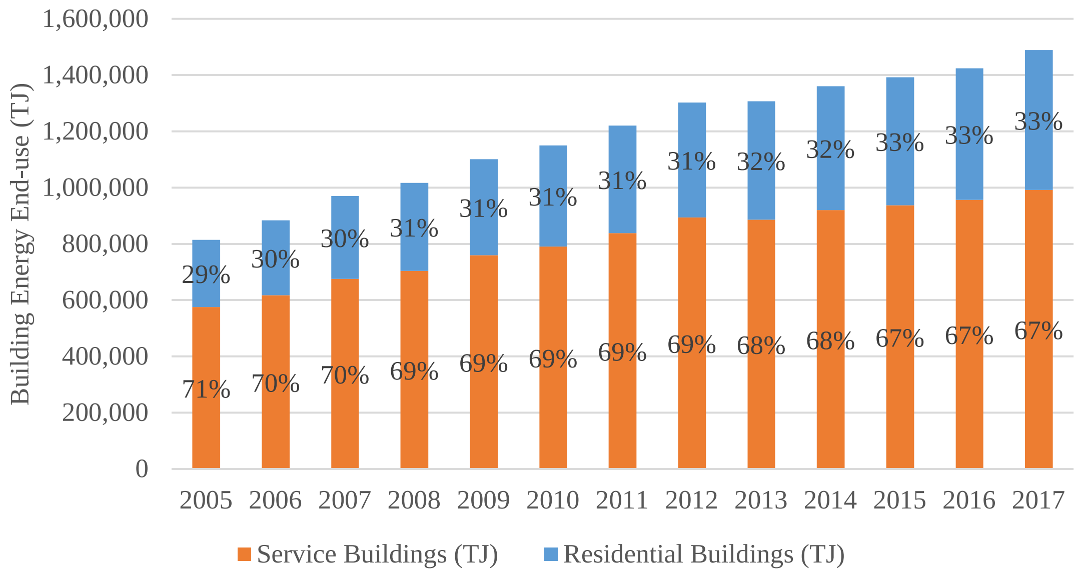


Figure 3 Building energy end-use of Beijing from 2005 to 2017 [5]

4.1.3 Review of Building Energy-Related Measures

Strategic Plans and Regulations	**Coverage**	**Building Type**	**Authority Level**	**Revisions**
Five-Year Development Plan for Energy Conservation	New and Existing	Residential and Service	Domestic	2006 (11th)/ 2011 (12th)/ 2016 (13th)/ 2021 (14th)
Beijing Municipal Green Building Development Action Plan (2020-2022) 《北京市绿色建筑创建行动实施方案（2020 年-2022 年）》	New and Existing	Residential and Service	City	2020

Building Energy-Related Policies and Measures				
Design Standard for Energy Efficiency of Residential Buildings (DBJ11-602; DB11/891)	New	Residential	City	2004/ 2006/ 2012 (2013)/ 2020 (2021)
Design Standard for Energy Efficiency of Public Buildings (DBJ01-621; DB11/687)	New	Service	City	2005/ 2009(2010) / 2015
Design Standard for Energy Efficiency of Public Buildings (GB 50189)	New	Service	Domestic	2005/ 2015
Green Building Measures				
Assessment Standard for Green Building (GB/T 50378)	New and Existing	Residential and Service	Domestic	2006/ 2014/ 2019
Design Standard of Green Building (DB11/938)	New and Existing	Residential and Service	City	2012(2013)
Beijing Municipal Green Building Development for Ecological City Action Plan (北京市发展绿色建筑推动生态城市建设实施方案)	New	Residential and Service	City	2013
Evaluation Standard for Green Building (DB11/T825)	New and Existing	Residential and Service	City	2005/ 2011/ 2015/ 2021
Measures to Existing Buildings				
Beijing Municipal Energy Efficiency of Buildings Project for Five-Year Plan (北京市“XX 五”时期民用建筑节能规划)	New and Existing	Residential and Service	City	2006 (11th)/ 2011 (12th)/ 2016 (13th)
Beijing Municipal Renovation Program of Existing Building 《北京市既有建筑节能改造专项实施方案》	Existing	Residential and Service	City	2008 (completed in 2010)

Technical Specification of Renovation of Energy Efficiency for Existing Residential Building (DB11/ 381)	Existing	Residential	City	2006/ 2016
Data Reporting / Disclosure				
Beijing Municipal Energy Efficiency of Civil Buildings Projects for 11th Five-Year Plan (北京市"十一五"时期民用建筑节能规划)	New and Existing	Service	City	2006 (11th)
Standard for Building Energy Performance Certification (JGJ/T288)	Existing	Residential and Service	Domestic	2012 (2013)
Energy-efficient Appliances Labelling				
China Energy Label	(for goods)	N/A	Domestic	2005
Government Leadership				
Beijing Municipal Energy Efficiency of Civil Buildings Projects for 11th Five-Year Plan (北京市"十一五"时期民用建筑节能规划)	New and Existing	Service	City	2006 (11th)
Tenant Programme				
Beijing Municipal Top Leading for Energy Efficiency (北京市能效领跑者 [7])	Existing	Services	City	2015-2018
Incentives				
Subsidies for Renovation of Existing Buildings	Existing	Residential and Service	Domestic	2007
Funds for Green Buildings	New	Residential and Service	Domestic	2014
Subsidies for energy-efficient appliances	N/A	N/A	Domestic	2015/ 2019

(Notice on implementation of energy conservation and emission reduction)				
Funds for ultra-low energy building (Interim Measures for the Management of Ultra-low Energy Demonstration Projects and Incentive Funds for Ultra-low Energy Building in Beijing)	New	Residential and Service	Domestic	2017
Human Behaviour				
Beijing Energy Conservation Promotion Week	N/A	N/A	City	2005
Beijing Green Lighting Project	N/A	N/A	City	2006
TV Program – Energy-saving Doctor	N/A	N/A	City	2006-2007
Energy-saving public service advertising campaign	N/A	N/A	City	2006
Green Olympic Action Plan	N/A	N/A	Domestic	2006-2008
Heating metering charges	Existing	Residential and Service	City	2012

4.1.4 Major Policy / Scheme for EE&C

4.1.4.1 Building Energy-Related Policies and Measures

The People's Government of Beijing Municipality (Beijing government) launched and frequently reviewed the standards of residential and public buildings to reduce building energy consumption by adopting energy-efficient measures. In the past years, design standards have been reviewed and revised with increasingly stringent requirements or targets in light of technological advancement and updated energy-saving targets.

4.1.4.1.1 Design Standard for Energy Efficiency of Residential Buildings (2004)

The Design Standard for Energy Efficiency of Residential Buildings was launched in 2004 (DBJ11-602) and revised in 2006, 2012 (DB11/891, implemented in 2013) and 2020 [8] (implemented in 2021) by the Beijing government. This design standard applies to new residential buildings. It covers passive building energy design features, such as the thermal transmittance (U-value) and shading coefficient of the façade, energy efficiency requirement for building services installations, as well as requirements for building services installation adopting renewable energy system.

4.1.4.1.2 Design Standard for Energy Efficiency of Public buildings (2005)

The Design Standard for Energy Efficiency of Public Buildings was launched in 2005 (DBJ 01-621) and revised in 2009 (DB11/687, and implemented in 2010) and 2015 [9] by the Beijing government. This design standard applies to new, expanded or major renovated services buildings. This design standard covers passive building energy design features and energy efficiency requirements for building services installations.

4.1.4.2 Green Building Measures

4.1.4.2.1 Assessment Standard for Green Building (2006)

The Assessment Standard for Green Building (GB/T 50378) was launched in 2006 territory-wide during the 11th Five-Year Plan. The China Green Building Design Label and China Green Building Operation Label for the new and existing buildings complied with the Assessment Standard for Green Building. The assessment standard applies to both residential and public buildings. The assessment standard was revised in 2014 and 2019 [10] with more detailed and relevant information for local practice by including practical experience and an evaluation of green building research achievements in recent years. It was introduced to achieve energy-saving by improving the building envelope performance, creating a good indoor environment, promoting renewable energy applications, and reducing energy consumption.

4.1.4.2.2 Design Standard of Green Building (2013)

The Design Standard of Green Building (DB11/938) was launched in 2012 and implemented in 2013 by the Beijing Government to promote the green design of residential and service buildings. The design standard covers planning, architectural, structural, mechanical and electrical, landscape and interior requirements.

4.1.4.2.3 Beijing Municipal Green Building Development for Ecological City Action Plan (2013)

The Beijing Municipal Green Building Development for Ecological City Action Plan was launched in 2013 by the Beijing government, which requires all new building projects to have a minimum of a one-star rating under the Green Building Standard. Under this plan, various green and sustainable features have been implemented, such as solar equipment, sewage treatment systems and rainwater recycling systems, to reduce the amount of electricity, gas and potable water required by new buildings in Beijing.

4.1.4.2.4 Evaluation Standard for Green Building (2015)

To echo the domestic Evaluation Standard for Green Building in China, the Beijing Government issued the Evaluation Standard for Green Building (DB11/T825) in 2015. The detailed requirements were adjusted according to the local climate and standards of Beijing.

4.1.4.3 Measures to Existing Buildings

4.1.4.3.1 Beijing Municipal Energy Efficiency of Buildings Project for 11th Five-Year Plan (2007)

During the 11th Five-Year Plan (2006-2010), the Beijing Municipal Energy Efficiency of Buildings Project was issued in 2007 by the Beijing government, with the following key actions,

- reviewing the energy efficiency standards;
- requiring all new buildings to comply with energy efficiency standards;
- providing green or low energy consumption building demonstration projects;

- renovating the existing building with energy efficiency and heating supply systems;
- accelerating renewable energy adoption;
- constructing energy efficiency monitoring system for Government buildings;
- implementing energy audit and data disclosure.

4.1.4.3.2 Beijing Municipal Renovation Program of Existing Building (2008)

The Renovation Program of Existing Building [11] was launched in 2008 by the Beijing government. The Program aimed to complete the energy-efficient renovation of residential and services existing buildings by 2010. The measures for existing buildings included low-cost retro-commissioning, and higher-cost retrofitting and renovation works.

4.1.4.3.3 Beijing Municipal Energy Efficiency of Buildings Project for Twelve Five-Year Plan (2011)

During the 12th Five-Year Plan (2011-2015), the Beijing Municipal Energy Efficiency of Buildings Project was issued in 2011 with a summary as listed below:

- 12% reduction in average heating energy consumption of existing buildings as compared with 2009;
- 30 million m^2 of existing residential buildings and 30 million m^2 of existing public buildings were required to be renovated into energy-efficient buildings; and
- Heat metering systems of the 150 million m^2 of existing buildings were to be renovated.

4.1.4.3.4 Beijing Municipal Energy Efficiency of Buildings Project for 13th Five-Year Plan (2016)

During the 13th Five-Year Plan (2011-2015), the Beijing Municipal Energy Efficiency of Buildings Project was issued in 2016. The Beijing Government implemented the third renovation program for existing buildings with a summary as listed below:

- Average energy consumption of new residential buildings built in 2020 should be reduced by 25% compared to existing residential buildings completed in 2015.

- 6% reduction in the average heating energy consumption of existing buildings compared with 2015.
- 30 million m^2 of existing residential buildings and 6 million m^2 of existing public buildings need to undergo energy-efficient renovation.
- 95% of the area served by an urban centralised heating system must use a heating network, gas, new energy or renewable energy.

4.1.4.4 **Change in Human Behaviour**

Under the initiative of a “Green Olympics”, since 2006, the Beijing Government has rolled out a series of campaigns, competitions, exhibitions, TV programs and courses in schools to achieve savings targets. In 2011, the Beijing government continued the energy conservation target set during the Olympics and incorporated it into the city development plan with the “Environment-friendly Beijing, Culture-enriched Beijing and Technology-empowered Beijing” strategies. The Beijing Government has also carried out public education activities to enhance the awareness within, and support from, society, focusing on the following aspects:

- Knowledge Sharing. Education activities about energy conservation and emissions reduction were carried out in communities, Government agencies, schools, enterprises, parks and industrial parks, hotels and restaurants, shopping malls and supermarkets, leisure facilities, public transport facilities and construction sites. A series of publications and leaflets were distributed to the public. Exhibitions such as the Beijing International Energy Conservation and Environmental Protection Exhibition were held to exchange knowledge and technology within the industry.
- Campaigns and competitions on the theme of energy conservation and emissions reduction, such as “National Low Carbon Day” and “Beijing Energy Conservation Promotion Week”. Making full use of the media to carry out promotional activities on the regulations, policies and guidelines on the topics of energy saving and efficiencies, such as the “Energy-saving Doctor” TV Program and advertisements.

A timeline of some of the activity’s timeline is shown below:

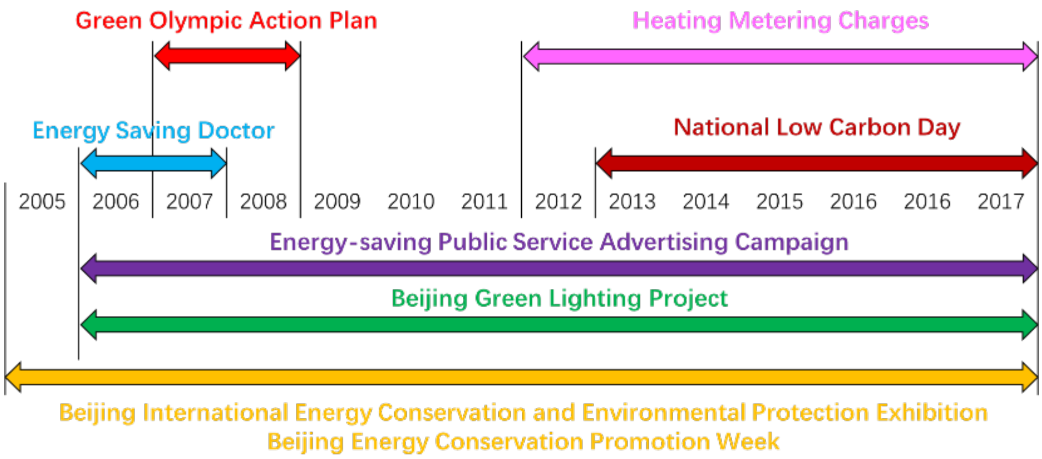


Figure 4: Public awareness activities timeline

4.1.5 **Data Reporting / Benchmarking / Disclosure**

4.1.5.1.1 Beijing Municipal Energy Efficiency of Buildings Project for 11th Five-Year Plan (2007)

As mentioned in clause 4.1.4.3.1, the Beijing Municipal Energy Efficiency of Buildings Project was issued in 2007 by the Beijing government. The project included constructing an energy efficiency monitoring system for Government buildings, implementing energy audits and disclosing energy data. As of 2010, 65 Government buildings and 258 large-scale public buildings installed power meters for monitoring different aspects of energy consumption and constructed the monitoring platform and energy consumption statistic template and reporting system.

4.1.6 **Financial Incentives**

4.1.6.1.1 Subsidies for the renovation of existing buildings

Since 2008, with the launch of the Renovation Program of Existing Building (2007), a subsidy has been provided for upgrading the building envelope and electrical and mechanical systems of eligible buildings. Eligible buildings include services and residential buildings. The related measures of the renovation program include the operational schedule of the buildings, air conditioning and heating systems, hot water systems, sub-meters, façade and windows, etc.

4.1.6.1.2 Funds for Green Building

In 2014, the Beijing Government published “Interim Measures on the Management of Incentive Funds for the Development of Green Buildings and Promotion of Green Ecological Demonstration Zone in Beijing”. Financial incentives were provided to China Green Building Labelled two-star and three-star projects.

Incentive funds were given to green ecological demonstration zones that meet certain conditions, with two to three green ecological demonstration zones assessed and awarded funds each year. The incentive funds were mainly used for the preparation of green ecological plans.

The scheme was reviewed in 2017, with half of the subsidy to be provided to eligible projects.

4.1.6.1.3 Subsidy for energy-efficient appliances

A subsidy for energy-efficient appliances named “Notice on implementation of energy conservation and emission reduction” was implemented by the Beijing Government in November 2015 and continued until November 2018. The second subsidy plan was implemented in February 2019 and continued until January 2022. Beijing citizens purchasing appliances with energy labels can get a cash subsidy. Examples of eligible products include home appliances such as TVs, refrigerators, air conditioners and water heaters.

4.1.6.1.4 Funds for Ultra-low Energy building

In 2017, the Interim Measures for the Management of Ultra-low Energy Demonstration Projects and Incentive Funds for Ultra-low Energy Building in Beijing were officially released. The measures regulate the management of demonstration projects and incentive funds for ultra-low-energy buildings in Beijing.

4.1.7 Key Drivers

With the continuous growth in GDP, the building energy end-use consumption in both service and residential sub-sectors has increased.

<u>Service Buildings</u>

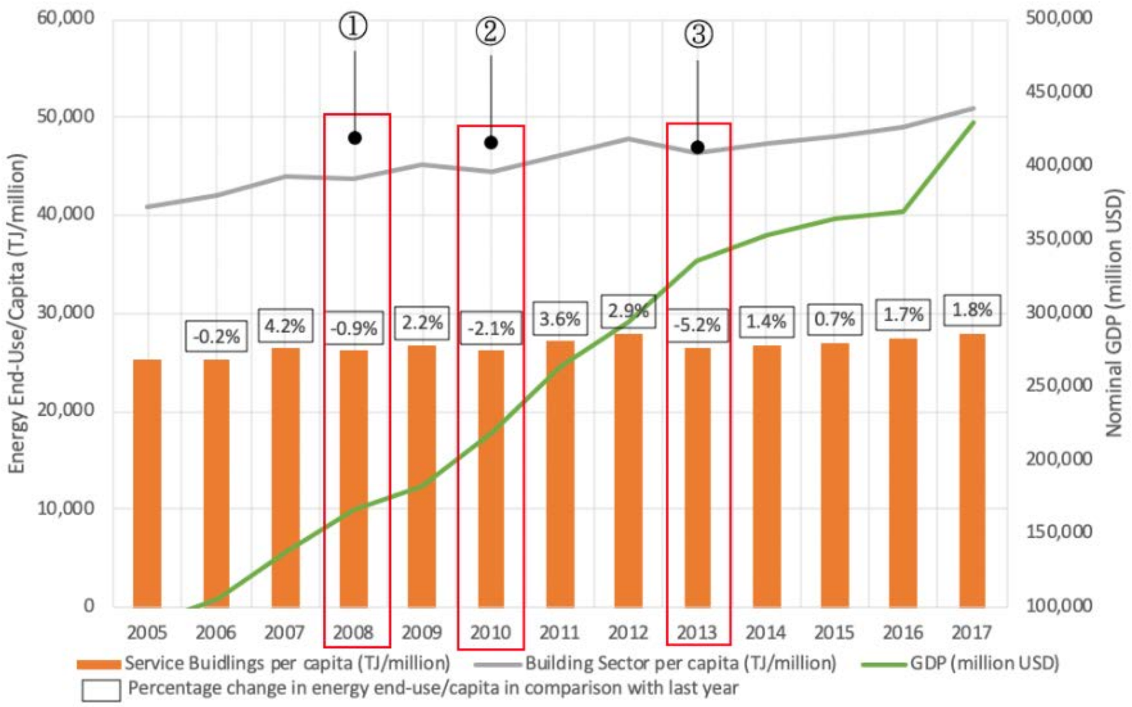
Figure 5 showed the trend of service buildings' energy end-use per capita in Beijing from 2005 to 2017. Reduction in energy end-use occurred in 2008, 2010 and 2013.

Since 2006, Beijing had promoted a "resource-saving, environment-friendly" city for the 2008 Beijing Olympic Games. The city's energy conservation and consumption reduction work achieved remarkable results. Compared to the preceding year in 2007, the energy intensity[3] dropped by 11.0%, exceeding the year plan's target.

The year 2010 was the final year of the 11th Five-Year Plan and the last year of the Beijing Municipal Renovation Program of Existing Building (2008). As a result of this program, 70% of existing boilers for space heating were upgraded, and 40.6 million m^2 of existing buildings were made more energy-efficient by renovating boiler rooms and old heating pipe networks. Energy efficiency upgrades were made to a total of 5.15 million m^2 of service buildings (general public buildings) and 8.25 million m^2 of service buildings (large public buildings).

The Design Standard for Energy Efficiency of Public Buildings and the Design Standard of Green Building were revised and implemented in 2010 and 2013 respectively. The impact of these revisions was likely to be reflected by the slight decrease in energy end-use per capita in 2013. The continuous review and update of standards were expected to contribute to reducing energy end-use per capita.

[3] Energy intensity calculated based on final energy demand (TJ)/nominal GDP (million USD)



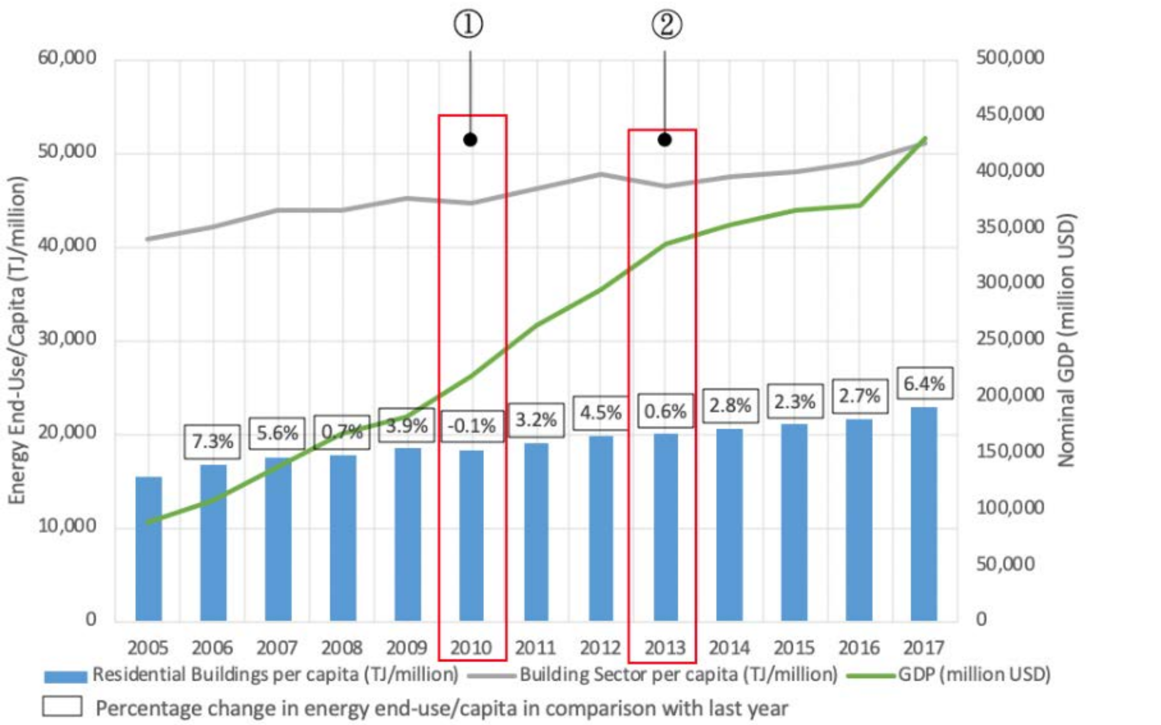
1) 2008: Beijing Government set the goal of a "resource-saving, environment-friendly" city (2006-2008).
2) 2010: Beijing Municipal Energy Efficiency of Buildings Projects for 11th Five-Year Plan (2006); Beijing Municipal Renovation Program of Existing Building (2008-2010).
3) 2013: revised Design Standard for Energy Efficiency of Public Buildings (2010), Design Standard of Green Building (2013)

Figure 5: Service buildings' energy end-use per capita in Beijing from 2005 to 2017

<u>Residential Buildings</u>

Figure 6 showed the trend of residential buildings' energy end-use per capita in Beijing from 2005 to 2017. There was a trend for increasing energy end-use from 2005 due to the increase in built area. A slight slowdown in this trend can be seen in 2010 and 2013. Similar to the service buildings, the reduction in energy end-use in 2010 benefited from the upgrade in boiler systems and renovation of the existing building at the end of the 11th Five-Year Plan. During the 11th Five-Year Plan (2006-2010), a total area of 13.87 m^2 of existing residential buildings underwent energy reduction renovations.

With the revised Design Standards for Energy Efficiency of Residential Buildings and Green Building, the impact of the revisions was expected to be observed from the slowed down in the increment of residential buildings' energy consumption from 2013.



1) 2010: Beijing Municipal Energy Efficiency of Buildings Projects for 11th Five-Year Plan (2006); Beijing Municipal Renovation Program of Existing Building (2008-2010)
2) 2013: revised Design Standard for Energy Efficiency of Residential Buildings, Design Standard of Green Building

Figure 6: Residential buildings' energy end-use per capita in Beijing from 2005 to 2017

Summary of Key Drivers

Regulating the energy efficiencies of new and existing buildings is essential for maintaining the current energy intensity level.

- **Updated Building Energy Code**

The mandatory standards for energy efficiency of buildings in Beijing covered both new and existing buildings and regulated from design to system evaluation stages of the building life cycle. These standards were updated frequently for more energy efficiency achievement.

- **Renovation Program of Existing Buildings**

Although addressing new buildings is vital, the renovation of existing buildings also provides a high energy-saving potential. The renovation program of existing buildings is a long-term process, which is based on Five-Year Development Plans. It aims to reduce central heating energy consumption and improve building energy efficiency. The main strategies include upgrading the building envelope, renovating the metering and temperature control system of the heating system, and improving daily operation management.

- **Change in Human Behaviour**

To prepare to host the Olympic Games in 2008, the Beijing government promoted the target of becoming a 'resource-saving, environment-friendly' city. The Government issued strict mandatory requirements on the energy efficiency of buildings, and transport emissions, and adopted new techniques and products. The campaign enhanced the public's awareness of the topic of energy-saving, leading to behavioural changes.

4.1.8 Gap Analysis

4.1.8.1 Current Energy Intensity Reduction Situation

By 2017, Beijing had reduced its energy intensity by 73.5% compared to its 2005 baseline. Apart from the rapid growth in GDP, contributions to the reduction in energy intensity came from the implementation of standards for energy-saving design, operation and renovation in building systems, as well as strict administrative management of the action plans for combating the increases in energy end-use despite the upgrades of living standards.

4.1.8.2 Energy Reduction Projection

Beijing was a developing city with soaring GDP growth during the period of this study. The increase in GDP compensated for the increase in energy end-use and resulted in a significant reduction in energy intensity. To align with the APEC Leader's goal of energy intensity reduction, the steep trend of increase in energy end-use shall be controlled by implementing more energy efficiency measures to slow down the increase in energy end-use.

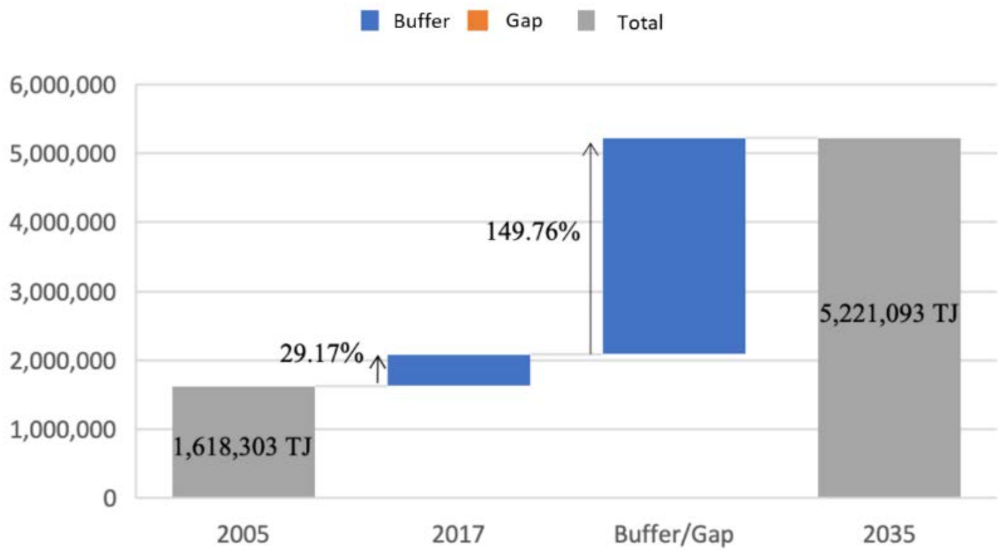


Figure 7 Energy end-use target of Beijing in 2035

4.1.9 **Latest Development in Building Energy-efficient Policy**

The building energy code drove industrial development and promoted the research and development of new products and talent exchange.

4.1.9.1.1 Energy Service Corporation (ESCO)

With the emerging need for the renovation and retrofitting of existing buildings, there is a market for Energy Service Corporations (ESCOs). t ESCOs support the building owners for the upgrading works with less upfront investment. The Beijing Government has set up a digital platform, named Energy Performance Contracting Investment and Finance Trading Platform, to regulate the ESCO market.

4.1.9.1.2 Ultra-low energy buildings from "Passive House"

Passive House is a voluntary standard for low-energy buildings which sets requirements on the façade insulation material and the airtightness of construction and is the first step to achieving an ultra-low energy building. Several projects, especially Government projects, have adopted the Passive House design, such as public rental housing in Baiziwan and a rehabilitation centre for the disabled.

An ultra-low energy building has strict requirements on building materials and parts due to its refined design and construction, which helps to promote the low-carbon transition and upgrading of the industry. The Government demonstrated the feasibility of achieving ultra-low energy buildings and set a goal for the industry. The development of ultra-low energy buildings will drive the development of the entire industrial chain from new economic growth points. The development of ultra-low energy buildings will be conducive to the transformation and upgrading of the building energy-saving industry, and lead the new momentum of supply-side structural reform.

4.1.9.1.3 Peaking carbon dioxide emissions and the 14^{th} Five Year Plan

In 2021, China aimed to reach a carbon dioxide emissions peak by 2030 and achieve carbon neutrality by 2060, with works such as readjusting its industrial structure and energy mix and vigorously developing the adoption of renewable energy in sandy areas, rocky areas and deserts.

Moreover, the 14^{th} Five-Year Plan of China was issued in 2021. In echoing the domestic 14^{th} Five Year Plan, the Beijing Government planned the renovation program for the existing district in August 2021.

4.2 Singapore

Singapore is a city-state economy located in Southeast Asia and is a developed economy. Singapore has an area of 720km^2 with a population of 5.612 million in 2017. The urban density of 7,796 persons/km^2.

According to APERC's Outlook [3], Singapore shows a significant energy intensity reduction among other developed economies.

According to energy data from the Energy Market Authority (EMA) of Singapore [12] and the International Energy Agency (IEA) [13], Singapore achieved a 59.1% energy intensity reduction in 2017, which was in line with APEC Leader's goal on energy intensity reduction.

As part of the contribution to the climate change agreement [14], Singapore issued Nationally Determined Contribution (NDC) and Long-Term Low Emissions Development Strategy (LEDS) in 2020. Singapore set an absolute greenhouse gases emissions target for peak emissions at 65MtCO2e[4] around 2030.

4.2.1 Final Energy Demand Overview

According to the energy data from the Energy Market Authority (EMA) [12], the total energy end-use in Singapore was estimated to be 616,565 TJ in 2017, where 65.7% of the energy end-use belonged to the Industrial Sector, 16.5% to the Transport Sector, 16.4% to the Building Sector, as illustrated in Figure 8. Of the 16.4% from the building sector, 4.9% of the energy end-use came from residential buildings and 11.5% from service buildings.

The transport sector was the second largest energy consumption sector. The energy end-use for the transport sector increased by 24.6% from 2005 to 2017 due to the expansion of new development areas, increased traffic and an increase in the total number of registered vehicles.

The industry sector was relatively large in scale in Singapore and is the largest energy-consuming sector. It mainly consisted of manufacturing, construction and utilities. The energy end-use consumption in the industrial sector increased by around 195.9% from 2005 to 2017 due to the expansion of the industrial sector in Singapore.

Although the building sector was not the dominant energy consumer, Singapore has maintained a similar level of energy end-use per capita in the building sector over the decades with the growth in both GDP and population. In connection with this, the availability of data, aggressive regulations and numerous schemes related to energy efficiency in the building sector in recent years is valuable for this study.

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[4] MtCO2e: million tons of carbon dioxide equivalent, a unit of carbon dioxide emission

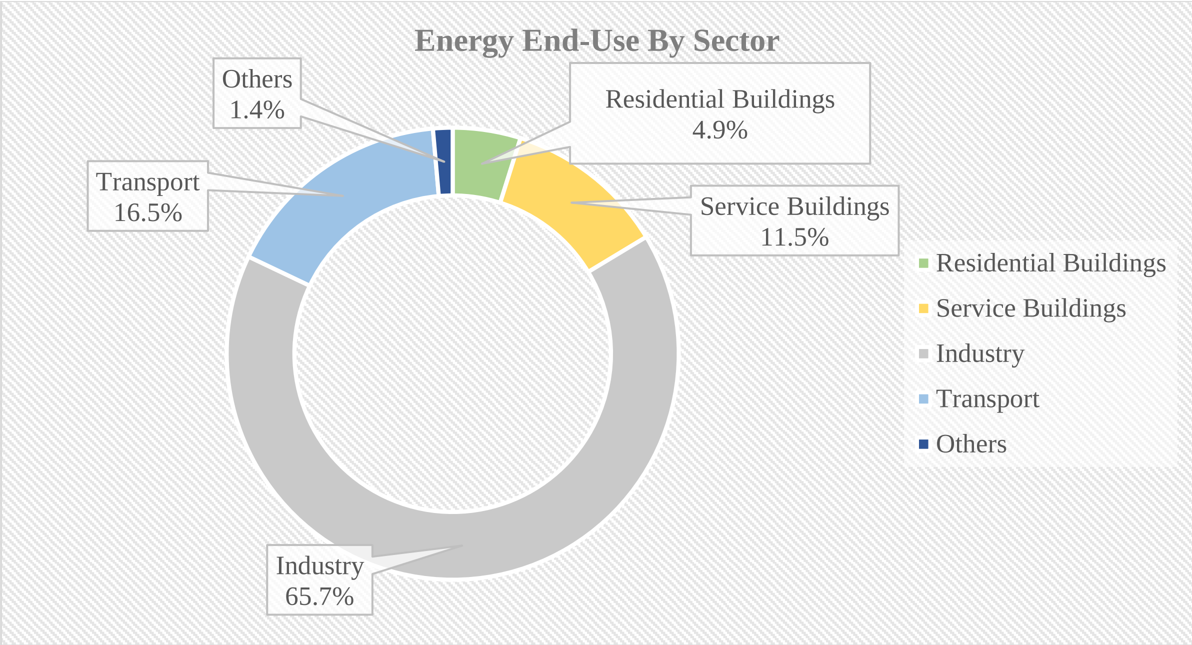


Figure 8 Energy end-use by sector of Singapore in 2017

Energy end-use data for 2017 was used for this study. The latest energy data for Singapore is available on Energy Market Authority's website.

According to Housing and Development Board (HDB) [15] in Singapore, the completion status of both residential and service buildings formed a similar pattern between 2007 and 2017. The newly constructed area rose sharply to a peak in 2014. The completed unit increased steadily over the decades and showing a stabilising trend since 2014. It would be expected that the urbanisation of Singapore has almost reached its peak with less new construction but more existing building stock.

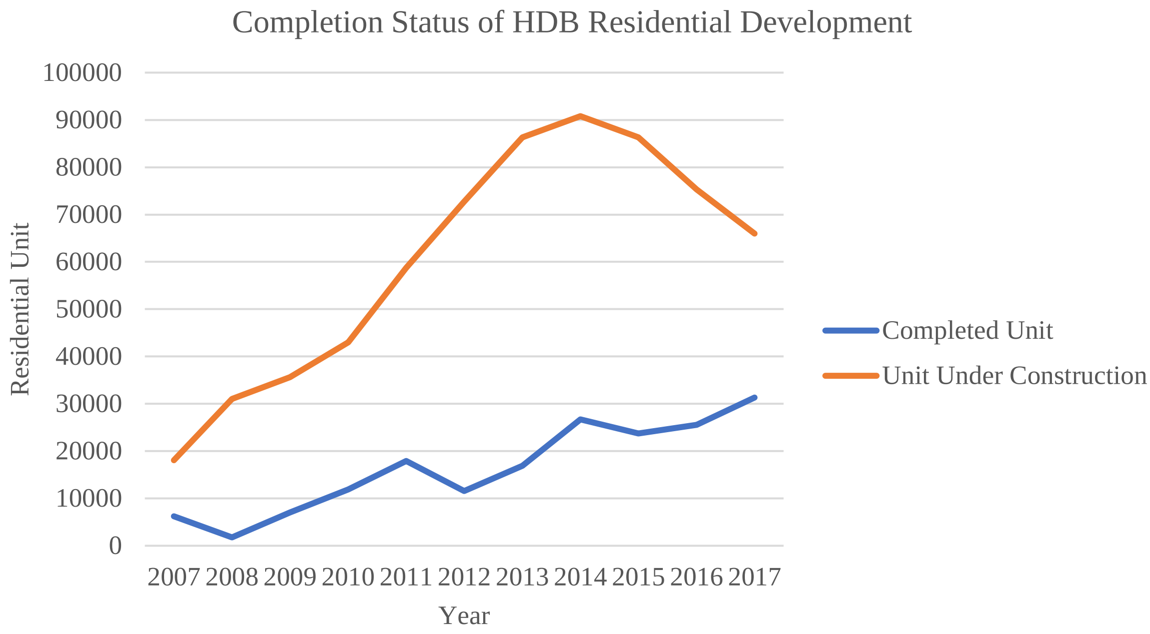


Figure 9 Completion Status of HDB Residential Development from 2007 to 2017

4.2.2 Building Sector Energy Consumption

In general, energy consumption in the building sector increased and reached a plateau since 2016, reaching 100,871 TJ in 2017, which was 16.4% of overall energy end-use. In the building sector, 70% of the energy consumption was spent on service buildings and 30% on residential buildings, as shown in Figure 10.

The energy consumption in service buildings increased by 42.7% from 2005 to 2017 and 16.9% for residential buildings, while GDP also increased by 167.4% over the same period and 31.6% for the population.

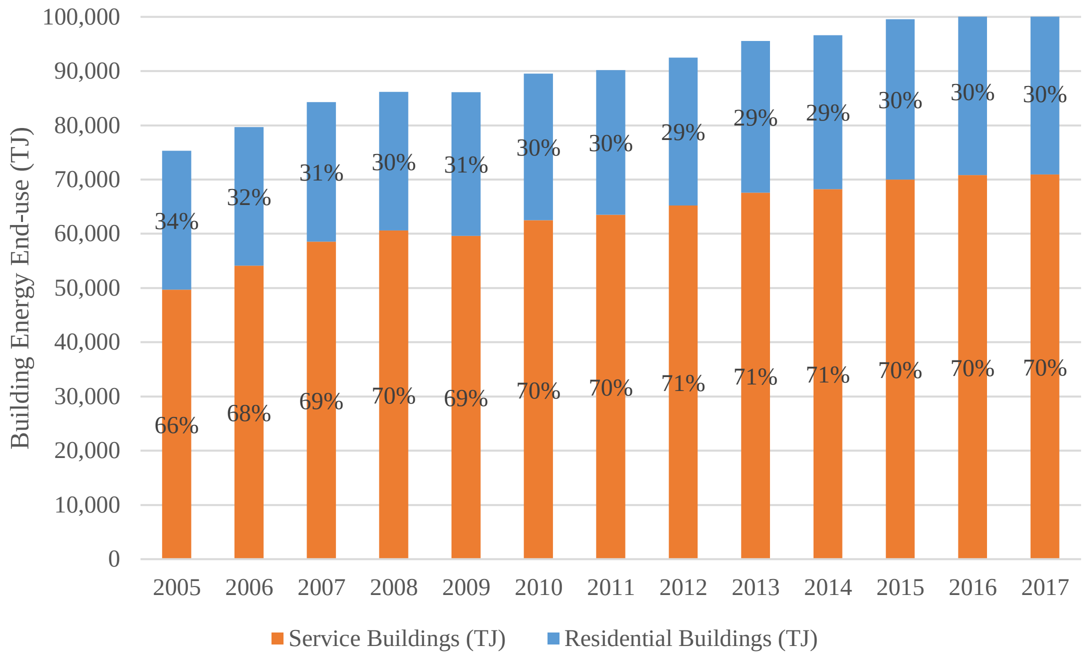


Figure 10 Building energy end-use of Singapore from 2005 to 2017

4.2.3 Review of Building Energy-Related Measures

Strategic Plans	Coverage	Building Type	Authority Level	Revisions
Sustainable Singapore Blueprint	New and Existing	Residential and Service	Domestic and City	2009/ 2021
Singapore Green Plan 2030	New and Existing	Residential and Service	Domestic and City	2021
Building Energy-Related Policies and Measures				
Code on Envelope Thermal Performance for Buildings	New	Residential and Service	Domestic and City	2004
SS 530 – Code of practice for Energy Efficiency Standard for Building Services and Equipment	New	Residential and Service	Domestic and City	2006 / 2014
SS 531 - Code of Practice for lighting of workplaces	New	Residential and Service	Domestic and City	2006 /2013/2019

SS 553 – Code of practice for air-conditioning and mechanical ventilation in buildings	New and Existing	Service (commercial, office and institutional buildings except for hospitals)	Domestic and City	2009/ 2016
Green Building Standards				
BCA Green Mark Scheme	New and Existing	Residential and Service	Domestic and City	2005/2008/ 2015/ 2021
Code for Environmental Sustainability of Buildings	New and Existing	Residential and Service (All types of the building)	Domestic and City	2008/2010/2012/ 2014/2021
Code on Environmental Sustainability Measures for Existing Buildings [16]	Existing	Services (offices, hotels, retail malls and mixed of these)	Domestic and City	2016/2019 (3rd edition will be effective from June 2022)
Measures to Existing Buildings				
Building Control (Environmental Sustainability Measures for Existing Buildings)	Existing	Service (Cover largely commercial buildings excluding data centres, utilities and transport/air/sea port facilities, residential and religious buildings)	Domestic and City	2013/2016
Code for Environmental Sustainability of Buildings	New and Existing	Residential and Service (All types of the building)	Domestic and City	2008/2010/2012/ 2014/2021
Building Control (Environmental Sustainability) Regulations	New and Existing	Residential and Service (All types of the building)	Domestic and City	2008
Code on Environmental Sustainability Measures for Existing Buildings	Existing	Services (offices, hotels, retail malls and mixed of these)	Domestic and City	2016/2019 (3rd edition will be effective from June 2022)
Minimum Energy Efficiency Standards (MEES) for Water-Cooled Chilled Water	New and Existing	Services (Industrial)	Domestic and City	2020

Systems in Industrial Facilities				
Data Reporting (Energy Audit)				
Building Control (Environmental Sustainability Measures for Existing Buildings)	Existing	Residential and Service	Domestic and City	2013/ 2016
Building Energy Submission System	Existing	Service	Domestic and City	2013/2016 /2019/2021
Code on Periodic Energy Audit of Building Cooling System	New and Existing	Service (Cover largely commercial buildings excluding data centres, utilities and transport/air/sea port facilities, residential and religious buildings)	Domestic and City	2010/ 2013/ 2014/ 2016/ 2020
Energy-efficient Appliances Labelling				
Mandatory Energy Labelling Scheme (MELS)	(for goods)	Residential	Domestic and City	2008/ 2014
Minimum Energy Performance Standards (MEPS)	(for goods)	Residential and Service (All types of the building)	Domestic and City	2011
Government Leadership				
Public Sector Taking Lead in Environmental Sustainability	New and Existing	Residential and Service	Domestic and City	2006/2014
GreenGov.SG [17]	New and Existing	Residential and Service	Domestic and City	2021
Tenant Programme				
user-centric Green Mark schemes [18]	New and Existing	Services (Office Interior, restaurants, supermarkets, retail and data centres)	Domestic and City	2014
Incentives				
Green Mark Incentive Schemes	New and Existing	Residential and Service	Domestic and City	2006/2009/2014

Energy Efficiency Fund	New and Existing	Service	Domestic and City	2021
Human Behaviour				
Energy Efficiency National Partnership Awards	(for companies/ organisations/ individuals)	Services (industry and public sectors)	Domestic and City	2011
Energy-efficient Singapore	New and Existing	Residential and Service (All types of the building)	Domestic and City	2016
Singapore Certified Energy Manager (SCEM) Programme and Training Grant	N/A	N/A	Domestic and City	2016
Sustainability in Singapore's Programme	New and Existing	Service	Domestic and City	2021

4.2.4 Major Policy / Scheme for EE&C

4.2.4.1 Building Energy-Related Policies and Measures

The Building Control Act includes the requirement of building works to be environmentally sustainable. The Building Control Act is followed by Building Control regulations, Building Control (Environmental Sustainability) Regulations (2008) and Building Control (Environmental Sustainability Measures for Existing Buildings) Regulations (2013). These are followed by the Code on Environmental Sustainability of Buildings, the Code on Environmental Sustainability Measures for Existing Buildings, and the Code on Periodic Energy Audit of Building Cooling System. These are incorporated as part of the compliance requirement to the extent prescribed in the building regulations.

In Singapore, the domestic standards are called the Singapore Standards. They are consensus-based, developed by and widely accepted by industry practitioners and other stakeholders, often serving as guidelines and standards to follow. The Code for Environmental Sustainability of Buildings also references some of these Singapore Standards. The standards addressed both passive and active building design, including the thermal performance of the building envelope and building equipment involved in ventilation, cooling and lighting.

Examples of Singapore Standards are as follows,

- SS530 – Code of practice for Energy Efficiency Standard for Building Services and Equipment
- SS531 - Code of Practice for lighting of workplaces
- SS553 – Code of practice for air-conditioning and mechanical ventilation in buildings
- SS554 - Code of practice for indoor air quality for air-conditioned buildings
- SS591 - Code of practice for long-term measurement of central chilled water system energy efficiency

These standards are incorporated as part of the compliance requirement to the extent prescribed in the building regulations.

4.2.4.2 Mandatory Energy Performance on Existing Buildings

4.2.4.2.1 Building Control (Environmental Sustainability) Regulations (2008)

Building Control (Environmental Sustainability) Regulations were effective in 2008 to advance sustainable development in Singapore as a result of section 49 of the Building Control Act. The amendment requires new and existing buildings to undergo major retrofitting with a GFA greater than 2,000 m² to meet minimum environmental sustainability standards. The requirements for the environmental sustainability of buildings are integrated with the Building Plan and TOP processes. The design process and submission shall be endorsed by a qualified person. From the end of 2021, only new and existing buildings involved in major retrofitting with GFA greater than 5,000 m² will be subjected to this requirement.

4.2.4.2.2 Building Control (Environmental Sustainability Measures for Existing Buildings) Regulations (2013)

The Building Control (Environmental Sustainability Measures for Existing Buildings) Regulations has implemented in Singapore since 2013. These regulations are to improve the minimum environmental sustainability standards of existing buildings and require a minimum energy efficiency standard when the buildings were going to be changed. The regulations require existing service buildings with GFA greater than 5,000 m² and have installed or replaced the building cooling system to meet minimum environmental sustainability standards as stipulated in the regulations.

4.2.4.3 Green Building Measures

4.2.4.3.1 BCA Green Mark Scheme (2005)

The Building and Construction Authority (BCA) launched the BCA Green Mark Scheme in January 2005. The scheme is a building benchmarking scheme that, among other categories, recognizes energy and resource reduction in the design and construction of residential and service buildings.

4.2.4.3.2 Code for Environmental Sustainability of Buildings (2008)

The "Code for Environmental Sustainability of Buildings" largely adopts the Building and Construction Authority (BCA) Green Mark framework to demonstrate compliance. After the first launch in 2008, the Code was updated in 2010, 2012 and 2014 to align with the latest Green Mark requirements.

The requirements can be classified into two main categories: energy-related requirements and other green requirements. "Energy-Related Requirements" relate to energy efficiency requirements including building envelope, air conditioning and ventilation, lift and lighting installations aspects. The "Energy-Related Requirements" help to enhance the minimum energy performance of application buildings.

In 2021, an amendment to "Building Control (Environmental Sustainability) (Amendment) Regulations 2021" was issued. From this amendment, all new and existing buildings involving existing buildings with major retrofit, with a GFA exceeding 5,000 m^2 will be subjected to the new requirements from the amendment. These buildings will be required to meet a 50% energy efficiency improvement from 2005 levels.

4.2.4.4 Government Taking Lead

4.2.4.4.1 Public Sector Taking Lead in Environmental Sustainability (2006)

In addition to regulatory controls, the Singapore Government has initiated several policies and measures since 2006 under the Public Sector Taking the Lead in Environmental Sustainability (PSTLES) initiative. According to the Public Sector Sustainability Plan (2017 – 2020), public sector buildings in Singapore aim to achieve an electricity reduction of 15% collectively by 2020 from a 2013 baseline.

To achieve such a target, all public buildings are required to set targets for energy reduction and submit an annual environmental scorecard to update their environmental performance. The public sector is encouraged to adopt Guaranteed Energy-saving Performance (GESP) contracting model for building retrofit projects, in which case, the energy performance can be guaranteed [19]. The initiative was revised in 2014 to ensure that public sector buildings comply with energy-related sustainability measures.

In 2021, new targets are provided under GreenGov.SG initiative.

4.2.5 Data Reporting / Benchmarking / Disclosure

4.2.5.1 Building Energy Submission System (2013)

Since 2013, building owners must submit building information and energy consumption data annually to BCA using an online submission portal called the Building Energy Submission System (BESS) [20]. The requirement was revised in 2016 which expanded the coverage of the requirement to healthcare facilities and tertiary institutions. In 2019, the requirement was further streamlined to target buildings of GFA exceeding 5,000 m^2. The BESS collects data from both utilities and building owners which is then published and shared as open data in the BCA Building Energy Benchmarking Report (BEBR) after the data has been verified. BCA published benchmarking reports annually to summarise the statistics and figures. The mandatory disclosure of building performance data will be implemented starting with commercial buildings from the end of 2021. The system helps to improve data transparency and the public's awareness of energy performance.

4.2.6 Financial Incentives

4.2.6.1 Green Mark Incentive Schemes (2006)

Singapore offers several financial incentive schemes under Green Mark Incentive Schemes. The financial incentive schemes are aimed to encourage the adoption of energy efficiency measures and practices, assist building owners in overcoming the high initial cost of existing building retrofitting and stimulate innovation and collaboration to achieve the goal of energy efficiency. Incentives under these schemes include monetary rewards and gross floor area concessions.

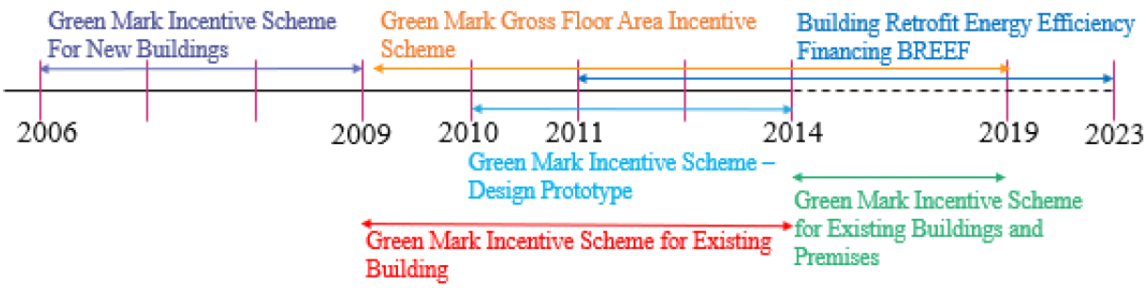


Figure 11 Timeline of Green Mark Incentive Scheme

Since 2006, BCA has progressively introduced various incentives to encourage private developers and building owners to strive for higher Green Mark rating and energy efficiency standards in their building development. It started with the $20 million Green Mark Incentive Scheme for New Buildings (GMIS-NB) to speed up the development of green buildings before making a decisive step to mandate a minimum environmental sustainability standard in 2008. In 2009, BCA issued the 2nd Green Building Masterplan and set a target to have at least 80% of the buildings in Singapore meet the minimum environmental sustainability standards by 2030. Besides mandatory regulations, several Green Mark Incentive Schemes provided rewards for success. The incentive schemes included several actions as below,

- In 2009, the Green Mark Incentive Scheme for Existing Buildings (GMIS-EB)
- From 2009 to 2019, the Green Mark Gross Floor Area Incentive Scheme for new buildings.
- From 2010 to 2014, the Green Mark Incentive Scheme - Design Prototype (GMIS-DP).
- From 2011 to 2023, the Building Retrofit Energy Efficiency Financing (BREEF) scheme.
- In 2014, the Green Mark Incentive Scheme for Existing Buildings and Premises (GMIS-EBP).

The Green Mark Gross Floor Area Incentive Scheme is a performance-based incentive scheme which awarded private developers and building owners with up to 1% and 2% bonus GFA for having achieved Green Mark GoldPLUS and Green Mark Platinum ratings respectively for their developments.

4.2.7 Key Drivers

Service Buildings

Figure 12 showed the trend of service buildings' energy end-use per capita in Singapore from 2005 to 2017. It depicted the variation in energy end-use per capita with an inclined trend until 2007 which, apart from a significant reduction of 4.5% in energy end-use in 2009, continued at a similar level afterwards.

The launch of BCA Green Mark by BCA in 2005 with incentive schemes in 2006 was considered to contribute to the reduction of energy end-use in service buildings for 2008 and 2009.

In 2008, the Building Control (Environmental Sustainability) Regulations and the Code for Environmental Sustainability of Buildings were launched, and the contribution to energy consumption reduction was expected and observed in the year 2010 and afterwards.

With the Building Control (Environmental Sustainability Measures for Existing Buildings), the Code on Periodic Energy Audit of Building Cooling Systems and the annual energy consumption reporting to the Building Energy Submission System launched in 2013, the rate of increase for energy consumption in service buildings was reduced which demonstrates the effectiveness of the launched policies and incentive programmes.

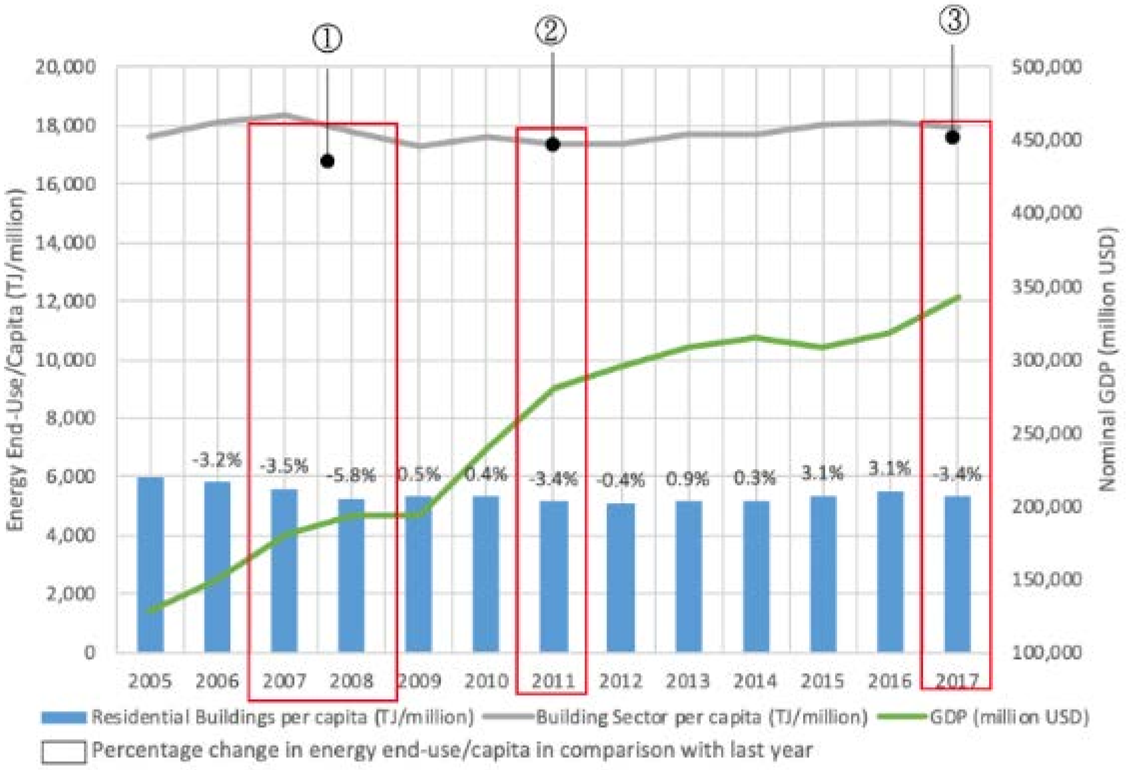
1) 2008-2009: BCA Green Mark (2005)
2) 2011: Building Control (Environmental Sustainability) Regulations, Code for Environmental Sustainability of Buildings (2008)
3) 2014: Building Control (Environmental Sustainability Measures for Existing Buildings) (2013)

Figure 12 Service buildings' energy end-use per capita in Singapore from 2005 to 2017

Residential Buildings

Figure 13 showed the trend of residential buildings' energy end-use per capita in Singapore from 2005 to 2017. Relatively significant step reductions in energy end-use per capita were observed in 2007, 2008, 2011 and 2017. The energy end-use reduction in residential buildings might be affected more by human behaviour changes and the weather.

When comparing the energy end-use per capita data of residential buildings from 2005 to 2017, there was an 11.2% reduction, which means the total energy end-use per person was reduced. The more energy-efficient behaviour might be a result of the Mandatory Energy Labelling Scheme (MELS) and Minimum Energy Performance Standards (MEPS) that were launched in 2008 and 2011.



1) 2007-2008: Great Recession since 2007
2) 2011: Residential envelope Transmittance Value (RETV) (2008); Mandatory Energy Labelling Scheme (MELS) (2008, 2009)
3) 2017: Enhanced coverage of appliances in the Mandatory Energy Labelling Scheme (MELS) and Minimum Energy Performance Standards (MEPS) (2014, 2015)

Figure 13 Residential buildings' energy end-use per capita in Singapore from 2005 to 2017

<u>Summary of Key Drivers</u>

After investigating the building energy end-use reduction and its relation to the implementation of various policies, the possible key drivers for energy reduction were summarised below.

- **Synergistic Effect of Green Mark and Building Control (Environmental Sustainability) Regulations**

The Building Control (Environmental Sustainability) Regulations use Green Mark certification criteria as a framework for buildings to demonstrate compliance to the regulations i.e. attaining a Green Mark score of 50 points under the Code. The assessment framework of Green Mark is adopted as the compliance method under the current regulatory requirement on the environmental sustainability of new buildings.

- **Mandatory Energy Performance Requirement for Existing Building**

The policy that regulates the energy efficiency of existing buildings has been strengthened over the years. The mandatory energy performance requirement initially only applied to the design and installation of major retrofits of existing buildings in 2008 but was significantly expanded in 2012 to cover all existing buildings with GFA greater than 5000sq m and have installed or replaced the building cooling system. After which, mandatory periodic energy audits are required to ensure cooling systems continue to operate efficiently through the building's lifespan.

- **Financial incentive schemes**

Several incentive schemes are provided in Singapore for stakeholders. Green Mark Incentive Schemes including GMIS-NB, GMIS-EB, and GMIS-EBP provided monetary incentives to accelerate the adoption of environmentally friendly building technologies and building design practices in new buildings, and offset the upfront costs of energy audits and energy improvement works in existing buildings, while GM GFA provided a GFA concession to encourage the development of buildings that attain higher-tier Green Mark ratings. The Green Mark Incentive Scheme for Existing Buildings encourages the adoption of energy efficiency measures and practices for owners of existing buildings and tenants, to offset the upfront cost of energy efficient retrofits, energy audits and energy improvement works. The Gross Floor Area (GFA) Incentive Scheme provides additional GFA for new buildings to achieve higher Green Mark ratings.

4.2.8 **Gap Analysis**

4.2.8.1 Current Energy Intensity Reduction Situation

Up to 2017, Singapore achieved energy intensity[5] reduction of 59.1% compared to its baseline in 2005. Under the current scenario, Singapore's energy intensity reduction aligned with the APEC Leader's goal.

4.2.8.2 Energy Reduction Projection

Compared with the baseline data in 2005, the trend for energy end-use is for it to increase, with an increment of 9.4% in 2017. Referring to the methodology stated in Section 2.4, a sufficient buffer of 63.1% from the 2017 performance in energy consumption is observed. If the current level of energy consumption can be maintained, it is expected that the energy intensity reduction will stay within the target threshold.

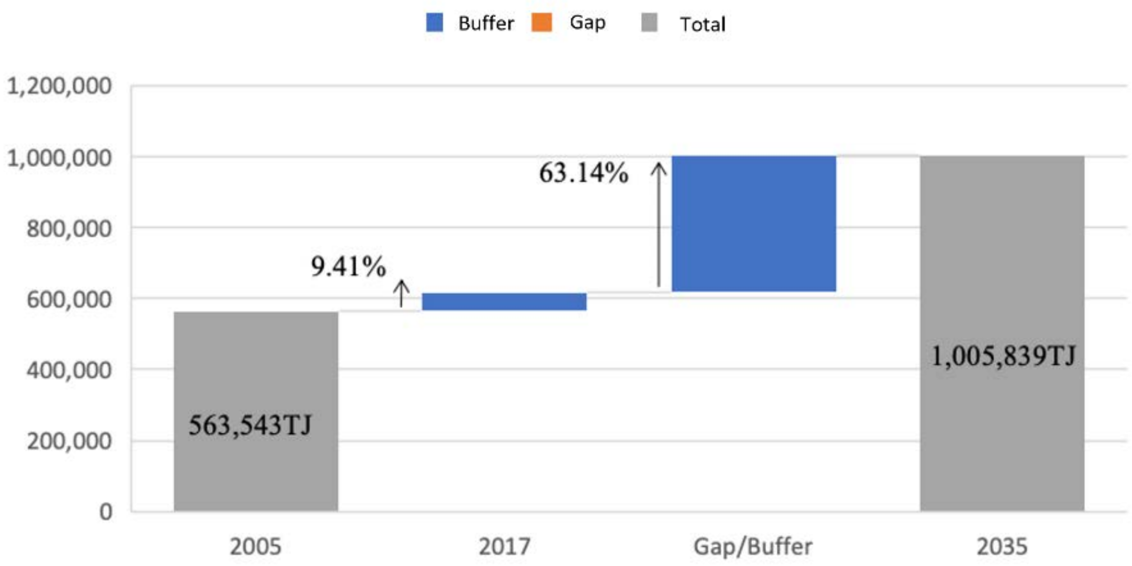


Figure 14 Energy end-use target of Singapore in 2035

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[5] Energy intensity calculated based on final energy demand (TJ)/nominal GDP (million USD)

4.2.9 **Latest Development in Building Energy-efficient Policy**

4.2.9.1 Super Low Energy Building Smart Hub (2019)

To accelerate the improvement of energy efficiency, the SLEB (Super Low Energy Building) Smart Hub [21] digital platform was launched in 2019 to provide resources on the latest Research, Development and Demonstration (RD&D) on energy-efficient technologies and solutions. Information and data on the tested technologies are showcased on the SLEB smart hub platform to help the market to adopt building energy-efficient solutions.

The SLEB smart hub provides a centralised domestic energy statistical database in the form of an interactive dashboard. Energy information such as Energy Efficiency Index (EEI), lighting power density (LPD), cooling load and chilled water system efficiency for different categories of buildings and specific buildings are provided for benchmarking and public information. The dashboard also displays trends in the adoption of energy efficiency and the amount of energy that can be saved by utilising the technologies according to Green Mark project records.

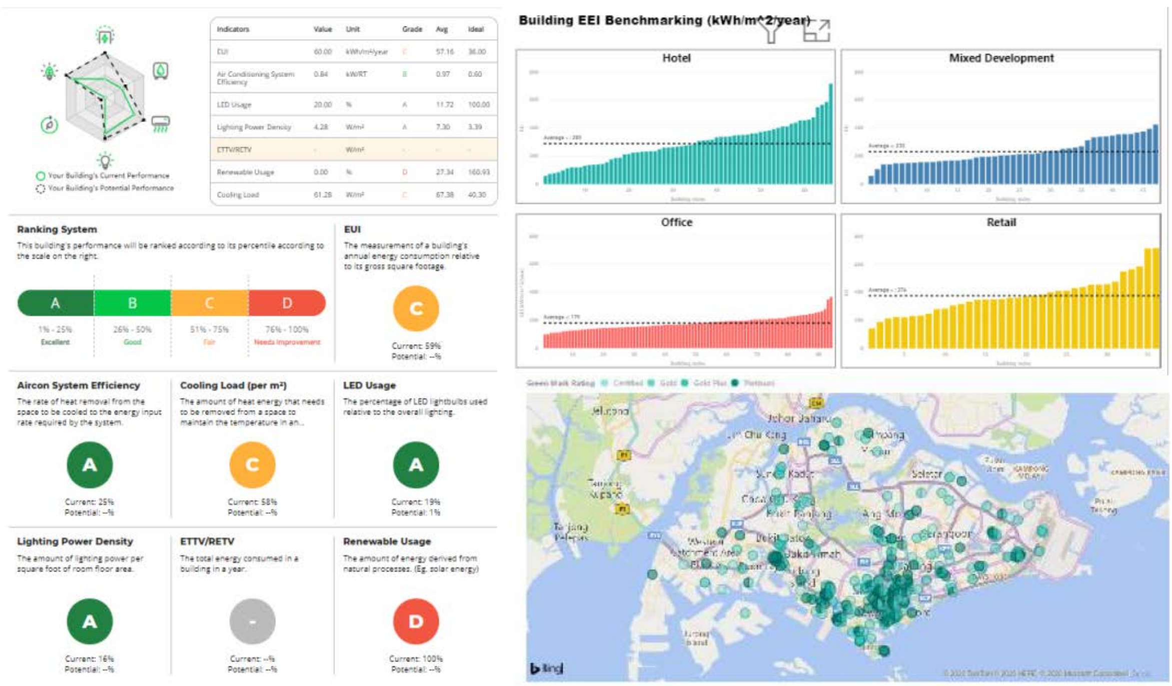


Figure 15 SLEB Smart Hub Interactive Energy Dashboard

4.2.9.2 Singapore Green Building Masterplan (SGBMP) (2021)

Further from the 2009 and 2014 editions, BCA and the Singapore Green Building Council updated the Singapore Green Building Masterplan (SGBMP) [22] and launched it in March 2021. The SGBMP sets targets of greening 80% of Singapore's buildings (by gross floor area, GFA) by 2030, 80% of new developments by GFA to be Super Low Energy (SLE) buildings by 2030 and achieving 80% improvement in energy efficiency for best-in-class green buildings by 2030.

4.3 Hong Kong, China

Hong Kong, China (HKC) is located in Southeast China and is a developed economy. HKC is a city-state APEC member economy with an area of 1,106km^2, among which around 25% are developed urban areas [23]. With a population of 7.5 million in 2019 [23], the urban density of HKC is 6680 persons/km^2 [23].

HKC is a financial, trading and business centre. Buildings account for around 65% of energy end-use. HKC is shortlisted due to the dominance of the energy end-use in the building sector and its significant reduction in energy intensity.

As stated in HKC's Energy-saving Plan published in 2015 [24], the target is to reduce the energy intensity by 40% by 2025 compared with a 2005 baseline.

4.3.1 Final Energy Demand Overview

Based on "*Hong Kong Energy End-use Data 2019*" [25] published by the Electrical and Mechanical Services Department (EMSD) of HKC, the total energy end-use in HKC stood at 286,270 TJ in 2017. Referring to data from the Census and Statistics Department, GDP grew by 88.3% from 2005 to 2017. Despite the significant economic growth during this time, the total energy consumption only increased by 2%. Approximately 65% of the energy end-use occurred in the building sector, followed by transport accounting for 30.9% and industry for 4.4%, as shown in Figure 16.

Transport is the second largest energy consumption sector. Within this sector the transport of passengers is the largest consumer, accounting for 69% of the energy consumption; it includes buses, taxis, cars, motorcycles, rail and marine. The energy end-use for the transport sector has reduced by around 10.4% since 2005, owing to the provision and promotion of the well-planned network of the public transportation system in HKC.

The industry sector is relatively small in HKC, consisting mainly of food and beverage, non-manufacturing, metal and machinery and textile and apparel. With that, the energy consumption for the industrial sector was the least among other sectors. The energy end-use consumption in the industrial sector has decreased by 35.9% since 2005 due to the shrinking of the industrial sector in HKC.

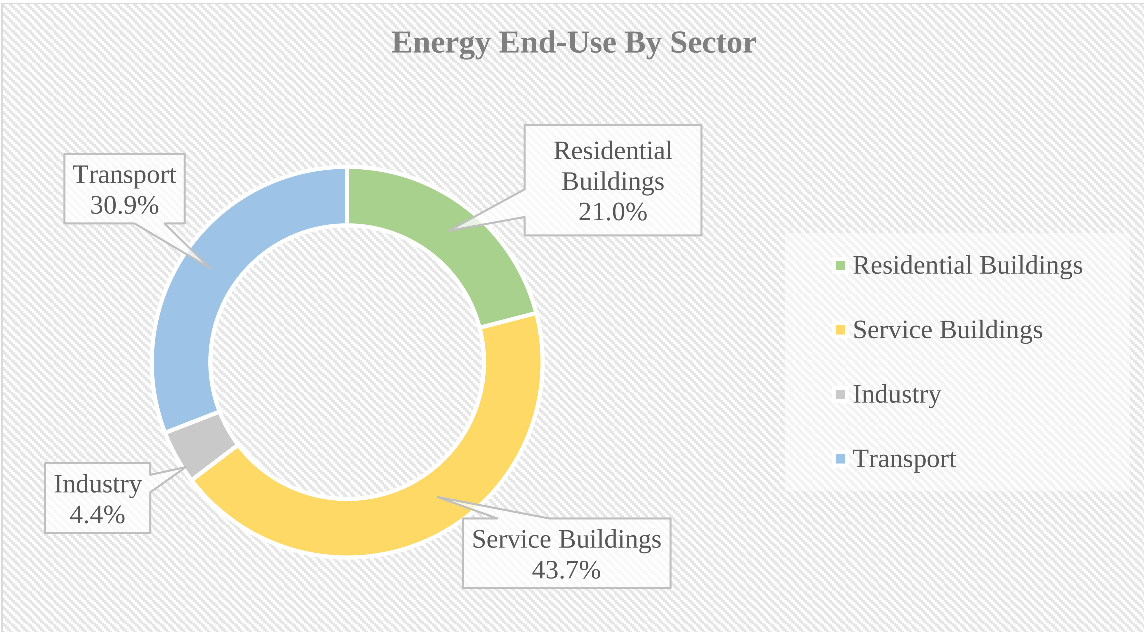


Figure 16 Energy end-use by sector of Hong Kong, China in 2017

According to the Hong Kong Rating and Valuation Department, the area of new constructions on service and residential buildings has reached a stabilised rate recently. With the limited land supply, housing demand is essential in HKC. The government's policy address 2021 has stated a 10-year plan to provide over 330 hectares of land for public housing units. It would be expected that the share of energy consumption under residential buildings will be further increased.

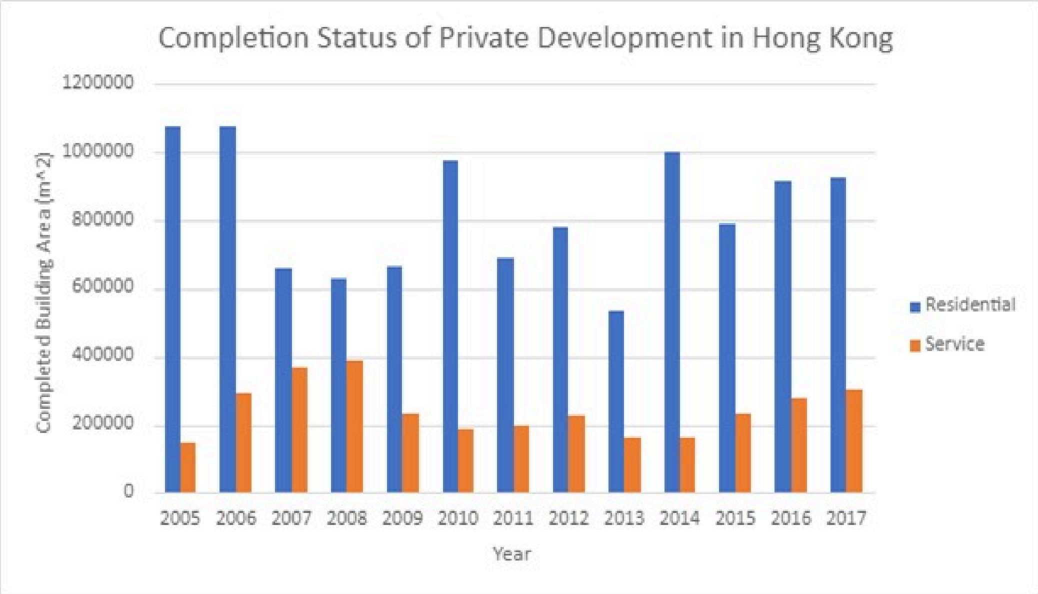


Figure 17 Energy end-use by sector of Hong Kong, China in 2017

4.3.2 Building Sector Energy Consumption

The building sector dominated the energy end-use in HKC in 2017. The service buildings sub-sector accounted for two-thirds of the total energy end-use in the building sector, a larger share than residential buildings. Compared with the data from 2005, the energy end-use in the building sector has demonstrated a slowly increasing trend until 2013. In particular, from 2012 to 2017, the energy end-use showed a relatively steady and stable trend, as shown in Figure 18. The most energy-consuming end-uses in buildings are air conditioning, cooking and lighting [25]. Buildings consume approximately 90% of the electricity used in HKC which makes building energy efficiency a top priority.

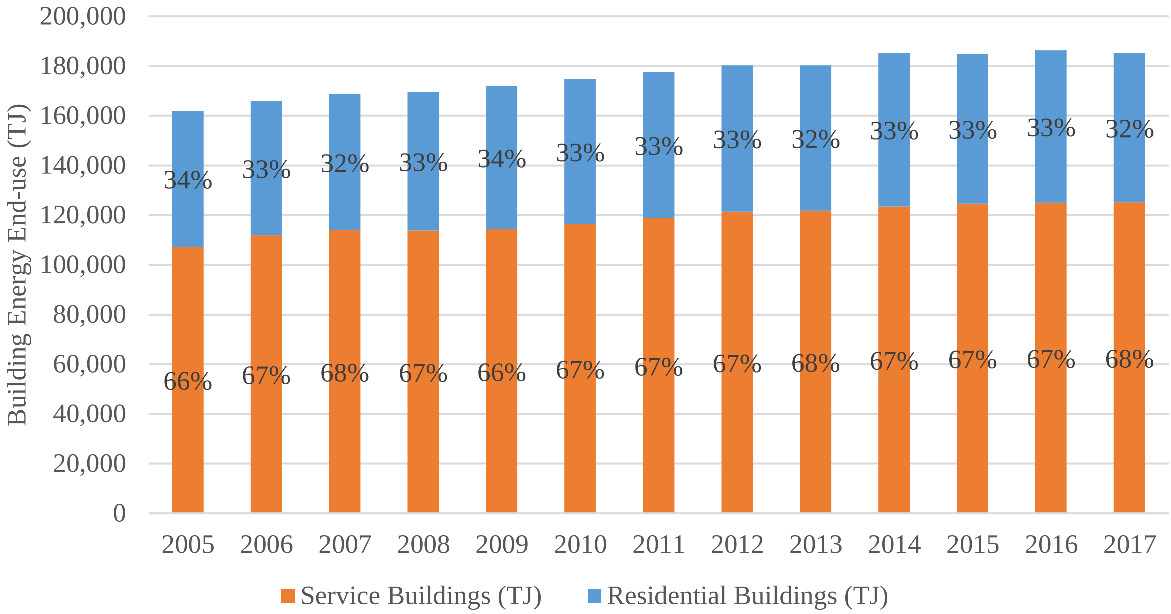


Figure 18 Building energy consumption of Hong Kong, China from 2005 to 2017

4.3.3 Review of Building Energy-Related Measures

Strategic Plans	**Coverage**	**Building Type**	**Authority Level**	**Revisions**
"Hong Kong Climate Action Plan"	N/A	N/A	City	2017/ 2021
Building Energy-Related Policies and Measures				
Code of Practice for Overall Thermal Transfer Value in Buildings	New	Service	City	1995/2011/2016
Building Energy Code	New and Existing	Residential and Service	City	2005/2007/2012/ 2015/2018
Guidelines on Design and Construction Requirements for Energy Efficiency of Residential Buildings	New	Residential	City	2014
Green Building Measures				
BEAM Plus	New and Existing	Residential and Service	City	2004/2010/2012/ 2020
Measures to Existing Buildings				
Technical Guidelines on Retro-commissioning	Existing	Service	City	2017/ 2018
Data Reporting / Disclosure				
Energy Audit Code	Existing	Service	City	2012/ 2015/2018
PNAP-APP151	New	Residential and Service	City	2011/2020
Energy-efficient Appliances Labelling				
Mandatory Energy Efficiency Labelling Scheme	(for goods)	N/A	City	2008 (2009) / 2016/ 2019/ 2021
Voluntary Energy Efficiency Labelling Scheme	(for goods)	N/A	City	2017
Government Leadership				
Target-based green performance framework for Green Government Buildings	New and Existing	Residential and Service	City	2009

Tenant Programme				
N/A	N/A	N/A	N/A	N/A
Incentives				
PNAP-APP151 (GFA Concession)	New	Residential and Service	City	2011/2020
EMSD Energy Efficiency Registration Scheme for Buildings (EERSB)	New and Existing	Residential and Service (All types)	City	1998/2018
Human Behaviour				
Save Energy Go Green	N/A	N/A	City	N/A
Energy-saving for All	N/A	N/A	City	N/A
TV Campaign and Ads	N/A	N/A	City	N/A

4.3.4 Major Policy / Scheme for EE&C

4.3.4.1 Building Energy-Related Policies with Regular Updates

4.3.4.1.1 Code of Practice for Overall Thermal Transfer Value in Buildings (1995) with Practice Note for AP, RPE & RGE - Energy Efficiency of Buildings - Building (Energy Efficiency) Regulation APP-67 (1995)

Since air-conditioning is the largest electricity consumer in the building, to reduce the use of air conditioning, the Buildings Department (BD) issued the Code of Practice (CoP) [26] for Overall Thermal Transfer Value (OTTV) in 1995 to outline the material for external wall and roof during building design and calculation methodology of OTTV value.

In 1995, the Practice Note APP-67 [27] was issued alongside the CoP for OTTV to regulate the OTTV value for service buildings. The Practice Note APP-67 was revised in 2011 and 2016 with tightened requirements on the OTTV value of service buildings.

4.3.4.1.2 Buildings Energy-efficiency Ordinance (BEEO), Building Energy Code (2012)

The development of the Building Energy Code for HKC started in 2005 and was revised in 2007, originally published as a voluntary scheme, Code of Practice for Energy Efficiency of Lighting Installation, Air Conditioning Installations, Electrical Installations, Lift and Escalator Installations.

In 2012, to further promote building energy efficiency, the Government enacted the Building Energy Efficiency Ordinance which mandated the compliance of the Building Energy Code (BEC) with the name "Code of Practice for Energy Efficiency of Building Services Installation". The BEC was revised with a set of design standards focusing on four key types of building service installations, including air-conditioning, lighting, electrical and lift and escalator installations. All new prescribed buildings and after undergoing major retrofitting works in existing prescribed buildings have to comply with the BEC.

The BEC is reviewed once every three years (revised in 2015 and 2018) to ensure that the BEC can keep pace with the times and can keep abreast of the latest technological advancement and the developments of international standards and practices on energy efficiency. Focus on non-residential buildings, the table below compares several major design requirement parameters for lighting, air-conditioning and lift installations and demonstrates the improvement throughout the development of different versions of the BEC code.

Table 1 Design Standards for Non-residential Building

	2005	**2007**	**2012**	**2015**	**2018**	**Improvement on design requirements in 2018 from 2005**
Lighting Power Density (W/m²)						50% - 60%
Office	23	17	15	12	10	
Lobby	22	15	12	11	10	
Corridor	15	12	10	8	8	
Chiller COP (Cooling)						10% - 20%
Air-cooled	2.7	2.8	2.8	3.2	3.2	
Water- cooled	5.2	5.7	5.7	5.8	5.8	
Maximum Electrical Power (kW) of Lift (Load<750kg Velocity < 1m/s)	7	6.7	6.7	6.5	6.2	10%

The BEC not only lay down the prescriptive compliance for building energy efficiency but also offers the performance-based approach for compliance.

Owners of newly constructed buildings are required to appoint a Registered Energy Assessors (REA), who should be a registered professional engineer in the electrical, mechanical, environmental or building services discipline under the Engineers Registration Ordinance (Cap.409) or a corporate member of the Hong Kong Institution of Engineers (HKIE) in the electrical, mechanical, environmental or building services discipline, or should have an equivalent qualification recognized by the HKIE as being of a standard not lower than that of a corporate member, to check and declared that the four key types of building services installations have been designed and installed following the BEC. The newly constructed building can then apply for the Certificate of Compliance Registration (COCR) from EMSD.

4.3.4.1.3 Guidelines on Design and Construction Requirements for Energy Efficiency of Residential Buildings (2014) with Practice Note for AP, RPE & RGE - Design & Construction Requirements for Energy Efficiency of Residential Buildings APP-156 (2014)

Following the PNAP-67 on service building OTTV, PNAP APP-156 introduce a similar definition for residential buildings, Residential Thermal Transfer Value (RTTV), which lays out the requirement on building envelope which targets the reduction of building air-conditioning and lighting demand for residential buildings. The guidelines set the following mandatory requirements on residential building facades.

Building Envelope	$RTTV_{wall} \leq 14W/m^2$ $RTTV_{roof} \leq 4W/m^2$
External Reflectance of glass	$ER_{glass} < 20\%$
Visible Light Transmittance of glass	$VLT_{glass} > 50\%$

Figure 19 Energy efficiency requirements for residential buildings

4.3.4.2 Measures to Existing Buildings

4.3.4.2.1 Energy Audit Code (2012)

In HKC, over 65% of the existing buildings are buildings over 20 years old. Many existing may therefore not fulfil the existing BEC requirement. The Guidelines on Energy Audit were first published in 2007 to encourage owners of existing commercial buildings to conduct an energy audit. It was not a mandatory requirement until the full implementation of the Buildings Energy Efficiency Ordinance (BEEO) in 2012, the "Energy Audit Code (EAC)" and the "Technical Guidelines on Energy Audit Code" were issued to layout the systematic procedures and requirements for a comprehensive energy audit. Since then, commercial buildings in HKC and commercial portion of composite buildings are required to conduct an energy audit following the EAC by every ten years for the four key types of central building service installations, namely air conditioning, lighting, electrical and lift and escalator installations. The building owner of the above buildings shall appoint a Registered Energy Assessor (REA) to conduct the energy audit. After the energy audit, the REA will then issue the Energy Audit Form (EAF) for the building owner to demonstrate compliance with the EAC.

The EAC is also reviewed regularly to keep up with technological advancement and international standards. The EAC sets out the technical guidance and details in respect of the energy audit requirements governing the central building services installation and the requirements are summarised as the following:

Energy consumption data and Energy Utilisation Index (EUI)	• Submit energy consumption data in the past 36 months. • The EUI per annum of the past 1st 12-month period of the building should be indicated in the Energy Audit Form.
Review of Energy Consuming Equipment	• Operation characteristics and energy consumptions of the central building services installations.
Identification of EMO	• Identify certain potential Energy Management. Opportunities (EMO) contribute to the reduction of energy consumption.
Cost Benefit Analysis of EMO	• Estimation of energy-saving and payback for each EMO.

4.3.4.2.2 Technical Guidelines on Retro-commissioning (2017 and 2018)

The “Energy-saving Plan for Hong Kong’s Built Environment 2015~2025+” states that “Retro-commissioning (RCx)” is one of the key initiatives to promote energy-saving for existing buildings. The performance of existing buildings, even those that were designed following the BEC, is not guaranteed due to various reasons including deviation in building operation and usage or the behaviour change of building occupants. RCx is a periodic assessment to check whether the building’s systems are performing as required and to identify any potential energy-saving opportunities.

“Technical Guidelines on Retro-commissioning (RCx)” was firstly implemented in 2017 as a systematic process to identify operational improvements and reduce energy consumption, and improve the indoor environment through regular check-ups on the performance of a building. Around 60 % of buildings aged over 25 years in HKC have significant energy-saving potential. The Technical Guidelines on RCx are aimed at building owners to reduce the operation and maintenance costs and ensure energy-consuming equipment is at its most efficient to ensure overall energy efficiency.

In 2018, “Technical Guidelines on Retro-commissioning” (2018 Edition) was issued to provide additional information on pre-RCx preparation, recommendations include data management and CCMS requirements, enrich the content in Measurement and Verification (M&V) methodology and introduce Key Performance Indices (KPIs) for monitoring.

EMSD is also embarking on a programme to conduct RCx in over 200 major Government buildings progressively from 2019-20 to 2025-26.

4.3.4.3 **Green Building Measures**

4.3.4.3.1 BEAM Plus Green Building Certification (2010)

BEAM Plus for New Buildings and Existing Buildings are voluntary certification schemes and were first launched in 2010 as an assessment tool for green building assessment. The assessment tool has been developed continuously over the past decade with revisions in 2012, 2015 and 2019. This green building rating certification scheme encourages organisations and companies to demonstrate their commitment to sustainable development.

4.3.4.4 Government Taking Lead

4.3.4.4.1 Target-based green performance framework for Green Government Buildings (2009)

The Government has taken the lead in improving building energy efficiency to encourage the wider building sector. In 2009, the Development Bureau and Environment Bureau published a joint circular letter for the green Government buildings "Target-based green performance framework for Green Government Buildings" [28]. It sets out a comprehensive framework for the green development of new and existing Government buildings in HKC.

New offices, recreational and community Government buildings were required to outperform the BEC requirement by at least 10% while cultural, school and hospital buildings were required to outperform the requirement by at least 5%. All existing Government buildings were required to achieve at least a 5% saving in total electricity consumption between 2009 and 2013, with 2007 as the base year.

In 2015, the framework was revised [29] to require all new Government buildings to achieve BEAM Plus Gold or above. In addition to that, a requirement for a carbon audit was added to report the Government building energy data. An additional requirement was imposed on Government buildings other than offices, recreational and community type, cultural, school and hospital buildings to achieve at least 3% energy reduction from BEC.

Type of Government Buildings	**Target**
New offices, recreational and community buildings	Outperform BEC requirements by at least 10% BEAM Plus Gold or Above
New cultural, school and hospital buildings	Outperform BEC requirements by at least 5% BEAM Plus Gold or Above
Other types of new Government buildings	Outperform BEC requirements by at least 3% BEAM Plus Gold or Above
All existing Government buildings	Achieve 5% savings on total electricity consumption with 2007 as the base year

4.3.4.5 **Energy-efficient Product Labelling**

Energy-efficient products not only consume less energy but also help protect the environment and save money in the long run. The Mandatory Energy Efficiency Labelling Scheme (MEELS) in HKC launched its first phase in 2009 which covered three types of products: room air conditioners, refrigerating appliances and compact fluorescent lamps (CFLs). The second phase of the scheme was implemented in 2011 which extended the coverage to washing machines and dehumidifiers. In 2019, MEELS entered the third phase and extended the coverage to three additional types of electrical products: televisions, storage-type electric water heaters and induction cookers. The coverage of types of room air conditioners and washing machines was also expanded.

Apart from MEELS, HKC also launched Voluntary Energy Efficiency Labelling Scheme (VEELS) in 2017 to encourage the public to select energy-efficient appliances. The scheme covered 22 types of household and office appliances, including 13 types of electrical appliances, seven types of office equipment and two types of gas appliances.

MEELS covered eight different types of prescribed products with each type of product differentiated into five grades according to energy efficiency. A product labelled Grade one (1) is the most energy-efficient in the market while a product labelled Grade five (5) is the least energy-efficient. The MEELS energy labels must be displayed on the prescribed products after the grace period in 2019. The importer or local manufacturer must apply for an energy label for the product before supplying the product in HKC. The MEELS scheme is reviewed regularly and the grading systems are upgraded to differentiate more energy-efficient products from less efficient products.

能源效益級別 Energy Efficiency Grade	製冷季節性表現系數 Cooling Seasonal Performance Factor (CSPF)	
	舊評級標準 Old Grading Standard	新評級標準 New Grading Standard
第1級 Grade 1	≥3	≥4.5
第2級 Grade 2	≥2.8	≥3.5
第3級 Grade 3	≥2.6	≥3.15
第4級 Grade 4	≥2.4	≥2.8
第5級 Grade 5	<2.4	<2.8

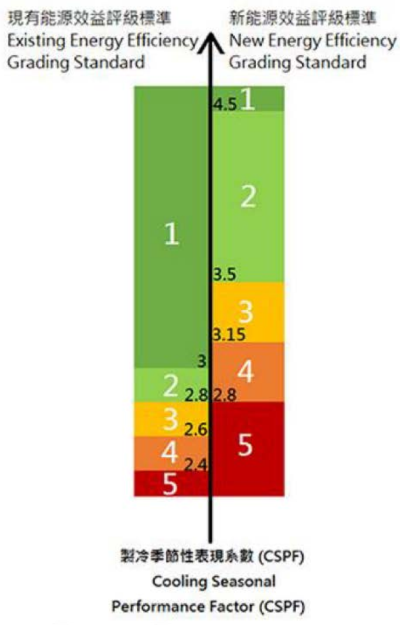


Figure 20 MEELS New Grading Standard

4.3.5 Financial Incentives

4.3.5.1 Building Design to Foster a Quality and Sustainable Built Environment (PNAP APP-151) (2011)

To promote building energy efficiency and a sustainable built environment in HKC, the Buildings Department (BD) issued the practice note PNAP APP-151 [30] in 2011, offering a 10% of Gross Floor Area (GFA) concession for new buildings in compliance with the requirements, in particular, the BEAM Plus Rating. The 10% GFA concession encourages the developers to invest in sustainable building design and increased the number of BEAM Plus-certified green buildings in HKC.

4.3.5.2 EMSD Energy Efficiency Registration Scheme for Buildings (EERSB)

As mentioned previously, buildings that participate in the Energy Efficiency Registration Scheme for Buildings (EERSB) that have obtained at least a BEAM Plus Bronze rating or the minimum award grading in other internationally recognised building environmental assessment systems, may claim for tax deduction to offset the capital expenditure incurred in procuring eligible energy efficient building installations.

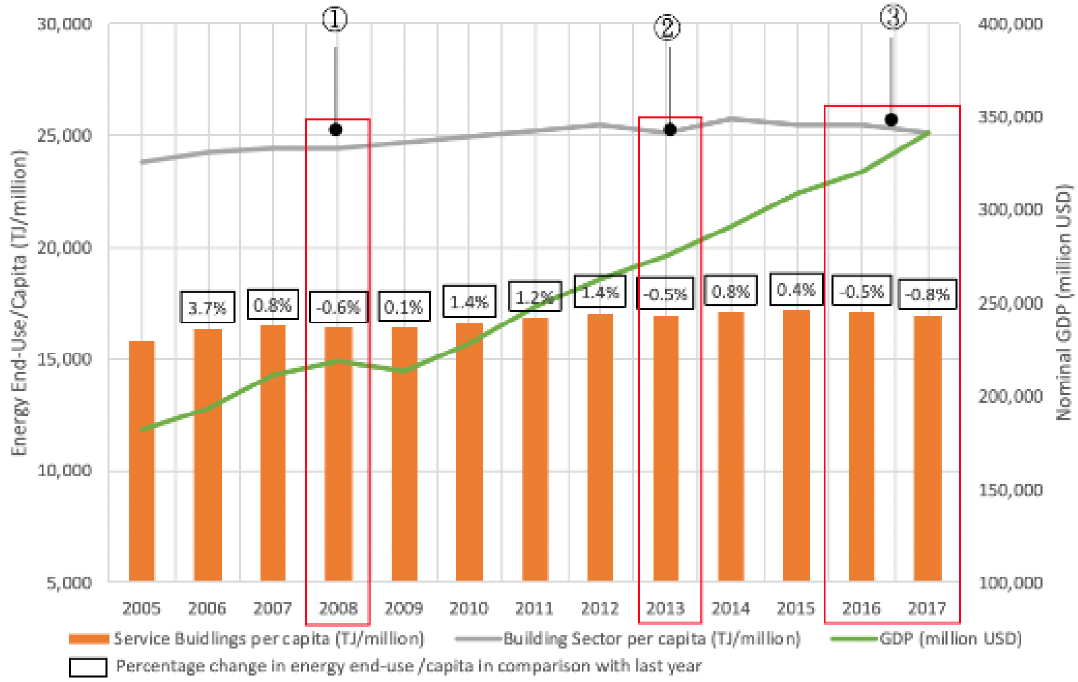
4.3.6 Key Drivers

Service Buildings

Figure 21showed the trend of service buildings' energy end-use per capita of HKC from 2005 to 2017. The energy end-use trend in service buildings in HKC is relatively steady despite the rapid growth in floor area. Energy end-use reduction compared with the preceding year is seen in 2008, 2013, 2016 and 2017 by 0.6%, 0.5%, 0.5% and 0.8%, respectively.

From 2009 to 2012, several policies were launched to promote energy-saving in service buildings such as the target-based Green Performance Framework for New and Existing Government Buildings and BEAM Plus for New Buildings and Existing Buildings, both of which have contributed to energy reductions since 2013.

In 2013, several energy-related codes, practice notes and policies were updated to stipulate more stringent energy-efficient requirements: the target-based green performance framework for new and existing Government buildings, BEAM Plus for New and Existing Buildings, carbon audit, the Building Energy Code and OTTV with PNAP APP-67. The regular revision of the policies has facilitated the reduction in energy end-use despite continuous growth in floor area and GDP. Moreover, with the incentive from Gross Floor Area concessions under PNAP APP-151, the investment from developers to incorporate sustainable building design and energy-efficient features into new building projects has increased. The impact of these policies was eventually reflected in the energy end-use reduction in 2016 and 2017.



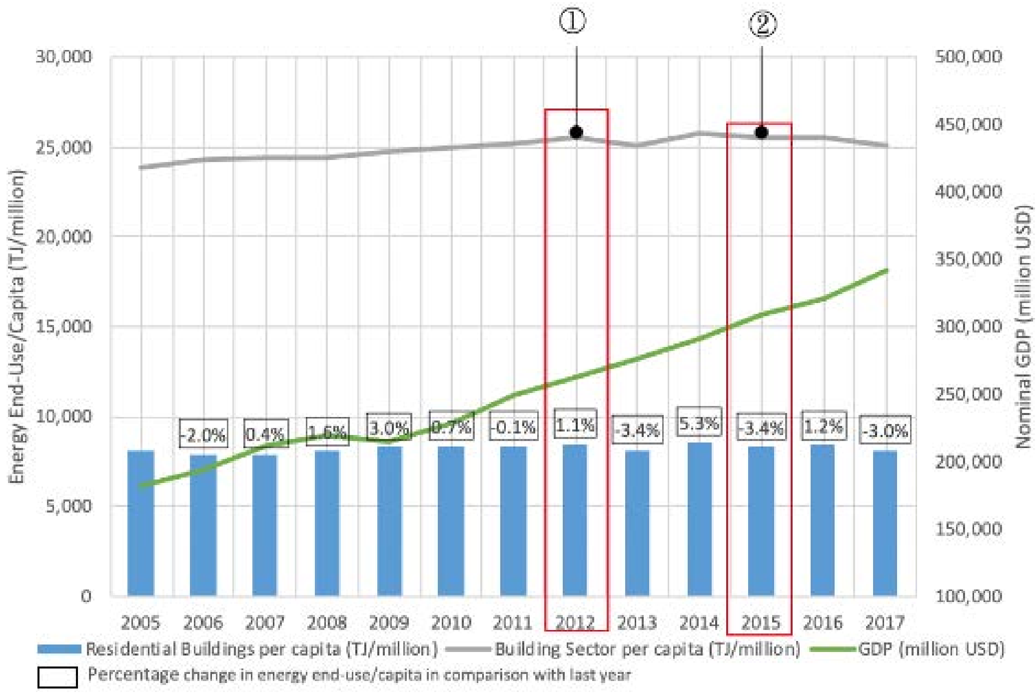
1) 2008: Great Recession since 2007 with reduced economic activity
2) 2013: Target-Based Green Performance Framework for New and Existing Government Buildings (2009); BEAM Plus for New Buildings and Existing Buildings (2010)
3) 2016-2017: Revision of Target-based green performance framework for Green Government Buildings for services (Government) buildings (2015), Building Energy Code (BEC) (2012, 2015), revision of BEAM Plus Existing Building v2.0 (2015) and Gross Floor Area concession under PNAP APP-151

Figure 21 Service buildings' energy end-use per capita in Hong Kong, China from 2005 to 2017

<u>Residential Buildings</u>

Figure 22 showed the trend of residential buildings' energy end-use per capita in HKC from 2005 to 2017. The percentage variation compared with the preceding year was within 5%. A reduction in energy end-use compared with the preceding year can be seen in 2013, 2015 and 2017 by 3.4%, 3.4% and 3.2% respectively.

In residential buildings, a reduction in energy consumption relies predominantly on increasing the efficiency of home appliances such as AC units and lighting, washing machines and dehumidifiers. The Mandatory Energy Labelling Scheme (MEELS) has raised the public's awareness of the energy efficiency of these products and encouraged them to select the most efficient products. The MEELS and the GFA concession under PNAP APP-151 have contributed to energy-saving since 2012. The impact of the BEC becoming mandatory and the BEAM Plus revision is reflected in the energy end-use reduction in 2015.



1) 2012: Mandatory Energy Efficiency Labelling Scheme (2009, 2011); PNAP APP-151 for applying GFA concession (2011)
2) 2015: Building Energy Code (2012, 2015), BEAM Plus (2010, 2012)

Figure 22 Residential buildings' energy end-use per capita in Hong Kong, China from 2005 to 2017

<u>Summary of Key Drivers</u>

- **Building Energy-Related Policies with Regular Updates**

The requirements are regularly made more stringent and expanded to coverage to align with the increasing energy demand of the city with higher living standards and a digitised living environment. The BEC, BEAM Plus and the Green Performance Framework for Green Government Buildings are regularly reviewed to help HKC achieve the planned energy reduction.

- **GFA Concession as Incentive**

The GFA concession is a reward for new buildings if they achieve the requirements for saving energy, sustainable design and green building certification. It has successfully encouraged developers to design and build green buildings in HKC. Up to 2017, over 1,000 BEAM Plus projects have been registered and achieved certification.

- **Improving Efficiency in Products**

The MEELS is widely promoted in HKC through television, commercial and public engagement events. The program has effectively increased the public's awareness of selecting more energy-efficient appliances to reduce household electricity costs.

4.3.7 Gap Analysis

4.3.7.1 Current Energy Intensity Reduction Situation

According to the energy end-use data [25], up to 2017, HKC achieved energy intensity[6] reduction of 31.4% compared with a 2005 baseline. This aligned with the APEC Leader's goal of energy intensity reduction.

4.3.7.2 Energy Reduction Projection

With 2005 as the baseline, the energy end-use increased by only 2.04% in 2017, as shown in Figure 23. Policies currently implemented demonstrate a positive impact on energy-saving. Referring to the methodology stated in Section 2.4, a sufficient buffer of 21.86% from the energy consumption in 2017 can be seen. To achieve further energy reduction targets, current policies on energy reduction should be maintained and reviewed frequently.

[6] Energy intensity calculated based on final energy demand (TJ)/nominal GDP (million USD)

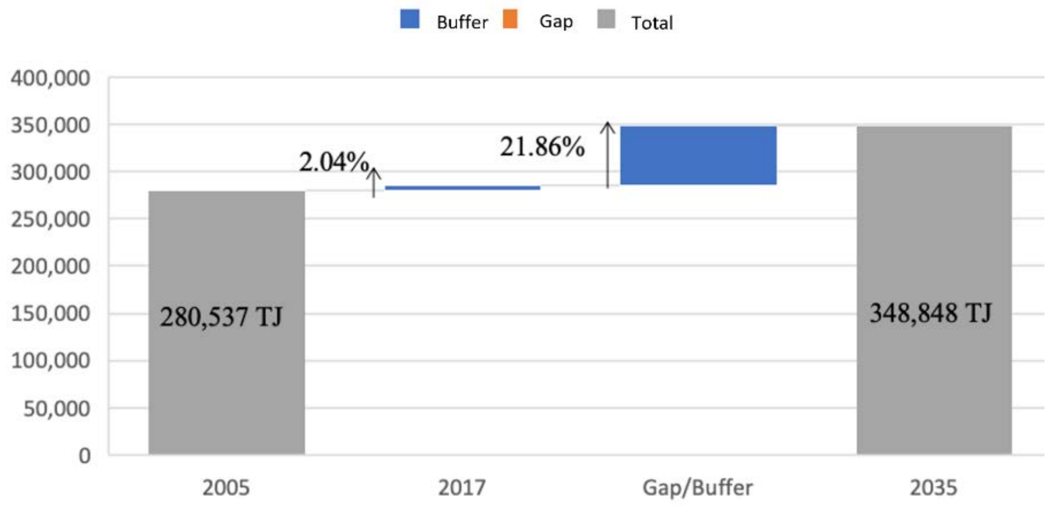


Figure 23 Energy End-use Target of Hong Kong, China in 2035

4.3.8 Latest Developments in Building Energy-efficient Policy

4.3.8.1 Green Building Certification on Data Centre (2020)

The demand for data centres has been continuously rising in recent years. The high power consumption of a data centre would inevitable increases the operating expense. HKC is committed to enhancing the energy efficiency of data centres. The Office of the Government Chief Information Officer (OGCIO) established the “Green Data Centres Practice Guide” in 2020 which recommends best practices for energy-efficient data centre design, procurement, operation and disposal.

The Hong Kong Green Building Council (HKGBC) also aimed to address the energy efficiency and environmental performance of data centres and launched the pilot green building certification schemes for data centres: BEAM Plus New Data Centres V1.0 (Beta 0) and BEAM Plus Existing Data Centres V1.0 (Beta 0) in 2020.

4.3.8.2 Hong Kong Climate Action Plan 2050 (2021)

In 2020, HKC declared would strive to achieve carbon neutrality before 2050. In 2021, HKC announced “Hong Kong's Climate Action Plan 2050” which sets out more proactive strategies and measures for reducing carbon emissions and would pursue more vigorous interim decarbonisation targets to reduce HKC's carbon emissions by 50 per cent before 2035 as compared to the 2005 level. The plan included four aspects - Net-Zero Electricity Generation, Energy Saving and Green Buildings, Green Transport and Waste Reduction.

For Energy Saving and Green Buildings, it is targeted to reduce the overall electricity consumption of buildings. Actions like promoting green buildings, improving buildings' energy efficiency and promoting a low-carbon lifestyle will be carried out to achieve the goal of reducing the electricity consumption of commercial buildings by 30 per cent to 40 per cent and that of residential buildings by 20 per cent to 30 per cent from the 2015 level by 2050 and to achieve half of the above targets by 2035.

4.4 Australia – City of Sydney

Sydney is located on the east coast of Australia. There are two definitions of Sydney – the Greater Region of Sydney and the City of Sydney. The factors related to the City of Sydney (hereafter as "Sydney") were considered in this study for considering the urbanised area and urban density. The City of Sydney is relatively small in an area of 27km2, but with a population of 0.2 million. Despite the smaller city area and population when compared to other selected cities, the urban density of Sydney is 7407 persons/km^2.

According to APERC's outlook [3], Australia achieved an aggregated 17% energy intensity reduction in 2016 as compared with the 2005 baseline.

The City of Sydney, located within the metropolitan area of Sydney – the most populous in Australia, met its grid electricity demand in July 2020 with 100% renewable energy and is committed to being net-zero by 2050 [31].

To achieve the target of a 70% reduction in carbon emissions by 2030 compared to 2006 levels [32], the energy consumption in buildings needs to be reduced by 31% according to the *Environmental Action 2016-2021 Strategy and Action Plan* [33].

Data is available from the website of the City of Sydney [34] and ".id community". Sydney is selected for this study because it is an urbanised city.

4.4.1 Final Energy Demand Overview

The City of Sydney consumed 26,053 TJ of energy in 2014. Despite economic growth of 37% between 2006 and 2014, the total energy end-use had reduced by 2.9% in 2014 compared with 2006.

Regarding the energy end-use in 2014 as shown in Figure 24, more than one-third of the total energy end-use was consumed by the transport sector, with the proportion consumed closely followed by the building sector, accounting for 37.2% and 33.3% of the total energy end-use respectively.

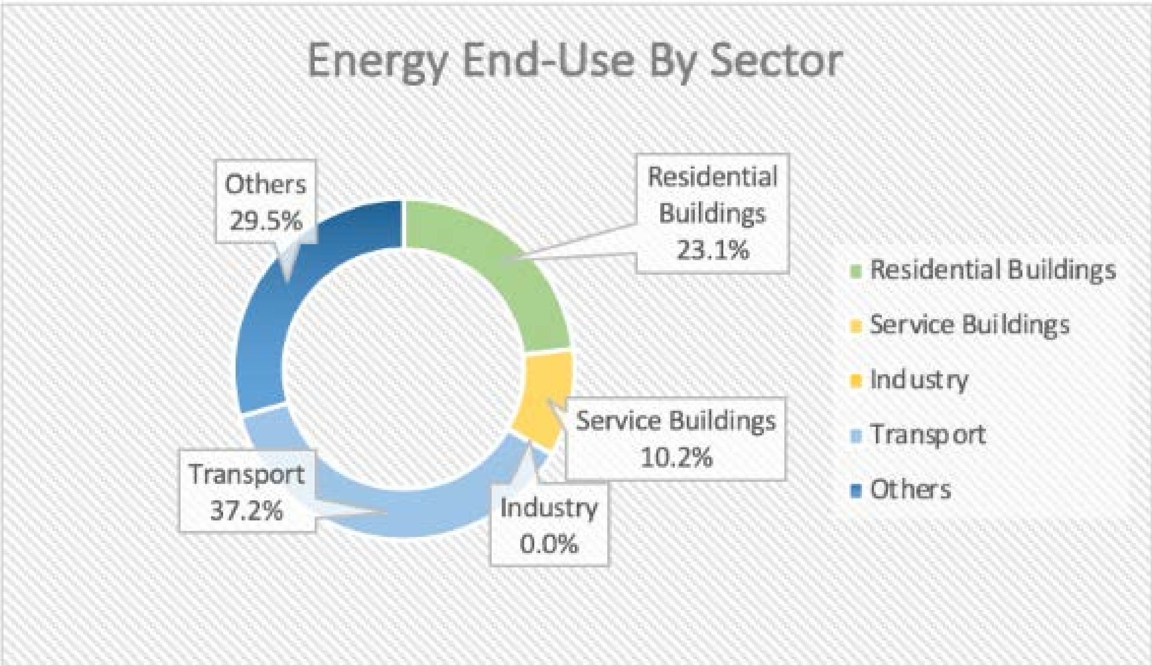


Figure 24 Energy End-use by Sector of City of Sydney in 2014

4.4.2 Building Sector Energy Consumption

The graph of building energy consumption in the City of Sydney is shown in Figure 25. A reduction of 16.6% in energy end-use was achieved in 2014 compared to the 2006 baseline. It is estimated that the total building floor area will increase by 29% from 2006 to 2030. Despite this continued rise in building floor area, the energy consumption reduction target is likely achievable if energy-efficient policies are implemented [32].

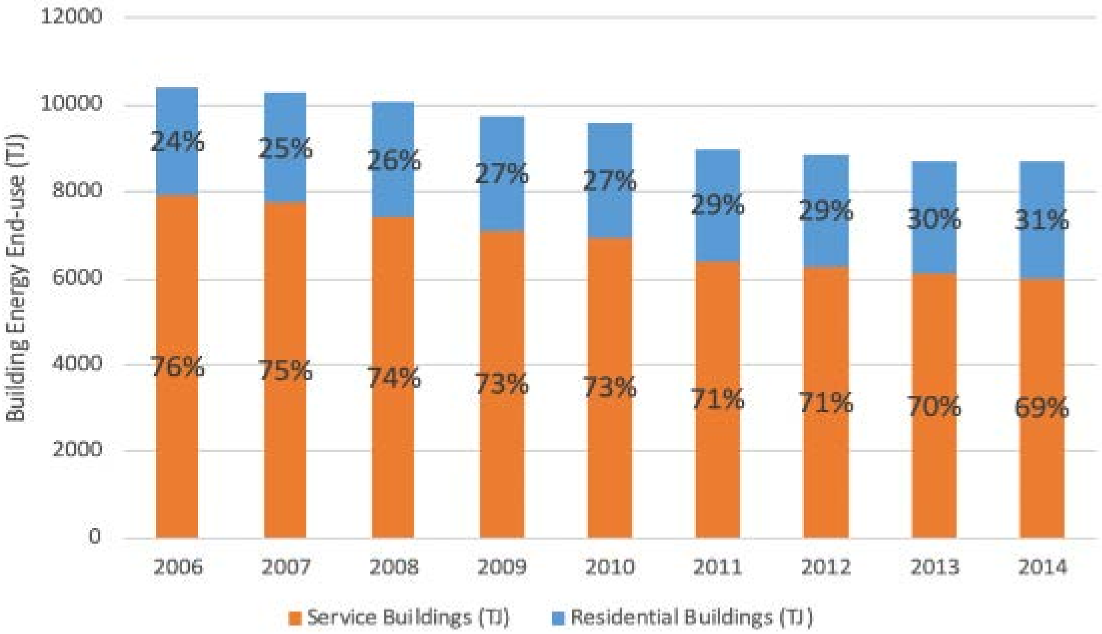


Figure 25 Building energy consumption of the City of Sydney from 2006 to 2014

4.4.3 Review of Building Energy-Related Measures

Strategic Plans and Regulations	Coverage	Building Type	Authority Level	Revisions
Sustainable Sydney 2030 [35]	New and Existing	Residential and Service	City	2013/ 2014/ 2017
Environmental Action Plan 2016-2021 (EAP)	N/A	N/A	City	2017
City Plan 2036 – Local Strategic Planning Statement	N/A	N/A	City	2020
Building Energy-Related Policies and Measures				
National Construction Code	New	Residential and Service	Domestic	2003/ 2006/ 2010
Green Building Standards				
National Australian Built Environment Rating System (NABERS)	New and Existing	Residential and Service	Domestic	2005

Green Star	New and Existing	Residential and Service	Domestic	2003
Measures to Existing Buildings				
NSW Energy Efficiency Action Plan	Existing	Service	State	2013
Data Reporting / Disclosure				
Building Sustainability Index	Existing	Residential	Domestic	2004
Commercial Building Disclosure (CBD)	Existing	Service	Domestic	2010
Energy-efficient Appliances Labelling				
Energy Rating Label	(for goods)	N/A	Domestic	N/A
Zoned Energy Rating Label	(for goods)	N/A	Domestic	2019
Government Leadership				
N/A	N/A	N/A	N/A	N/A
Tenant Programme				
The Better Buildings Partnership	Existing	Service	City	2011
Incentives				
NSW Energy-savings Scheme	Existing	Residential	State	2009
Public Awareness				
N/A	N/A	N/A	N/A	N/A

4.4.4 Major Policy / Scheme for EE&C

4.4.4.1 Building Energy-Related Policies and Measures

4.4.4.1.1 National Construction Code (2003)

Expanded from the Building Code of Australia, the "National Construction Code" (NCC) [36] first introduced energy efficiency in 2003 and expanded to cover a wider range of building types in 2006. A more stringent energy-efficient policy was added in 2010. The code applies to all new buildings and buildings with significant renovations. It sets out energy performance levels that significantly impact energy consumption in buildings including the building envelope, the air-conditioning and ventilation system and lighting.

4.4.4.2 Measures to Existing Buildings

4.4.4.2.1 NSW Energy Efficiency Action Plan (2013)

The New South Wales (NSW) Energy Efficiency Action Plan [37] was launched in 2013 by the NSW government, which committed to achieving an energy-saving target of 16,000 GWh by 2020. The action plan included policies such as supporting 220,000 low-income households to reduce energy use by 20% by 2014, retrofitting 50% of commercial floor space to achieve a 4-star NABERS energy rating by 2020, revising the Energy-savings Scheme as well as investigating a voluntary residential energy rating system.

4.4.4.3 Building Labelling

4.4.4.3.1 Green Star (2003)

Green Star [38] is a voluntary multi-criteria green building labelling system launched by the Green Building Council of Australia. It assesses the building in its design, construction and operational stages in nine performance categories. The rating awards service and residential buildings up to 6 stars according to their sustainability performance. As of the fiscal year 2020, Green Star has avoided 840 million kgCO_2 emissions per year, which is equivalent to the energy use of 90,690 households per year.

4.4.4.3.2 National Australian Built Environment Rating System (2005)

The “National Australian Built Environment Rating System” (NABERS) [39] is a domestic rating tool that benchmarks the environmental performance of a building according to its annual energy consumption against other buildings of similar size and usage. It is only valid for 12 months to ensure the rating represents the latest operational performance. The rating system can be applied to data centres, residential dwellings, hotels, offices and shopping centres. It was a voluntary tool when it was first launched in 1998 but was later widely adopted in other building sustainability policies, e.g. the Commercial Building Disclosure (CBD) and Green Star, etc.

4.4.4.4 **Energy-efficient Appliances Labelling**

4.4.4.4.1 Zoned Energy Rating Label (2019)

The Energy Rating Label is launched by the Australian Government and is mandatory on air conditioners, clothes dryers, computer monitors, dishwashers, fridges, freezers, washing machines and TV.

Besides the Energy Rating Label, the Australian Government introduced Zone Energy Rating Label in 2019 for providing a seasonal efficiency rating for three distinct climate zones across Australia. The label is adopted territory-wide.

4.4.4.5 **Tenant Program**

4.4.4.5.1 The Better Buildings Partnership (2011)

The Better Buildings Partnership consisted of several projects that achieved a 70% greenhouse gas emission reduction target taken from "Sustainable Sydney 2030". It is a collaboration between leading property owners and leaders within the industry to develop collaborative solutions and initiatives to achieve a substantial enhancement in energy reduction and environmental performance in existing service buildings [40]. The partnership program, including Green Leasing, Tenant Engagement and Expand the Band avoided the energy consumption of 2.6TJ and achieved an energy reduction of 33% compared to the 2006 baseline [41]. Approximately 59% of the commercial office space in the CBD of Sydney has also joined the partnership.

4.4.5 Data Reporting / Benchmarking / Disclosure

4.4.5.1.1 Building Sustainability Index (2004)

The Building Sustainability Index (BASIX) [42] is a territory-wide system, enacted in 2004, mandates all new residential dwellings, as well as existing buildings with major renovations, to assess their energy and water consumption with the online BASIX assessment tool and then commit to sustainable building design. Based on the project location, specific energy and water targets for the residential development have to be achieved to obtain the BASIX certificate.

4.4.5.1.2 Commercial Building Disclosure (2010)

The Commercial Building Disclosure (CBD) Program [43] was established by the Building Energy Efficiency Disclosure Act 2010 and is managed by the Australian Government Department of Industry, Science, Energy and Resources. The program is applicable for commercial office space of 1000 square metres or more and is offered for sale or lease territory-wide. The program is aimed to improve the energy efficiency of Australia's large office buildings and to ensure prospective buyers and tenants are informed. A Building Energy Efficiency Certificate (BEEC) will be provided from the program with NABERS star ratings and a tenancy lighting assessment of the relevant area of the building.

4.4.6 Financial Incentives

4.4.6.1 NSW Energy-savings Scheme (2009)

The Energy-saving Scheme (ESS) [44] was launched by the NSW Department of Planning, Industry and Environment (DPIE) under the NSW Electricity Supply Act 1995 and is administered by the Independent Pricing and Regulatory Tribunal (IPART). The ESS provides tradable Energy-savings Certificates (ESCs) as financial incentives to adopt energy-saving and energy-efficient products and services in NSW households.

4.4.7 **Key Drivers**

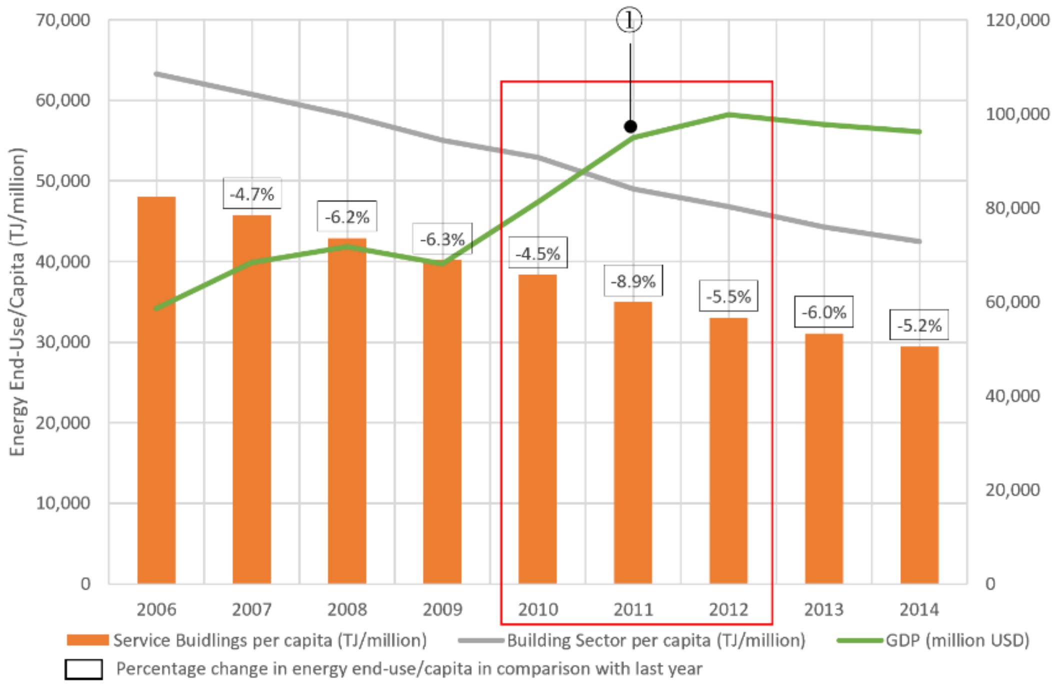
Based on the study on the currently enforced policies, the major key drivers are summarised below.

<u>Service Buildings</u>

A gradual decreasing trend is observed from 2006 to 2014 in the energy end-use per capita of service buildings in the City of Sydney, a relatively significant reduction of 8.9% can be seen in 2011.

With the wide adoption of the "National Australian Built Environment Rating System" (NABERS) in the service buildings, the environmental performance of a building according to its annual energy consumption against other buildings of similar size and usage was assessed. This rating system acted as benchmarking for building owners to evaluate their building energy consumption.

After 2011, the continuous reduction of energy end-use per capita of service buildings was observed. Commercial Building Disclosure Program and the voluntary Better Building Partnership Program are having a positive impact on energy-saving in the city.



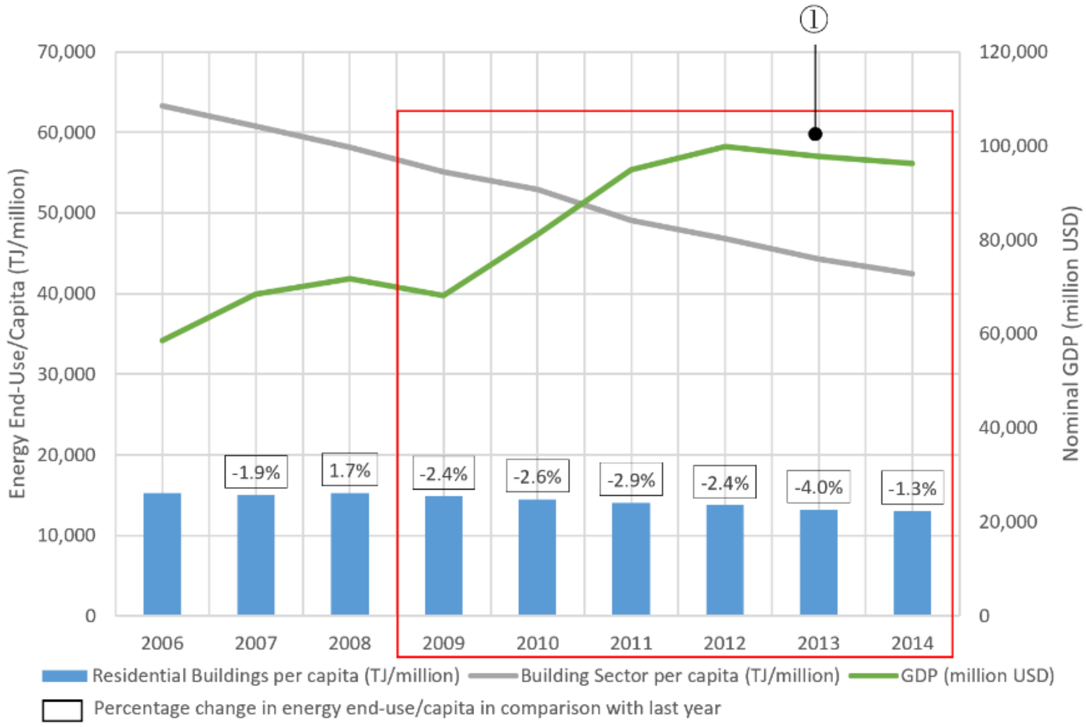
1) 2010- 2012: National Australian Built Environment Rating System;
After 2011: Commercial Building Disclosure; Better Building Partnership

Figure 26 Service buildings' energy end-use per capita in the City of Sydney from 2006 to 2014

Residential Buildings

Energy end-use per capita of residential buildings in the City of Sydney from 2006 – 2014 followed a generally decreasing trend. A relatively significant reduction of 4.0% in energy end-use can be seen from 2012 to 2013.

One of the key drivers of energy end-use is the increase in utility rates. In Australia, the investment in electricity networks would be recovered through electricity bills and resulted in a substantial increase in the utility rate. The relatively high domestic price of energy in the city provides incentives for people to opt for more energy-efficient products and buildings, as well as energy-saving behavioural changes.



1) Investment in the electricity network

Figure 27 Residential buildings' energy end-use per capita in the City of Sydney from 2006 to 2014

Summary of Key Drivers

An overall decreasing trend in energy use for the building sector was observed between 2006 and 2014. The reduction in energy end-use is generally due to the adoption of energy efficiency policies, a structural change in the energy-intensive industry and an increase in the utility rate.

- **Building Rating System**

The voluntary NABERS building rating tool is also a key driver to reduce energy consumption in the City. In particular, NABERS is incorporated with several energy efficiency programmes and policies, including the Commercial Building Disclosure Program and Energy-savings Scheme of New South Wales. According to the NABERS annual report of the fiscal year 2019, with the NABERS rating, an average reduction of 38% and 24% in energy use was achieved for offices and retail (both service) buildings after multiple ratings respectively [45].

- **Better Building Partnership Program**

The Better Buildings Partnership included projects for Green Leasing, Tenant Engagement and Expand the Band which encouraged public engagement in energy efficiency and conservation. Up to 2019, 59% of the commercial office space in the CBD of Sydney has also joined the partnership, resulting in an energy reduction of 33% in 2016 when compared with the 2006 baseline.

4.4.8 Gap Analysis

4.4.8.1 Current Energy Intensity Reduction Situation

Regarding available data from 2006 to 2014, the City of Sydney achieved an energy intensity [7] reduction of 40.9% in 2014 compared to the 2006 baseline, which is in line with the APEC energy intensity reduction target.

4.4.8.2 Reduction Target Projection

A reduction of 2.9% in energy end-use was observed in 2014 compared with the 2006 baseline, as shown in Figure 28. By maintaining the current effort in energy-saving strategies, Sydney can achieve the energy reduction target by 2035.

[7] Energy intensity calculated based on final energy demand (TJ)/nominal GDP (million USD)

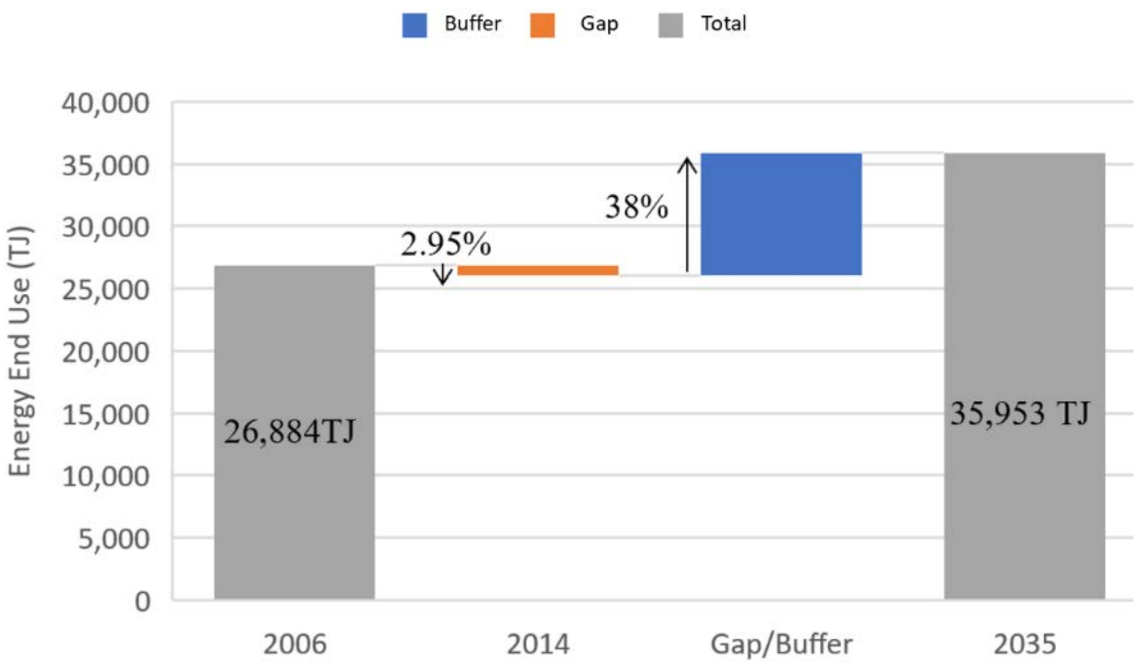


Figure 28 Energy end-use target of City of Sydney in 2035

4.4.9 **Latest Development in Building Energy-efficient Policy**

4.4.9.1 Sustainable Sydney 2030 (2013)

The strategic plan "Sustainable Sydney 2030" was published in 2013 by the City of Sydney. The plan was revised in 2014 and 2017 and will be updated every four years. There are ten strategic directions to guide the future of the city, including "a leading environmental performer" and "Sustainable development, renewal and design".

The "Sustainable Sydney 2050" is under preparation as of the mid of year 2021. The plan will update on several City strategies, such as,

- A City for All: Towards a socially just and resilient Sydney, Social Sustainability Policy and Action Plan 2018–2028
- Creative City: Cultural Policy and Action Plan 2014–2024
- Environmental Action 2016–2021: Strategy and Action Plan
- Adapting for Climate Change – A long-term strategy for the City of Sydney (2015)
- Urban Forest Strategy (2013)

- Housing Issues Paper (2015)
- Innovate Reconciliation Action Plan 2015–2017
- Resilient Sydney: A strategy for city resilience 2018

4.4.9.2 Environmental Action Plan 2016-2021 (2017)

The City of Sydney issued the Environmental Action Plan 2016-2021 (EAP) (2017) for achieving carbon neutrality and ensuring that 50 per cent of the city's energy comes from renewables by 2050. The investment would be made for accelerating the development of renewables and supporting Sydney's first net-zero emissions building. In 2021, the first affordable net-zero-energy homes were delivered to a greenfield site in Sydney.

In 2021, the report "Planning for net zero energy buildings" [46] is introduced by the City of Sydney. The reports recommend performance standards for net zero energy offices, shopping centres, hotels, multi-unit residential, and mixed-use developments (including new and major retrofits).

4.4.9.3 City Plan 2036 – Local Strategic Planning Statement (2020)

The City Plan 2036 - Local Strategic Planning Statement (the Planning Statement) is issued by the City of Sydney in 2020 with setting outs the 20-year vision for land use planning in the city, the basis or context for planning, and the planning priorities and actions, etc. The planning priorities are named Infrastructure, Liveability, Productivity, Sustainability, and Governance and implementation. For Sustainability, one of the priorities is to develop buildings and places that will be net zero energy by 2050, use water more efficiently, and help reduce waste.

To reduce greenhouse gas emissions from building, the energy requirements for residential and commercial buildings under BASIX legislation and the "National Construction Code" are targeted to higher BASIX Energy scores and NABERS Energy ratings for specific sites in the Local Environmental Plan 2012. In 2021, the performance standard pathways framework to achieve net zero energy buildings will be implemented for achieving the priority.

4.5 Japan - Tokyo

In 2016, Japan is the 5th largest energy consumer in the APEC region and has a developed economy. According to APERC's outlook [3], Japan achieved a 17% reduction in energy intensity[8] in 2016 when compared to the 2005 baseline. With GDP data [47] [48] from Japan's Statistical Yearbooks and the Cabinet Office, population data from Tokyo Statistical Yearbooks [49] and energy end-use data from the Tokyo Metropolitan Government (TMG), Tokyo has sufficient data available and is selected for this study.

Tokyo is a highly urbanised city where buildings account for more than half of energy end-use. Tokyo is shortlisted due to its continuous overall reduction in energy consumption which includes the building sector. Considering the data obtained from the Bureau of Environment [50], the calculated energy intensity[9] reduction was 24.2% achieved in 2017 with 2005 as the baseline in Tokyo.

The Tokyo Metropolitan Government (TMG) is determined to reduce greenhouse gas (GHG) emissions by 30% and reduce energy consumption by 38% compared to 2000 levels [51]. Various measures have been explored and implemented, including increasing the power supply through renewable energy, creating a world-first hydrogen-based society and developing net-zero energy buildings (ZEB) and net-zero energy houses (ZEH).

4.5.1 Final Energy Demand Overview

Based on data collected from the Bureau of Environment [50], the total energy end-use in Tokyo stood at 621,000 TJ in 2017. Despite economic growth of 6.9% from 2005 [48] to 2017 [47], the total energy end-use was reduced by 20.7% from the 2005 baseline. Approximately 70.7% of the energy end-use is consumed by the building sector, followed by the transport and industry sectors accounting for 21.0% and 8.2% respectively, as shown in Figure 29.

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[8] Energy intensity calculated based on final energy demand (toe)/ GDP (2016 USD million PPP)

[9] Energy intensity calculated based on final energy demand (TJ)/nominal GDP (million USD)

Transportation is the second largest consumption sector after the building sector, among which road transportation contributes 90% of the energy consumption. The energy end-use for the transport sector has reduced by around 40.3% since 2005, owing to the decrease in the total number of registered vehicles and kilometres travelled. TMG is deploying a financial scheme to promote Zero Emission Vehicles [52] including hydrogen-fuelled vehicles.

The industry sector in Tokyo mainly consists of manufacturing, followed by construction. The energy end-use consumption in manufacturing decreased by 30.7% from 2005 to 2017, while the construction industry demonstrated a slightly increasing trend, which also indicated an increase in the total building stock.

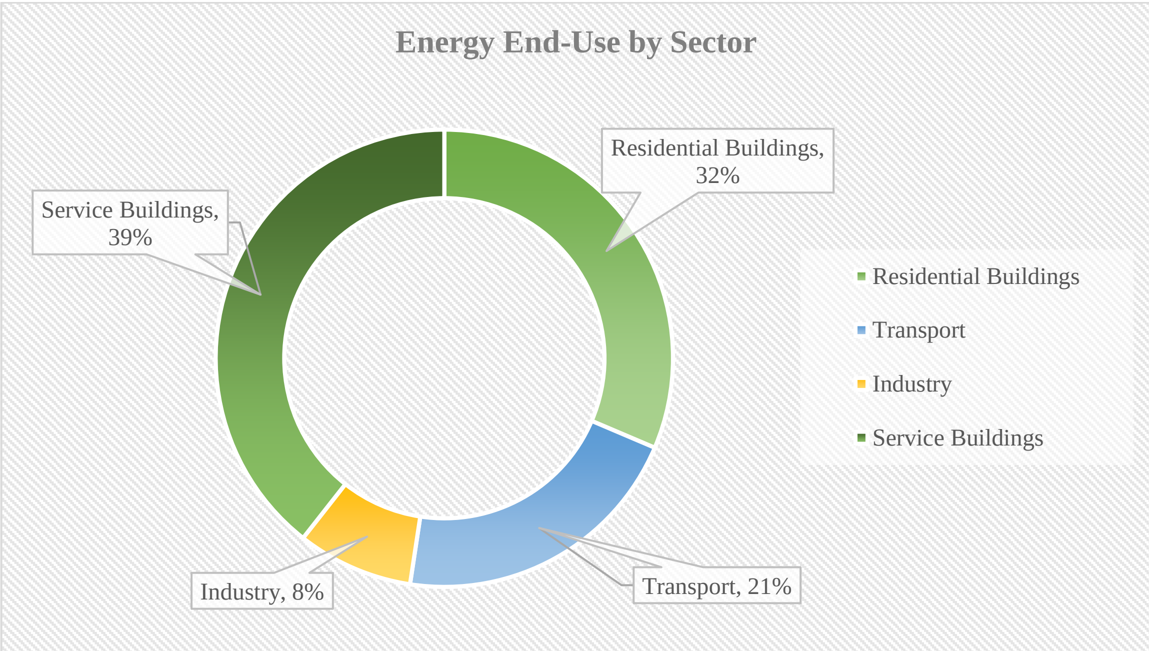


Figure 29 Energy end-use by sector of Tokyo in 2017

The total building area in Tokyo has increased marginally over the years with almost a steady building stock in recent years, especially for the service building sector. The floor areas for residential buildings are almost triple that of service buildings.

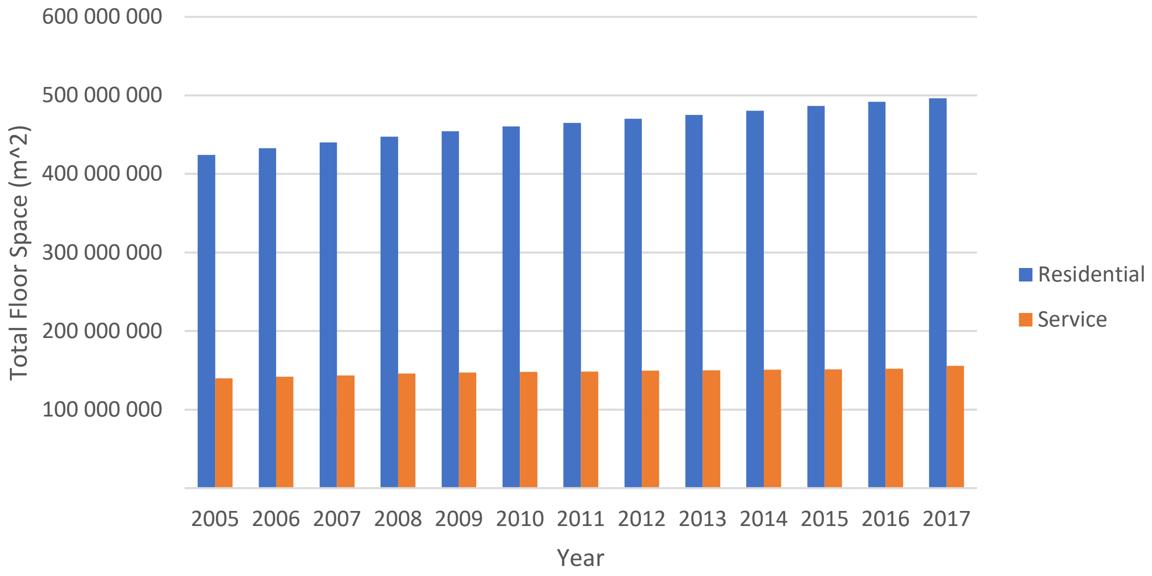


Figure 30 Total floor area of buildings in Tokyo

4.5.2 Building Sector Energy Consumption

In 2017, the building sector dominated the energy end-use in Tokyo. The service buildings sub-sector toke up the larger share, which accounts for 57% of total energy end-use. Compared with a 2005 baseline, the energy end-use in the building sector demonstrated a declining trend until 2017, with a total reduction of 12.4%.

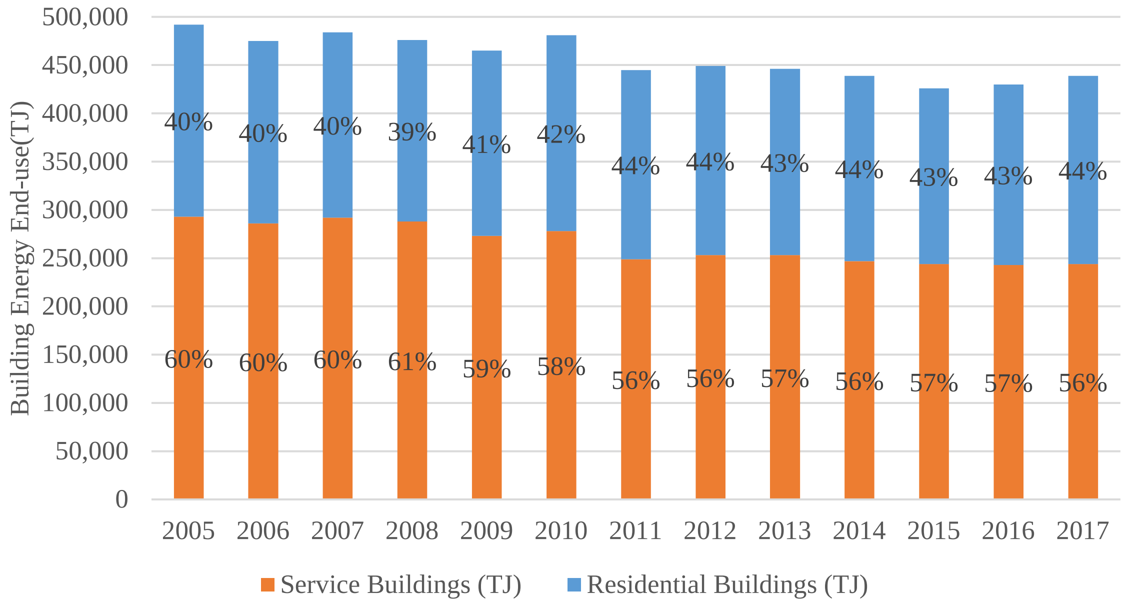


Figure 31 Building energy consumption of Tokyo from 2005 to 2017

4.5.3 Review of Building Energy-Related Measures

Strategic Plans and Regulations	**Coverage**	**Building Type**	**Authority Level**	**Revisions**
Zero Emission Tokyo	New and Existing	Residential and Service	City	2019
Building Energy-Related Policies and Measures				
Act on the Rational Use of Energy	New	Residential and Service	Domestic	1979/1999/2002/ 2008/2013/2017
Building Energy Efficiency Act	New	Residential and Service	Domestic	2015
Green Building Standards				
Comprehensive Assessment System for Built Environment Efficiency (CASBEE)	New and Existing	Residential and Service	Domestic	2001
Tokyo Green Building Program [53]	New	Residential and Service	City	2002/2005/2010

Measures to Existing Buildings				
Tokyo Carbon Emissions Reduction Programme	Existing	Service	City	2002/2005
Tokyo Cap-and-Trade Program	Existing	Service (Commercial and Industrial)	City	2010
Data Reporting / Disclosure				
Tokyo Carbon Reduction Reporting Programme for Small and Medium Sized Facilities	Existing	Selective Service	City	2006
Tokyo Green Labelling for Residential Buildings	Existing	Residential	City	2005/2010
Tokyo Energy Performance Certificate	New and Existing	Service	City	2010
Building-Housing Energy-efficiency Labelling System	Existing	Residential and Service	Domestic	2013
Zero Energy Building (ZEB) labelling scheme	New and Existing	Residential and Service	Domestic	2016
Energy-efficient Appliances Labelling				
Top Runner Programme	N/A	N/A	Domestic	1999/2006/2009/ 2010/2013/2015
Leading & Low-carbon Technology	N/A	N/A	Domestic	
Government Leadership				
N/A	N/A	N/A	N/A	N/A
Tenant Programme				
Tenant GHG Emission Reduction Report Program	Existing	Service (Industrial)	City	2010
Incentives				

Tokyo Tax Reduction Scheme on Energy-savings Promotion	Existing	Service	City	2009
Existing Building Energy Conservation Promotion Project	Existing	Service	Domestic	2015
GFA concession for Building Energy Efficiency Act	New	Residential and Service	Domestic	2017
ZEB subsidy program	New	Residential and Service	Domestic	2017
Public Awareness				
'Cool Biz' Initiatives	N/A	N/A	Domestic	Since 2005

4.5.4 Major Policy / Scheme for EE&C

4.5.4.1 Building Energy-Related Policies and Measures

The Act on the Rational Use of Energy was established in 1979 in response to the severe economic damage caused by the oil crisis at the domestic level. The Act imposes requirements on energy-efficient measures on buildings, transport and appliances, which sets the domestic-wide foundation for Japan's energy efficiency polity. The act was first launched to target factories. The act has been amended several times to drive energy performance improvement. The coverage of the code is further expanded to cover business establishments, including some service buildings in 1998. The coverage of the Act has been expanded for buildings with an area larger than 2,000 m^2 for both residential and service building types in the 2005 revision, which also mandates the application of energy-efficient measures in the periodic reporting.

Under the Act on the Rational Use of Energy, the Ministry of International Trade and Industry (MITI) and the Ministry of Construction (MoC) have issued a set of building standards for service and residential buildings.

- Criteria for Clients on the Rationalisation of Energy Use for Buildings for service buildings (CCREUB)
- Design and Construction Guidelines on the Rationalisation of Energy Use for Houses (DCGREUH)

- Criteria for Clients on the Rationalisation of Energy Use for Houses (CCREUH)

The design code is a combination of performance and prescriptive approach to guide the energy-efficient design in buildings, covering the insulation of the building envelope as well as heating, ventilation and air conditioning (HVAC), lighting, water heating and lifting equipment. Similar to China, the design value under each design element is adjusted according to the climate zones. The structure of the design codes is shown in the table below.

Table 2 Structure of Building Energy Codes in Japan

	Commercial	Residential	
	CCREUB	**DCGREUH**	**CCREUH**
Building Envelope	1. Heat loss through the building envelope	1. Thermal insulation 2. Thermal performance of the building envelope 3. Thermal performance of windows and doors	1. Maximum annual heating and cooling loads by climate zone 2. Standards for equivalent clearance areas by climate zone 3. Condensation control
HVAC	2. Air conditioning and heating 3. Mechanical ventilation (except for air conditioning and heating)	4. Ventilation plans 5. Heating, cooling and hot water supply plans 6. Airflow plans	4. Ventilation volume 5. Prevention of indoor air contamination from heating and hot water systems 6. Planned operation of heating and cooling systems 7. Ventilation routes for heat dissipation
Lighting	4. Lighting	Not Applicable (N.A.)	N.A.
Hot water	5. Hot water supply	(See 5. Heating and cooling, and hot water supply plans	N.A.
Other	6. Lifting equipment	7. Information on building operation and maintenance (" how to live")	N.A.

CCREUB is a mixture of performance base and prescriptive-based methodology for service buildings (commercial buildings). CCREUB adopts the Perimeter Annual Load (PAL) and Coefficient of Energy Consumption (CEC) for each component for assessment of building envelopment and the efficiency, of building systems, including façade, MVAC, Lighting, hot water system and vertical transportation. The PAL is defined as;

$$\text{PAL} = \frac{\text{Annual thermal load of the inside perimeter zone } (MJ/year)}{Total\ floor\ area\ of\ the\ inside\ ambient\ space\ of\ each\ floor\ (m^2)}$$

The CEC is defined as:

$$\text{CEC of each piece of equipment} = \frac{Design\ energy\ consumption\ (MJ/year)}{\text{Standard energy consumption (MJ/year)}}$$

The design guidelines for residential buildings, DCGREUH and CCREUH, focus more on the building envelope performance. DCGREUH sets prescriptive building energy codes for residential buildings, which set guidelines on the standard heat transfer coefficient (U-values) of the building envelope and glazing. CCREUH sets performance-based requirements on the maximum allowable annual heating and cooling loads by climate zone, which is essentially a performance standard for the building envelope as a whole.

Since 2013, given the significant increase in energy consumption and the high potential of energy efficiency in the building sector, a new design code has been promulgated. A new performance-based indicator, Building Energy-efficient Index (BEI), has been introduced. BEI requires a whole building energy calculation and sets the standards for the total energy consumption from all systems including building envelope and building service systems. The BEI is defined as:

$$\text{BEI} = \frac{Design\ energy\ consumption\ (MJ/year)}{\text{Standard energy consumption (MJ/year)}}$$

The standard energy consumption is calculated through the web-based calculation program [54] based on building area and building type. BEI is categorised according to the building types. The standard energy consumption is based on the measured energy data collected from data reporting before 2013 and reviewed through the increasing data based over the years.

The BEI also conveniently formed the basis of a future revision of the building energy design code, building energy labelling system (BELS) and net-zero buildings (ZEB).

4.5.4.1.1 Building Energy-efficiently Act (2015)

In consideration of the energy crisis since the Great East Earthquake as well as mitigating the increasing trend in energy consumption in the building sector. A Building Energy-efficiently Act was promulgated in 2015. This Act provides mandatory requirements on energy efficiency standards for large-scale non-residential buildings and incentive measures for energy labelling schemes.

Buildings with a floor area greater than 2,000m² are mandated to obtain a BEI of less than one. The Japanese Government also intends to expand the coverage to buildings with a floor area greater than 300m² starting from 2021.

4.5.4.2 Reduction Target on Existing Building

4.5.4.2.1 Tokyo Carbon Emissions Reduction Programme (2002)

Tokyo Carbon Emissions Reduction Programme (CERP) was enacted in 2000 and implemented in 2002 voluntarily by Tokyo Metropolitan Environmental Security Ordinance for existing buildings. With the CERP, it was required for large facilities (annual energy consumption of 1,500kL or more crude oil equivalent) to report emissions and reduction plans. There was no critical penalty imposed on no-reduction emission, with the CERP aimed to promote voluntary basis reduction under the emission reduction target set by the building owner. The plan was revised in 2005 with the introduction of the verification plan and become mandatory in 2008 with a penalty mechanism.

4.5.4.2.2 Tokyo Cap-and-Trade Program (2010)

Building upon the foundation of CERP, the Tokyo Cap-and-Trade Program was launched in 2010 by Tokyo Metropolitan Ordinance, targeting the reduction of carbon emissions of existing service buildings and manufacturing factories, especially for large facilities (annual energy consumption of 1,500kL or more crude oil equivalent).

There were about 1200 buildings in Tokyo, including 453 (36.7%) office buildings. The programme is divided into phases, where the target of carbon emissions reduction in commercial buildings are 8%, 17%, 27% and 35% in phase 1 (2010-2014), phase 2 (2015-2019), phase 3 (2020-2024) and phase 4(2025-2030) respectively. Up till 2018, a 27% reduction has been achieved compared to base-year emissions [55].

The reduction target rate varies slightly depending on the type of buildings, with baseline CO2 emission set based on the average from any three consecutive years between 2002 and 2007. Currently, the Cap-and-Trade Program is in the third phase with a reduction target of 27% for service buildings and 25% for industrial buildings.

If these buildings fail to meet the reduction target in a given phase, a target of 1.3 times the shortage will be imposed on top of the next phase's reduction target during the next phase as a penalty to the building owners.

Table 3 Tokyo Cap-and-Trade Program - Planning Period & Target

Baseline	**1st phase 2010-2014**	**2nd phase 2015-2019**	**3rd phase 2020-2024**
3 consecutive years between 2002 and 2007	**8% or *6% reduction** from bas line	**17% or *15% reduction** from baseline	**27% or *25% reduction** from baseline

The Tokyo Cap-and-Trade Program has been to be successful during its years of practice. Most of the applicable buildings under the Tokyo Cap-and-Trade Program chose to adopt energy efficiency measures to achieve the reduction target. The Bureau of Environment of the Tokyo Metropolitan Government has summarised the major measures adopted. The most effective and most adopted measures for energy-saving in service buildings are changing the heating equipment to a heat pump and upgrading the high-efficiency lighting fixture with proper controls. [55]

Table 4 Major Energy-efficient and Conservation Measures under Tokyo Cap-and-Trade Program

Measures to reduce CO2	Number	Total reduction (t-CO2)	Category
High-efficiency heat source equipment	420	158,266	Retrofit
High-efficiency pump & Control	362	34,175	Retrofit
High-efficiency AC unit	419	41,067	Retrofit
High-efficiency VRF unit	111	3,858	Retrofit
VAV system	38	6,619	Retrofit
Outdoor air-cooling system	279	25,699	Retrofit
CO2 control of fresh air	127	17,827	Retrofit
Heat recovery unit	45	3,818	Retrofit
High-efficiency fan	281	20,021	Retrofit
Change temperature setting in summer	122	14,978	RCx
Pre-cooling/heating control	32	674	RCx
Change the start-up time	141	14,405	RCx
Building Management System	46	8,623	RCx
Demand Control	7	2,337	RCx
High-efficiency lighting and control	2055	145,249	Retrofit
Change intensity of illuminance	305	21,549	Retrofit
Daytime light off	21	698	RCx
EV control	134	3,025	RCx

4.5.4.3 **Green Building Standards**

4.5.4.3.1 Tokyo Green Labelling for Residential Buildings (2005)

This Green Labelling program was first introduced in 2005 by Tokyo Metropolitan Ordinance for residential buildings. It is a mandatory requirement for newly built residential buildings larger than 5,000 m^2 to display their energy rating. In 2010, the program was updated to include buildings with more than 2,000 m^2 as the applicable residential buildings.

4.5.4.3.2 Tokyo Energy Performance Certificate (2010)

The Energy Performance Certificate form is part of the Green Building Program (GBP) established by TMG which was implemented in 2002. The GBP request large buildings (above 5,000m^2) to work aggressively to reduce the use of energy. Subject to TMG's evaluation standards, building owners are striving to reduce environmental impacts. In 2010, TMG launch the Energy Performance Certificate for new service buildings with a total floor area greater than 10,000m^2. The building owners are required to issue an Energy Performance Certificate to potential building buyers or tenants, which creates a real-estate market that values the energy performance of buildings.

4.5.4.3.3 Building-Housing Energy-efficiency Labelling System (2013)

Building-Housing Energy-efficiency Labelling System (BELS) is a territory-wide programme. The BELS is a voluntary third-party green building labelling system, which was launched in 2013 for service buildings. New and existing service buildings are required to assess and display their building energy label for the public. Starting in 2016, BELS has been expanded to cover residential buildings.

Figure 32 BELS label

4.5.4.3.4 Zero Energy Building (ZEB) labelling scheme (2016)

In 2016, the Ministry of Environment launched the net-zero energy building (ZEB) labelling scheme territory-wide. The new labelling scheme stimulates collaboration among the industries through the designer (act as ZEB Planner) and the developer (ZEB leading owner) certified by the Ministry of Environment under the ZEB program.

Table 5 ZEB rank since 2016

	Excluding Renewable Energy	Including Renewable Energy
ZEB	More than 50% reduction	More than 100% reduction
Nearly ZEB	More than 50% reduction	75% to 100% reduction
ZEB Ready	More than 50% reduction	-
ZEB Oriented	Office/ School/ Factory more than 40% Hotel/ Hospital/ Department store/ Restaurant/ Hall more than 30% *More than 10,000m² building	-

4.5.4.4 **Change in Human Behaviour**

4.5.4.4.1 Room condition

HVAC normally accounts for the major share of energy end-use in buildings, especially service buildings. Hence, the design and operation conditions in the air-conditioned area greatly affect the energy end-use. After the Great East Japan earthquake, the general public is more aware of energy conservation and the design room temperature is 28 deg.C in summer and 20 deg.C in winter.

4.5.4.4.2 'Cool Biz' Initiatives (2005)

The Ministry of the Environment is promoting COOL CHOICE, a domestic movement to encourage people to make smart choices that contribute to combating global warming, such as switching to products and services and making lifestyle choices that contribute to a decarbonised society.

As one of the key measures of COOL CHOICE, the Government is promoting "Cool Biz" territory-wide, which encourages people to adjust room temperatures to an appropriate level and to wear light clothing appropriate to ambient conditions. The Ministry of the Environment has been advocating since 2005 a lifestyle that does not rely on excessive air conditioning and allows people to live comfortably during the summer months by implementing various measures.

In addition to the change of clothes, the Government has announced specific actions such as installing high-efficient air conditioners, blinds to reduce solar radiation and green curtains.

The campaign period of the Cool Biz is usually from May to the end of September, however wearing appropriate clothing is recommended throughout the year.

4.5.4.5 **Energy-efficient Product Labelling**

4.5.4.5.1 Top Runner Programme (1999)

In response to the Kyoto Conference on Preventing Global Warming (COP3) held in 1998, the "Top Runner Standard" was established in 1999 at the domestic level, which set energy-efficient requirements on small appliances found mainly in residential buildings and offices. The Top Runner programme requires the collaboration of manufacturers and importers. Manufacturers are required to guarantee that at least 50% of the products sold in a target year fulfil the Top Runner standard under the corresponding catalogue.

省エネ基準達成率	多段階評価
121%以上	★★★★★
114%以上121%未満	★★★★
107%以上114%未満	★★★
100%以上107%未満	★★
100%未満	★

Figure 33 Top runner label for home appliances

The programme was reviewed in 2006, 2009, 2010, 2013 and 2015 with more stringent requirements and covering additional elements, such as insulations, glazing, LED Lamps, motors and AC units for commercial use.

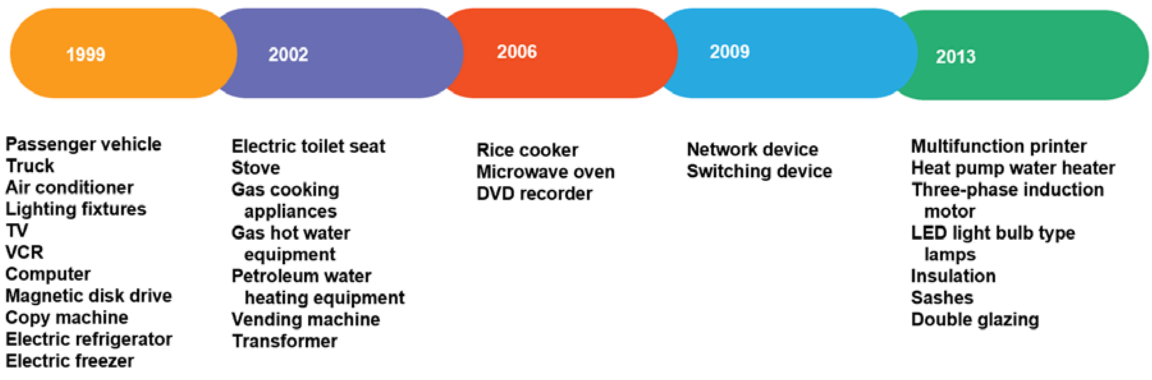


Figure 34 Product Coverage of Top Runner Programme

4.5.4.5.2 Leading & Low-carbon Technology

Leading & Low-carbon Technology (L2 Tech) is a voluntary labelling scheme awarded for high-efficiency products territory-wide. Based on the examination results by Certification Review Committee established under the L2-Tech Certification System, the Ministry of the Environment has published the results as the L2-Tech Certified Products List. In Japan, instead of showing the lowest standard, showing the highest level of efficiency is the key driver to improving products.

Table 6 Example performance of L2-Tech

Product	L2-Tech required level
Chiller (Water-cooled chiller 500RT-600RT)	COP 6.5 IPLV 9.1
VRF unit (16~22.4kW)	APF 6.7
Lighting (Downlight)	145.4 lm/W
Boiler <1000kW	96%
Boiler < 1000kW (Latent Heat Recovery Type)	103% (LPG), 105% (City gas)

4.5.5 Data Reporting / Benchmarking / Disclosure

4.5.5.1 Tokyo Carbon Reduction Reporting Programme for Small and Medium Sized Facilities (2010)

The Carbon Reduction Reporting Programme for Small and Medium-Sized Facilities (SMEs) was introduced in 2010 by the Tokyo Metropolitan Ordinance, covering small and medium existing service buildings (annual energy consumption of between 30kL to 1,500kL crude oil equivalent) in Tokyo. It requires the submission of a mandatory report stating the carbon emissions and progress of energy-saving measures by the building owners. The carbon reporting programme not only motivates the building owners to improve the energy efficiency of the building but also allows the Government to acquire data for benchmarking the building energy performance in Tokyo.

4.5.6 Financial Incentives

4.5.6.1 Tokyo Tax Reduction Scheme on Energy-savings Promotion (2009)

The scheme was launched in 2009 for small and medium facilities. The scheme offers a tax reduction to these facilities for reducing their environmental impact.

4.5.6.2 GFA concession for Building Energy Efficiency Act (2017)

As part of the Building Energy Efficiency Act launched territory-wide in 2017, GFA concessions are awarded to new buildings designed for energy-saving performance.

4.5.6.3 ZEB subsidy program

The Ministry of the Environment is promoting ZEB (Net-Zero Energy Building) with incentives in territory-wide. Two-thirds of ZEB-related equipment (AC equipment, ventilation, Lighting, BEMS etc.) can be supported by the subsidy. Buildings achieving ZEB with the support of the program are required to report energy usage data for three years.

4.5.7 Key Drivers

Service Buildings

Figure 35 showed the trend of service buildings' energy end-use per capita in Tokyo from 2005 to 2017. A significant drop in energy end-use per capita was observed in 2009 and 2011 by 6.0% and 10.6% respectively, compared with the preceding year.

In 2008, TMG revised the Carbon Emission Reduction Program (CERP) from voluntary to mandatory. The CERP applied to large facilities, which contributed to a large portion of the energy consumption from the service sub-sector, and resulted in a significant energy reduction for service buildings, as observed in 2009.

In 2011, the power shortage due to the Great East Japan Earthquake forced the public to adopt power-saving measures to prevent blackouts. These measures included changing the temperature setting on air conditioners and turning off lights. This immediately resulted in a reduction of peak demand in the summer of 2011, which continued thereafter.

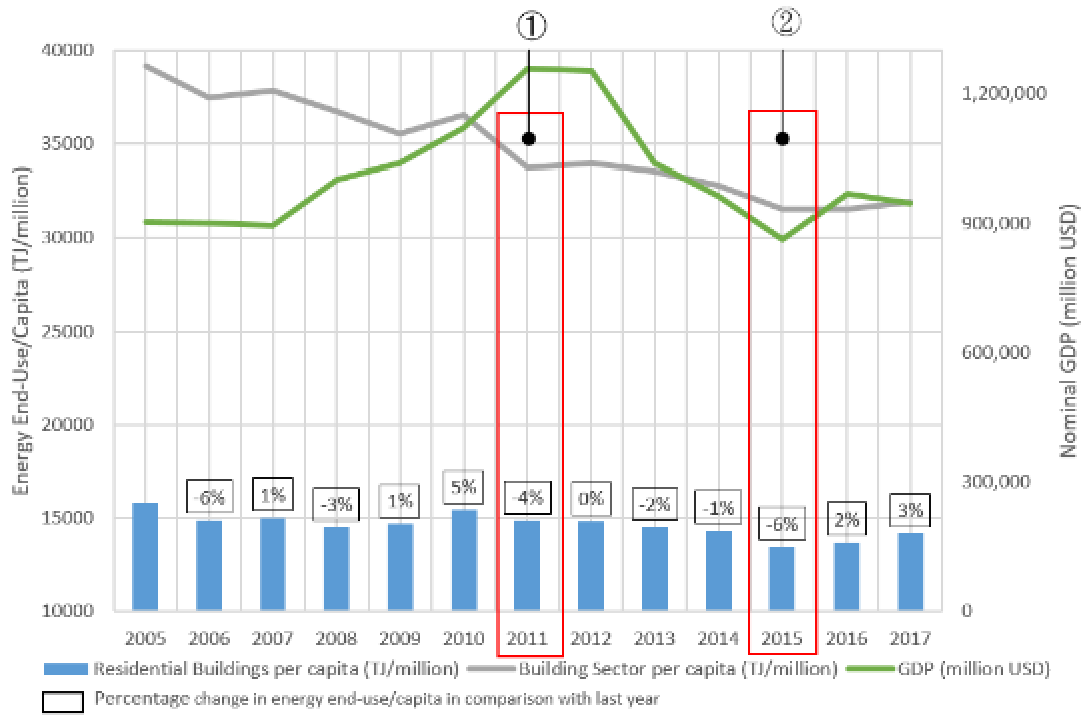
1) 2009: Carbon Emission Reduction Program (CERP)
2) 2011: East Japan Earthquake

Figure 35 Service buildings' energy end-use per capita in Tokyo from 2005 to 2017

Residential Buildings

Figure 36 showed the trend of residential buildings' energy end-use per capita in Tokyo from 2005 to 2017. It is observed that the energy consumption in residential buildings varied during the study period: energy reduction occurred in 2006, 2011 and 2015, but energy consumption increased in 2010 and 2017.

In residential buildings, energy consumption is significantly impacted by human behaviour and weather. Similar to the service buildings, the power crisis in 2011 after the Great East Japan Earthquake stimulated public awareness and action on saving energy to prevent blackouts. The impact of weather on energy consumption in residential buildings could be seen in 2015, which was a year with a hot winter.



1) 2011: Great East Japan Earthquake result in a power crisis and behaviour change;
2) 2015: Hot winter

Figure 36 Residential buildings' energy end-use per capita in Tokyo from 2005 to 2017

Summary of Key Drivers

- **Performance requirements on existing buildings through Tokyo Cap-and-Trade Program**

Existing buildings account for 94% of the total building stock in Tokyo. The Tokyo Cap-and-Trade Program sets mandatory requirements on reduction targets for large service buildings, which stimulates them to adopt energy-efficient equipment and adopt renewable energy application approaches to achieve the target.

- **Human Behavioural Change**

To cope with the power crisis associated with the Great East Japan Earthquake, behavioural changes were observed in the public which included citizens, building owners, tenants and manufacturers through the adoption of energy-saving measures, such as a change in perception of the required comfort level for lighting and temperature. As a result, the public realised that they could reduce their power consumption dramatically. The behaviour learned while tackling blackouts has been maintained which has contributed to continuous energy consumption reduction in Tokyo.

4.5.8 Gap Analysis

4.5.8.1 Current Energy Intensity Reduction Situation

Up to 2017, Tokyo achieved an energy intensity[10] reduction of 24.2% as compared to 2005 as the baseline, which aligned with the APEC Leader's goal of energy intensity reduction.

4.5.8.2 Reduction Target Projection

In 2017, Tokyo achieved a 20.7% reduction in energy end-use as compared with a 2005 baseline. With the gently growing GDP, a further 7.1% reduction is required to achieve the

[10] Energy intensity calculated based on final energy demand (TJ)/nominal GDP (million USD)

APEC's reduction target, as shown in Figure 37. Implementation of the current energy reduction policy with more stringent requirements is essential to maintain the current trend for energy reduction.

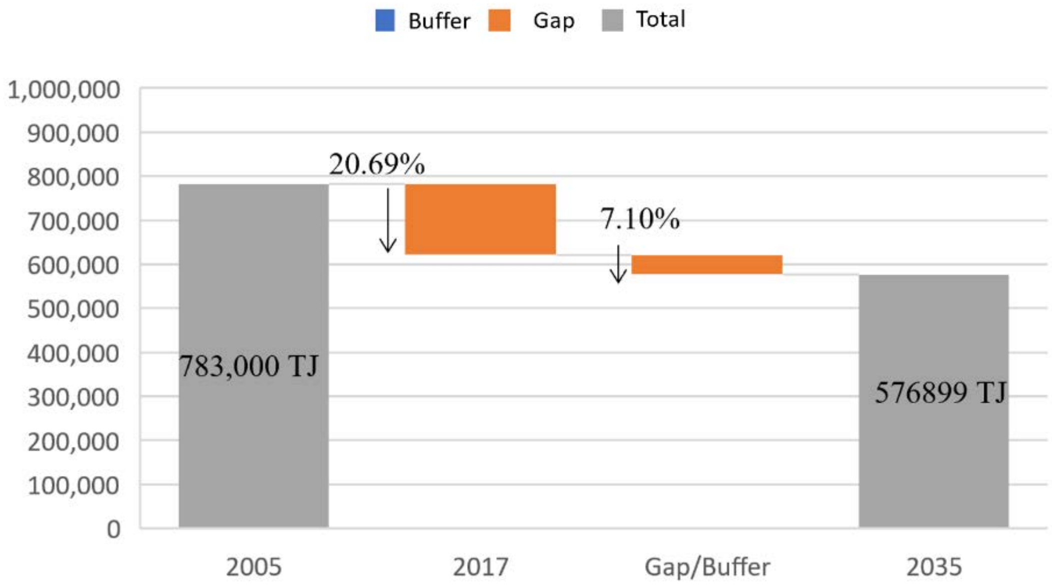


Figure 37 Energy end-use target of Tokyo in 2035

4.5.9 **Latest Development in Building Energy-efficient Policy**

TMG has determined policy targets for 2020 and 2030 to aggressively develop cutting-edge environmental and energy initiatives focusing on the Tokyo 2020 Games and beyond. TMG has set a GHG reduction target of 30% and an energy consumption reduction target of 38% as compared with 2000 levels. Several building energy-efficient policies have been revised again with greater coverage or more stringent requirements.

4.5.9.1 Promoting Energy Efficiency Measures at Home

To encourage additional energy efficiency action at home, TMG continues promoting LED lights and expanding the introduction of energy-efficient home appliances and housing with high energy-efficient performance.

Lighting accounts for one of the major energy consumption in the household. Through the LED light bulb exchange campaign from 2017 to 2018, TMG promoted the switch to LED lighting with high energy consumption.

In addition, since October 2019, TMG has started new action to grant Tokyo Zero Emission Points that can be exchanged for gift certificates or LED light bulb coupons. The points will be given to Tokyo residents who have replaced their air conditioners, refrigerators or water heaters, which typically consume larger amounts of energy, with those having a high energy-efficient performance.

4.5.9.2 Zero Emission Tokyo Strategy

In 2019, Tokyo declared it would seek to become a “Zero Emission Tokyo”, aimed to limit the rise in average global temperature to 1.5°C and set a goal of net zero CO2 emissions by 2050. Tokyo Metropolitan Government formulated the “Zero Emission Tokyo Strategy” [56] with the “Tokyo Climate Change Adaptation Policy,” the “Tokyo Plastic Strategy” and the “Tokyo ZEV Promotion Strategy”. It included the goal of having all buildings in Tokyo be zero emission buildings by 2050 with the following actions on this goal,

- Increase the number of zero-emission facilities through the Tokyo Cap-and-Trade Program, Tokyo Green Building Program, etc
- Support the introduction of the Tokyo Zero Emission House specification which ensures energy-efficient performance to make it widely adopted
- Encourage switching to high-energy-efficient home appliances
- Promote energy management utilising AI and IoT

4.6 The United States – New York City

New York City is a populous city in the US with an area of 785km^2. It has a population of 8.62 million and an urban density of 10,985 persons/km^2.

In 2016, the United States (US) had the 2nd largest energy consumption in the APEC region. According to APERC's outlook [3], the US achieved a 17% in energy intensity[11] reduction in 2016.

According to data collected by the New York City (NYC) Mayor's office and the Bureau of Economic Analysis from the US Department of Commerce, a 37.5% intensity reduction was achieved in 2017 compared with a 2005 baseline [57].

New York City has issued and frequently updated the citywide sustainability target and plan since 2008. New York City is committed to reducing greenhouse gas (GHG) emissions through the legislation of local laws. In alignment with the Paris Agreement, New York City's latest target was established through Executive Order 26 in 2017 [58]. In addition, to accelerate the ultimate goal of achieving GHG emission reduction under "80 × 50" [59] [60], an additional interim target has been set to achieve 40% GHG emission reduction by 2025 and 50% by 2030.

4.6.1 Final Energy Demand Overview

Based on the data collected from the NYC Mayor's office, New York City consumed 1193 PJ of energy in 2017. The rapid economic growth of 66.8% as compared to 2017 with 2005, resulted in an increase in the total energy end-use by 4.2%. Almost 70% of the energy end-use was consumed by the building sector, followed by the transportation and the industry sectors, which accounted for 21.6% and 10.8% respectively, as shown in Figure 38. As the building sector accounted for almost three-quarters of the energy end-use, energy reduction in the building sector is critical to meeting APEC's target.

[11] Energy intensity calculated based on final energy demand (toe)/ GDP (2016 USD million PPP)

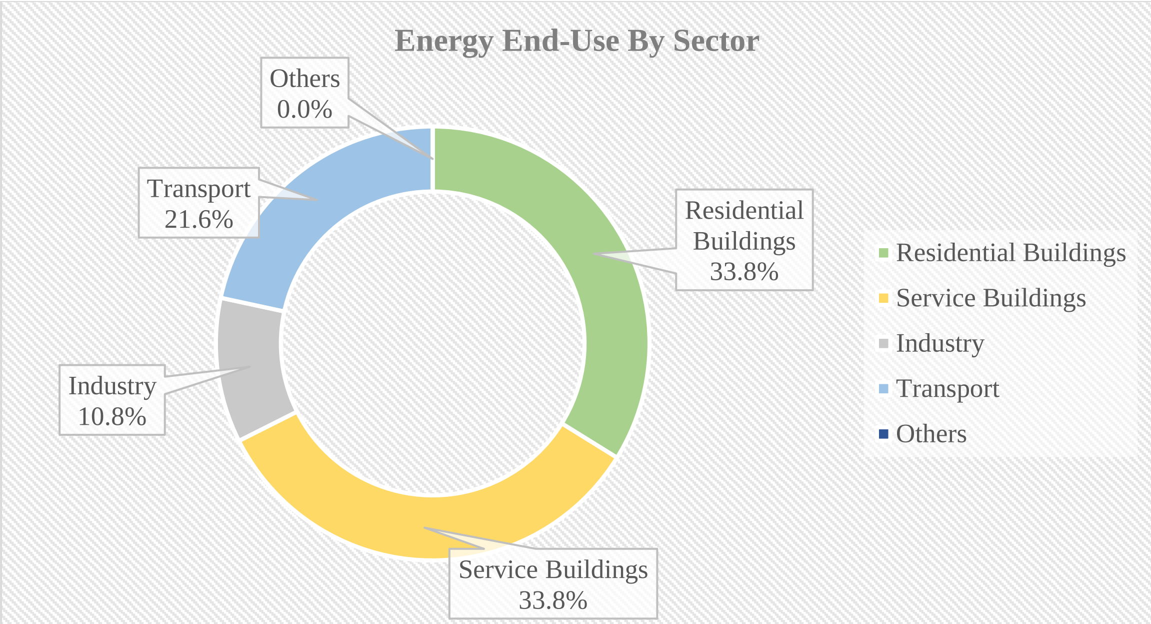


Figure 38 Energy End-use by Sector of NYC in 2017

The existing buildings in New York City are mostly built during construction booms in the 1920s, 1950s and 2000s. There are nearly one million buildings in NYC that collectively contribute to the high-energy end-use in the building sector. Residential buildings account for the largest portion of building floor area at 68%. Among all buildings in NYC, buildings with a floor area over 5,000m² represent 2% of the total building stock but account for 45% of the total energy consumption in the city. The majority of these buildings are for residential use [61], as shown in Figure 39. Hence, NYC's energy-efficient policy puts the energy reduction in existing buildings and large buildings at high priority. To address the issue, the Mayor set up the Building Technical Working Group (TWG) to identify the best strategies to cut GHG emissions in existing buildings and new constructions.

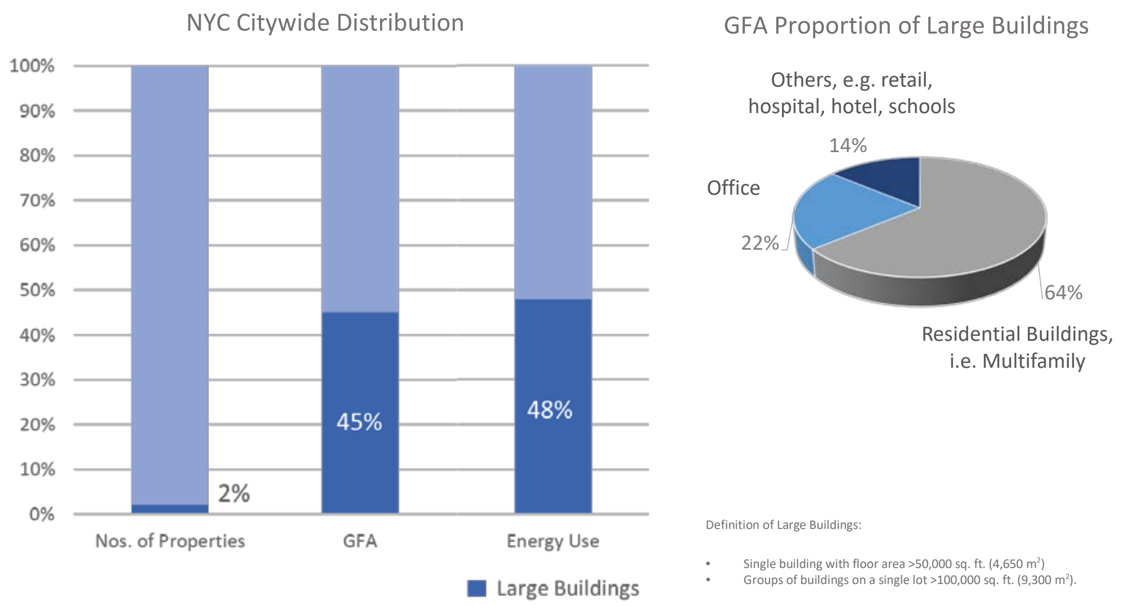


Figure 39 Building Typology Characteristics in NYC [61]

4.6.2 Building Sector Energy Consumption

In 2017, the building sector dominated the energy end-use in New York City. The energy end-use in the building sector has maintained a similar level as the 2005 baseline.

Both service and residential buildings accounted for half of the total building energy end-use. The total building energy consumption fluctuated between approximately 650,000TJ and 800,000TJ from 2005 to 2017, as shown in Figure 40. A sudden drop in total building energy consumption was observed in 2013, with the lowest recorded level at slightly below 650,000TJ. The energy end-use reduction in 2013 was due to the implementation of policy for buildings which will be discussed in the following sections.

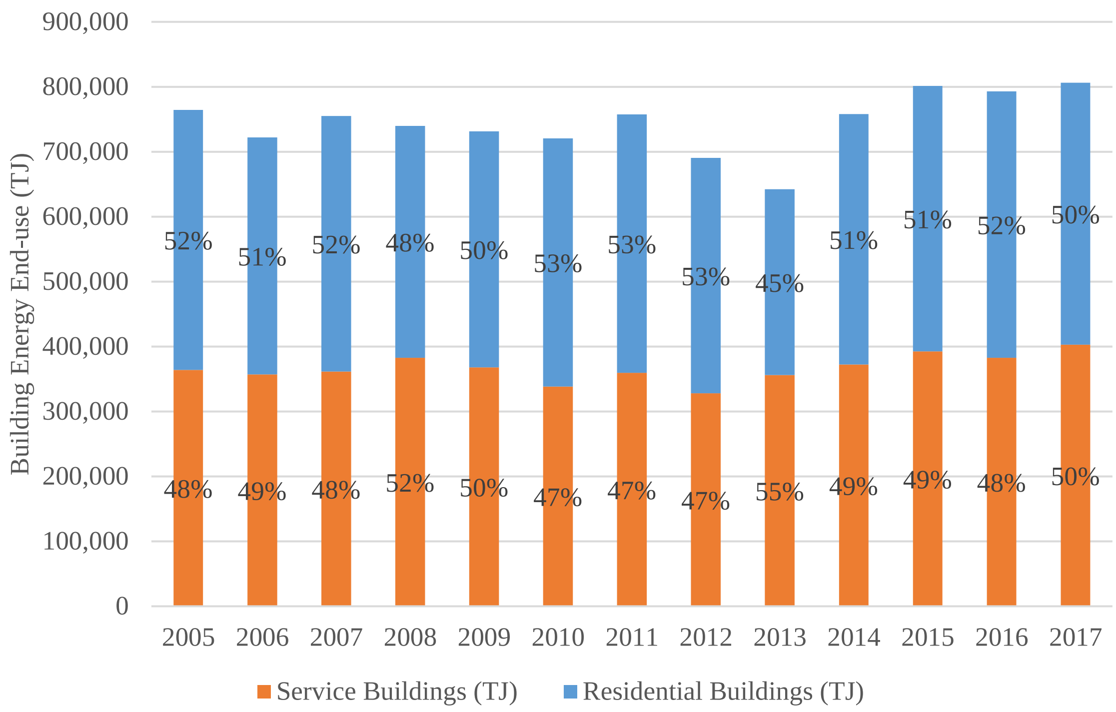


Figure 40 Building energy consumption of NYC from 2005 to 2017

The subsequent rise in energy end-use from 2013 to 2015 was more related to NYC's climate shift. Located in the humid subtropical variety zone, both cooling and heating provisions are needed in NYC. Due to the increased number of heating degree-days during 2012-2014 and cooling degree-days during 2014-2016 respectively, extra energy demand for heating and cooling energy was required [62]. Weather-normalised data showed a decreasing trend in building energy end-use from 2010 to 2015 with a total reduction of 14% [63]. The increase starting from 2017 could also be due to the installation of air conditioning systems in all 11,500 public school classrooms by 2022, as only 26% were originally air-conditioned [64].

4.6.3 Review of Building Energy-Related Measures

Strategic Plans and Regulations	**Coverage**	**Building Type**	**Authority Level**	**Revisions**
plaNYC/OneNYC	N/A	N/A	City	2013/ 2015
Under 2 MOU	N/A	N/A	City	2015
80 × 50 plan	N/A	N/A	City	2016
Building Energy-Related Policies and Measures				
ASHRAE 90.1	New	Residential and Service	Domestic	2004/ 2007/ 2010/ 2013/ 2016
International energy conservation code (IECC)	New	Residential and Service	Domestic	2004/ 2009/ 2012/ 2015
New York State Energy Conservation Construction Code (ECCCNYS)	New	Residential and Service	State	2002/ 2007/ 2010/ 2013/ 2016/ 2020
New York State Energy Conservation Construction Code (NYCECC)	New	Residential and Service	City	2011/ 2014/ 2016/ 2020
Green Building Standards				
Leadership in Energy and Environmental Design	New and Existing	Residential and Service	Domestic	2009/ 2013
Measures to Existing Buildings				
GGBP LL87 Energy Audits and Retro-commissioning	Existing	Residential and Service	City	2009
GGBP LL88 Lighting upgrade and Sub-metering	Existing	Service	City	2009
LL97 GHG emission limits	Existing	Residential and Service	City	2019
Data Reporting / Disclosure				
GGBP LL84 Benchmarking	Existing	Residential and Service	City	2009
LL33 Energy Star Rating	Existing	Residential and Service	City	2018

Energy-efficient Appliances Labelling				
ENERGY STAR	N/A	N/A	Domestic	1992
Government Leadership				
LL31 50% energy-saving	New	Service	City	2016
LL32 LEED Gold certification	New	Service	City	2016
Tenant Programme				
ENERGY STAR Tenant Space	New and Existing	Service	Domestic	2020
Incentives				
Energy Efficiency Portfolio Standard (EEPS)	N/A	N/A	State	2008
NY Green Bank	N/A	N/A	State	2013
EmPower New York	N/A	N/A	State	2015
Green Housing Preservation Program	N/A	N/A	City	2015
NYC Retrofit Accelerator	N/A	N/A	City	2015
New York City Energy Efficiency Corporation	N/A	N/A	City	2015
Human Behaviour				
GreeNYC	N/A	N/A	N/A	N/A
NYC Carbon Challenge [65]	N/A	N/A	N/A	2007

4.6.4 Major Policy / Scheme for EE&C

4.6.4.1 Building Energy-Related Policies and Measures

Owing to the unique federal systems in the US, the building energy code in New York City is developed and structured by several parties.

4.6.4.1.1 Energy codes - ASHRAE 90.1 and IECC

Energy codes are the foundation of state-level and city-level energy codes and are developed by two technical institutions, ASHRAE and the International Codes Council. ASHRAE develops the model commercial energy code, known as 90.1. The International Code Council develops the International Energy Conservation Code (IECC), which contains chapters for both residential and commercial buildings. Every stakeholder in the industry was allowed to submit proposals to change the code. The final decision will be decided through voting by the committee member of the institution. The code will be revised every three years. The Department of Energy (DOE) participated in the development process and published the energy-saving results from the new version compared to the old version.

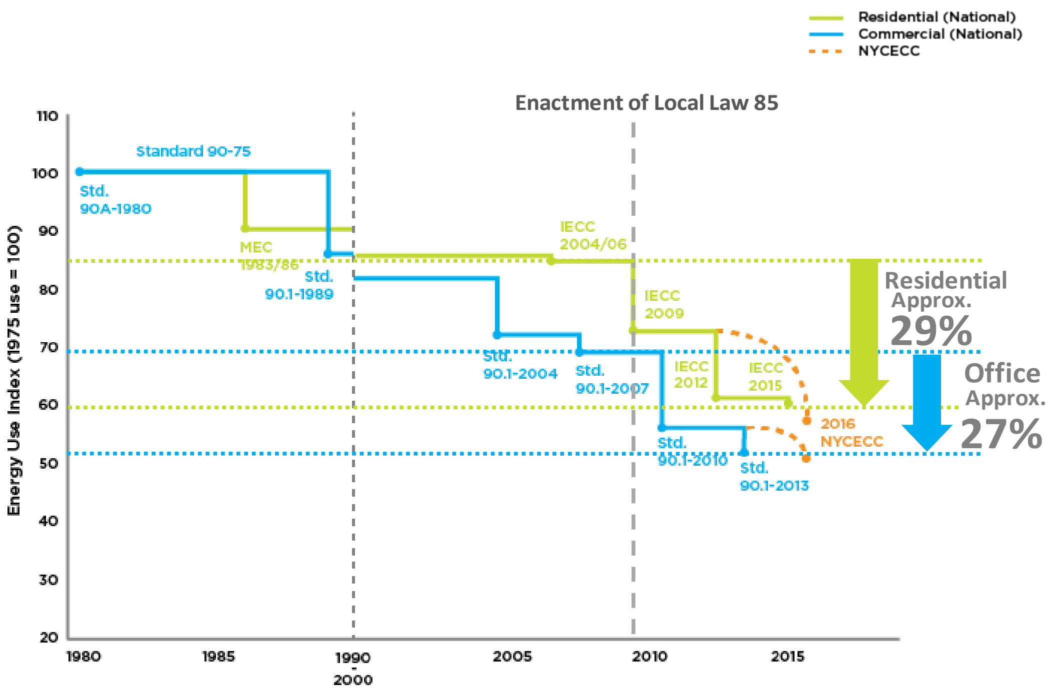
ASHRAE and IECC define the requirements for systems and thermal performance of buildings according to different climate zones. The Energy codes are mandatory and include overall performance targets for the building envelope and electrical and mechanical services systems. The mandatory requirements specify the design features and construction practices to be followed, such as the thermal property of the envelope, and maximum external lighting power density. On the other hand, the overall performance-based assessment requests a dynamic whole building energy modelling to demonstrate the compliance of total annual energy cost considering the integrated effect of the lighting, HVAC systems and lift system.

4.6.4.1.2 Energy Conservation Construction Code of New York State (ECCCNYS) and New York City Energy Conservation Code (NYCECC)

New York State started to adopt the domestic model energy codes (ASHRAE 90.1 and IECC) at the state level and establish ECCCNYS [66] in 1979. In 2009, under the comprehensive framework of the Greater Greener Building Plan (GGBP) of NYC, LL85 was enacted to establish NYCECC, which comprised NYC local laws and the latest ECCCNYS. By New York State law, the city-level energy code (i.e. NYCECC) must be more stringent than ECCCNYS [67]. The revision will be made to ECCCNYS and NYCECC when there is an update in the Energy codes. In addition, as established in LL85, it is required to be periodically updated to maintain the City of New York's position as a leader in sustainable construction policies and practices.

ECCCNYS and NYCECC were revised periodically to catch up with the latest revision in ASHRAE and IECC as well as to align with the overall sustainability plan. Since the enactment of LL85, the Codes have tightened by approximately 27% and 29% are recorded for office and residential buildings respectively, with estimated energy savings of 9% and 32% for office and residential buildings respectively [68], as shown in Figure 41.

Figure 41 Improvement of Energy Code over time [68]



4.6.4.2 **Measures to Existing Buildings**

4.6.4.2.1 Greener, Greater Building Plan (GGBP) of New York City (2009)

Due to the unique building typology characteristic in NYC, the Greener, Greater Building Plan (GGBP) [61] involves a comprehensive set of building efficiency laws that primarily impact buildings that were 2% of the gross floor area in NYC. Buildings with areas over 5,000 m² are covered under this Plan which contributes to 45% of the total citywide energy end-use.

4.6.4.2.2 Energy Audits & Retro-commissioning: Local Law 87 (LL87) of 2009

Local Law 87 of 2009 (LL87/2009) [69] [70] as part of the Greener, Greater Building Plan (GGBP). Enacted in 2013, the LL87/2009 introduced the requirement for energy audits and retro-commissioning to enhance the energy performance of buildings. Large buildings[12] are required to conduct energy audits and retro-commissioning once every 10 years, and file energy efficiency reports to the NYC Department of Buildings. The implementation of this local law comes with a penalty in terms of fines for a late submission.

By combining the energy audit, which diagnoses the deficiency in the building energy system and operation, and retro-commissioning, which is a low-cost solution for performance improvement and optimisation of an existing control, the immediate improvement in final energy demand and plan of upgrading the building service system can be derived.

[12] Single building with floor area >50,000 sq. ft., Groups of buildings on a single lot >100,000 sq. ft., Groups of buildings held in the same ownership of same board of managers together with floor area > 100,00 sq. ft.

Table 7 Summary of energy audits and r etro-commissioning of Local Law 87

Items	**Energy Audits**	**Retro-commissioning**
Objectives	Analysis of energy equipment, systems, envelope and operations in the building to identify the cost-effective options and provide recommendations in energy-saving	Testing and re-tuning of systems in the existing building to improve its energy efficiency
Scope	Base building system (excluding system and equipment of tenants): • HVAC • Electrical and Lighting • Domestic hot water • Building envelope • Conveying system	
Expertise involvement	Qualified Energy Auditor	Qualified retro-commissioning agent
Standard	Level 2 Energy Survey and Analysis of Procedures for Commercial Building Energy Audits, ASHRAE 2011 edition	25 nos. of testing items in Local Law 87
Tools	Building Energy Asset Score Audit by US Department of Energy	Excel-based Retro-commissioning Reporting Tool
Remarks	Implementation of solution is optional	Correction of deficiency and issue before the submission of the Energy Efficiency Report is compulsory The retro-commissioning must be performed in the heating and cooling season

4.6.4.2.3 Lighting & Sub-metering: Local Law (LL88) of 2009

Local Law 88 of 2009 (LL88/2009) was part of the Greener, Greater Building Plan (GGBP). The LL88/2009 introduced the requirement for upgrading the lighting in non-residential spaces through the improvement of lighting control and the replacement of highly efficient luminaires to reduce lighting energy consumption.

In addition, non-residential lighting accounts for approximately 18% of building energy use in the city. However, the majority of the electricity consumed by tenants in many large non-residential buildings is unknown because most large buildings only have one master electricity meter which measures the amount of electricity used by the entire building. Installation of submeters for each tenant basis would provide data and information on the electricity consumption pattern of tenants [71].

Subsequently, in 2016, Local Law 132 and Local Law 134 were enacted to further expand the scope of the policy, mandating more buildings with smaller floor areas than that of Local Law 88, i.e. greater than 25,000 sq. ft. to install sub-meters and upgrade lighting systems.

4.6.4.3 **Energy-efficient Product Labelling**

4.6.4.3.1 ENERGY STAR (1992)

The ENERGY STAR for products was launched in 1992 by the U.S. Environmental Protection Agency (EPA), under the authority of the Clean Air Act Section 103(g). EPA is responsible for setting product performance levels, educating consumers and businesses, and supporting the efforts of manufacturers, retailers and utilities. The ENERGY STAR certified products are recognised as a choice of energy efficiency products for consumers and businesses to purchase.

4.6.4.4 **Tenant Program**

4.6.4.4.1 ENERGY STAR Tenant Space (2020)

Besides products, ENERGY STAR also certificates homes, commercial building properties and tenant space. The ENERGY STAR Tenant Space was launched in 2020 by the U.S. Environmental Protection Agency (EPA) as a voluntary scheme. The ENERGY STAR Tenant Space is recognised for energy-efficient office spaces in the United States.

4.6.5 **Data Reporting / Benchmarking / Disclosure**

4.6.5.1 Benchmarking and Energy Efficiency Grading: Local Law 84 (LL84) of 2009 & Local Law 133 of 2016 (LL133) of New York City (2016)

Local Law 84 from 2009 (LL84/2009) was part of the Greener, Greater Building Plan (GGBP). The LL84/2009 regulates buildings over 5,000m², regardless of building type, to disclose and benchmark energy and water consumption data annually via the ENERGY STAR Portfolio Manager Tool by US EPA [72].

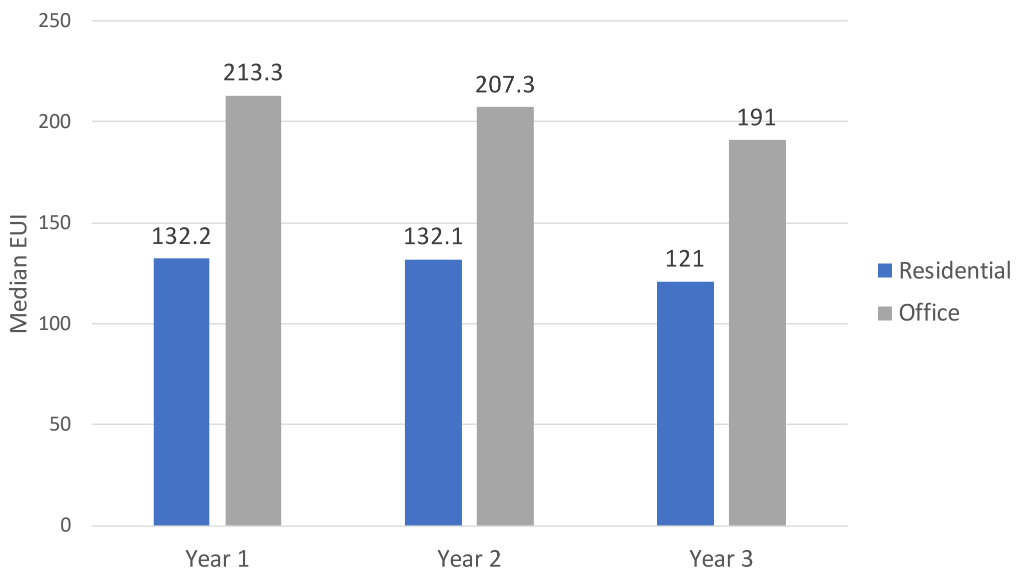


Figure 42 Median EUI in "Large Buildings" (reported data of LL84) [72]

A decreasing trend of reported median energy use intensity (EUI) was observed for both residential and commercial buildings, as shown in Figure 42, despite the slight increase in the number of reporting buildings.

Cumulative energy savings of 5.7%, equivalent to dollar savings of approximately US$267,000,000, were achieved in the first four years after the policy was introduced. This early evidence demonstrated the positive impacts of energy-saving from this policy [73].

Besides actual reduction in final energy demand, in office buildings, in particular, the benchmarking and disclosure policy also contributes to raising public awareness. NYC building owners and managers confirmed the policy plays a role in energy use decisions. Research also demonstrates a growing early interest in acquiring energy consumption data from building tenants and investors.

With the success of LL84, NYC amended the law with LL133 [74] in 2016 to expand the coverage of buildings obligate for benchmarking and reporting.

Table 8 Policy Coverage of Local Law 84 and its expansion of Local Law 133

	Local Law 84 of 2009	Local Law 133 of 2016
1	Single building with floor area >50,000 sq. ft.	Single building with floor area >25,000 sq. ft.
2	N/A	Groups of buildings held in the same ownership of the same board of managers together exceed a floor area of 100,00 sq. ft.

4.6.6 Financial Incentives

4.6.6.1 NY Green Bank of New York State (2013)

The Green Bank of New York State was established in 2014. The NY Green Bank provides financing assistance to building owners on the purchase of energy efficiency and/or renewable energy assets. The NY Green Bank is sponsored by the NYC government. It aims to cooperate with the private sector to speed up the development of clean energy. This also allowed a reduction in taxes for consumers [75].

4.6.6.2 EmPower New York of New York State (2015)

The EmPower New York [76] is a program launched by the New York State. The program offered a grant for low-income residents to upgrade their existing household equipment and supported them with energy-saving tips and a free home energy assessment to identify energy-saving opportunities.

4.6.6.3 Green Housing Preservation Program of New York City (2015)

Green Housing Preservation Program [77] was launched in 2015 to provide low-interest or interest-free loans to allow small and medium-sized residential buildings to conduct remediation and improvement works to enhance energy efficiency and water conservation. The program targeted to reduce building energy consumption by at least 20%.

4.6.6.4 Energy Efficiency Portfolio Standard (EEPS) of New York State (2008)

The New York State Public Service Commission (PSC) established an Energy Efficiency Portfolio Standard (EEPS) [78] for electric and natural gas in 2008. The PCS provided funding to utility companies for energy efficiency programmes to reduce electricity usage by 15% by 2015 state-wide, which included New York City.

With the establishment of EEPS, Con Edison, in New York City, launched ten energy efficiency electric and gas programs from 2009 to 2015 for service and residential buildings, which achieved annual savings of over 730 GWh [79].

4.6.6.5 NYC Retrofit Accelerator (2015)

NYC Retrofit Accelerator is a free efficiency and customised advisory service provided since 2015 to privately owned buildings to navigate the energy and water retrofit process. The professional partners included Advanced Energy Group (AEG), Building Energy Exchange (BE-Ex), Local Initiatives Support Corporation (LISC) NYC, etc. The program aims to reduce greenhouse gas emissions of the city by roughly one million metric tons per year by 2025 by facilitating retrofits in approximately 1,000 properties per year [80].

4.6.6.6 New York City Energy Efficiency Corporation (NYCEEC)

NYCEEC was established and endowed by New York City (NYC) in 2011 with USD 37.5 million of federal grant funding. It is a non-profit finance company that provides land and financing solutions for energy efficiency and clean energy projects, with innovative technology and applications evaluated on a case-by-case basis. With the initial investment from federal grant funding, NYCEEC generates has attracted additional funding from the public sector (federal, city and state), commercial lending institutions, and philanthropy. NYCEEC demonstrate a successful example of the potential market in energy efficiency investment.

4.6.7 Key Drivers

<u>Service Buildings</u>

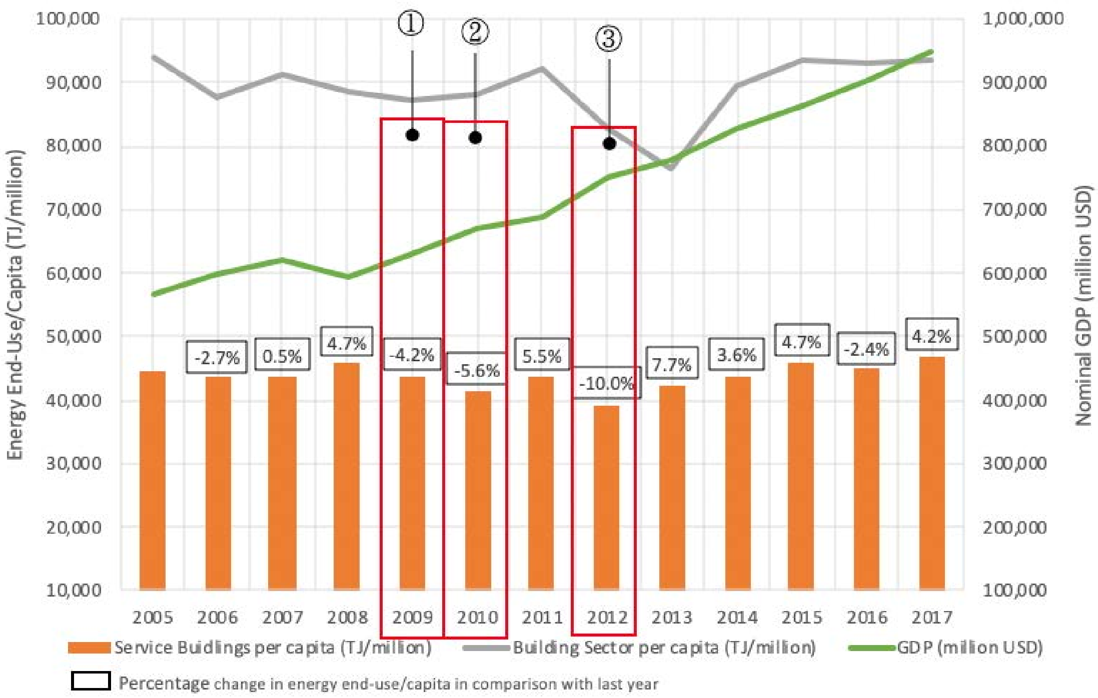
Figure 43 showed the trend of service buildings' energy end-use per capita in New York City from 2005 to 2017. Significant energy end-use reductions per capita were observed in 2009, 2010 and 2012, which accounted for reductions of 4.2%, 5.6% and 10.0% respectively.

The first marked reduction in energy end-use per capita of service buildings of 4.2% occurred in 2009 due to the Great Recession 2008, which resulted in fewer economic activities and a surge in the unemployment rate in New York City 2009 at 9.3% [81].

The subsequent reduction in energy end-use per capita of 5.6% in 2010 was likely related to Local Law 88 of 2009 (LL88) and Local Law 85 of 2009 (LL85) of GGBP. LL88 requires lighting equipment to be updated according to the local code standard in non-residential spaces and the installation of sub-metering for commercial tenants. LL85 mandates the adoption of the New York City Energy Conservation Code in new buildings and the renovation of existing buildings.

An energy reduction per capita of 10.0% was observed in 2012, resulting in the lowest service buildings energy consumption per capita recorded from 2005 to 2017. According to the US Department of Energy, the energy consumption reduction correlates with the enactment of Local Law 84 of 2009 (LL84) in GGBP which required designated buildings to report and benchmark their energy and water consumption on an annual basis. The significant drop in energy consumption was due to the release of benchmarking data in the private sector in 2012 because the private sector responded to the data transparency as energy data would result in publicity for high-profile commercial buildings.

In addition, the State and City's Energy codes under the ECCCNYS and NYCECC were revised with more stringent requirements in 2010. The Energy codes will also contribute to the energy reduction of newly constructed service buildings.



1) 2009: Effect of the Great Recession since 2008
2) 2010: Local Law 88 of 2009 (LL88) and Local Law 85 of 2009 (LL85) of GGBP
3) 2012: Local Law 84 of 2009 (LL84) in GGBP and revision of ECCCNYS and NYCECC

Figure 43 Service buildings' energy end-use per capita in NYC from 2005 to 2017

<u>Residential Buildings</u>

Figure 44 showed the trend of residential buildings' energy end-use per capita in New York City from 2005 to 2017. Similar to service buildings, the energy consumption per capita in residential buildings fluctuated, with an exceptionally low energy consumption per capita in 2013. Significant reductions in energy end-use compared to previous years were observed in 2008, 2012 and 2013, with reductions of 10.3%, 10.2% and 21.8% respectively.

The Great Recession in 2007 – 2008 contributed to the drop in energy end-use per capita in residential buildings in 2008. With the increase in the unemployment rate from 5.0% in 2007 to 9.3% in 2009 in New York State [81], people were more careful with their expenditures. Research has demonstrated the correlation between household income and household energy consumption [82].

The enactment of Local Law 87 in 2009 (LL87) of GGBP as well as the revision of State and City's Energy Code in 2010 and 2011 respectively led to a subsequent decrease in energy consumption of residential buildings in 2013. LL87, which became effective in 2013, mandated regular energy audits and retro-commissioning in large existing buildings, including residential buildings with large energy use. Significant reductions were due to retrofitting older buildings with improved insulation and energy efficiency, especially during the heating season.

1) 2008: The effect of the Great Recession (2008)
2) 2012-2013: Local Law 87 of 2009 in GGBP, Revision of ECCCNYS and NYCECC

Figure 44 Residential buildings' energy end-use per capita in NYC from 2005 to 2017

Summary of Key Drivers

- **Revision of Building Energy Code**

The new buildings in NYC are governed by both the state-level and city-level energy codes (i.e. ECCCNYS and NYCECC). The energy codes have been mandated through Local Law (LL) 85 since 2009. Energy codes have been regularly revised every three years, which ensures the latest technology and design to reduce energy demand have been incorporated into new buildings.

- **Renovation for existing buildings**

To fulfil the city's 80x50 roadmap of 80% GHG reduction target by 2050, compared to the 2005 baseline, NYC must regulate its energy consumption, especially in the building sector. Nearly all existing buildings in NYC need to be retrofitted [not a complete thought …..]. Local Law 87 of 2009 mandates not only the professional energy audit but also the retro-commissioning of large buildings - buildings over 5,000 m² in floor area - every ten years. This policy mandate and encourage retro-commissioning as a low-cost measure for improving energy efficiency. The energy efficiency of building systems during operation has been enhanced, especially in older buildings.

- **Benchmarking of building energy consumption and data reporting**

Local Law 84 of 2009 (LL84) of the GGBP mandates the benchmarking and reporting of energy consumption data annually. A contentious response from building owners has been observed, in which the transparency of energy data leads to publicity for high-profile buildings. This enhanced the awareness of building energy consumption for building owners.

4.6.8 Gap Analysis

4.6.8.1 Current Energy Intensity Reduction Situation

Up to 2017, New York City achieved an energy intensity[13] reduction of 36.6% compared with the 2005 baseline, which aligned with the APEC Leader's goal [what is the goal about? If the goal is no longer valid, use "aligned"].

[13] Energy intensity calculated based on final energy demand (TJ)/nominal GDP (million USD)

4.6.8.2 Reduction Target Projection

Compared with the 2005 baseline, the energy end-use has demonstrated an increasing trend of 4.2%, [use past tense if talking about 2017 (4.2%)] as shown in Figure 45. To fulfil the APEC's energy intensity reduction target, more stringent requirements and policies for energy reduction must be implemented to flatten the curve. Referring to the methodology stated in Section 2.4, a gap of 3.5% exists from the energy consumption performance in 2017 to the 2035 energy intensity reduction target.

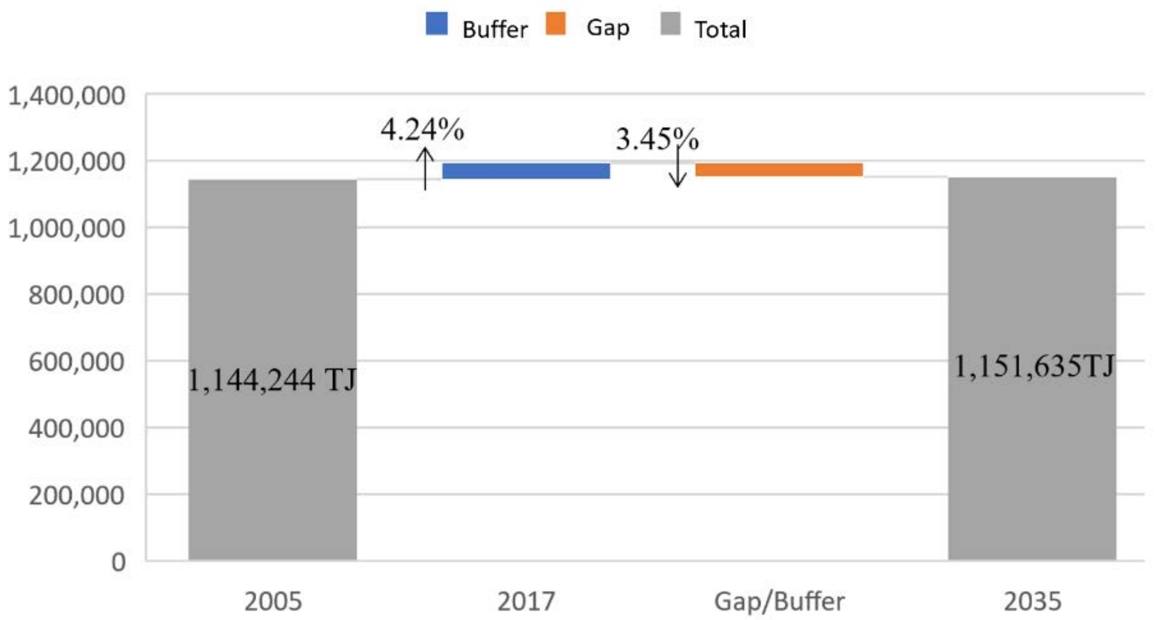


Figure 45 Energy end-use target of NYC

4.6.9 Latest Development in Building Energy-efficient Policy

In 2019, New York City released the "OneNYC 2050" and New York City's Green New Deal. These strategies included actions for further reducing emissions, including more renewable energy [meaning not clear, "including more renewable energy" is one of the strategies?], expanding energy efficiency in buildings and reducing the reliance on fossil fuel vehicles. It required all large existing buildings of 25,000 square feet or more to make efficiency upgrades that lower their energy usage and emissions.

4.7 The Republic of Korea - Seoul

Seoul is the capital city of the Republic of Korea. Approximately 20% of the population of the Republic of Korea lives in Seoul, with a 9.9 million population in 2015 as reported in the Census 2015. With an area of around 606 km^2 in Seoul, the city has an urban density of 16,364 persons/km^2.

The Republic of Korea is located in Asia and is a developed economy. According to APERC's outlook [3], the Republic of Korea achieved a 13% of energy intensity[14] reduction in 2016 as compared with the 2005 Baseline.

As announced in the 8th Basic Plan for long-term electricity supply and demand in 2017 [84] by the Ministry of Trade, Industry and Energy, the final energy consumption was targeted to reduce by 14.5% and improve energy intensity by 12.3% by 2031 when compared with the Business-as-Usual scenario (BAU).

According to data from the Seoul Metropolitan Government [83] and KOSIS, Seoul achieved a 42.7% of energy intensity[15] reduction in 2017 from the 2005 baseline.

Seoul has introduced various energy-related policy measures to improve energy efficiencies and is selected for this study.

4.7.1 Final Energy Demand Overview

According to data from the Seoul Metropolitan Government [83], there was economic growth of 93.4% from 2005 to 2017. Despite the rapid economic growth, the total energy end-use reduced by 1.1% in 2017 from the 2005 baseline in the KESIS report. The total energy end-use was 628,648 TJ in 2017, 31.5% of the total was consumed in service buildings, 28.7% in residential buildings, 27.6% in transport and 10.7% in the industry sector, as shown in Figure 46.

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[14] Energy intensity calculated based on final energy demand (toe)/ GDP (2016 USD million PPP)

[15] Energy intensity calculated based on final energy demand (TJ)/nominal GDP (million USD)

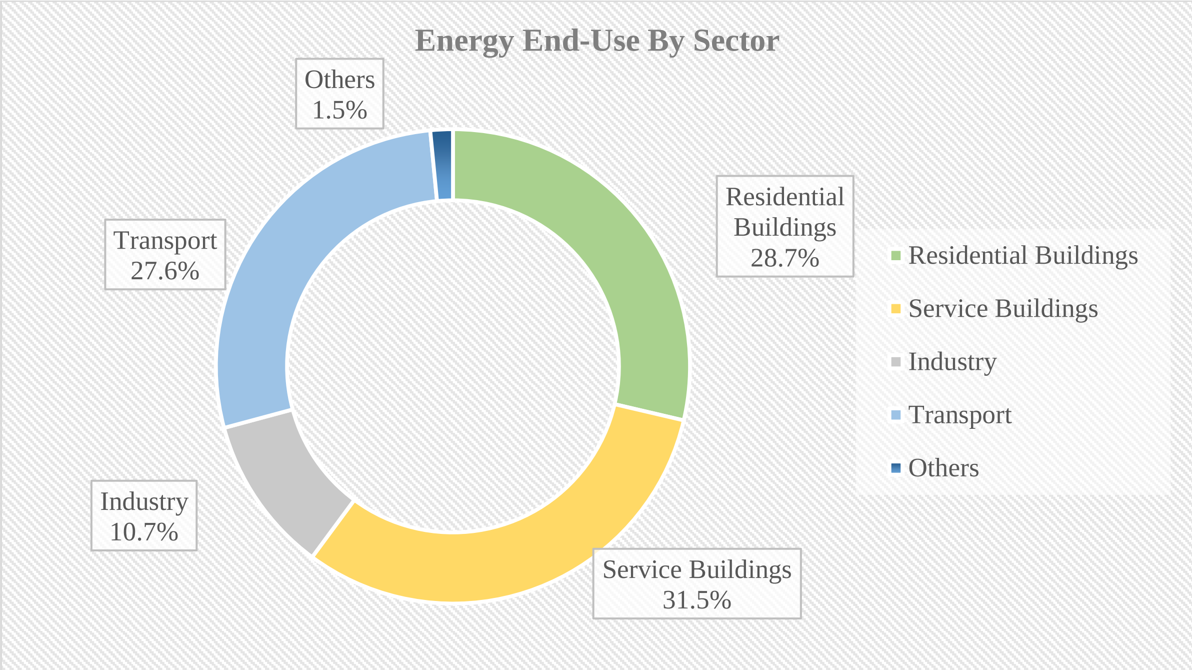


Figure 46 Energy end-use by sector of Seoul in 2017

4.7.2 Building Sector Energy Consumption

The building sector accounted for 60.2% of the total energy consumption in 2017. The total energy consumption for the building sector in Seoul was similar from 2005 to 2017, with some fluctuation around the average of 377,152 TJ. The energy end-use in the building sector demonstrated an increasing trend from 2005 and a peak in 2010, as shown in Figure 47. In addition, residential buildings and service buildings had similar shares of the total building energy consumption.

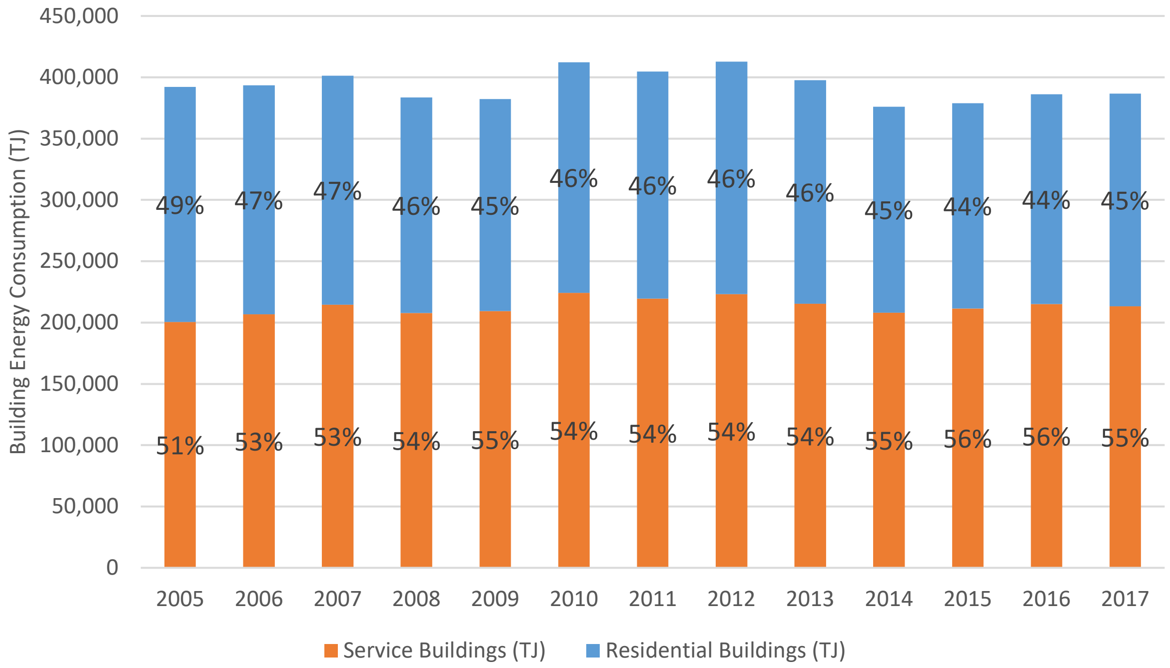


Figure 47 Building Energy Consumption of Seoul from 2005 to 2017

4.7.3 Review of Building Energy-Related Measures

Strategic Plans and Regulations	Coverage	Building Type	Authority Level	Revisions
Energy Use Rationalisation Act [85]	N/A	N/A	Domestic	2007/ 2008/ 2009/ 2010/ 2011/ 2013/ 2015/ 2016
Green Buildings Construction Support Act [86]	New	Residential and Service	Domestic	2012/ 2013/ 2014/ 2015/ 2016/ 2017
Korea Energy Master Plan [87]	N/A	N/A	Domestic	2008/ 2014
Korean New Deal and Green New Deal	N/A	N/A	Domestic	2021
Building Energy-Related Policies and Measures				
Building Energy Code Compliance (BECC)	New	Residential and Service	Domestic	2003/ 2008/ 2010/ 2011/ 2013
Seoul Green Building Design Guideline	New	Residential and Service	City	2010/ 2012/ 2013

Green Building Standards				
Green Standard for Energy and Environmental Design (G-SEED)	New and Existing	Residential and Service	Domestic	2012
Seoul Green Building Design Guideline	New	Residential and Service	City	2010/ 2012/ 2013
Measures to Existing Buildings				
Building Energy and GHG Target Management Scheme	Existing	Service	Domestic	2010
One Less Nuclear Power Plant	New and Existing	Residential and Service	City	2012
Data Reporting / Disclosure				
Energy Use Rationalisation Act – Article 32 Energy Audit	Existing	Service	Domestic	2010
Building Energy-efficiently Rating (B.E.E.R.)	New and Existing	Residential and Service	Domestic	2010
Seoul Green Building Design Guideline	New	Residential and Service	City	2010/ 2012/ 2013
Certification of Zero Energy Buildings	New and Existing	Residential and Service	Domestic	2017
Energy-efficient Appliances Labelling				
Energy Efficiency Labelling and Standard	(for goods)	N/A	Domestic	1992
High-efficiency Appliance Certification	(for goods)	N/A	Domestic	1992 (1996)
E-Standby	(for goods)	N/A	Domestic	1999
Government Leadership				
Energy Use Rationalisation act – Article 8	New and Existing	Service	Domestic	2011
Tenant Programme				

N/A	N/A	N/A	N/A	N/A
Incentives				
Energy Audit Assistance	Existing	Services (Small and medium-sized companies)	Domestic	2007-2014
Building Retrofit Program	Existing	N/A	City	2008
Green Building Subsidies Act	N/A	N/A	Domestic	2009
Supports to Promote High-Efficiency Equipment	N/A	N/A	Domestic	2012-2014
Subsidy for Green Remodelling Program	Existing	N/A	Domestic	2013
Subsidy for Building Energy Management System Programme	New and Existing	N/A	Domestic	2017
Public Awareness				
One Less Nuclear Power Plant	N/A	N/A	City	2012
Promise of Seoul	New and Existing	Residential and Service	City	2015

4.7.4 Major Policy / Scheme for EE&C

Based on Article 41 of the Basic Law on Low Carbon Green Growth and Clause 1 of Article 10 of the Energy Law, the Ministry of Trade, Industry and Energy (MOTIE) of the Korean Government issued the Korea Energy Master Plan 2008 and revised it in 2014. The Master Plan aimed to respond to climate change and greenhouse gas emissions reduction. Two visions from the Master Plan are "Moving toward a low energy consumption society" and "Creating new growth engines and job opportunities through green energy and green technology". For power supply and demand, it targeted to reduce electricity demand by 7.6% by 2020 and 12.4% by 2030 in the 2008 Master Plan and revised to reduce electricity demand by 15% by 2035 in the 2014 Master Plan. The Korean Government has a more aggressive target on electricity demand reduction in territory-wide strategy.

4.7.4.1 Building Energy-Related Policies and Measures

4.7.4.1.1 Building Energy Code Compliance (BECC) (2003)

The Building Energy Code Compliance (BECC) [88] was launched in 2003 by the Korean Energy Agency (KEA) for new buildings territory-wide. The BECC is applicable for new buildings with a gross area greater than 500 m^2 under the Building Design Standards for Energy Saving and Green Building Promotion Act. The BECC was revised in 2008, 2010, 2011 and 2013 for raising the insulation or heat transmission coefficient requirement or implementing other programs, such as the Total Annual Energy Consumption program in 2011 for office buildings with an area greater than 10,000 m^2 and The Green Building Promotion Act 2013.

4.7.4.1.2 Seoul Green Building Design Guideline (2010)

In 2010, Seoul Metropolitan Government launched the Seoul Green Building Design Guideline (the Guideline). The Guideline is mandatory for all buildings and includes five aspects: Environmental Performance, Environmental Management, Energy Performance, Energy Management and Renewable Energy Implementation. This Guideline refers to several domestic programmes, such as building energy labelling programmes (e.g. B.E.E.R.) and green building certification programmes (e.g. G-SEED) and Energy Performance Index (EPI).

4.7.4.2 Monitor and restrict high energy use companies

4.7.4.2.1 Building Energy and GHG Target Management Scheme (2011)

The Buildings Energy and GHG Target Management Scheme (BGHG) was implemented by the Ministry of Environment in 2011 as a core measure to meet the GHG reduction target [89]. From Article 42 of the Low Carbon Green Growth Main Act (Climate Change Response and Energy Target Management), and Articles 26-34 of the Enforcement Decree of the Low Carbon Green Growth Standard Law, organisations with a high level of GHG emissions and energy consumption shall monitor their energy performance, and achieve GHG emissions and energy targets between the Government and the companies with incentives and penalties subject to the fulfilment of the targets.

4.7.4.2.2 One Less Nuclear Power Plant (2012)

One Less Nuclear Power Plant was an initiative of the Seoul Metropolitan Government launched in 2012. This initiative includes measures to facilitate the energy efficiency of buildings, such as a tighter maximum energy limit and the Building Retrofit Program. The energy cap system is 190kWh/m²-year and 280kWh/m²-year for new residential and service (commercial) buildings. In the Republic of Korea, the services buildings include public offices, underground shopping centres, large office buildings etc. The Building Retrofit Program (BRP) aims to improve energy efficiency and prevent energy leakage in 12,200 buildings by 2014. The BRP is applicable for individual houses, office buildings, public rental houses etc.

4.7.4.3 Green Building Standards

4.7.4.3.1 Green Standard for Energy and Environmental Design (G-SEED) (2012)

Green Standard for Energy and Environmental Design (G-SEED) is a territory-wide standard. G-SEED certifies eco-friendly buildings that have saved energy and reduced environmental pollution throughout their life-cycle. It applies to new buildings, existing buildings and also Green Remodelling buildings. The certification provides four grades (Best, Excellent, Superior and General) and is presented with stars. The G-SEED assessment considers various aspects, including land use and transport, energy and pollution, materials and resources etc. The G-SEED was revised in 2013 to enhance its positive impact and require buildings with a total area of more than 3,000m² shall be mandatory to obtain the G-SEED certification.

4.7.4.3.2 Zero Energy Building Certification (ZEB) (2017)

Zero Energy Building Certification (ZEB) was established in 2014 and implemented in 2017. In ZEB, the Energy Independent Rate (EIR) is adopted. EIR is the ratio of primary energy production per unit area produced by renewable energy compared to primary energy production per unit area. ZEB is a five-grade system, grade one to five represents an EIR from 100% to 40%.

4.7.4.4 **Public engagement**

4.7.4.4.1 One Less Nuclear Power Plant (2012) – Eco-mileage program

The eco-mileage program is a public engagement program for reducing the final energy consumption. Households or organisations that achieve a 10% reduction in final energy demand based on the monthly average of the previous two years will register for the program. The program provided coupons for public transportation or buying energy-efficient appliances and changed the public's behaviour to choose a low-carbon lifestyle. In addition, it considered the six-months average electricity consumption to encourage continuous energy conservation instead of short-term behaviour change.

4.7.4.4.2 Promise of Seoul (2015)

Further on One Less Nuclear Power Plant, the Seoul Metropolitan Government provided more efforts in tackling climate change and launched the Promise of Seoul in 2015. The Promise of Seoul is a goal-oriented policy with detailed action plans on 36 tasks in 10 different areas - Energy, Transportation, Air Quality, Resource Recycling, Water, Ecology, Urban Agriculture, Health, Safety and Urban Planning. For the Energy area, Seoul aimed to reduce energy consumption by 5 million TOE and 20 million tons of GHG emissions by 2030 by saving and efficiently using energy. Actions for different stakeholders are provided in the plan and summarised in the table below.

Table 9 Summary of actions for Energy from the Promise of Seoul

Citizen	- Sign up for Eco-mileage and check energy consumption more than one time a month - Reduce unnecessary energy loss in heating and cooling by enhancing insulation - Purchase products with high energy efficiency - Attend education on energy and climate change
Business	- Improve the energy efficiency of the production process and products - Set and implement the goal of reducing energy consumption for a building - Comply with the proper room temperature at offices and working places - Purchase and use highly energy-efficient office supplies - Change a signboard and landscape lighting to highly efficient lighting devices
Seoul Metropolitan Government	- Foster energy saving culture by extending the members of Eco-mileage - Enlarge the distribution of LED lighting to the private sector - Activate Building Retrofit Project (BRP) - Broaden the support of energy diagnosis

4.7.4.5 Energy-efficient Product Labelling

In the Republic of Korea, for energy efficiency management programs, the Ministry of Industry, Trade and Energy (MOTIE) and the Korea Energy Agency (KEA) are responsible for mandating efficiency standards and implementing energy-saving policies, respectively.

4.7.4.5.1 Energy Efficiency Labelling and Standard (1992)

The Energy Efficiency Labelling and Standard was launched, based on Article 15 of the Energy Use Rationalization Act, in 1992 by the Korea Energy Agency (KEA). The standard covers the labelling of energy efficiency rating of products in five-grade levels and bans the products that do not meet the minimum energy performance standards (MEPS). Compared to the 5th-grade products, 1st-grade products save 30-40% energy consumption. The labelling standard helps consumers to identify energy-efficient applicants.

4.7.4.5.2 High-efficiency Appliance Certification Program (1996)

The High-efficiency Appliance Certification Program is voluntary. This program was launched in 1996 by KEA based on Article 22 of the Energy Use Rationalization Act. The program aims at maximizing energy saving by raising the technological standards of small manufacturers and enterprises (SMEs) when developing and producing products. The program covers 45 product types, such as inductor motors, boilers, pumps, LED lamps, etc.

4.7.4.5.3 e-Standby Program (1999)

The e-Standby Program is mandatory and implemented by KEA based on Article 18 (Designation of target products for the e-Standby program), Article 19 (Designation of target products to attach a warning label), Article 20 (Indication of products with lowest standby power), and Article 21 (Monitoring on products targeted under the e-Standby program). The program was for reducing the standby power of electronic appliances and office equipment. 21 types of products were covered under the program, including computers and set-top boxes.

In 2004, the Republic of Korea set a goal that the standby power of all electronic products was reduced to below 1W by 2010 in “Standby Korea 2010”. Products that meet the 1-Watt standby power standard are entitled to the ‘Energy Saving Label.’ If the product fails to meet the standard, the ‘Standby Warning Label’ would be displayed on the product. The implementation of this program comes in 3 phases: the Voluntary phase (2005-2007); Preparation for Transition to a Mandatory phase (2008-2009); and the Mandatory phase (after 2010). Further from the 2010 target, the standby power consumption of all electronic appliances was targeted to be below 0.5W by 2015. From 2003 to 2011, 45% less standby power per alliance and 25%less annual domestic standby power consumption was observed. By 2012, 99.5% of the targeted products of the e-Standby Program had excellent standby power.

4.7.5 Data Reporting / Benchmarking / Disclosure

4.7.5.1.1 Energy Performance Index

The Energy Performance Index (EPI) is introduced by the Korea Energy Management Corporation (KEMCO) territory-wide. The EPI is a web tool [90] for managing building energy with a point system. The EPI considers various aspects of a building, including the architectural elements (e.g. Building Envelope U-value), Machinery (e.g. COP of chiller) and electricity (e.g. adoption ratio of LED lighting). According to the BECC, the new buildings with a gross area greater than 500 m^2 shall obtain at least 65 points (75 points for public buildings) for having the building permit.

4.7.5.1.2 Buildings Energy Efficiency Rating (2001)

Buildings Energy Efficiency Rating (B.E.E.R.) is to assess and certify energy-efficient buildings in terms of energy consumption and GHG. The B.E.E.R. is a mandatory ten-grade certification system. The new residential buildings in the public sector shall with a certification higher than level two when the system was launched in 2001. The requirement tightened to level one in 2011. The application expanded to include non-residential buildings in 2013. The assessment considers the CO_2 emissions and energy consumption for heating, cooling, hot water, lighting and ventilation of buildings.

4.7.6 Financial Incentives

4.7.6.1 Energy Audit Assistance (2007-2014)

KEA supported small and medium-sized companies with 70%-90% of audit costs in the year 2007 to 2014.

4.7.6.2 Building Retrofit Program (2008)

The Building Retrofit Program (BRP), which began in 2008, is a financing program that gives low-interest-rate loans as incentives for retrofitting projects in Seoul. The program has undergone a continuous increase in its magnitude of support, such as the interest rate had been reduced from 3.0% to 1.5% from 2008 to 2016.

4.7.6.3 Green Building Subsidies Act

G-SEED certifies eco-friendly buildings that save energy and reduce environmental pollution throughout their lifecycle. From 2009, obtaining G-SEED could grant acquisition-registration tax reduction and an increase in price ceiling.

The ZEB is supported by the Green Building Construction Support Act, which certifies buildings with exceptionally high efficiency based on an Energy Independent Rate (EIR). ZEB grants GFA concession as an incentive based on the ZEB grading the building has achieved.

4.7.6.4 Supports to Promote High-Efficiency Equipment (2012)

KEA has launched several actions to promote high-efficiency equipment since 2012. In 2012, the Public Procurement Service was required to purchase high-efficiency equipment. In 2013, the procurement requirement of high-efficiency equipment expanded to public institutions and was recommended for apartments and office buildings with an area greater than 3,000m². In 2014, loans and tax incentives were provided to investments in projects that involve high-efficiency certified equipment.

4.7.6.5 Subsidy for Green Remodelling Program (2013)

Given that 74% of the existing residential buildings in the Republic of Korea are older than 15-year, Green Remodelling Program was introduced by the Ministry of Environment (MOE) in 2013. The subsidy is for home renovation costs in terms of instalments, including the cost of replacing double-pane windows and high-efficiency building insulation materials. The owners can pay the cost in monthly instalments. The Government agency will lend support in interest costs depending on the building’s energy efficiency rating. In 2016, the Green Remodelling Program included the public sector with an annual territory-wide competition on energy performance, safety and application of new technologies.

4.7.6.6 Subsidy for Building Energy Management System Programme (2017)

The subsidy for the Building Energy Management System (BEMS) Programme was launched in 2017 for existing service buildings. 50% of the investment to BEMS was subsidised with a maximum of 20 million won.

4.7.7 Key Drivers

Service Buildings

Figure 48 shows the trend of service buildings' energy end-use per capita in Seoul from 2005 to 2017. There were significant energy end-use reductions per capita in 2008, 2012 and 2013 with 6.0%, 7.8% and 5.0%.

In 2008, the Great Recession affected economic activities and resulted in energy consumption reduction. Moreover, the effect of the Building Energy Code (BEC, 2003) and standardisation of the energy performance index for effective management of building energy and the Energy Audit Assistance services provided to small and medium enterprises also contributed to the slow increment and even reduction of energy consumption in service buildings.

Between 2005 to 2011, a series of policies were launched and demonstrated effective energy-saving in service buildings. The revision of Building Energy Code (BEC) Compliance enhanced the building envelope performance and reduced energy consumption of various building systems. The Buildings Energy and GHG Target Management Scheme (BGHG) required high energy consumption service buildings to achieve a certain level of energy reduction. The Seoul Green Building Design Guideline sets more stringent requirements for buildings in Seoul. The energy-saving requirement on existing buildings slowed down the energy end-use during the rapid GDP growth and finally showed the impact on energy reduction after 2010.

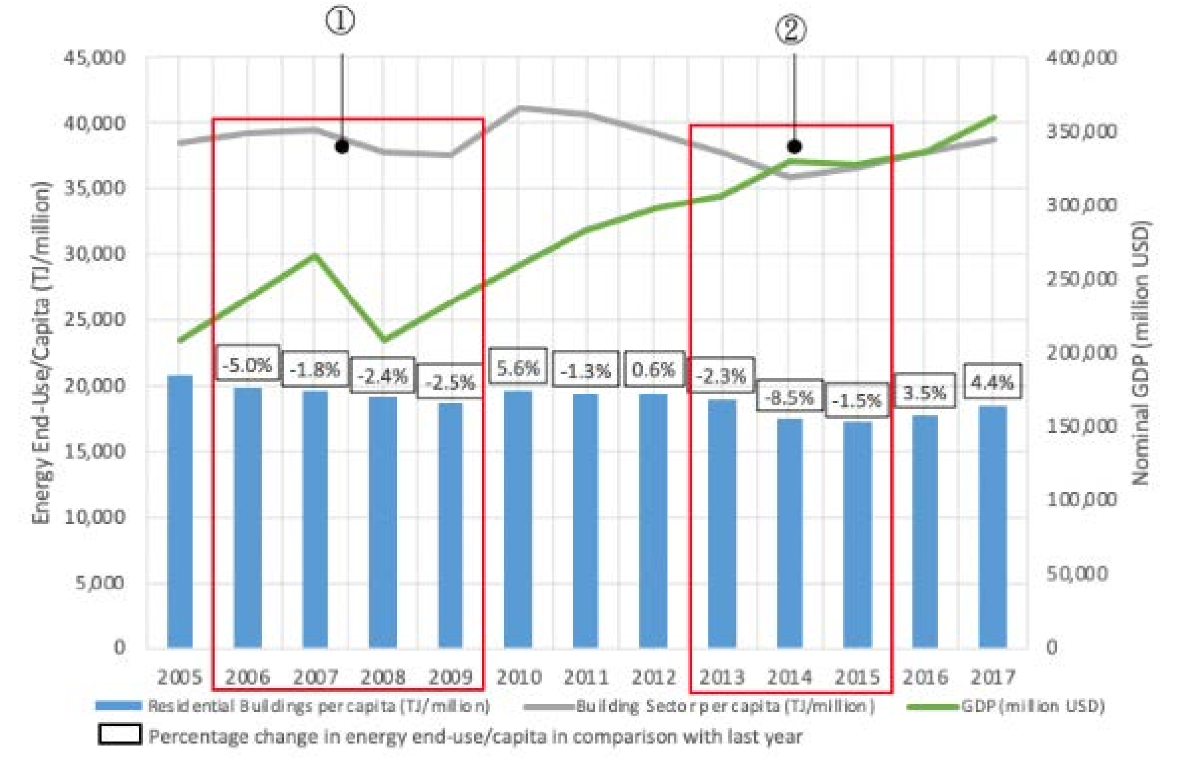
1) 2008: Great Recession, Building Energy Code (BEC), Energy Audit Assistance
2) 2012-2013: Revisions of BEC, Buildings Energy & GHG Target Management Scheme (BGHG), Seoul Green Building Design Guideline

Figure 48 Service buildings' energy end-use per capita in Seoul from 2005 to 2017

Residential Buildings

Figure 49 shows the trend of residential buildings' energy end-use per capita in Seoul from 2005 to 2017. The energy end-use trend in residential buildings decreased from 2006 to 2009 but increased from 2010 to 2013 and slightly decreased from 2013 to 2015. In residential buildings, the dominant energy consumption would rely on the efficiency of home appliances, such as AC units and lighting. The Energy Efficiency labelling and Standard and e-Standby Program addressed the standby energy consumption and contributed to energy-saving the year after 2010.

In addition, the One Less Nuclear Power Plant campaign (2011), especially the eco-mileage program engaged the citizens to adopt energy-saving behaviours with financial incentives, which successfully fostered the public's participation in realising the outcome of the policy.



1) 2006-2009: Revision of Energy Efficiency labelling and Standard and launching of the Voluntary Phase of E-Standby Programme in 2004

2) 2013 – 2015: Launching of the mandatory phase of the E-Standby Programme, One Less Nuclear Power Plant, Seoul Green Building Design Guideline

Figure 49 Residential buildings' energy end-use per capita in Seoul from 2005 to 2017

Summary of Key Drivers

- **Building Energy Code and Building Labelling**

The Building Energy Code (BEC) Compliance is launched and updated with a more stringent requirement to achieve the corresponding energy or emission reduction targets. The Seoul Green Building Design Guideline targets a reduction than the BEC through mandatory requirements on Building Energy Efficiency Rating (BEER) and G-SEED rating.

- **Monitor and restrict high energy use companies**

The Building Energy and GHG Target Management Scheme (BGHG) requires high energy consumption companies or enterprises to achieve the agreed energy and emission target in their service buildings. The policy directly addresses the largest energy consumer and also demonstrates to the public that large companies have the social responsibility to contribute more to energy-saving.

- **Public engagement**

The city-wide campaigns “One Nuclear Plant Campaign” and “Promise to Seoul” engage different stakeholders to participate in adopting measures to reduce electricity, water and natural gas consumption. By recommending actions at each stakeholder’s level, offering financial support to building retrofit, replacing LED bulbs and rewarding achievement in energy-saving of individual households or businesses, the citizen voluntarily adopts energy-saving measures.

4.7.8 **Gap Analysis**

4.7.8.1 Current Energy Intensity Reduction Situation

Up to 2017, Seoul achieved an energy intensity[16] reduction of 42.7% as compared with a 2005 baseline, which was aligned with the APEC Leader's target of energy intensity reduction.

4.7.8.2 Reduction Target Projection

As compared with the 2005 baseline, the energy end-use has demonstrated a decreasing trend of 1.1%, as shown in Figure 50. To fulfil the APEC's energy intensity reduction target, a more stringent requirement to the current energy reduction policy is essential to flatten the increasing curve and meet the target.

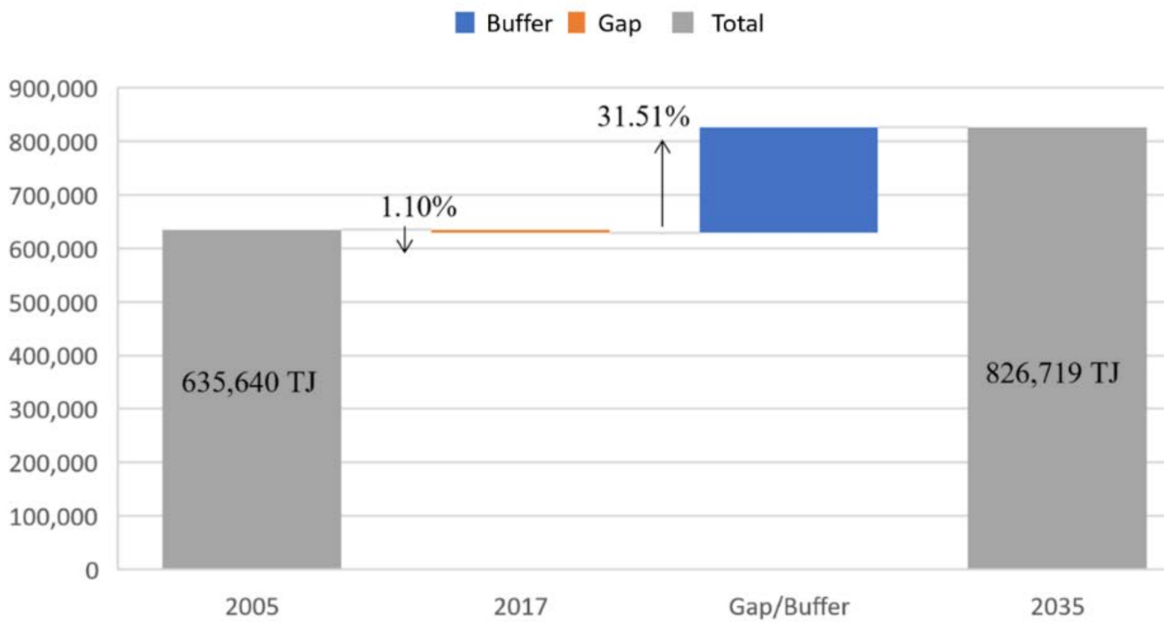


Figure 50 Energy end-use target of Seoul in 2035

[16] Energy intensity calculated based on final energy demand (TJ)/nominal GDP (million USD)

4.7.9 Latest Development in Building Energy-efficient Policy

In 2021, the Korean New Deal (K-New Deal) was launched. This plan aimed at green recovery from the COVID-19 pandemic while eventually reaching the goal of zero emissions by 2050. The "green" part of the plan is known as the Green New Deal. The Green New Deal involves investing in advanced technology initiatives to create jobs, such as the installation of solar panels on public buildings, installing smart meters for smart grids formation, forming microgrid communities with renewable energy and energy storage systems in regional areas, and creating decentralised, low-carbon energy systems for island areas.

5 Findings

5.1 Key drivers identified

Based on the study on enforced building policies and historical building energy end-use data among the shortlisted cities, key drivers were identified by mapping the policy timelines with the energy intensity reduction and categorised into the following seven aspects.

Table 10 Summary of overall identified key drivers

Key Drivers	Details	Applicability for New Building (NB) / Existing Building (EB)	Residential (R) / Services (S) Building
Building Energy Code and Policy	Building Codes/ Regulations/ Ordinances/ Laws related to energy efficiency requirements for buildings, both passive and active aspects.	NB/EB	R/S
Green Building Standards	Policy or program for buildings to achieve green building	NB/EB	R/S
Data Disclosure to the Public	Policy or program for buildings to disclose building energy consumption to the public, such	NB/EB	R/S

(Benchmarking)	as energy labelling, energy rating, EUI		
Periodic Data Reporting (Energy Audit)	Policy or program for buildings to conduct regularly energy audits and provide enhancement measures	EB	R/S
Reduction Target for Existing Building (Trade/Policy)	Policy or program requiring the existing buildings to carry out effective measures to reduce energy consumption to a certain level, through policy or trading program	EB	S
Appliances Energy Labelling	Policy or program requiring appliances to be labelled with energy-efficient rating, including minimum energy performance and highly efficient energy performance	NB/EB	R
Government Leadership	Policy or program requiring governmental buildings to adopt EE&C measures	NB/EB	R/S
Tenant Program	Policy or program promoting the partnership with the tenant and building owners	EB	S

5.2 Overview of Implementation of Key Drivers

The implementation methods of the key drivers were summarised into the following categories:

- Mandatory enforcement through law or policy
- Voluntary implementation with or without incentives
- No specific policy implemented yet

Table 11 Policy Map

Key Drivers	**Beijing**	**Singapore**	**Hong Kong, China**	**City of Sydney**	**Tokyo**	**New York City**	**Seoul**
Building Energy Code and Policy	M	M	M	M	M	M	M
Green Building Measures	M	M	V	V	M	M	M
Measures to Existing Building	M	V	V	V	M	M	M
Data Reporting (Energy Audit)	M	M	M	M (Commercial office area > 1000 m^2)	M	M	M
Data Disclosure / Benchmarking	M	M	N/A	M (Residential)	M	M	M
Energy-efficient Appliances Labelling	M	M	M	M	M	V	M
Government Leadership	V	M	M	N/A	N/A	M	M
Tenant Program	V	V	N/A	V	M	V	N/A

Notes:

(M) Mandatory

(V) Voluntary

(N/A) Not Implemented

5.3 Global Trends from policy overview

5.3.1 The Building Energy-Related Policies and Measures

The Building Energy Code was an effective key driver in promoting final energy demand in buildings. The code mandated new buildings and existing buildings with major renovation work.

The building energy code, with different names in different economies, sets requirements for the building envelope and the electrical and mechanical systems. Due to the different climates, occupants' perceptions, living habits and needs, each city has developed its standards and index to assess energy efficiency.

For the building envelope, most cities not only regulate the thermal property of walls and glazing but also set a threshold on the overall thermal transfer performance. This left flexibility to the architect for designing the insulation, wall thickness and the window-to-wall ratio (WWR). For the electrical and mechanical systems, most cities set requirements on the performance of individual equipment, including chiller, boiler efficiency and lighting power density.

Table 12 Comparison of different approaches to the Building Energy Code

Implementation Methodology	Pros	Cons	Applied Cities
Performance Base	• High Flexibility • Allow for non-standard technology	• Required skilled personnel	New York City; Tokyo; Hong Kong, China; Singapore
Prescriptive Base	• Clear standards • Easy Implementation	• Low flexibility	Hong Kong, China; Singapore; Beijing; Seoul; New York City

In addition, regular revision of the building energy codes is essential to ensure that the requirements are kept up with the advancing technology in the building market and adjusted to align with the emission target of the city. Hong Kong, China updates the building energy code every three years, with more stringent requirements in each revision to uplift the energy-efficient design in the building market.

5.3.2 Renovation of Existing Buildings

For urbanised cities, existing buildings account for a large share of the building energy consumption. All cities have set energy consumption or GHG emission reduction targets. Financial support helps the building owners to meet the reduction targets. The policy also stimulates a new service provider, Energy Service Corporation, which provides upgrading services by promising agreed energy performance and delayed payment to the investment.

Moreover, many cities have adopted emission trade programmes. Tokyo has the first carbon trade programme, managed by the city and focusing on buildings in the urban environment. Sydney has also launched the voluntary Energy-saving Certificates (ESCs) for trading emission trade programme to stimulate the building owner's participation in energy efficiency and conservation in 2009, followed by Beijing launching the pilot emission trading schemes in 2013. The approach of adopting emission trading is a growing trend globally.

5.3.3 Periodic Data Reporting

To monitor the energy consumption from the building sector and identify opportunities for improvement of energy-saving in existing buildings, all the cities have mandatory requirements to carry out Energy Audits.

Table 13 Comparison of implementation methodology for energy audit

Implementation Methodology	Pros	Cons	Example City
Online self-reporting	• Easy Implementation • High frequency	• Risk of data forgery	Beijing; New York City; Tokyo
Energy Audit by 3rd Party	• Data Accuracy	• Required skilled personnel • Low frequency	New York City; Hong Kong, China; Singapore (*), Seoul; Beijing
Real-time data monitoring	• High frequency • Avoid data manipulation	• Data privacy • Cost in Infrastructure	Beijing; Singapore (*)

(*) denotes: only applicable for buildings subjected to corresponding regulations

The objectives of the energy audit are to review the performance of passive and active building systems to maintain or even improve efficiency through the identified energy-saving measures. Singapore has required the existing building, which has installed or replaced its cooling systems since 2013, to carry out 3rd party energy audit at a frequency every three years to ensure that the building service systems do not deteriorate from the designed conditions.

In most cities, although data reporting is compulsory, which allows the Government body and public to understand the distribution of energy performance, the mitigation measures identified from the energy audit are not compulsory. Hence, the energy audit itself does not directly contribute to energy reduction in the building sector. Greener Greater Building Plan LL87 in

New York City mandate the energy audit and the retro-commissioning of existing buildings. Hong Kong, China has also established guidelines on retro-commissioning for existing buildings, which standardises the process of retro-commissioning for regulating the energy performance of buildings.

5.3.4 Building Labelling Scheme

The building labelling scheme can be generally divided into two categories, building energy labelling schemes and green building labelling schemes. The labelling scheme is developed at a domestic level. Each city would control the minimum energy consumption reduction rating.

5.3.4.1 Energy Labelling Scheme

Building energy labelling schemes focus solely on the energy consumption of the buildings, either assessed by the design data through whole building energy modelling for new buildings or by the operation data for existing buildings. Tokyo, Seoul and New York City adopt and mandate the domestic standard for building energy labelling, e.g. BEI in Japan, B.E.E.R. in the Republic of Korea and Energy Star in the United States, at the city level.

5.3.4.2 Green Building Labelling Scheme

Green building labelling schemes not only assessed energy consumption but considered also other parts related to the carbon emission during the operation of the buildings. The related parts included the material used, water use, site location, indoor environment, etc. All the selected cities have green building labelling schemes tailor-made for the economies.

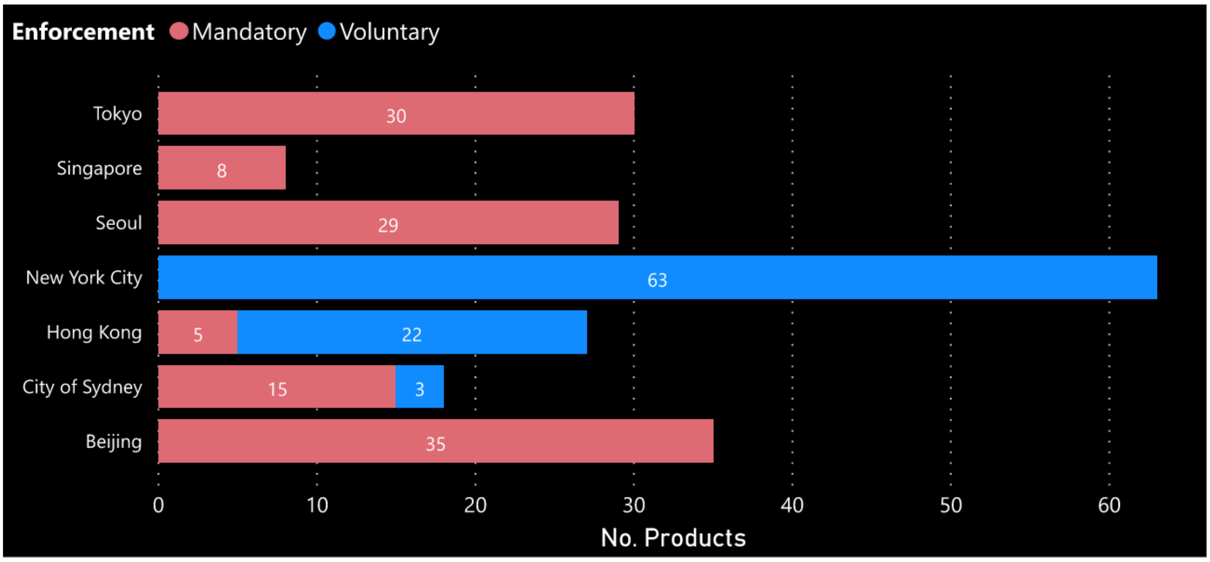
5.3.5 Energy-efficient Product Labelling

Mandatory energy labelling requirements were provided in the selected cities and launched at the domestic level to facilitate the public in choosing energy-efficient appliances and raise public awareness of energy-saving.

Beijing, Hong Kong, China, Tokyo, Singapore, Seoul and the City of Sydney mandated energy labelling requirements for electrical appliances, including air conditioning units, refrigerating machines, lighting, motors, cloth dryers etc. In most cities, such as Tokyo, Singapore, Seoul, the City of Sydney and Beijing, minimum energy performance requirements are set for the covered appliances. In particular, the e-Standby Program in the Republic of Korea [91] was the first to impose compulsory requirements on energy consumption during standby mode.

In addition, appliances in New York City and Tokyo are also subject to a voluntary labelling scheme, i.e. ENERGY STAR in U.S. and Leading and Low-Carbon (L2 Tech) in Japan. The scheme celebrates and promotes the competition for products to achieve a high level of energy efficiency, which will challenge the manufacturers to supply the market with more advanced and innovative products.

Table 14 Comparison of Energy-efficient Product Labelling Scheme



5.3.6 Public Awareness and Behaviour Change

5.3.6.1 Utility Price

The City of Sydney has demonstrated that energy end-use may relate to utility price, which induces a change in human behaviour. As the utility price directly affects the living expenditure of a household, an increase in utility price stimulates the user's awareness of the issue and changes in behaviour to adopt the energy-saving practice.

5.3.6.2 Public Campaign

Government and technical institutions can influence the public by setting up guidelines and recommendations for design temperature in cooling and heating season. In addition, public awareness and energy-efficient human behaviour can be encouraged through public education and incentives. Advertisements on TV and public transport systems, as well as a memorable slogan for the city or territory-wide campaign, are effective in educating the public, for example, the Green Olympic in Beijing and the One Less Nuclear Plant initiatives in Seoul.

5.3.7 Incentives

Effective financial incentive schemes and non-financial incentive schemes are effective to assists the implementation of both mandatory and voluntary policies as well as promoting green building designs. The incentives are divided into the following categories.

- Financial Incentives applicable to both new buildings and existing buildings:
  - Funds to compensate upfront investments;
  - Rewards for outstanding performance buildings
  - Rebate for purchasing energy-efficient appliances
  - Tax deduction for building implementing energy-saving measures
  - Low-interest loan for building implementing energy-saving measures
  - Carbon emissions trade program

- Non-Financial Incentives:
  - GFA concessions for new buildings

- Expert support for energy efficiency advice
- Public recognition through awards

Table 15 Comparison of Incentive Schemes in the selected cities

Key Drivers	**Green Building Standards**	**Periodic Data Reporting (Energy Audit)**	**Reduction Target for Existing Building**	**Appliances Energy Labelling**
Beijing	Rewards	Funds	Funds	Funds
Singapore	GFA, Funds	N/A	N/A	N/A
Hong Kong, China	GFA, Tax	N/A	Funds	N/A
The City of Sydney	N/A	N/A	Trade	N/A
Tokyo	GFA	N/A	Tax, Funds Trade	Funds
New York City	N/A	Expert	Funds, Expert, Loan	N/A
Seoul	GFA, Tax	N/A	Funds, Tax	N/A

5.4 Synergies among Policies

From this study, none of the drivers exists independently. The building energy code formed the basis of other policies, the green building and super low energy labelling schemes assessed based on the additional improvement from the building energy code.

Taking the case of the Republic of Korea as an example, the B.E.E.R. and G-SEEDs provided minimum energy performance requirements for different building types. Financial incentive schemes were provided to buildings according to the level of labelling of B.E.E.R. and G-SEEDs.

The synergy of each key driver is summarised in the figure below, with five being the most relevant policies in the five-grade system.

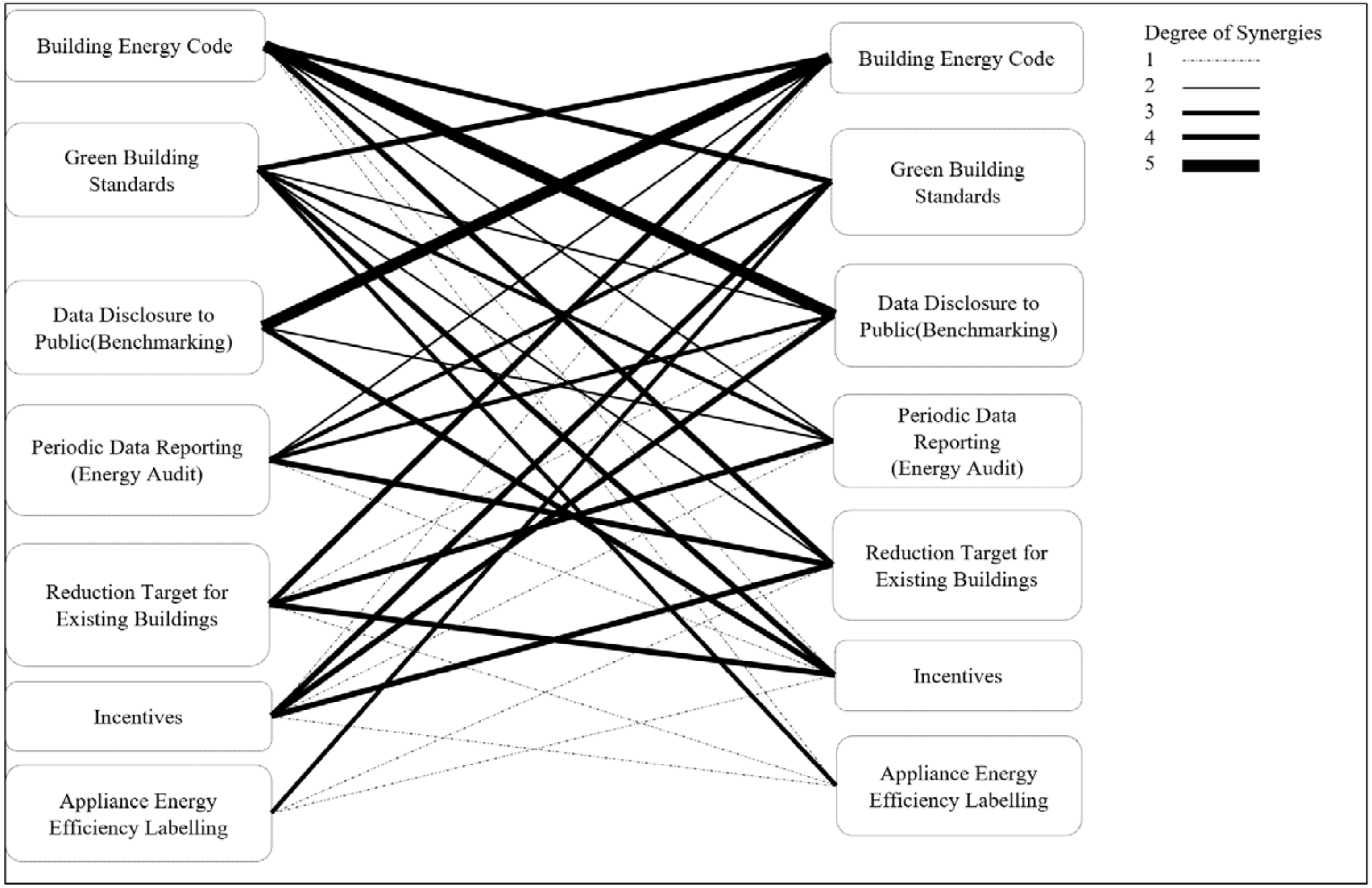


Figure 51 Synergies among key drivers

5.5 Recommended Framework and Implementation

5.5.1 Overall Action Plan and Roadmap

The achievement of energy reduction is the collaboration of all the stakeholders of the policymaker, building owners, designers, operators and tenants. The Government shall set an energy reduction plan with a roadmap and identify a delegated agency to monitor the implementation of each EE&C policy. The target and achievement should be reviewed periodically with the stakeholders. The plan may need to be adjusted according to the historical data and new conditions such as the latest COVID situation.

5.5.2 Recommended Framework

Building Energy Code as the mandatory foundation of the policy infrastructure: The Building Energy Code should be developed with stakeholders' suggestions. The code should apply to all building types and cover the passive building system and the electrical and mechanical services with regular review.

Data Reporting and Data Disclosure: The Government should collect energy performance data to verify the policies' effectiveness. The energy performance data should be disclosed to the public through labelling systems or benchmarking systems to raise public awareness and stimulate the competition between building owners to strive for higher performance.

Advanced Performance Target Supported with Incentives: More aggressive saving targets should be established with financial or non-financial incentives to enhance participation and adopt more advanced technologies.

Energy-efficient Appliances: Minimum energy performance should be established to regulate the energy consumption for appliances, which would directly impact energy-saving in residential buildings. The appliances in residential buildings should be the minimum coverage of the minimum energy performance scheme and then expanded to office equipment in service buildings. The standby power labelling scheme can be considered voluntary.

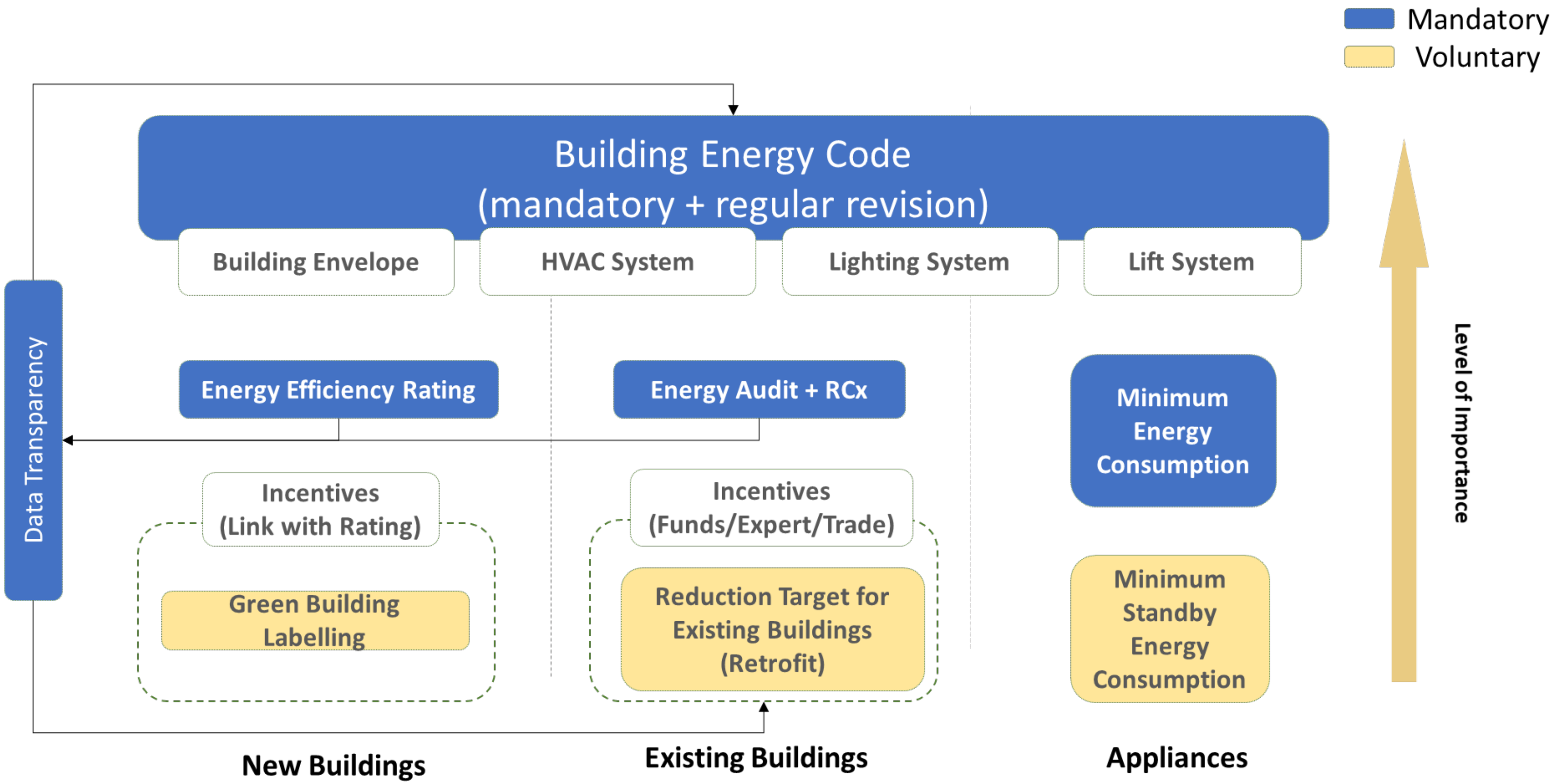


Figure 52 Recommended Framework

6 Potential Innovation and Technology Opportunities

Existing buildings play a significant role in energy end-use. The number of existing buildings will increase with the new construction turning into the existing building. Hence, apart from the building energy code applicable to new buildings, the operation of existing buildings and infrastructure will also contribute to energy end-use reduction. This section will review the I&T opportunity for building and infrastructure operation.

6.1 Intelligent Building Energy Management System (iBEMS)

Building Management System (BMS) was a tool to assist facility managers in operating the building. In recent years, an intelligent Building Energy Management System (iBEMS) coupled with the Internet of things (IoT), cloud and 5G technologies were introduced. The iBEMS detects real-time indoor conditions, identifies operation issues related to building energy efficiency and occupant's comfort and provides a solution dynamically. The iBEMS allows a faster response for the building operators to tackle any operation issue and reduces the systems' downtime.

The integration of IoT and smart sensors to the BMS system allows the historical system performance data and Indoor Environmental Quality (IEQ) parameters to be collected and analysed using machine learning technologies, then automatically diagnosing possible building operation issues that deteriorate the building energy efficiency and occupants' comfort. With the building data collected, the IoT technologies can also establish a predictive building control model for coordinated advanced control of multiple building service systems, including air conditioning and mechanical ventilation (ACMV), lighting and shading, providing real-time and optimal control strategies for electrical and mechanical services.

Projects of IoT integration in BMS have been tested in buildings in Hong Kong, China and Singapore, including the application of "Intelligent Building Automation and Analytics using Model-Predictive Control (MPC)" and "Integrated Thermal Comfort Management (iTCM) System" applied in Nanyang Technological University, Singapore; and the "NEURON Heath" technologies applied in various commercial developments in Hong Kong, China. The pilot project has demonstrated significant improvement in energy-saving as well as occupant's well-being.

6.2 3D Digital Twin for City

Urbanised cities are generally characterised as highly complex infrastructures, traffic and economy. Through 5G, big data, IoT, cloud platforms, virtual reality and 3D modelling, it is now possible to transfer the matrix of a city into a digital world and enable the Government to test solutions through a parametric study.

The 3D digital twin model includes various information, such as demographics, climate, pollutants or traffic conditions. Besides the buildings' energy use can be collected by the digital twin, simulation of new control measures for estimating the impact can be conducted in the "virtual city". The data collection function facilitates the benchmarking exercise and assists the energy management opportunities A comprehensive digital twin model would come in handy for urban energy planning. The impact on energy consumption can be estimated and compared under different policy scenarios.

6.3 Smart Grid

A smart grid is an electrical grid that includes a variety of operation and energy measures, such as smart meters, smart appliances, renewable energy resources, and energy-efficient resources. A smart grid allows electronic power conditioning and controls the production and distribution of electricity. The aim is to create a more efficient system and better-informed citizens that can add value within a strategic framework. The smart grid can be adopted at a relatively smaller scale, such as district-level or clusters of mixed-use buildings, to reduce peak energy consumption through load balancing and more reliable resource supply.

6.4 Blockchain Data Collection

With emerging technologies like the Internet of Things (IoT), artificial intelligence (AI), big data techniques and machine learning to be applied in the energy industry, these will create a complex data system in terms of heterogeneity, operability, and scalability. These would be highly susceptible to cybersecurity risks, malicious attacks and fraud. Blockchain provides a decentralised architecture and benefits security, authentication, transparency and robustness. Blockchain is suitable for the data system that requires:

- Trustworthy transactions
- Data Integrity and Transparency
- Data need to be updated by many stakeholders

There were a lot of studies related to blockchains with carbon and energy trading. The research of "Blockchain of Carbon Trading for UN Sustainable Development Goals" in 2020 demonstrated how blockchain technology could record the carbon credits and measure carbon emission rights for achieving the SDG goals. The research "Privacy-Preserving Energy Trading Using Consortium Blockchain in Smart Grid" was published in 2019 with revealed the application mechanism of blockchain in smart grids.

6.5 Feed-in Tariff (FiT)

To increase renewable energy (RE) adoption, many APEC member economies launched the Feed-in Tariff (FiT) to incentivise the general public and private sector investment in RE power generation. The power generated could be sold to the power companies at a rate higher than the normal electricity tariff rate to help recover the costs of investment in installing the RE systems.

6.6 District Cooling Infrastructure for Residential District

The District Cooling System (DCS) has been proven successful in many large commercial and cultural districts in the APEC economies, for example, the DCS in Kai Tak Development in Hong Kong, China and the Marina Bay DCS in Singapore. With load diversity and centralised chilled water production, DCS effectively reduces air conditioning energy. The application of DCS in a residential district is the next frontier for DCS. The technology is also applicable for centralised hot water production in the cool climate area.

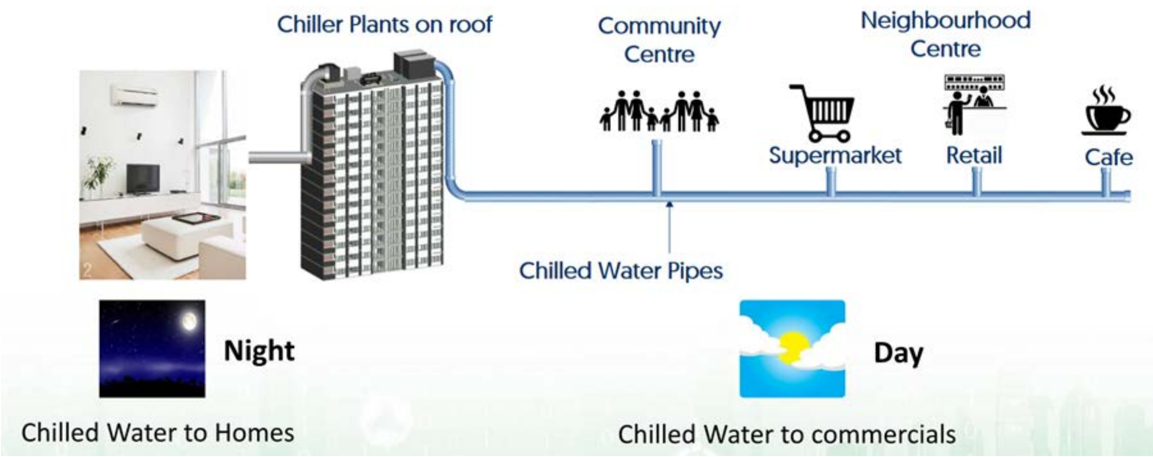


Figure 53 District Cooling Concept for Residential District

7 Conclusion

APEC member economies play significant roles in achieving global energy intensity reduction targets. With the urbanisation of developing economies, it is expected a dramatic increase in energy demand in the future. Urbanisation and population growth shall increase the building energy end-use. This project studied the key drivers and identified effective policies for improving energy efficiency in building sectors.

The selected cities for this study had a decreasing trend in energy intensity reduction and aligned with the APEC Leader's goal. Considering the population growth and improving living standards, it is critical to implement EE&C policy in buildings and adopt innovative technology to ensure economic growth while minimising the energy demand.

This report revealed a framework for EE&C policy in the building. EE&C policy requires cross-discipline collaboration among the industry. A top-down plan with the participation of the public and citizens is essential to maximise the outcome of the policy. The Government should set the target, develop standards, oversee the implementation progress and maintain a balance among stakeholders. A dedicated agency responsible for coordinating different parties is helpful to ensure the policy and incentives enacted are well operated. Professional training to cultivate authorised persons can be provided for fostering the quality and cost-effective implementation of the technology. Also, financial support to incentivise the stakeholders is needed.

Through the ESCOs in various cities, it has been proven that the energy industry is profitable. Although financial support is required as an upfront investment, it generally can be payback through the energy saved over the years of operation, which brings up the building owner and users' interest to upgrade and adopt EE&C equipment and measures.

This report reveals a general framework for EE&C policy in building, however, it should be adjusted according to the culture, public habits and existing legislation system in the economies. For developing cities, the first step is to take measurements and collect standardised data on the current situation, which would allow the policymaker to understand the baseline to deal with. The establishment of the policies is the beginning of achieving the EE&C in building, professional training shall be provided to cultivate authorised persons with technical know-how to foster the quality and cost-effective implementation of the technology as well as financial support which incentivises the stakeholders to in contributing to the reduction goal.

8 Appendix A

According to APERC's Outlook [3], the energy intensity reduction for the APEC cities is summarised below.

	Energy Intensity (toe/ million USD (Constant 2010)					Reduction in 2017 with 2005 Baseline
APEC Member Economies/ Year	**2005**	**2010**	**2015**	**2016**	**2017**	
People's Republic of China	**264.1**	**221.4**	**190.5**	**182.4**	**168.6**	**-36.2%**
Papua New Guinea	245.1	198.4	165.0	160.2	157.8	-35.6%
Hong Kong, China[17]	**37.1**	**29.3**	**25.5**	**25.0**	**23.9**	**-35.4%**
Chinese Taipei	141.0	112.1	97.1	97.1	93.8	-33.5%
Indonesia	209.0	183.1	152.6	142.2	145.3	-30.5%
Malaysia	168.3	140.6	131.3	133.8	129.9	-22.8%
The Philippines	143.3	124.6	112.1	113.4	111.5	-22.2%
Republic of Korea	**123.0**	**109.0**	**99.2**	**98.6**	**97.1**	**-21.1%**
Japan	**52.6**	**48.6**	**43.0**	**42.5**	**42.0**	**-20.1%**
The United States	**98.1**	**91.9**	**82.4**	**81.4**	**79.3**	**-19.2%**
Canada	113.7	104.1	95.1	92.7	93.6	-17.7%
Australia	64.9	60.4	55.8	599.3	53.5	-17.6%
New Zealand	87.0	82.2	75.3	73.1	73.0	-16.1%
Thailand	214.5	206.2	192.4	187.4	181.1	-15.6%
Russia	286.9	249.4	238.1	243.7	248.5	-13.4%
Viet Nam	414.6	393.2	383.3	378.7	368.6	-11.1%
Mexico	101.8	3554.9	93.6	92.4	91.1	-10.5%
Chile	106.9	104.5	93.5	96.4	96.0	-10.2%
Singapore	**41.3**	**40.8**	**38.6**	**37.9**	**37.4**	**-9.3%**
Peru	104.7	104.6	100.6	100.9	95.5	-8.8%
Brunei Darussalam	48.8	58.2	67.3	64.0	68.8	40.9%

Among the economies with top energy intensity reductions, the data availability has been assessed. Seven-member economies with city-level data on area, population, GDP, final energy demand and building end-use energy consumption, have been selected, namely the People's

[17] Hong Kong's latest data released in 2020 demonstrate an Energy Intensity of 21.8 toe/million USD (constant 2018) and a further reduction of 1.2% of energy intensity from the 2005 Baseline.

Republic of China; Singapore; Hong Kong, China; Australia; Japan; the United States and the Republic of Korea.

The source of data for this study are summarised in the below table.

City	**Area**	**Population**	**GDP**	**Energy end-use**
New York City	U.S. Census	U.S. Census Bureau	Bureau of Economic Analysis, U.S. Department of Commerce	State & Local Energy Data, U.S. Department of Energy
Beijing	Beijing Municipal Statistics Bureau	Beijing Municipal Statistics Bureau	Beijing Municipal Statistics Bureau	Beijing Municipal Statistics Bureau
Tokyo	Geospatial Information Authority of Japan	Statistics of Tokyo	Cabinet Office	Bureau of Environment
Seoul	Korean Statistical Information Service	Korean Statistical Information Service	Korean Statistical Information Service	Korean Energy Statistical Information System; Seoul Metropolitan Government
Hong Kong, China	Hong Kong Census and Statistics Department	Hong Kong Energy End-use Data 2019	Hong Kong Energy End-use Data 2019	Hong Kong Energy End-use Data 2019
Singapore	Singapore Government Data Website	Singapore Department of Statistics	Singapore Department of Statistics	Singapore Energy Market Authority
City of Sydney	.id community, City of Sydney	.id community, City of Sydney	.id community, City of Sydney	Open Data, City of Sydney

9 Appendix B

Workshop Summary of the webinar held in Hong Kong, China on 23 March 2021.

10 References

[1] U. Nations, "World Urbanization Prospects 2018," 2018.

[2] APEC, "Sustainable Urban Development Report," 2018.

[3] APEC, "APERC Energy Demand and Supply Outlook | 7th Edition | Methodology," [Online].

[4] OECD, "GDP long-term forecast," 2020. [Online]. Available: https://data.oecd.org/gdp/gdp-long-term-forecast.htm.

[5] "Beijing Statistical Yearbook 2019," 2019. [Online]. Available: http://202.96.40.155/nj/main/2019-tjnj/zk/indexch.htm.

[6] "National Data," [Online]. Available: http://data.stats.gov.cn/easyquery.htm?cn=E0103.

[7] B. M. C. o. D. &. Reform, "關于公布 2015 年度北京市能效領跑者單位名單的通知," [Online]. Available: http://fgw.beijing.gov.cn/gzdt/tztg/202004/t20200417_1818402.htm.

[8] B. I. o. A. Design, "Design standard for energy efficiency of residential buildings (DB11/ 891-2020)," [Online]. Available: http://www.jianbiaoku.com/webarbs/book/156534/4560281.shtml.

[9] B. I. o. A. Design, "Design Standard for Energy Efficiency of Public Buildings (DB11/687-2015)," [Online]. Available: http://www.jianbiaoku.com/webarbs/book/9970/3198158.shtml.

[10] TERAO, "FROM CHINA GREEN BUILDING LABEL 2014 TO CHINA GREEN BUILDING LABEL 2019: WHAT ARE THE MAJOR CHANGES?," [Online]. Available: https://teraoasia.com/2019/08/27/china-green-building-label-2019/.

[11] 市住房城乡建设委, "北京市既有建筑节能改造专项实施方案," 8 10 2008. [Online]. Available: http://zjw.beijing.gov.cn/bjjs/xxgk/zcjd/318285/index.shtml.

[12] "Singapore Energy Statistic 2019, Energy Market Authority".

[13] IEA, "International Energy Agency," [Online]. Available: https://www.iea.org/.

[14] S. National Climate Change Secretariat, "Submission Of Singapore's Enhanced Nationally Determined Contribution And Long-Term Low-Emissions Development Strategy To The United Nations Framework Convention On Climate Change," [Online]. Available: https://www.nccs.gov.sg/media/press-release/submission-of-singapores-enhanced-nationally-determined-contribution-and-long-term-low-emissions-development-strategy.

[15] "HDB Annual Reports," Housing and Development Bureau, [Online]. Available: Housing and Development Bureau.

[16] B. a. C. Authority, "Regulatory Requirements for Existing Buildings," [Online]. Available: https://www1.bca.gov.sg/buildsg/sustainability/regulatory-requirements-for-existing-buildings.

[17] E. Singapore, "GreenGov.SG," [Online]. Available: https://www.e2singapore.gov.sg/programmes-and-grants/programmes/greengovsg.

[18] G. o. Singapore, "E2 Singapore - Buildings," [Online]. Available: https://www.e2singapore.gov.sg/overview/buildings.

[19] "Public Sector Taking the Lead in Environmental Sustainability (PSTLES)," Energy Efficient Singapore, [Online]. Available: https://www.e2singapore.gov.sg/programmes-and-grants/programmes/public-sector-taking-the-lead-in-environmental-sustainability. [Accessed 28 June 2021].

[20] "Building Energy Submission System," Building and Construction Authority, [Online]. Available: https://www.bca.gov.sg/bess/. [Accessed 28 June 2021].

[21] S. S. Hub, "Super low energy smart hub," [Online]. Available: https://www.sleb.sg/.

[22] BCA, "Singapore Green Building Masterplan," [Online]. Available: https://www1.bca.gov.sg/buildsg/sustainability/green-building-masterplans.

[23] "GovHK Hong Kong – the Facts (https://www.gov.hk/en/about/abouthk/facts.htm)".

[24] "Energy Saving Plan for Hong Kong's Built Environment 2015~2025+, Environmental Bureau, 2015".

[25] "Hong Kong Energy End-use Data 2019, Electrical and Mechanical Services Department".

[26] "Code of Practice for Overall Thermal Transfer Value in Buildings," [Online]. Available: https://www.bd.gov.hk/doc/en/resources/codes-and-references/code-and-design-manuals/OTTV1995_e.pdf.

[27] "Practice Note for Authorised Person, Registered Structural Engineers and Registered Geotechnical Engineers APP-67," 2019. [Online]. Available: https://www.bd.gov.hk/doc/en/resources/codes-and-references/practice-notes-and-circular-letters/pnap/APP/APP067.pdf.

[28] "Development BureauTechnical Circular NO. 5/2009, Environmental Bureau Circular Memorandum NO. 2/2009".

[29] "Development Bureau Technical Circular No. 2/2015 and Environment Bureau Circular Memorandum No. 3/2015 on Green Government Buildings".

[30] "Practice Note for Authorised Persons, Registered Structural Engineers and Registered Geotechnical Engineers APP-151," [Online]. Available: https://www.bd.gov.hk/doc/en/resources/codes-and-references/practice-notes-and-circular-letters/pnap/APP/APP151.pdf.

[31] The City of Sydney, "We've made the switch to 100% renewable energy," City of Sydney News, 1 July 2020. [Online]. Available: https://news.cityofsydney.nsw.gov.au/articles/weve-made-the-switch-to-100-renewable-energy. [Accessed 28 July 2020].

[32] The City of Sydney, "Energy Efficiency Master Plan: Improving Energy Productivity 2015-2030," City of Sydney, City of Sydney, 2015.

[33] The City of Sydney, "Environmental Action 2016-2021 Strategy and Action Plan," City of Sydney, 2017.

[34] The City of Sydney, "Electricity consumption - City of Sydney LGA," City of Sydney, 27 Oct 2017. [Online]. Available: https://data.cityofsydney.nsw.gov.au/datasets/electricity-consumption-city-of-sydney-lga-2005-06-to-2014-15. [Accessed 15 Apr 2020].

[35] The City of Sydney, "Sustainable Sydney 2030: Community strategic plan," [Online]. Available: https://www.cityofsydney.nsw.gov.au/strategies-action-plans/community-strategic-plan.

[36] Australian Building Codes Board (ABCB), "National Construction Code," Australian Building Codes Board (ABCB), 2019. [Online]. Available: www.abcb.gov.au. [Accessed 15 Apr 2020].

[37] Office of Environment and Heritage, NSW, "NSW Energy Efficiency Action Plan," 2013. [Online]. Available: https://www.environment.nsw.gov.au/resources/energyefficiencyindustry/130588-energy-efficiency-action-plan.pdf. [Accessed 20 July 2020].

[38] Green Building Council Australia, "What is Green Star," 2021. [Online]. Available: https://new.gbca.org.au/rate/green-star/. [Accessed 28 July 2020].

[39] National Australian Built Environment Rating System, "National Australian Built Environment Rating System," National Australian Built Environment Rating System, 2020. [Online]. Available: https://www.nabers.gov.au/. [Accessed 15 Apr 2020].

[40] City of Sydney, "The Better buildings Partnership," City of Sydney, 2011. [Online]. Available: https://www.betterbuildingspartnership.com.au/about/. [Accessed 15 Apr 2020].

[41] City of Sydney, "Better Buildings Partnership Annual Report of FY2016," City of Sydney, City of Sydney, 2016.

[42] Department of Planning, Industry and Environment, NSW Government, "BASIX," [Online]. Available: https://www.basix.nsw.gov.au/iframe/90-about-basix/basix-and-the-development-process.html. [Accessed 28 July 2020].

[43] A. Government, "Commercial Building Disclosure (CBD) Program," [Online]. Available: https://www.cbd.gov.au/program/overview/overview.

[44] Independent Pricing and Regulatory Tribunal, "Energy Savings Scheme," [Online]. Available: https://www.ess.nsw.gov.au/Accredited-Certificate-Providers. [Accessed 20 November 2020].

[45] National Australian Built Environment Rating System, "NABERS Annual Report 2018/19," [Online]. Available: https://nabers.info/annual-report/2018-2019/life-of-program-statistics/. [Accessed 5 May 2020].

[46] C. o. Sydney, "Planning for net zero energy buildings," 7 6 2021. [Online]. Available: https://www.cityofsydney.nsw.gov.au/surveys-case-studies-reports/planning-for-net-zero-energy-buildings.

[47] Statistics of Tokyo, "経済活動別都内総生産（名目） ," [Online]. Available: https://www.toukei.metro.tokyo.lg.jp/keizaik/kk-houkoku.htm. [Accessed 16 July 2020].

[48] Cabinet Office, "経済活動別県内総生産（名目）," [Online]. Available: https://www.esri.cao.go.jp/jp/sna/data/data_list/kenmin/files/contents/main_h26.html. [Accessed 16 July 2020].

[49] Statistics of Tokyo, "地域別人口," [Online]. Available: https://www.toukei.metro.tokyo.lg.jp/tnenkan/2017/tn17qa020300.xls. [Accessed 30 July 2020].

[50] "Bureau of Environment, Final Energy Consumption and Greenhouse Gas Emissions in Tokyo," [Online]. Available: https://www.kankyo.metro.tokyo.lg.jp/climate/zenpan/emissions_tokyo.html.

[51] Tokyo Metropolitan Government, "Creating a sustainable city," September 2019. [Online]. Available: https://www.kankyo.metro.tokyo.lg.jp/en/about_us/index.files/creating_a_sustainable_city_2019_e.pdf. [Accessed 3 August 2020].

[52] K. M. Tokyo, "Tokyo ZEV Promotion Strategy," [Online]. Available: https://www.kankyo.metro.tokyo.lg.jp/en/about_us/zero_emission_tokyo/strategy.files/Full-ver.ZEV-strategy.pdf.

[53] K. M. Tokyo, "Green Building Program," [Online]. Available: kankyo.metro.tokyo.lg.jp/en/climate/build.files/TMGs_Green_Building_Program_overview.pdf.

[54] "BEI web-based calculation program," [Online]. Available: https://www.kenken.go.jp/becc/.

[55] Bureau of Environment, Tokyo Metropolitan Government, "Results of Tokyo Cap and Trade Program in the 9th Fiscal Year," [Online]. Available: https://www.kankyo.metro.tokyo.lg.jp/en/climate/index.files/9thYearResult.pdf. [Accessed 16 July 2020].

[56] B. o. E. T. M. Government, "Zero Emission Tokyo Strategy," 27 12 2019. [Online]. Available: https://www.kankyo.metro.tokyo.lg.jp/en/about_us/zero_emission_tokyo/strategy.html.

[57] NYC Mayor's Office of Sustainability, "Inventory of New York City Greenhouse Gas Emissions," NYC.gov, 2005. [Online]. Available: https://nyc-ghg-inventory.cusp.nyu.edu/#inventories. [Accessed 15 Apr 2020].

[58] The City of New York Office of The Mayor New York, "Executive Order No. 26 - Climate Action Executive Order," 2 June 2017. [Online]. Available: https://www1.nyc.gov/assets/home/downloads/pdf/executive-orders/2017/eo_26.pdf. [Accessed 4 Aug 2020].

[59] New York League of Conservation Voters Education Fund, "Getting NYC to 80x50," 6 September 2017. [Online]. Available: https://nylcvef.org/getting-nyc-80x50/. [Accessed 4 August 2020].

[60] NYC Mayor's Office of Sustainability, "New York City's Roadmap to 80x50," NYC Mayor's Office of Sustainability, New York City, 2014.

[61] NYC Mayor's Office of Sustainability, "One City Built to Last Technical Working Group Report: Transforming New York City Buildings for a Low-carbon Future," NYC Mayor's Office of Sustainability, New York City, 2016.

[62] National Oceanic and Atmospheric Administration, National Weather Service, "Monthly Cooling and Heating Degree Day Data at New York State," New York State Energy Research and Development Authority, 8 Apr 2020. [Online]. Available:

https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Weather-Data/Monthly-Cooling-and-Heating-Degree-Day-Data. [Accessed 15 Apr 2020].

[63] Urban Green Council, "New York City's Energy and Water Use 2014 and 2015 Report," NYC Mayor's Office of Sustainability, New York City, 2017.

[64] NYC May's Office, "Official Website of the New York City," New York City. [Online].

[65] NYC Mayor's Office of Sustainability, "Carbon challenge," 2020. [Online]. Available: https://www1.nyc.gov/site/sustainability/our-programs/carbon-challenge.page. [Accessed 7 May 2020].

[66] Division of Building Standards & Codes, Department of State, New York State, "NYS Uniform Code and Energy Code Update," New York State, 2 Sep 2016. [Online]. Available: https://www.dos.ny.gov/DCEA/CodeUpdate.html. [Accessed 15 Apr 2020].

[67] New York City, "NYC Energy Conservation Code," NYC Buildings, 2020. [Online]. Available: https://www1.nyc.gov/site/buildings/codes/energy-conservation-code.page. [Accessed 10 October 2020].

[68] C. Halfnight, "New Energy Code Means Big Efficient," ACEEE and Urban Green Council, 14 July 2016. [Online]. Available: https://www.urbangreencouncil.org/content/news/new-energy-code-means-big-efficiency-gains-city-and-state. [Accessed 20 October 2020].

[69] NYC Buildings, "Energy Audits and Retro-commissioning," 2020. [Online]. Available: https://www1.nyc.gov/site/buildings/business/energy-audits-and-retro-commissioning.page. [Accessed 12 September 2020].

[70] Urban Green Council, "Local Law 87: Energy Audits & Retro-commissioning (Version 9)," March 2015. [Online]. Available: https://urbangreencouncil.org/sites/default/files/ll87_presentation_v9_15.05.19.pdf. [Accessed 28 July 2020].

[71] NYC Mayor's Office of Sustainabilitiy, "LL88: Lighting Upgrades & sub-metering," 2020. [Online]. Available: https://www1.nyc.gov/html/gbee/html/plan/ll88.shtml. [Accessed 20 October 2020].

[72] NYC Mayor's Office of Long-Term Planning & Sustainability, "plaNYC New York City Local Law 84 Benchmarking Report," September 2014. [Online]. Available: http://www.nyc.gov/html/planyc/downloads/pdf/publications/2014_nyc_ll84_benchmarking_report.pdf. [Accessed 15 November 2020].

[73] US Department of Energy, "New York City Benchmarking and Transparency Policy Impact Evaluation Report," May 2015. [Online]. Available: http://www.newportpartnersllc.com/PDFs/NewportPublications/DOE_NYC_Benchmarking_Transparency_Policy_Impact_Evaluation_May2015.pdf. [Accessed 12 July 2020].

[74] NYC Department of Buildings, "Benchmarking," NYC Department of Buildings, 31 Oct 2016. [Online]. Available: https://www1.nyc.gov/site/buildings/business/benchmarking.page. [Accessed 15 Apr 2020].

[75] Green Bank Network, "New York Green Bank," 2 June 2020. [Online]. Available: https://greenbanknetwork.org/ny-green-bank/. [Accessed 15 July 2020].

[76] New York State Energy Research & Development Authority, "EmPower New York," 2015. [Online]. Available: https://www.nyserda.ny.gov/All-Programs/Programs/EmPower-New-York. [Accessed 19 June 2020].

[77] NYC Department of Housing Preservation and Development, "Green Housing Preservation Program," Community Retrofit NYC, 2015. [Online]. Available: https://www1.nyc.gov/site/communityretrofitnyc/green-housing/green-housing-preservation-program.page. [Accessed 15 Apr 2020].

[78] Department of Public Service, New York State, "Energy Efficiency Portfolio Standard," 3 May 2020. [Online]. Available: http://www3.dps.ny.gov/W/PSCWeb.nsf/All/06F2FEE55575BD8A852576E4006F9AF7?OpenDocument. [Accessed 7 May 2020].

[79] R. Craft, "Energy Efficiency & Distributed Generation: The implications for utilities, their business model and regulatory structure," 18 November 2014. [Online]. Available: https://investor.conedison.com/static-files/e3e508c1-3a77-422f-aca2-0e0c9ae0fdfb. [Accessed 7 May 2020].

[80] Press Office of New York City, "Mayor de Blasio Launches Retrofit Accelerator, Providing Key Support for Buildings to go Green as NYC Works Toward 80X50," 28 September 2015. [Online]. Available: https://www1.nyc.gov/office-of-the-mayor/news/651-15/mayor-de-blasio-launches-retrofit-accelerator-providing-key-support-buildings-go-green-as. [Accessed 7 May 2020].

[81] Department of labour, New York State, "Local Area Unemployment Statistics Program," March 2020. [Online]. Available: https://labor.ny.gov/stats/laus.asp. [Accessed 7 May 2020].

[82] N. M. C. M. Jean-Michel Cayla, "The role of income in energy consumption behaviour: Evidence from French households data," *Energy Policy,* vol. 39, no. 12, pp. 7874-7883, 2011.

[83] Seoul Metropolitan Government, "2018 에너지백서," [Online]. Available: http://news.seoul.go.kr/env/archives/504122.

[84] "8th Basic Plan for Long-term Electricity Supply and Demand in 2017, Ministry of Trade, Industry and Energy".

[85] KLRI, "ENERGY USE RATIONALIZATION ACT," [Online]. Available: https://elaw.klri.re.kr/eng_mobile/viewer.do?hseq=40181&type=sogan&key=13.

[86] KLRI, "GREEN BUILDINGS CONSTRUCTION SUPPORT ACT," 2019. [Online]. Available: https://elaw.klri.re.kr/eng_mobile/ganadaDetail.do?hseq=46773&type=abc&key=GREEN%20BUILDINGS%20CONSTRUCTION%20SUPPORT%20ACT&param=G.

[87] MOTIE, "Korea Energy Master Plan," [Online]. Available: https://www.motie.go.kr/common/download.do?fid=bbs&bbs_cd_n=72&bbs_seq_n=209286&file_seq_n=2.

[88] K. E. Agency, "Building Energy Code Compliance," 2015. [Online]. Available: https://dco.energy.or.kr/renew_eng/energy/buildings/worksheet.aspx.

[89] "FRAMEWORK ACT ON LOW CARBON, GREEN GROWTH, Korean Legislation Research Institute".

[90] KEMCO, "Energy Performance Index," [Online]. Available: www.kemco.or.kr/building/v2/.

[91] K. E. Agency, "E Standby Performance," [Online]. Available: https://eep.energy.or.kr/business_introduction/present_condition.aspx.