Assessment of the impact of climate change on current and future requirements for heating and cooling of office buildings in Japan

by

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3 September 2012

A Dissertation submitted in part fulfilment of the

Degree of Master of Science Built Environment:

Environmental Design and Engineering

Bartlett School of Graduate Studies

University College London

ACKNOWLEDGMENTS

From the Bartett School of Graduate Studies, I deeply appreciate my supervisor Dr. Ben Croxford, who encouraged me throughout the process. His critical advice and guidance have always been helpful. I'm also profoundly grateful to Dr. Anna Mavrogianni and Ms. Stephanie Gauthier for providing their valuable support.

From the Graduate School of Science and Engineering, Kagoshima University in Japan, I would like to express my gratitude to Assoc. Prof. Kazuhiro Soga, who gave me useful weather files and resources.

I would also like to thank all of my MSc EDE classmates and staff members for their friendship and encouragement throughout this study year.

Finally, this dissertation is dedicated to my beloved wife, Naoko, who has always stood by me. Without her dedicated and heartfelt support this would not have been possible.

ABSTRACT

Global climate change is making the mild Japanese climate significantly warmer, which is expected to have a substantial impact on building energy consumption (MEXT et al. 2009). This dissertation reviews the recent policies, rules, regulations, and measures which can contribute to reducing energy use for office buildings in Japan. The potential impacts of climate change on the cooling and heating loads for offices are also investigated by means of thermal analysis simulations at three sites over three periods; 1981-2000 (1990s), 2031-2050 (2040s), and 2081-2100 (2090s).

This study reveals that under the IPCC's A2 carbon emission scenario, substantial reductions of energy consumption are expected if the full measures that are currently available are implemented. However, the reduction rates can change in each location and each period due to regional climate characteristics and climate change. In Sapporo, the expected reduction rate would be better; 34.7 % in the 1990s, 39.3 % in the 2040s, and 43.4 % in the 2090s. In contrast, in Tokyo and Naha, it will be worse; 58.6 % and 50.2 % in the 1990s, 53.9 % and 41.0 % in the 2040s, and 45.0 % and 32.3 % in the 2090s, respectively. Additionally, sufficient reductions in the heating/cooling loads and energy use do not necessarily mean that the CO_2 emissions reduction targets will be achieved. Because electricity conversion factors could be worse due to revisions of the national energy plan triggered by the Fukushima nuclear accident would reduce the dependency on nuclear power in the future.

Meanwhile, around one-third of the office building stock in the chief cities of Japan dates from before 1981 (JREI 2011). This means that Japan still has a vast quantity of old offices without sufficiently effective energy measures. In addition, measures introduced in the study are typical. Moreover, technological improvements in the future are not fully considered. With more specific and up-to-date technologies, much greater energy reductions could be completed. Furthermore, a brief economic analysis suggests that these measures could be competitive with nuclear power generation, especially in the future.

Overall, office buildings in Japan have enormous potential to reduce energy requirements and related CO_2 emissions without resorting to nuclear power generation. In other words, reducing nuclear dependency could be covered by promoting effective energy saving measures in building sectors in terms of both CO_2 emissions and economical aspects.

CONTENTS

List of Figures and Tables

List of Abbreviations

ACENR	Advisory Committee on Energy and Natural Resources
AIJ	Architectural Institute of Japan
AMeDAS	Automated Meteorological Data Acquisition System
ANRE	Agency for Natural Resources and Energy
APF	Annual Performance Factor
BEMS	Building Energy Management System
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CEC	Coefficient of Energy Consumption
CIBSE	Chartered Institution of Building Services Engineers
COP	Coefficient of Performance
CPI	Consumer Price Index
EA	Expanded AMeDAS
ECCJ	Energy Conservation Center, Japan
EEC	Energy and Environment Council
ESCO	Energy Service Company business
FEPC	Federation of Electric Power Companies of Japan
FY	Fiscal Year
GBP	Great Britain Pound
HVAC	Heating, Ventilation, and Air-Conditioning
IPCC	Intergovernmental Panel on Climate Change
JaGBC	Japan GreenBuild Council
JMA	Japan Meteorological Agency
JPY	Japanese Yen
JREI	Japan Real Estate Institute
JSBC	Japan Sustainable Building Consortium
METI	Ministry of Economy, Trade and Industry
MEXT	Ministry of Education, Culture, Sports, Science and Technology
MIC	Ministry of Internal Affairs and Communications
MLIT	Ministry of Land, Infrastructure and Transport
MOE	Ministry of the Environment
NPU	National Policy Unit
PAL	Perimeter Annual Load
RCM20	Regional Climate Model 20
RH	Relative Humidity
SRES	Special Report on Emissions Scenarios
TAS	Thermal Analysis Software
TMY	Typical Meteorological Year
TRY	Test Reference Year
WCED	World Commission on Environment and Development
ZEB	Zero Energy Buildings
1990s	1981-2000
2040s	2031-2050
2090s	2081-2100

NOTES

The exchange rate used in the dissertation is 1GBP = 125.75 JPY. This was the official exchange rate on 24th Aug 2012, provided by the Citibank Japan.

Word count: 10,938

1. INTRODUCTION

The most widely held definition for sustainable development is that of the World Commission on Environment and Development (WCED 1987), which says that such development: “meets the needs of the present without compromising the ability of future generations to meet their own needs.” In other words, sustainable development attempts to preserve natural resources so that the needs of future generations will be provided for, minimizes greenhouse gasses, and reduce global warming.

Recently, interest in sustainability has grown exponentially in conjunction with compelling scientific evidence on the contributions of anthropogenic factors to global climate. Global climate change is making the mild Japanese climate significantly warmer, which is expected to have a substantial impact on energy consumption and related CO_2 emissions (MEXT et al. 2009). The Japanese government ratified the Kyoto Protocol in 2002 and has been attempting to create a low carbon society. As a result, in 2008 the Prime Minister of Japan released a new vision entitled “Towards a Low-Carbon Society” which includes setting up a long-term target to reduce 60-80 % CO_2 emissions by 2050 from the 1990 level (“ 2050 Japan Low-Carbon Society” scenario team 2008).

In Japan in recent years, energy consumption in the commercial sector has increased, especially in office buildings for heating and cooling (ANRE 2011a, ECCJ 2011b). Thus, promoting a reduction of heating and cooling demand and related CO_2 emissions in offices is a major task for attaining the national target. It is also important to consider the influence of expected climate change in space heating and cooling. Thought over the life of the buildings, office buildings should be designed considering these current influences, as 2050 is close at hand. However, actual conditons are such that these influences are not considered carefully during the design stage.

Additionally, Japan’s energy policy is facing a major turning point. The Great East Japan Earthquake and accident at the Fukushima Daiichi Nuclear Power Station laid bare the risks associated with nuclear power and exposed the vulnerabilities of and strains on Japan’s energy supply system. There are discussions toward equation of Japan’s future energy policy that pay sufficient attention to controlling demand, though current policy places priority on the supply side (ACENR 2011). Thus, reducing energy consumption in office buildings, which is one of the major fields on the demand side, would be required more strictly in the near future.

This study will review the recent policies, rules, and regulations which can contribute to reducing energy use in office buildings. In addition, the results of a computational study on the energy consumption and related CO_2 emissions for heating and cooling of offices in several sites throughout Japan, currently and in the future, will be presented. The aim of the dissertation is to develop a detailed analysis of changes in building space cooling and heating due to climate change, and to propose effective measures such as refurbishment technologies that could reduce the CO_2 emissions of office buildings in Japan by 70% by the year 2050.

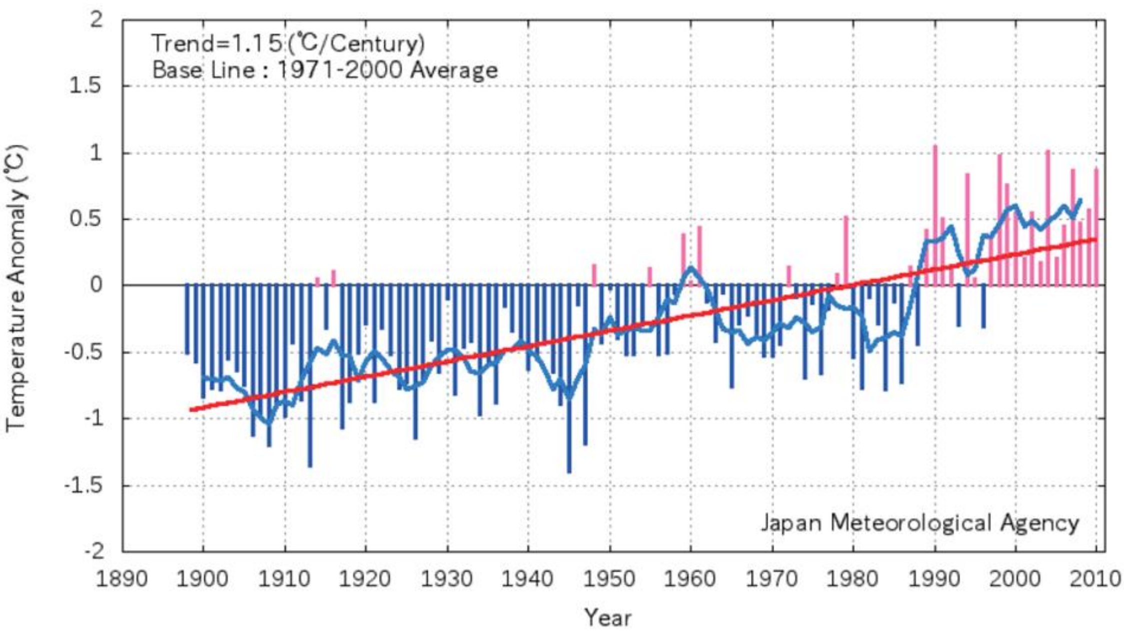
The dissertation is structured as follows:

- Chapter 2 contains background on the climate change and energy consumption trends in Japan, as well as an overview of existing studies on the impact of climate change on office buildings.
- Chapter 3 includes a review of the current policies, rules, regulations and measures for reducing energy consumption in offices in Japan.
- Chapter 4 introduces the weather files and the computer simulation models employed as methodological approaches.
- Chapter 5 includes the results of a computational study and evaluates their significance, as well as economic aspects.
- Chapter 6 concludes with the study and summarizes the expected potential for CO_2 emissions reductions in future Japanese offices.

2. BACKGROUND

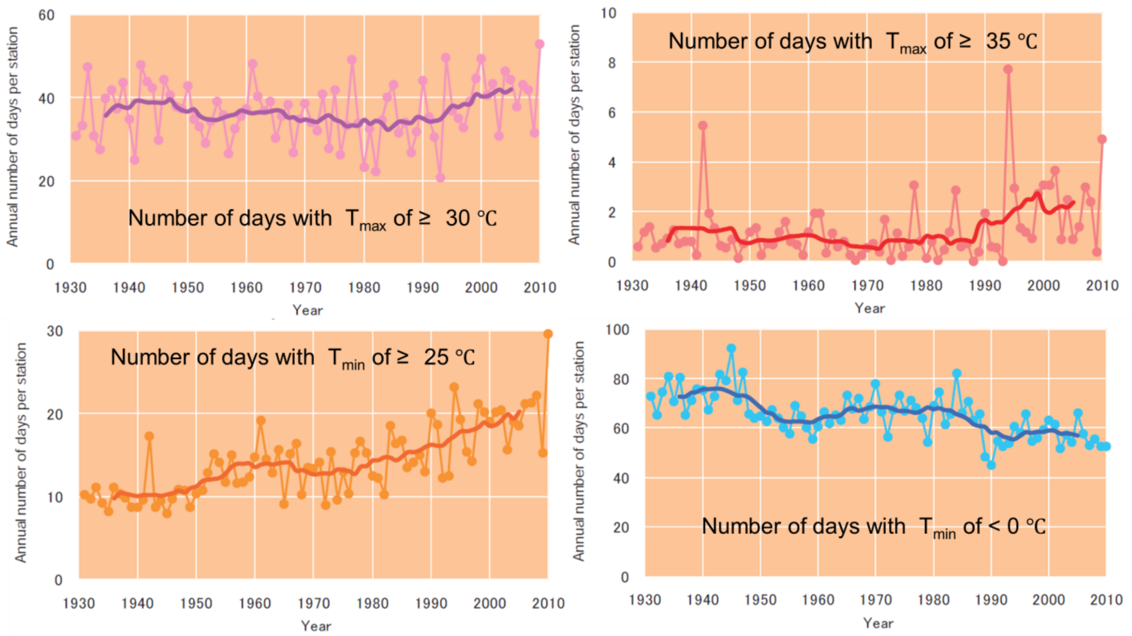
2.1. Climate Change

The fourth assessment report published by the Intergovernmental Panel on Climate Change (IPCC 2007) declared that “warming of the climate system is unequivocal.” It also stated that “most of the observed increase in global mean temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.”. Throughout the 20th century, Japan experience temperature increases of almost 1.15 °C, with the period after 1990 being the hottest since records began (Fig 2.1). As temperatures grow, the annual number of days with maximum temperatures (T_{max}) of $\geq$ 30 °C, days with T_{max} of $\geq$ 35 °C, and days with minimum temperatures (T_{min}) of $\geq$ 25 °C increased, while that of days with T_{min} of < 0 °C decreased (Fig 2.2-2.3).



The blue line shows the five-year running mean. The red line is the long-term trend.

Fig 2.1 Annual surface temperature anomalies from 1898 to 2010 in Japan (JMA 2011)



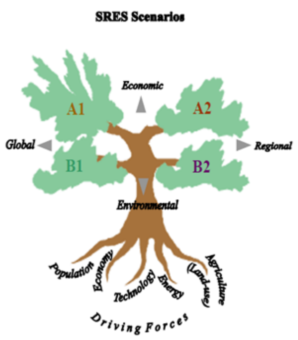
The thin line shows the annual number of days. The heavy line shows the 11-year running mean.

Fig 2.2 Changes in the annual number of days with T_{max} of ≥ 30 °C, T_{max} of ≥ 35 °C, T_{min} of ≥ 25 °C, and T_{min} of < 0 °C in Japan (JMA 2011)

Number of days with T_{max} of ≥ 30 ℃		
Trend +0.30 day/10 years	Mean for 1931-1960	36.5 days
	Mean for 1981-2010	37.5 days
Number of days with T_{max} of ≥ 35 ℃		
Trend +0.16 day/10 years	Mean for 1931-1960	1.0 days
	Mean for 1981-2010	1.8 days
Number of days with T_{min} of ≥ 25 ℃		
Trend +1.37 day/10 years	Mean for 1931-1960	11.0 days
	Mean for 1981-2010	17.6 days
Number of days with T_{min} of < 0 ℃		
Trend -2.36 day/10 years	Mean for 1931-1960	69.8 days
	Mean for 1981-2010	59.4 days

Fig 2.3 Long-term trend of the annual number of days with T_{max} of ≥ 30 °C, T_{max} of ≥ 35 °C, T_{min} of ≥ 25 °C, and T_{min} of < 0 °C in Japan (JMA 2011)

The IPCC provided results for different emission scenarios explicitly in their report. The scenarios are roughly divided into four categories: two categories (speed of economic growth: fast and slow) times two categories (level of the progress of globalization). The A1 scenario family is categorized into three sections based on choices of technological innovations in energy systems (Fig 2.4). The global and Japan temperature by the end of the 21st century is expected to keep increasing as the CO_2 concentration rises. Fig 2.5 indicates that in Japan under the A2, A1B, and B1 scenarios, the temperature will increase by 4.0 °C , 3.2 °C, and 2.1 °C, respectively, throught the 21st century. This means that under all scenarios, the temperature increase in Japan will be higher than the global average (by 3.4 °C , 2.8 °C, and 1.8 °C, respectively).



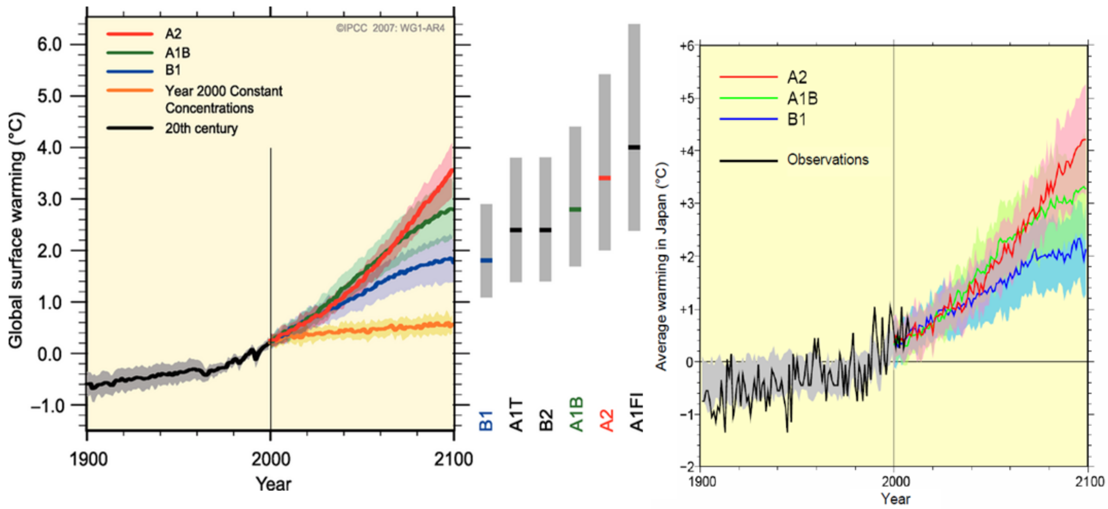
A: Society that emphasizes economic growth
A1FI: emphasis on fossil energy sources
A1T: emphasis on non-fossil energy sources
A1B: emphasis on a balance between all energy sources

B: Sustainable society in harmony with the environment

1: Case in which regional disparity narrows and globalization advances

2: Case in which regional uniqueness intensifies

Fig 2.4 Four categories in the Special Report on Emissions Scenarios (SRES) (IPCC 2000, MEXT et al. 2009)



Shading denotes the ±1 standard deviation range of individual model annual averages. The grey bars at the centre indicate the best estimate (solid line within each bar) and the likely range of global warming.

Fig 2.5 Projected mean temperature change of the earth and Japan (IPCC 2007, MEXT et al. 2009)

2.2. Energy in Japan

Energy consumption in Japan can be divided into three sectors, namely the industrial sector, the commercial/residential sector, and the transport sector. Fig 2.6 shows that the two global oil crises of the 1970s were turning points which saw Japan achieve considerable success in energy conservation. In the industrial sector, the amount of energy use has remained roughly about the same level after the oil crises. On the other hand, in both the commercial/residential and the transport sectors, the amount has dramatically grown. Especially in the commercial sector, comprising offices/buildings of business and service industry, it has increased most rapidly among all sectors. This sector consumes energy almost as three times as at the time of the first oil crisis.

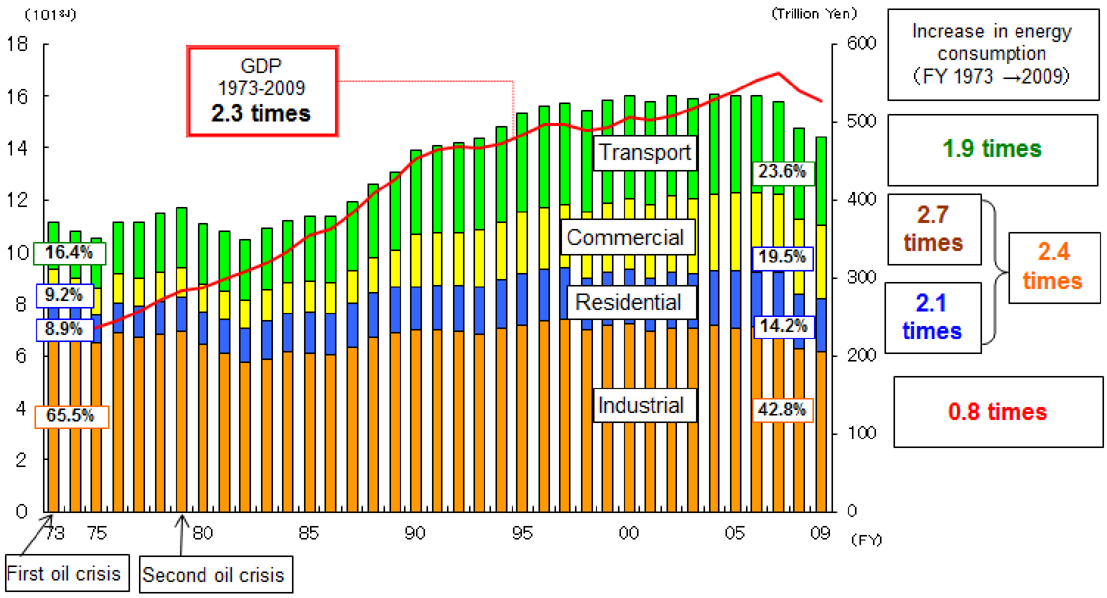


Fig 2.6 Trends in energy consumption and GDP in Japan (ANRE 2011a)

Fig 2.7 shows that recently offices have been consuming the largest amount of energy in the commercial sector. The causes for this include the increase in the total floor area and the accompanying increase in air-conditioning. For example, both energy use and floor area in 2009 increased by around 40 % compared to 1990 (Fig 2.8). The Japan Low-Carbon Society project proposed reducing energy demand by 40 % (relative to the 2000 value) in the commercial sector to achieve the proposed 70 % CO_2 emissions reduction by 2050. Moreover, studies show that between 80 % and 85 % of a building's life cycle energy demand occurs during its operating phase (Sharma et al. 2011, Suzuki and Oka 1998). Furthermore, more than 40 % of the total energy consumption in the use or occupation phases comes from space heating and cooling (Fig 2.9). Thus, promoting a decrease in heating/cooling demand and the related CO_2 emissions in offices is required.

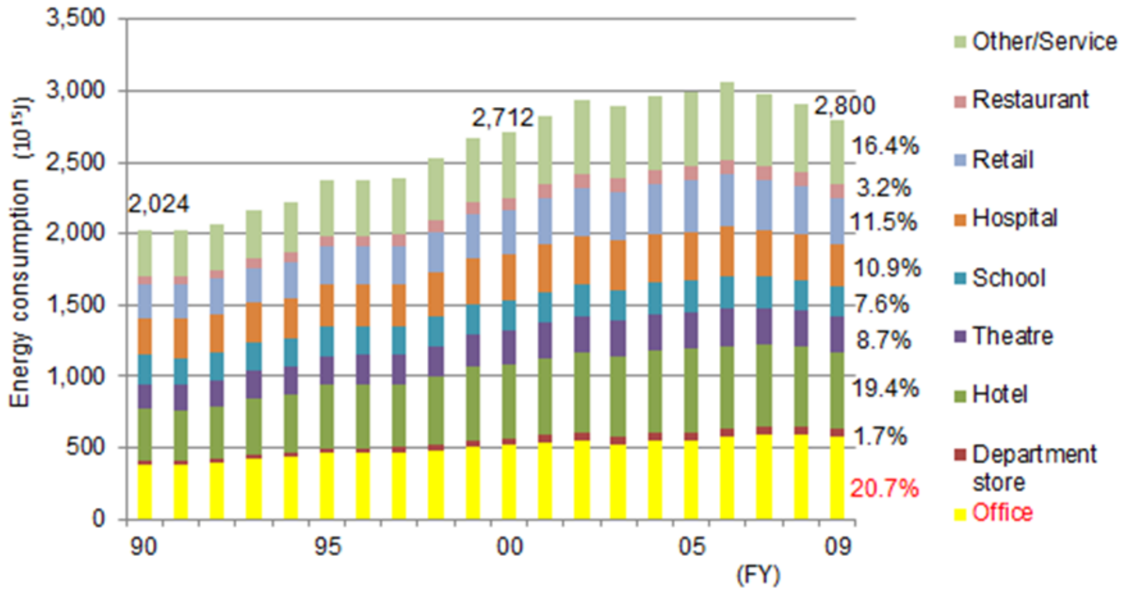


Fig 2.7 Trends in energy consumption by sector within the commercial sector in Japan (ANRE 2011a)

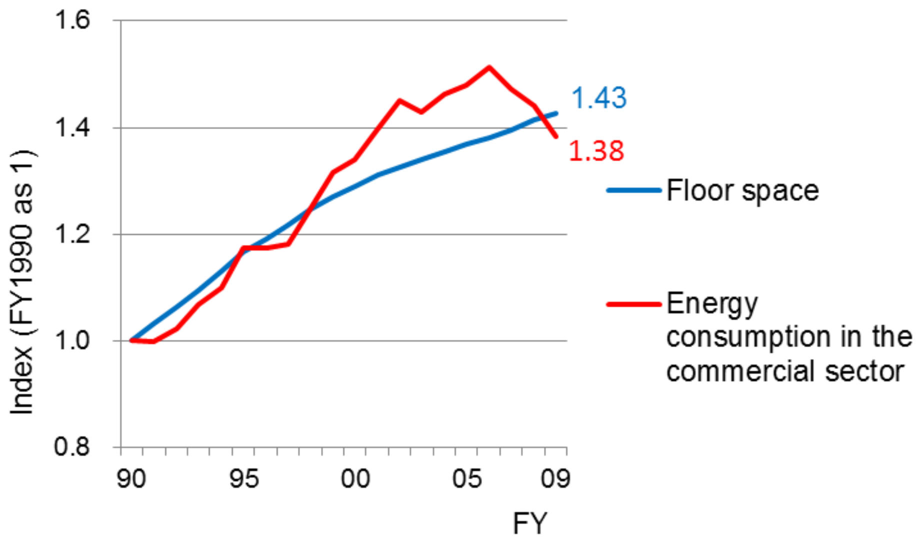


Fig 2.8 Trends in the total energy consumption in the commercial sector and floor space in Japan (ANRE 2011a)

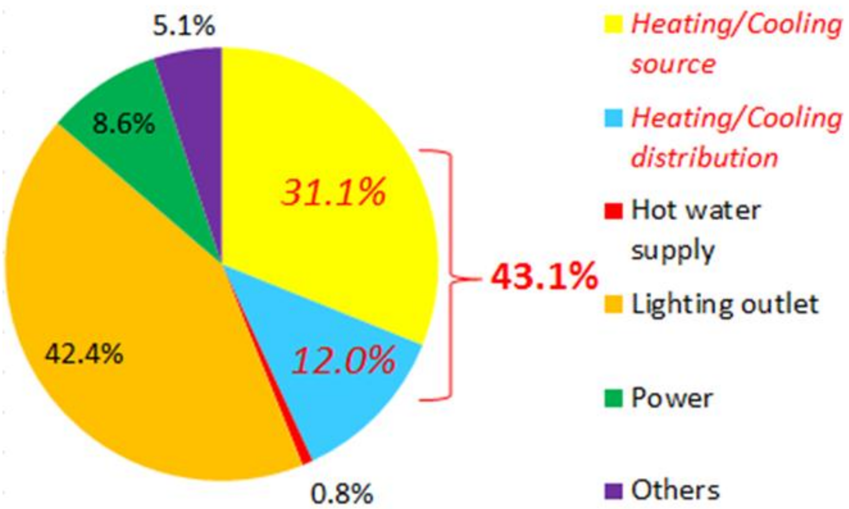


Fig 2.9 Energy consumption percentage of a tenant building with a rentable ratio of more than 60 % in Japan (ECCJ 2011a)

Fig 2.10 presents the primary energy consumption per unit of GDP for different countries worldwide and is normalized against Japan's figure for this. This shows that Japan's energy efficiency is higher than the other countries, and there is less potential to reduce energy consumption in Japan than in the other countries. Thus in order to reduce energy consumption in Japanese offices, the original measures which other contries have not perfectly utilized should be adopted.

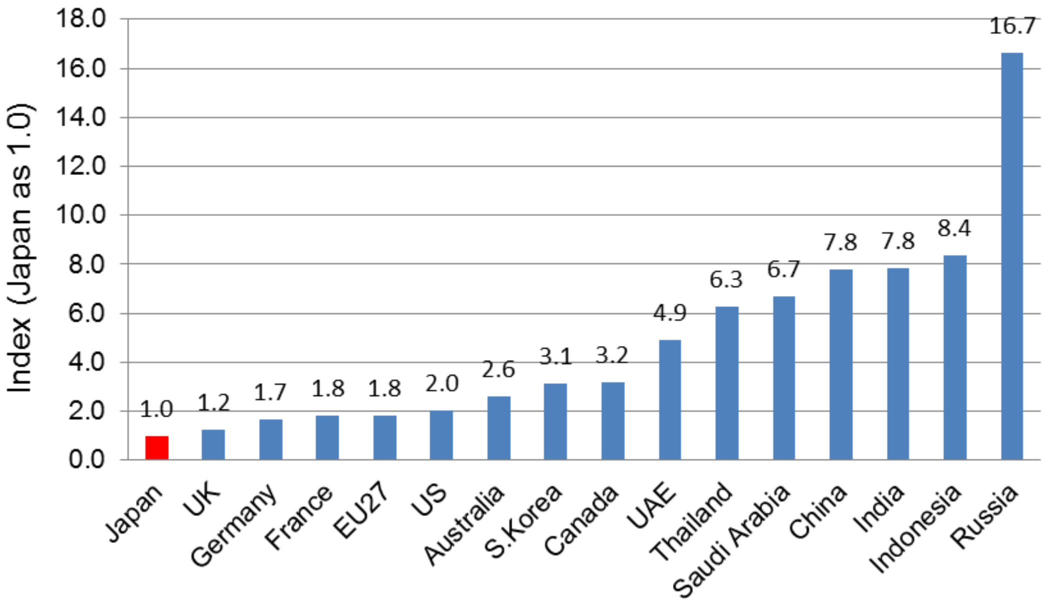


Fig 2.10 Primary energy consumption per unit of GDP of countries (2008) (ANRE 2011a)

In addition, the revisions of the national energy plan triggered by the Fukushima nuclear accident would reduce dependence on nuclear power in the future, although at present around 30 % of electricity is generated by nuclear power (Fig 2.11). This might lead to significantly increased electricity conversion factors (kgCO_2/kWh).

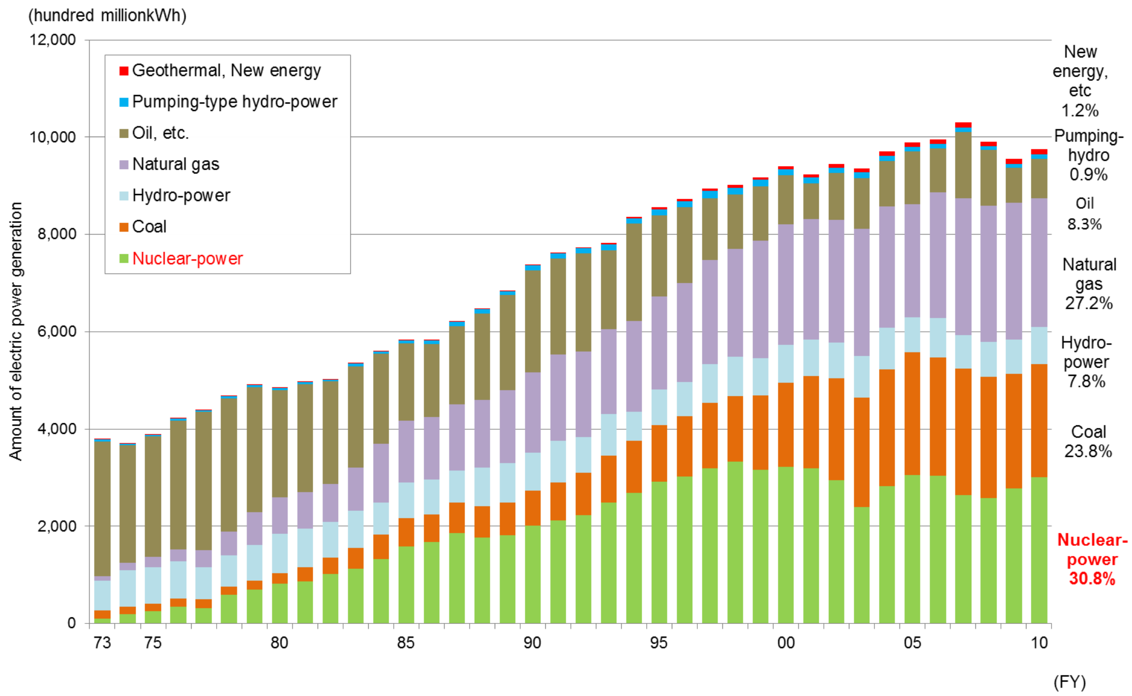


Fig 2.11 Trends in the amount of electric power generated in Japan (for general electricity business) (ANRE 2011a)

2.3. Overview of the Existing Studies on the Impact of Climate Change on Office Buildings

The intent here is to provide an overview of the existing studies on the impact of climate change on office buildings and constructing design weather data for future climates. The purpose in this is to highlight some relevant studies which have investigated how certain physical factors in office buildings affect the energy consumption and related CO_2 emissitions, and how they interect with each other.

There have been a number of studies on the impact of climate change on energy use in office buildings worldwide. Additionally, work has started in many countries to develop weather files suitable for building energy demand simulations that take into consideration future climate change scenarios. They were largely building-specific and adopted either the degree-days method (e.g. in Switzerland (Frank 2005) and the US (Belzer et al. 1996)) or building energy simulation techniques using modified typical meteorological/reference year (TMY/TRY) hourly weather data (e.g. in Australia (Sheppard et al. 1997, Guan 2009), the UK (Day et al. 2009), and the US (Scott et al. 1994)). In general, to construct the weather years, the typical values from each month are selected from a long period of weather data and combined. These studies generally show that cooling loads would increase while heating loads would decrease in a warming climate. Specific building location, building characteristics and internal factors have a large impact on building energy demands (Aebischer et al. 2007, Crawley 2008, Jenkins et al. 2008). Some efficient measures to reduce energy use have been presented such as super insulation, thermal mass, night cooling, and reducton of internal heat gains (CIBSE 2005, Frank 2005, Jenkins et al. 2009). While some researchers have studied the effects of total energy consumption in office buildings on global warming, few have examined how each strategy is likely to impact reductions in energy demand in future offices, especially in Japan. Moreover, few have shown the most effective measures and their impact to get the target reduction of CO_2 in future Japanese offices.

In Japan, the current hourly weather data (1981-2000), which is similar to TMY/TRY, have been constructed (Soga and Akasaka 2004) and this was utilized in this study. Two types of future weather data (2031-2050, 2081-2100), which are based on the A2 climate change scenario of the IPCC, were also constructed by Kubota and Soga (2010), and then Kokuryo et al. (2010) and Kubota et al. (2010) calculated the cooling/heating loads in typical offices at three sites (Sapporo, Tokyo, and Naha) over three periods (1981-2000, 2031-2050, and 2081-2100). They refuted the notion that cooling loads will increase while heating loads will decrease as the years go by at each site. In Sapporo, the decrease in the heating loads could be more than the increase in the cooling loads, and consequently the total energy use will decrease. In Tokyo and Naha, the increase in the cooling loads could be more than the decrease in the heating loads, and consequently the total energy use will increase. In Naha, the increase in total energy consumption will be much larger than that in Tokyo. In addition, they proved that temperature is the most important factor in cooling/heating loads. After this, these future weather data were improved by Soga (2011). In this study, these latest current and future weather data were utilized. In Chapter 4, the approach to constructing these data will be introduced.

3. BUILDING ENERGY CONSERVATION POLICIES, LAWS, AND MEASURES IN JAPAN

The main reason why in Japan the industrial sector has performed much better than the other sectors would be the fact that relevant regulations and measures were primarily focused on promoting energy efficiency in the industrial sector (Sato 1999). As such, the application of an appropriate regulatory framework and supporting measures in the commercial sector should lead to energy savings in office buildings. In this chapter, some main building energy conservation policies, rules, and measures in Japan will be introduced.

3.1. Basic Energy Plan

In 2010, the government released the revised Basic Energy Plan. The basic perspective of this revised plan is that the energy supply and demand structure must be reformed further in order to strengthen energy security, address global warming, and at the same time achieve economic growth centred on energy. In order to reduce CO_2 generated by energy use in the commercial (business) sector, the spread of net Zero Energy Buildings (ZEB) will be promoted by carrying out research and development aimed at improving the efficiency of equipment and lighting, reinforcing and mandating energy conservation standards for buildings, and giving incentives for the adaption of energy conservation equipment and high-efficiency air conditioners.

There are discussions toward reviewing the current Basic Energy Plan from its zero base and calculating a new plan to include a new energy mix and measures for its realization. This discussion is based on the enormous damage due to the Fukushima nuclear accident (ACENR 2011). Particularly with regard to nuclear power, the nation's highest priority must be to ensure the public's safety. Noting that the discussion has not reached a conclusion, the following basic directions have already been seen (Fig 3.1).

(1) Fundamental reinforcement of energy and electricity conservation measures by considering reforming user behaviour and social infrastructure
(2) Accelerated development and use of renewable energies to the maximum degree possible
(3) Effective utilization of fossil fuels, beginning with a shift to natural gas, while giving maximum consideration to the environmental burden
(4) Reduced dependency on nuclear wherever possible
(three options regarding the amount of electricity generated by nuclear power are proposed; 0 %, 15 %, or 20-25 %)

Fig 3.1 Basic directions of new Basic Energy Plan (ACENR 2011, NPU 2012)

3.2. Law Concerning the Rational Use of Energy

3.2.1. Instructions for specified business operators

The Energy Conservation Law, which was revised in 2002, aims to extend measures targeting the industrial sectors through to the commercial sectors such as offices buildings. In 2008, the regulatory structure was changed from regulating each workplace to regulating the whole company. Companies that consume large amount of energy (the total consumption of fuel and electricity is 1,500 kL or more per year in crude oil equivalent) throughout the entire company are designated as “specified business operators” and obliged to regulate all of its workplaces even if single workplaces are too small to be exempted independently. As a result, the regulatory coverage for total energy use in the commercial sector is expected to increase from around 10 % to 50 % (ECCJ 2011b).

“Specified business operators” are required to prepare and submit a mid-to-long term plan, and report annually the status of their energy utilization to the competent authority. In addition, they have to appoint an “energy management control officer” and “energy management planning promoter”. The former position shall be filled with a person who supervises and manages the implementation of the business (executive-level employee). It means the person shall implement energy management for a company as a whole with a bird’s eye view. The latter position shall be a person who has completed training courses concerning energy management or who has a qualified energy manager’s license. When the competent authority finds the energy-saving mesures for “specified business operators” to be gravely insufficient, the authority will instruct them to make improvements and announce to the public the name of them.

3.2.2. Instructions for specified buildings

Commercial buildings that have a total floor area of “2,000 m^2 or more” and “300 m^2 or more to less than 2,000 m^2” are designated as “type 1 specified buildings” and “type 2 specified buildings,” respectively. Construction clients and owners of specified buildings who intend to construct or extensively modify the buildings are required to submit a mandatory report on energy-saving measures to the competent authority before construction. After the completion of the construction or modifications, the clients and owners are required to submit periodic reports on energy-saving measures. When the competent authority finds the energy-saving mesures for “type 1 specified buildings” to be gravely insufficient, the authority will instruct them to make improvements and announce to the public the name of them. Likewise, when the authority finds the energy-saving mesures for “type 2 specified buildings” to be gravely insufficient, the authority will advise them to make improvements and announce to the public the name of them.

3.3. Energy Conservation Measures for Commercial Buildings

3.3.1. Standards of Judgment for Buildings on the Rational Use of Energy

Standards of Judgment for Construction Clients and Owners of Specified Buildings on the Rational Use of Energy for Buildings were released in 2009 (METI and MLIT 2009). The standards are used for commercial buildings (with a total area of over 300 m^2), and cover the insulation of the building envelope as well as heating, ventilation, and air-conditioning (HVAC), lighting, water heating, and vertical transport or lifting equipment (Appendix 1).

On the one side, the performance criteria has two energy indicators for buildings; Perimeter Annual Load (PAL) for the energy performance of the building envelope (equation 3.1, Fig 3.2), and Coefficient of Energy Consumption (CEC) for the energy performance of the building equipment (equation 3.2-3.3). The lower the numbers for both of these indicators, the better the energy efficiency of the building. The minimum numbers for these are provided (Fig 3.3), but PAL should be corrected for building size by using scale correction coefficients (Fig 3.4), because the lower average floor area is, the greater influence this has on energy consumption, in terms of the building envelope. Twelve climate zones are referenced mainly for calculating the annual thermal loads of the indoor peremeter zones (Fig 3.5). Since minimum PAL in office buildings is constant over the 12 zones, it could be explained that the regional climate characteristics have not been fully taken into consideration.

On the other side, specification criteria (function point method) can be used as an easier method when the total area of a building is 5,000 m^2 or less. When this is under 2,000 m^2, simple specification criteria can be used as the easiest method. The standards about commercial buildings reference three climate zones: a cold zone (covering the far north), an ordinary zone (covering most of Japan), and a tropical zone (Fig 3.5). Each climate zone has requirements for specific building envelope components which receive different scores according to the impact on energy consumption efficiency. The total score of the building envelope is calculated by summing the scores for location, orientation, shape, and function. Each building must get a score of more than 100. Although this criteria is not applied to large offices, it could be suggested that the regional climate characteristics are not fully taken into consideration because Japan has been divided into only three climate zones.

$$PAL = \frac{Annual\ \ thermql\ \ load\ \ of\ \ the\ indoor\ \ perimeter\ \ zones\ \ (\frac{MJ}{year})}{Floor\ \ area\ \ of\ \ the\ indoor\ \ perimeter\ \ zones\ \ (m^2)}\ (3.1)$$

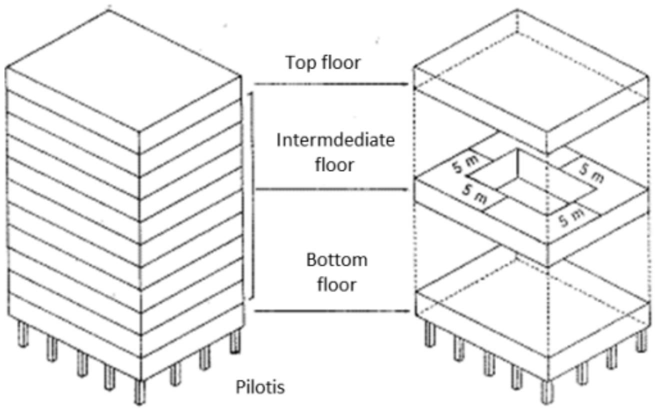


Fig 3.2 Definition of indoor perimeter zone of PAL (ECCJ 2011b)

$$CEC = \frac{Annual\ \ primary\ \ energy\ \ consumption\ \ \ of\ the\ target\ \ equipment\ \ (\frac{MJ}{year})}{Annuwal\ \ assumed\ \ load\ \ of\ \ the\ relavant\ \ use\ \ (\frac{MJ}{year})}\ (for\ Air\text{-}conditioning\ and\ Hot\ Water)\ (3.2)$$

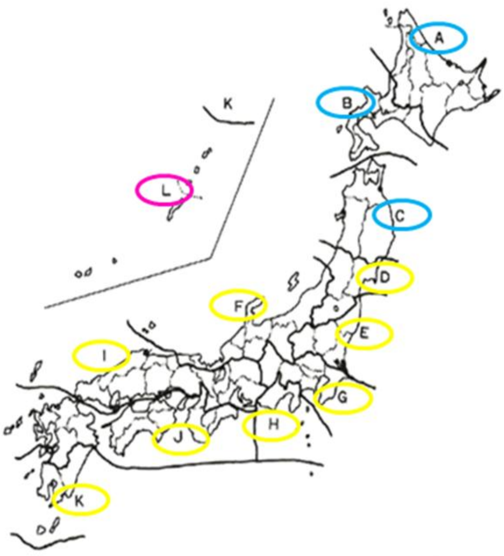
$$CEC = \frac{Annual\ \ primary\ \ energy\ \ consumption\ \ \ of\ the\ target\ \ equipment\ \ (\frac{MJ}{year})}{Annual\ \ assumed\ \ primary\ \ energy\ \ consumption\ \ \ of\ the\ target\ \ equipment\ \ (\frac{MJ}{year})}\ (for\ Ventilation,\ Lighting\ and\ Lift\ Equipment)\ (3.3)$$

PAL (MJ/m^2/year)	CEC				
	Air-conditioning	Ventilation	Lighting	Hot Water	Lifting Equipment
300	1.5	1.0	1.0	In the case of 0<lx*≤7 1.5 In the case of 7<lx*≤12 1.6 In the case of 12<lx*≤17 1.7 In the case of 17<lx*≤22 1.8 In the case of 22<lx* 1.9	1.0
*value calculated by dividing the sum of the length of the circulation piping for supplying hot water and that of the primary piping (unit: m) by the daily mean of the total amount of the hot water consumed (unit: m^3)					

Fig 3.3 Minimal number of PAL and CEC in office buildings (ECCJ 2011b)

Floor number (excluding basement)	Mean floor area (m^2)			
	50 or less	100	200	300 or more
1	2.40	1.68	1.32	1.20
2 or more	2.00	1.40	1.10	1.00

Fig 3.4 Scale correction coefficients of PAL (METI and MLIT 2009)



	Number of climate zones	Symbols in the figure
Performance criteria	12	A-L
Specification criteria	3	Blue circle: cold zone, Yellow circle: ordinary zone, Red circle: tropical zone

Fig 3.5 Climate zones for Japanese standards

3.3.2. Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)

The Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) is a tool for assessing and rating the environmental performance of buildings and the built environment. CASBEE was launched in 2001 by the Japan GreenBuild Council (JaGBC) and Japan Sustainable Building Consortium (JSBC). In order to reflect a building's life cycle, CASBEE has four basic assessment tools: for Pre-design, for New Construction, for Existing Building and for Renovation (Fig 3.6). CASBEE also includes seven specific tools; for Detached Houses, for Temporary Construction, Brief Versions, Local Government Versions, for Heat Island Effect, for Urban Development. and for Cities. Each tool is designed to accommodate a wide range of building types, including offices. Buildings with high ratings under CASBEE may be allowed to have an additional floor or more floor space than buildings without high ratings (Appendix 2).

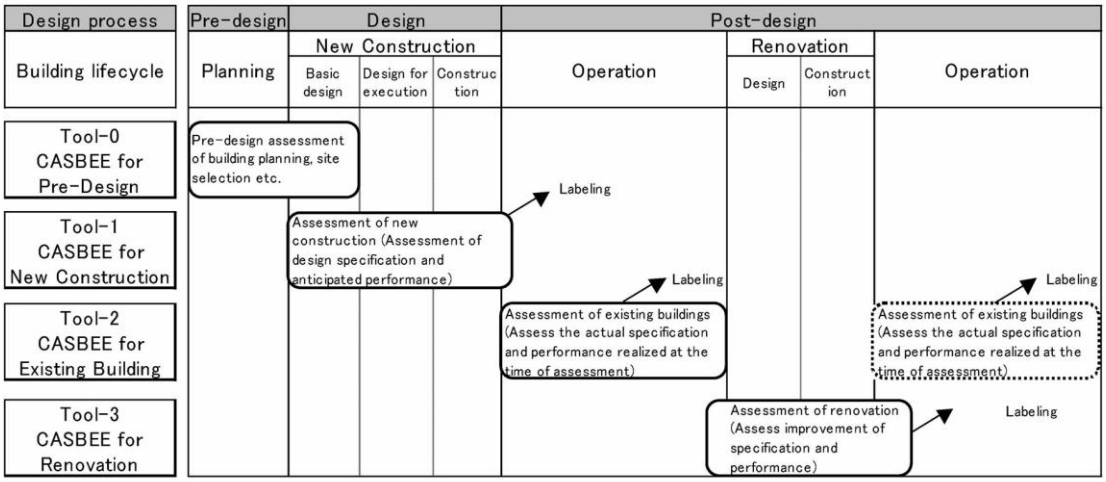


Fig 3.6 Building life cycle and the four basic assessment tools in CASBEE (JaGBC and JSBC 2012)

3.3.3. Financial support measures

(1) Loan programme with special interest rates (FY2010)

This programme is applied to only small and medium-sized enterprises. Equipment items must satisfy the following conditions; newly acquired equipment should improve by more than 25 % compared to existing average equipment, replacement equipment should improve by more than 40 % compared to the replaced equipment (Appendix 3).

(2) Tax incentive programme (Green Investment Tax Cut) (FY2011)

Business operators who purchase equipment with high energy conservation functions are eligible for a special depreciation of up to 30 % of the equipment acquisition cost or 7 % of the investment tax credit. The former applies to all business operators, while the latter applies only to small and medium-sized ones.

(3) Subsidy programme (FY 2010)

The government prepares a complehensive range of subsidies for those who will introduce energy conservation facilities, projects and technologies (Appendix 4).

3.3.4. Top runner programme

In 1998, as part of the rivised Energy Conservation Law, mandatory energy efficiency standards were set based on the most efficient product (top runner) commercially available in a given category. Each manufacturer and importer must meet the standards for that category by the target year decided for each category. The period for products to meet the standards is usually in the range of four to eight years from the base fiscal year. Starting with nine products in 1998, it expanded to 23 products by 2010 and is now considered one of the major pillars of Japanese climate policy (Kimura 2010). If there is a remarkable gap in the energy efficiency between the products and judgment standards, the government offers necessary advice and recommendations to reduce the gap. If this advice is not followed, the recommendations are made public and the manufacturer may be ordered to follow them.

Fig 3.7-3.8 present the expected energy conservation effects and achieved efficiency improvements of major office products by this programme, respectively. It is suggested that the efficiency improvements of lighting equipment between 1997 and 2012 is approximately 40 %. It is also suggested that efficiency improvements of office automation apparatus is much better than that of lighting equipment, although both figures do not show all office appliances.

Product		Fiscal year		Efficiency improvement (Expectation)
		Target	Base	
Air conditioners		2015	2006	18.2%
Lighting equipment	Fluorescent light equipment	2012	2006	7.7%
	Bulb-shaped fluorescent lamps			3.2%
Copying machines		2006	1997	30.8%
Computers		2011	2007	78.0%
Space heaters	Gas	2006	2000	1.4%
	Oil			3.8%
Gas water heaters	for space heating (with no hot water supply function)	2008	2002	3.3%
	for space heating (with hot water supply function)			1.1%
Oil water heaters		2006	2000	3.5%

Fig 3.7 Designated major office products and their expected energy conservation effects (ECCJ 2011b)

Product	Fiscal year		Efficiency improvement	
	Target	Base	Initial expectation	Result
Air conditioners	2004*	1997**	66.1% increase in COP	67.8%
Fluorescent light equipment	2005	1997	16.6% increase in lm/W	35.6%
Copying machines	2006	1997	30.8% decrease in kWh/year	72.5%
Computers	2007	2001	69.2% decrease in kWh/year	80.8%

* 2004freezing year : 1/10/2003 through 30/9/2004, ** 1997freezing year : 1/10/1996 through 30/9/1997

Fig 3.8 Efficiency improvement of major office products achieved by the top runner programme (ECCJ 2011b)

3.3.5. Dissemination and outreach measures for equipment

(1) Energy labeling programme

The energy-saving labeling system was established to provide customers with information about the energy efficiency of appliances. Starting with five products in August 2000, it expanded to 18 products by July 2010. The labeling presents target timing to meet the target (target fiscal year), what percentage a given product achieves improvements in energy efficiency (energy conservation standard achievement rate), and how much energy a given product consumes (annual energy consumption). It provides products with one of two colours to inform consumers of whether a given product meets the target standard (green) or not (orange) (left side in Fig 3.9).

Following the introduction of the original labeling programme refered to above, the new appliance labeling programme was established to provide information on running costs (expected annual electricity bill). A given product is rated as five levels symbolized by the number of stars; the more efficient a given product, the greater its number of stars. A border line of 100 % target achievement is described under the stars. (right side in Fig 3.9)

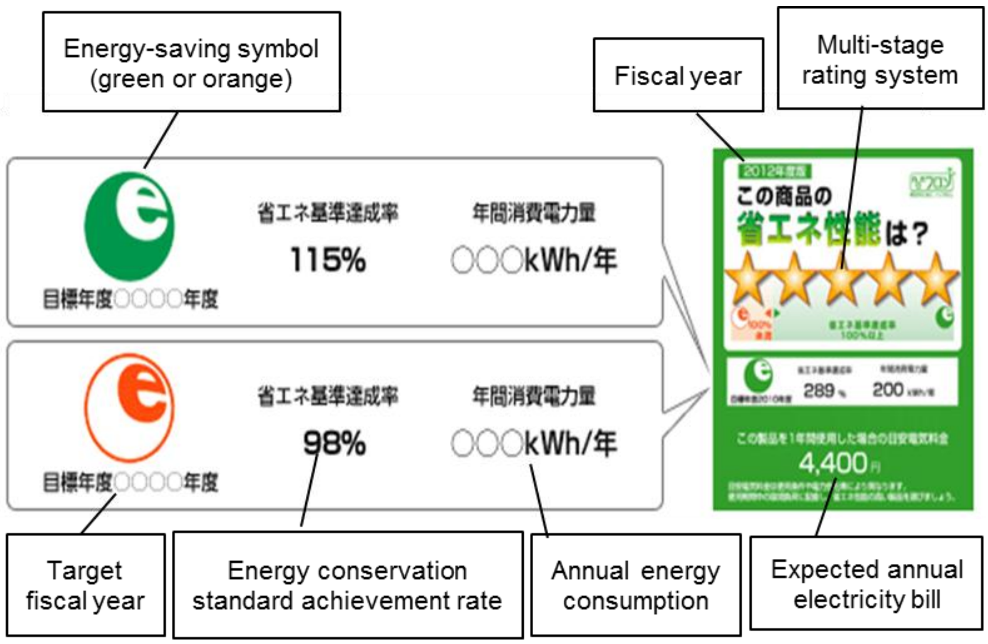


Fig 3.9 Energy-saving label

(2) Energy efficient product retailer assessment programme

A retailer commendation programme was introduced to further accelerate the popularization of energy efficient products. Appliance retail shops that are active in promoting and selling these products are selected as “top energy efficient product retailer promotion stores.” Additionally, particularly excellent shops are given awards such as the Minister of Economy, Trade and Industry Award. Excellent shops that are selected and receive awards can use the specified label (Fig 3.10).

Fig 3.10 Energy efficient product retailer promotion shop label

(3) International energy star programme

The international energy star programme was introduced in the US in 1992 to identify and promote energy efficient products. There are a wide range of available items including products (e.g. office equipment, lighting) and buildings (e.g. offices). In 1995, Japan joined only in the application of office equipment such as personal computers, printers, copy machines, and so on.

3.3.6. Promotion of commercial Building Energy Management System (BEMS)

Building Energy Management System (BEMS) ensures recognizing real-time building conditions by using IT technology. For example, based on the data sent from temperature/humidity/carbon dioxide concentration sensors and human detective sensors in each room, air-conditioning and lighting are controlled adequately at a central monitoring/control unit. Additionally, energy consumption data is analyzed and then future energy demand is estimated to adjust the air-conditioning control.

3.3.7. Promotion of Energy Service Company business (ESCO)

Energy Service Company (ESCO) offers comprehensive services for energy savings to customers. ESCO proposes a wide variety of energy-saving measures (e.g. system, efficient operation of equipment). During the implemention of ESCO business, customers in return pay part of the energy savings achieved (e.g. reduced utility bills). In FY2008 in Japan, the order volume of ESCO business accounted for 34 % within the total amount of repair work for energy conservation (ECCJ 2011b). For the further promotion of ESCO, this business is being promoted in the public sector, fund procurement (low-interest loans) is being faciliated, and improvements are being made in the recognition of this business (business explanation meetings).

3.3.8. Relaxation temperature setting and dress code

In 2005, Ministry of the Environment (MOE) promoted office building air-conditioning settings of 28 ℃ during summer. MOE also encourages office workers to wear cool and comfortable clothes in the workplace during the summer (“Cool Biz”). Similarly, air-conditioning settings of 20 ℃ and warm clothes are promoted during the winter (“Warm Biz”).

3.4. Summary

Due to the impact from the Fukushima nuclear accident Japanese energy policy will be revised; however, the effects of this and its influence on the CO_2 emission reduction targets have not been clearly specified, and in all probabiliy a larger total amount of CO_2 emission reductiosn than was anticipated in the previous plan will be required.

Meanwhile, Japanese standards for the energy performance of office building envelope and equipment are based on the annual loads of perimeter floor area and equipment efficiency. As a result, the insulation of the envelope, windows, solar shading, and lighting, appliances and HVAC systems should be considered during the design stage. Additionally, a wide variety of supports and efforts for saving energy are being promoted by not only the government but also the private sector as well. However, the standards and measures are across-the-board, and the precedence and effects of measures for efficiency improvements are not entirely clear. Moreover, there are concerns that the current regional climate characteristics are not entirely being taken into consideration, given that there are a wide range of climates throughout Japan. Furthermore, there are no indications and discussions in terms of the impact of climate change on energy consumption in the future.

4. METHODOLOGY

This dissertation aims to quantify how each strategy will impact the heating and cooling requirements in both current and future offices. The study simulated an office with typical construction, heat gains, and operational patterns with Thermal Analysis Software (TAS). In order to simulate this accurately, the latest Japanese weather files were utilized. In this chapter, the current and future weather data, as well as the building models employed will be introduced. Several strategies for reducing heating/cooling demand that have been considered will also be introduced.

4.1. Weather Files

4.1.1. Reference weather year

The most popular dense array system for weather data acquisition in Japan is the Automated Meteorological Data Acquisition System (AMeDAS) by the Japan Meteorological Agency (JMA); however, the data from AMeDAS is not available for building energy calculations because of a lack of climate elements, missing data, and so on. Thus, new weather data that expanded on the original AMeDAS data was developed as Expanded AMeDAS (EA weather data) (Akasaka et al. 2003). EA weather data are hourly data obtained from 842 stations throughout Japan over 20 years (1981-2000 (1990s)). EA weather data was reformatted considering not only equality of the monthly mean of each weather parameter but also equality of the frequancy of each day's value (Soga and Akasaka 2004). As a result, a reference weather year (Standard EA weather data) was constructed (Appendix 5).

4.1.2. Future weather files

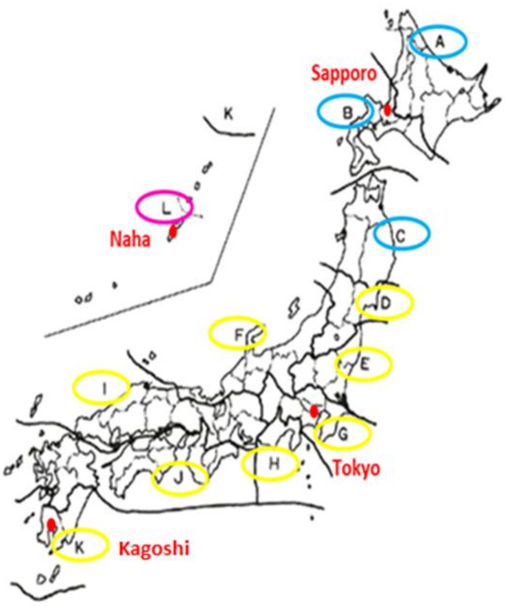
JMA (2005) put on view two types of future weather data in Japan: 2031-2050 (2040s) and 2081-2100 (2090s). There are 46 types of data such as dairy air temperature (mean, maximum, and minimum), humidity ratio, wind direction and speed, degree of cloudiness (upper-air, middle-air, and lower-air observation), precipitation, and more in 11,881 meshs whose distance within each site is 20 km in all directions. These data originated with AMeDAS data, and were made by specific software named Regional Climate Model 20 (RCM20) developed by JMA. Scenario A2 of the IPCC was adopted through a series of simulations. However, there are no data of horizontal global solar radiation and atmospheric radiation, which are essential for building energy calculations. Additionally, these data is daily, not hourly.

Soga (2011) developed two types of hourly future weather data (2040s, 2090s) available for building energy calculations (Appendix 6). He chose 833 data from 11,881 meshs as base data. The 833 data are ones which are located in nearest to the sites observed by JMA

(AMeDAS). He calculated horizontal global solar radiation and atmospheric radiation by using statistical functions. As a result, the new weather data were considered to be predicted values of air temperature, absolute humidity, nocturnal radiation quantity, solar radiation quantity, and wind direction and velocity. In this study, Soga's weather data was transformed to be suitable for TAS input by using specific converter software (Croxford 2012).

4.1.3. Site selection

As mentioned before, the Japanese standards about commercial buildings reference several climate zones by criteria based on their topographical characteristics. The largest city in each climate zone of specification criteria was selected as the subject of the simulation's research. As a result, Sapporo (cold zone), Tokyo (ordinary zone), and Naha (tropical zone) were selected (Fig 4.1). Fig 4.2-4.3 show that in every site air temperature increases according to the period; 1990s, 2040s, and 2090s (Appendix 7). As relative humidity, no clear change was indicated between the periods (Fig 4.4-4.5) (Appendix 8).



City	Latitude (deg.N)	Longitude (deg.E)
Sapporo	43.06	141.35
Tokyo	35.68	139.77
Naha	26.20	127.69

Blue circle (A-C): cold zone,
Yellow circle (D-K): ordinary zone,
Red circle (L): tropical zone

Fig 4.1 Location of the three locations selected in Japan*

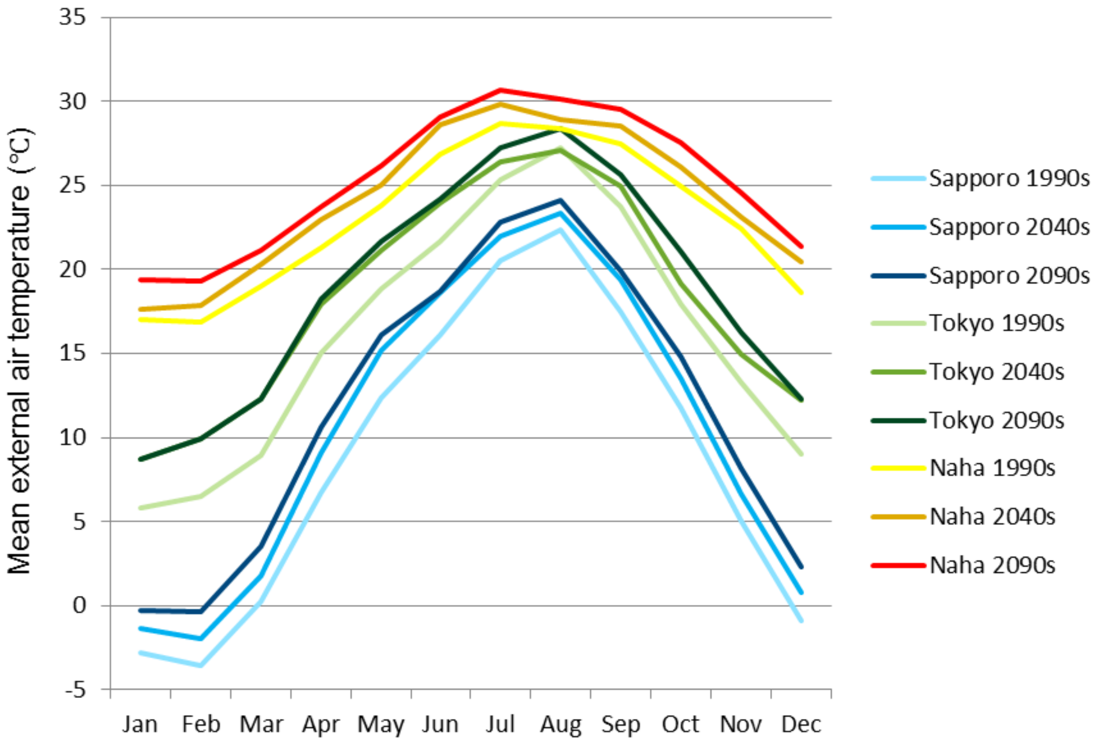


Fig 4.2 Monthly mean external air temperature

Air temperature (℃)	Sapporo			Tokyo			Naha		
	1990s	2040s	2090s	1990s	2040s	2090s	1990s	2040s	2090s
Mean	8.9	10.7	11.8	16.2	18.3	18.9	23.0	24.1	25.2
Median	9.3	11.5	12.8	16.6	18.8	19.5	23.5	24.6	25.6
Minimum	-12.4	-11.0	-8.9	-0.2	2.4	2.5	11.1	11.6	13.7
Maximum	34.8	34.1	35.8	35.2	35.3	37.3	32.6	34.0	34.6
Standard Deviation	9.6	9.6	9.3	8.0	7.0	7.4	4.7	4.8	4.6

Fig 4.3 Yearly external air temperature values

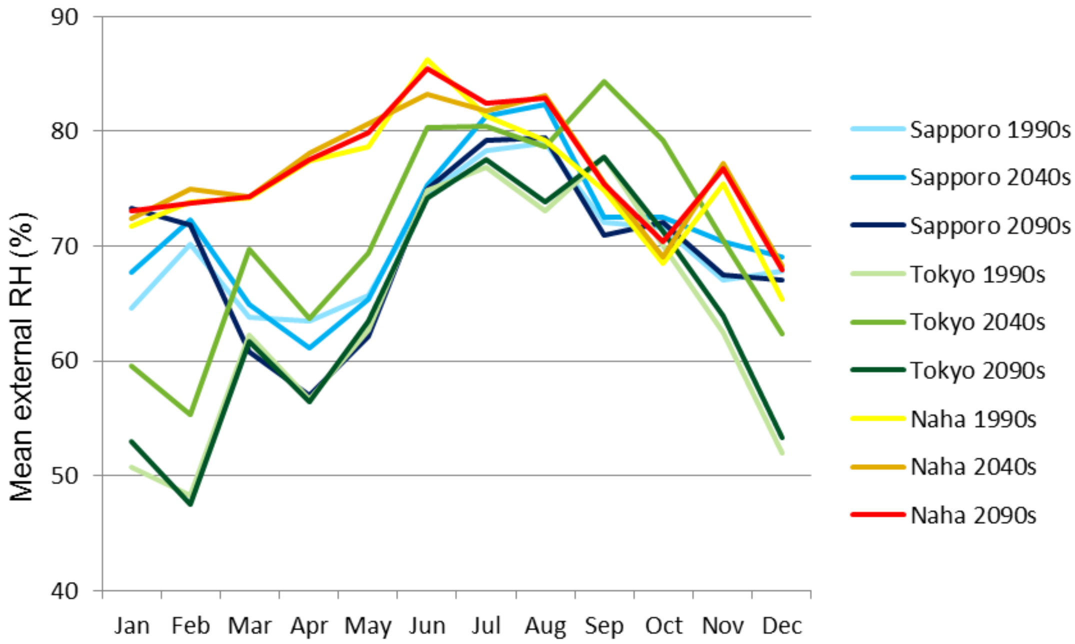


Fig 4.4 Monthly mean external relative humidity

RH (%)	Sapporo			Tokyo			Naha		
	1990s	2040s	2090s	1990s	2040s	2090s	1990s	2040s	2090s
Mean	69.8	71.2	69.7	64.0	71.2	64.6	75.5	76.5	76.7
Median	71.5	73.2	71.6	66.2	73.5	66.7	77.1	78.4	78.2
Minimum	22.1	14.8	13.9	16.5	20.5	17.5	33.6	36.0	36.8
Maximum	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Standard Deviation	14.8	15.4	15.1	19.3	18.7	18.4	12.6	12.4	11.9

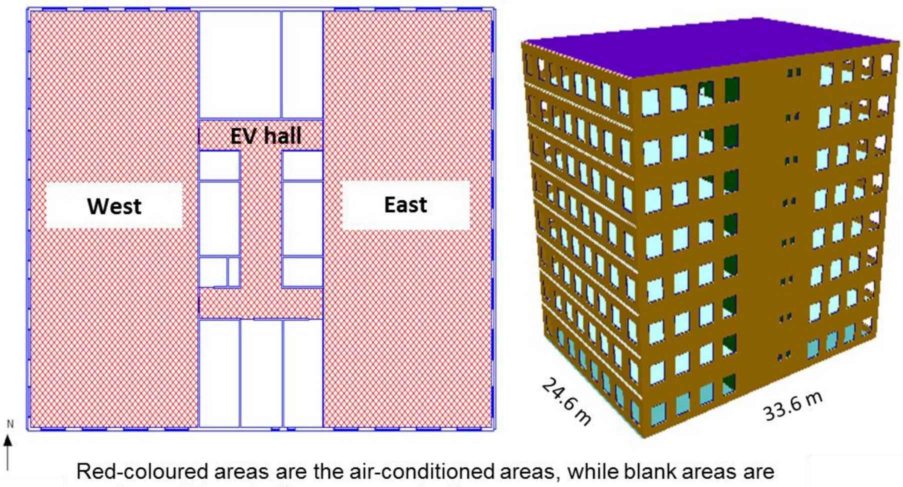
Fig 4.5 Yearly external relative humidity values

4.2. Office Building Model

4.2.1. Base model

A geometrical model was defined; an eight-storey building with dimensions of 33.6 m wide, 24.6 m deep, and 3.6 m high (3.8 m high at ground floor) based on previous models of office buildings widely used for simulations in Japan (Takizawa 1985). The office building oriented with the longer sides facing north-south. Now, around one-third of the office building stock in the chief cities of Japan dates from before 1981 (JREI 2011). Thus, this model is considered to be representative of a typical, air-conditioned office in Japanese cities in the 1990s, with a total floor area of 6,612 m^2, of which the air-conditioned floor area is 5,250 m^2 (east and west office zones and EV hall zone, Fig 4.6).

Consequently, the shape and orientation were set as fixed parameters although they influence the total energy use in a building and the solar energy that it receives (Mingfang 2002). With this layout, in winter maximum solar gains can be achieved while in summer efficient shading should be considered. Additionally, this orientation can provide maximum daylight and the related unpleasant glare. Thus blinds should be utilized effectively, especially in south façades. A typical wall construction was used and windows were single glazed with 30 % glazing ratio in office zones (Appendix 9).



Red-coloured areas are the air-conditioned areas, while blank areas are un-air-conditioned utility spaces and toilets.

Fig 4.6 Office building model and zoning for typical 1990s type buildings (a representative floor plan and outward)

Buildings are usually categolized as fast or slow in response to heat transfer. The response to the changes in the environmental temperature is defined by the thermal response factor f_r (equation 4.1-4.2). Buildings with low thermal response factors (f_r<4) are categolized as lightweight buildings, while those with high thermal response factors (f_r>4) are categolized as heavyweight buildings (CIBSE 2006). In this study, the thermal mass of the windows was ignored because tinted types of glazing were not examined and solar radiation would be transmitted through clear glass to the interior rather than stored. As a result, f_r of the base model was 2.37 and estimated as a lightweight building.

$$f_r = \frac{\sum(AY)+C_v}{\sum(AU)+C_v} \quad (4.1)$$

$$C_v = \frac{NV}{3} \quad (4.2)$$

Where

A: surface areas (m²)

Y: thermal admittance (W/m²K) (Y-value)

U: thermal transmittance (W/m²K) (U-value)

$_v$: ventilation conductance (W/K)

V: volume of the room (m³)

N: room air change rate (ach)

Current guidelines recommend that 10 L/s per person fresh air be provided for an office building. Given that the occupant density in office zones and EV hall zones are estimated to be 0.2 and 0.03 person/m^2, respectively. Take the one office area of the base floor for example, the size of one office area is 12.3×24.6×3.6, for area=302.6 m^2 and volume=1,089.3 m^3. For the given occupant density, 302.6×0.2≒60 people, the fresh air requirement is 600 L/s, hence the air change rate is 600×3.6/1089.3≒2 ach. The air change rate for EV hall zones was calculated by 0.3 in the same way. Meanwhile, air infiltration is hard to estimate because this parameter depends on the building and weather conditions. Therefore an air change rate of 2.0 ach (office zones) and 0.3 ach (EV hall zone), and infiltration rate of 0.25 ach, were fixed (Fig 4.7).

The internal heat gains and the target temperature and relative humidity were defined data from the previous model in Japan (Fig 4.7-4.9) (Takizawa 1985); however Saturday was defined as a non-working day considering the recent trend in Japan despite the fact that Saturday morning was defined as a working day in the previous model (Fig 4.11).

Zone		Floor area (m^3)	Infiltration (ach)	Ventilation (ach)	Lighting heat gain (W/m^2)	Occupants					Equipment	
						Density ($person/m^2$)	Sensible heat gain		Latent heat gain		Sensible heat gain (W/m^2)	Latent heat gain (W/m^2)
							(W/person)	(W/m^2)	(W/person)	(W/m^2)		
Office	east	2401.0	0.25	2.00	20.0	0.20	75.0	15.0	55.0	11.0	20.0	0.0
	west	2401.0	0.25	2.00	20.0	0.20	75.0	15.0	55.0	11.0	20.0	0.0
EV hall		448.2	0.25	0.30	10.0	0.03	75.0	2.3	55.0	1.7	0.0	0.0

Fig 4.7 Internal conditions for the base model for typical 1990s type office buildings

Season		Temperature (°C)	RH (%)
Winter	(Jan-Apr + Dec)	21-24	40-60
Summer	(Jun-Sep)	23-26	45-65
Mid season	(Other)	21-25	40-65

Fig 4.8 Target temperature and relative humidity for the base model for typical 1990s type office buildings

Non-working day	Weekend	Sunday, Saturday
	Holiday	1-3 Jan, 15 Jun, 11 Feb, 20 Mar, 29 Apr, 3-5 May, 20 Jul, 17 Sep, 24 Sep, 8 Oct, 3 Nov, 23 Nov, 23 Dec, 29-31 Dec, Monday make up holiday (when holidays fall on Sunday)
Working day	Weekday	Other (9.00 AM-18.00 PM)

Fig 4.9 Definition of non-working day and working day for typical 1990s type office buildings

4.2.2. Improved model

Some parameters were changed through a series of simulations, and each effect was researched. The following factors were improved to be estimated as an improved model. In the following figures, the improved factors are shown in red ink. Meanwhile, Japan is increasing its supply of renewable energy (ANRE 2010), but this is outside of the scope of this study.

(1) Lighting and equipment improvements (Reducing internal heat gains)

Recently the efficiency of office appliances has improved significantly by technological innovations, and efficiency improvements in lighting and equipment can be estimated at 40 % and much more than 40 %, respectively (Fig 3.7-3.8, p.22). As a result, the internal heat gains for the improved model were reduced dramatically compared to the base model (Fig 4.10). In the future, such efficiency will be improved more than estimated in Fig 4.10; however, this was ignored in this study since there is no guidelines on future targets at this time.

Zone		Lighting heat gain (W/m^2)		Equipment heat gain (W/m^2)			
				Sensible		Latent	
		Base model	Improved model	Base model	Improved model	Base model	Improved model
Office	east	20.0	12.0	20.0	10.0	0.0	0.0
	west	20.0	12.0	20.0	10.0	0.0	0.0
EV hall		10.0	6.0	0.0	0.0	0.0	0.0

Fig 4.10 Internal heat gains of lighting and equipment

(2) Relaxation of the indoor air quality target

A voluntary action to relax the set temperature of air conditioners has been carried out recentry in Japan (p.25). The plan recommends setting the temperature higher in the summer and lower in the winter compared to the usual settings. In improved models, the target temperature and relative humidity in each season are relaxed by 1-2 ℃ and 5 %, respectively (Fig 4.11).

Season		Temperature (°C)		RH (%)	
		Base model	Improved model	Base model	Improved model
Winter	(Jan-Apr + Dec)	21-24	20-24	40-60	40-65
Summer	(Jun-Sep)	23-26	23-28	45-65	45-70
Mid season	(Other)	21-25	20-26	40-65	40-70

Fig 4.11 Target temperature and relative humidity

(3) Building envelop improvement (Improvement of glazing, walls and the roof)

Window glazing is one of the weakest thermal control factors in building interiors, and double glazing is an effective method for both cold and hot climate conditions. In cold climates, the best option is double glazing with a film coating that limits the heating of the window surface. In hot climates, the best is double clear glazing (Pacheco et al. 2012). Since there were no small differences between the climates of the three locations selected in this study, both double glazing windows with low-e coating and double clear glazing were examined as the improved models.

Additionally, in order to control heat loss in buildings and reduce heating and cooling demand, adding to the thickness of the insulation within external walls and the roof should be considered. Because this stabilizes internal temperatures and reduces heat transfer between the indoors and outdoors. In this study, insulation that had been doubled (50 mm) and quadrupled (100 mm) was examined for the thickness of insulation.

Overall, a combination of double glazing with low-e coating and quadrupled insulation, and that of double clear glazing and doubled insulation were simulated as the improved models. Comparisons of the thermal transmittance (U-value) of each element between the base model and the two improved models are shown in Fig 4.12. The glazing ratio and blinds were not changed from the base model.

Model	Description	U-value ($W/m^2/K$)		
		Window	External wall	Roof
Base model	single clear glazing with blind, polystyrene insulation (25 mm) on external walls and the roof	5.731	0.624	0.428
Improved model 1	double clear glazing with blind, doubled insulation (50 mm) on external walls and the roof	2.000	0.361	0.286
Improved model 2	double glazing with low-e coating with blind, quadrupled insulation (100 mm) on external walls and the roof	1.510	0.208	0.184

Fig 4.12 Building elements

(4) Overhangs

Shading devices on building façades control the amount of solar radiation received by the building, and can therefore reduce the energy consumption at certain times of the year, though they are counter-productive at other times (Pacheco et al. 2012, Yang et al. 2006). For example, in the summer they could decrease the cooling loads by increasing the solar protection, while increasing the heating loads in the winter. Past studies have proposed that they should be designed so that their position can be adapted to the season of the year (Bouchlaghem 2000). Thus in this study, the monthly cooling/heating loads were examined by using projecting horizontal overhangs that can be folded back or removed. They were set on both east and west facades and their material was assumed to be aluminium, which is typical in Japan (Fig 4.13).

Shaded surface	Depth	Vertical offset from top edge of shaded surface	Transmittance
Windows on east/west façades	1.0 m	0.2 m	0.92

Fig 4.13 Overhangs

(5) Night cooling

Night cooling is an effective passive strategy, especially in non-residential buildings with a high cooling demand and with no night occupation. This strategy helps to decrease demand peaks and operation periods of air-conditioning equipment (Pacheco et al. 2012). However, it is important to control this ventilation strategy appropriately in terms of avoiding over-cooling and optimizing heat absorption. In this study, night cooling was switched on only when the internal temperature exceeded 18 ℃ and only when the external temperature exceeded 12 ℃. Night cooling was operated only when both conditions were met at the same time. Night cooling was planned to begin at 22.00 PM and continue all night before stopping at 7.00 AM.

One important consideration in the parametric analysis is the thermal mass of the construction (Kolokotroni et al. 2011). Since the base model was defined as a lightweight building, not only the base model but also other construction models should be examined. As the internal walls of the base model are made of concrete, only the materials of internal floors were changed as the thermal mass. This improvement made improved model heavyweight building as f_r of 4.11 (Fig 4.14). As a result, the effect of night cooling for heating/cooling loads reducion was examined by using two models.

Base model (lightweight, fr=2.38)					
	Area (m^2)	U (W/m^2K)	Y (W/m^2K)	AU	AY
External wall	3375.60	0.62	0.43	2092.87	1451.51
Internal wall	815.84		2.16		1762.21
Internal floor	5785.92		0.72		4165.86
Roof	826.56	0.44	0.36	363.69	297.56
Ground floor	826.56		0.26		214.91
Sum				2456.56	7892.05
Improved model (heavyweight, thermal mass, fr=4.11)					
	Area (m^2)	U (W/m^2K)	Y (W/m^2K)	AU	AY
External wall	3375.60	0.62	0.43	2092.87	1451.51
Internal wall	815.84		2.16		1762.21
Internal floor	5785.92		1.10		6364.51
Roof	826.56	0.44	0.36	363.69	297.56
Ground floor	826.56		0.26		214.91
Sum				2456.56	10090.70

Fig 4.14 Construction properties for thermal response factor

5. RESULTS AND DISCUSSION

5.1. Base Model

Fig 5.1-5.2 indicate that the total heating/cooling loads are different depending on their location despite using the same model. Naha has a much greater need for air-conditioning than the other two locations. It also shows that in Tokyo and Naha almost all of the air-conditioning loads comes from cooling (Naha has no heating loads), and the total air-conditioning loads significantly increases depending on the period because of increases in the cooling loads due to climate change. In the 2040s, the total heating/cooling loads in Tokyo and Naha will rise by approximately 15 % and 10 %, respectively, compared to the 1990s. After the 2040s, the total loads will continue growing by a similar ratio. While in Sapporo it will stay almost constant since the decrease in the heating loads will balance out the increase in the cooling loads. From the 2040s onward, the cooling loads might exceed the heating loads. These results are generally the same as the previous work using a different weather file and different software (Kokuryo et al. 2010, Kubota et al. 2010).

		Air-conditioning loads (kWh/m^2/year)			Percentage change compared to the 1990s
		Heating loads	Cooling loads	Total loads	
Sapporo	1990s	38.43	34.91	73.34	-
	2040s	30.22	45.29	75.50	3.0%
	2090s	23.79	51.22	75.01	2.3%
Tokyo	1990s	3.98	73.13	77.12	-
	2040s	1.14	87.68	88.82	15.2%
	2090s	0.95	97.14	98.09	27.2%
Naha	1990s	0.00	134.50	134.50	-
	2040s	0.00	148.20	148.20	10.2%
	2090s	0.00	161.12	161.12	19.8%

Fig 5.1 Heating/cooling loads of the base model and percentage change compared to the 1990s

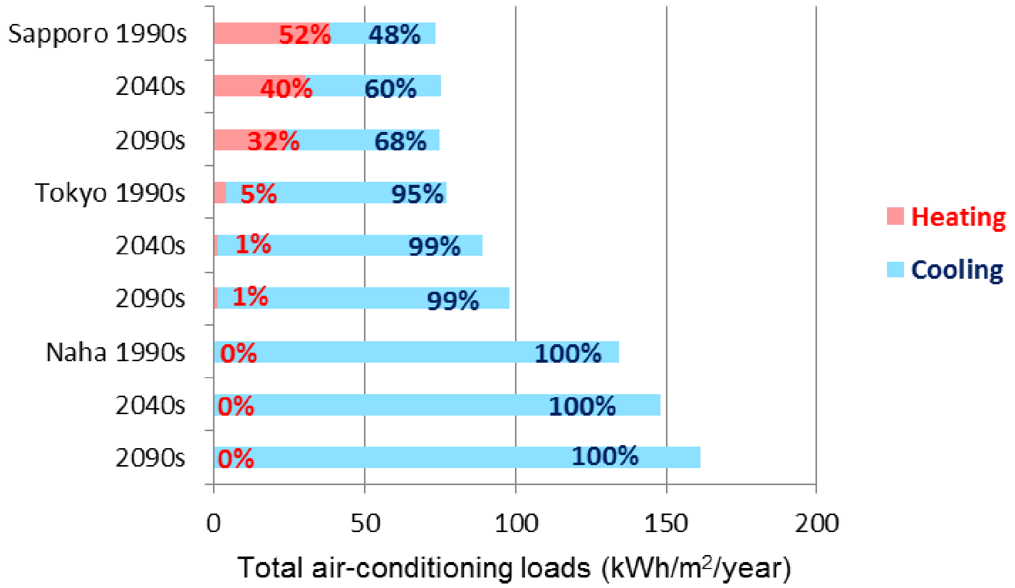


Fig 5.2 Heating/cooling loads of the base model

Fig 5.3 shows that the percentage of the heating/cooling loads in the east office zone and west office zone is almost identical. Fig 5.4-5.5 describe the heating/cooling loads profile on a typical day in the winter and the summer, respectively, and suggest that the timing and zone for the peak loads will be similar in each location in the future (Appendix 10-12). For example, in every period in Sapporo during the summer the morning peak was found in the east office zone and the afternoon peak is found in the west office zone. Thus, differences in the heating/cooling loads between the east office zone and the west office zone could be considered to be unimportant in every location over every period.

In Sapporo the percentage of the heating loads in the EV hall zone out of the total loads is much larger than that of Tokyo and Naha. This suggests that in order to reduce the energy consumption in Sapporo, a strategy of decreasing the heating loads for not only zones with windows (including perimeter areas) but also zones with no windows should be more important than for the other two locations.

Percentage of the heating/cooling loads out of the total loads		Heating loads				Cooling loads			
		East office	West office	EVhall	Total	East office	West office	EVhall	Total
Sapporo	1990s	19.0%	19.5%	13.9%	52.4%	23.4%	23.5%	0.7%	47.6%
	2040s	14.2%	14.6%	11.2%	40.0%	29.3%	29.5%	1.2%	60.0%
	2090s	10.8%	11.2%	9.7%	31.7%	33.2%	33.5%	1.6%	68.3%
Tokyo	1990s	0.9%	1.0%	3.3%	5.2%	45.4%	46.4%	3.1%	94.8%
	2040s	0.1%	0.1%	1.0%	1.3%	47.4%	47.9%	3.4%	98.7%
	2090s	0.1%	0.1%	0.8%	1.0%	47.3%	47.8%	4.0%	99.0%
Naha	1990s	0.0%	0.0%	0.0%	0.0%	47.4%	47.6%	5.0%	100.0%
	2040s	0.0%	0.0%	0.0%	0.0%	47.1%	47.4%	5.6%	100.0%
	2090s	0.0%	0.0%	0.0%	0.0%	46.9%	47.1%	6.0%	100.0%

Fig 5.3 Percentage of the heating/cooling loads of the base model by zone

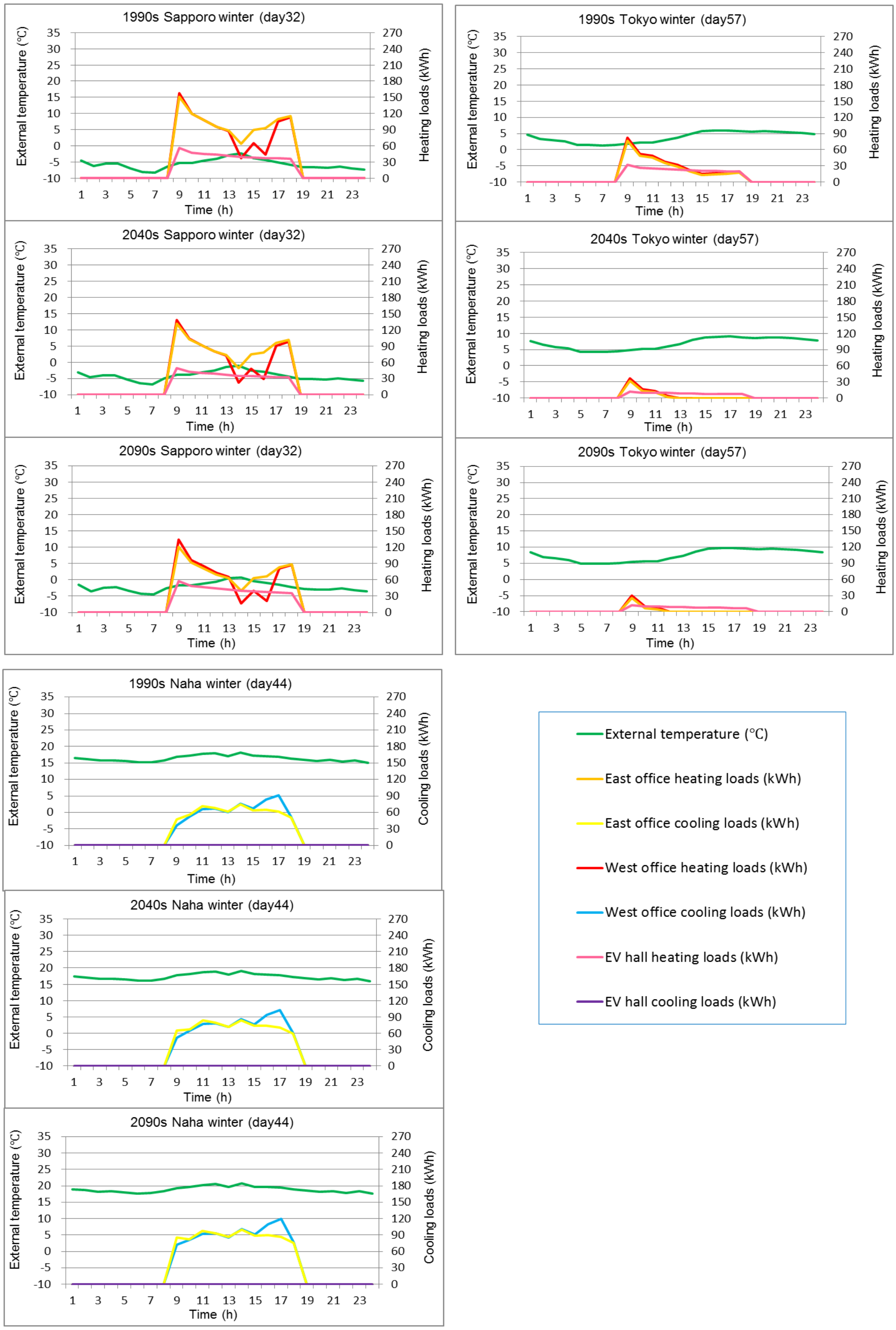


Fig 5.4 Heating/cooling loads profile of the base model on a typical winter day

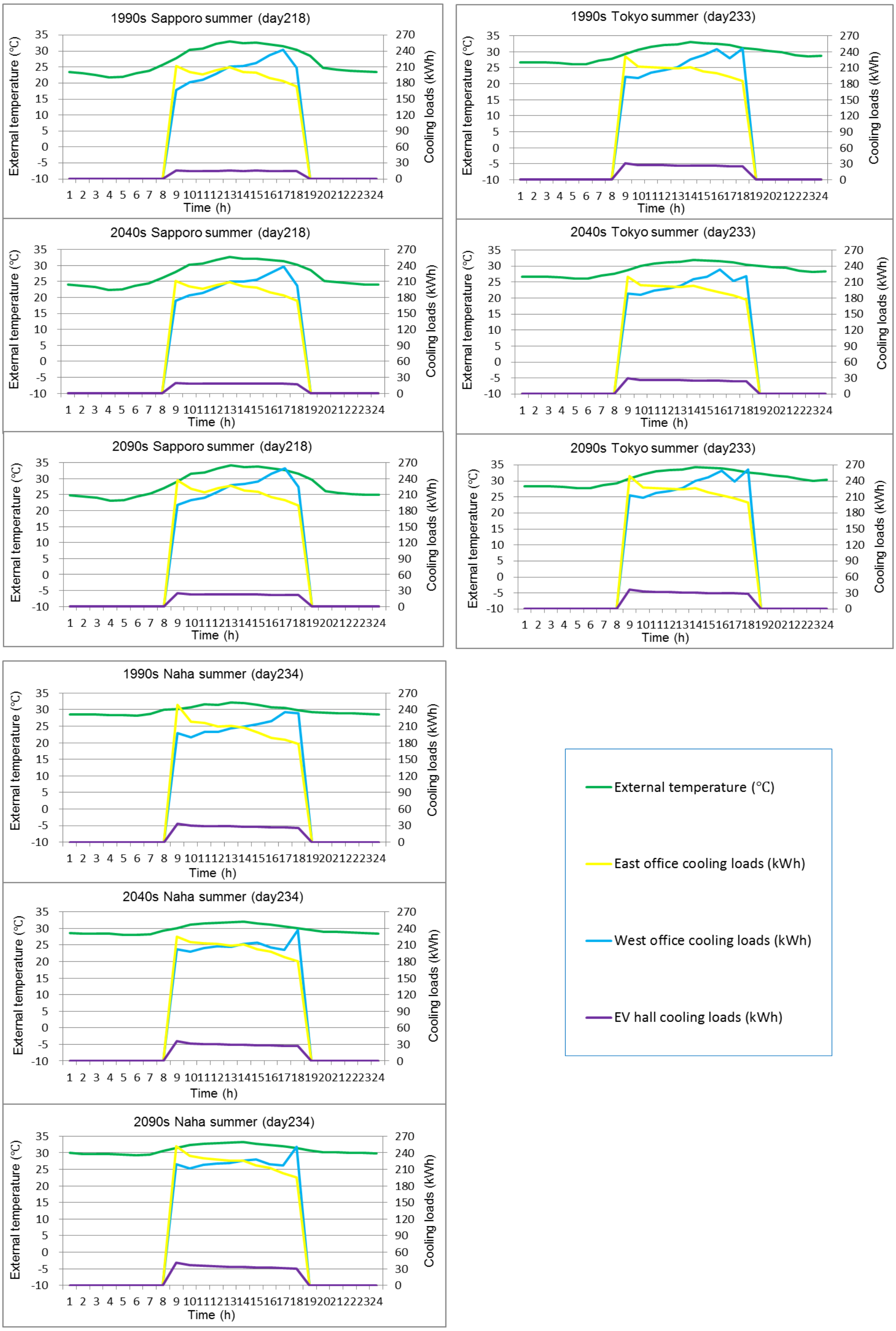


Fig 5.5 Cooling loads profile of the base model on a typical summer day

Fig 5.6 indicates that monthly trends in the heating/cooling loads in each location would be almost the same over every period (Appendix 13).

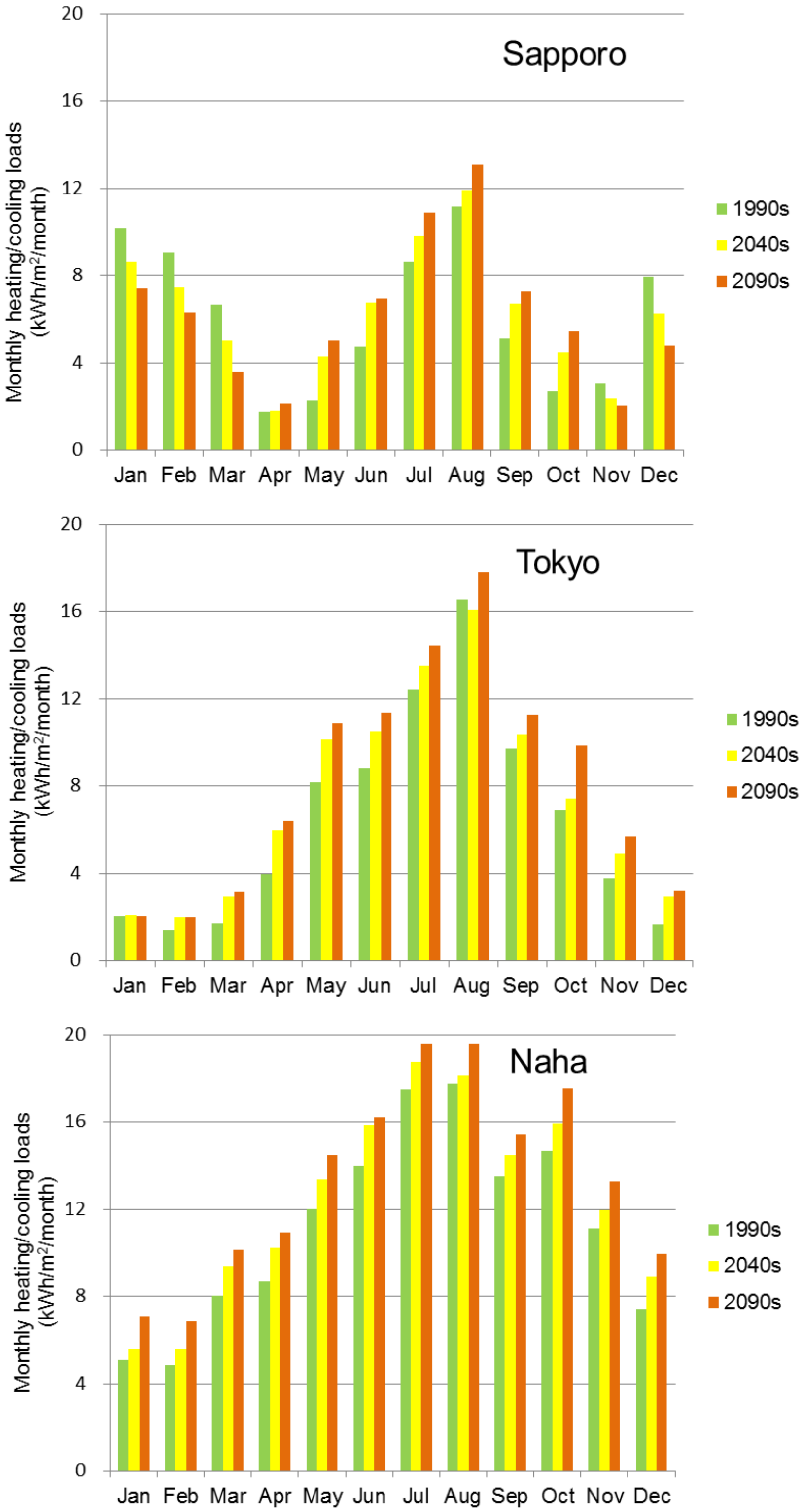


Fig 5.6 Monthly heating/cooling loads of the base model

5.2. Improved Model

Effective strategies for reducing energy in each location and their effects (percentage of energy reduction) will be calculated individually. After the individual effects of each strategy are demonstrated, a series of comparative analyses for each strategy against climate change will be made by showing summary figures. Finally, the cumulative effect of all of the selected strategies will be calculated, as the performance of some measures can be influenced by the other measures and some changes should be made to obtain accurate estimates.

5.2.1. Effects of each strategy

(1) Lighting and equipment improvements (Reducing internal heat gains)

Fig 5.7 shows the total heating/cooling loads and percentage change compared to the 1990s base model by lighting and equipment improvements in each location and each period. For example, in Tokyo the total loads in the 1990s could be decreased from 73.34 kWh/m^2/year (Fig 5.1, p.40) to 56.21 kWh/m^2/year, and the reduction rate compared to the 1990s base model is 27.1 %; however, the reduction rates would be worse; 23.7 % in the 2040s and 12.4 % in the 2090s.

It is shown that only the current period (1990s) in Sapporo indicates a small increase (1.6 %) in the air-conditioning load; however, it is important to note that this strategy will decrease not only the heating/cooling loads but also electricity for using appliances. Since the expected electricity use reduction in Sapporo (approximately 16.5 kWh/m^2/year) would be over 20 % of the total heating/cooling load, this strategy could lead to dramatic reductions in the total energy consumption in every location. Moreover, in Sapporo the total heating/cooling loads will drop in the future. This means that in Sapporo as climate change gets warmer, installing improved lighting and equipment could provide greater efficiency improvements that would negate the effects of climate change.

		Air-conditioning loads (kWh/m^2/year) and percentage change compared to the 1990s base model		
		Heating loads	Cooling loads	Total loads
Sapporo	1990s	56.04 (+45.8%)	18.48 (-47.0%)	74.52 (+1.6%)
	2040s	45.86 (+19.3%)	25.92 (-25.8%)	71.77 (-2.1%)
	2090s	38.42 (0.0%)	30.43 (-12.8%)	68.85 (-6.1%)
Tokyo	1990s	9.94 (+149.4%)	46.27 (-36.7%)	56.21 (-27.1%)
	2040s	3.42 (-14.1%)	55.38 (-24.3%)	58.81 (-23.7%)
	2090s	3.09 (-22.4%)	64.43 (-11.9%)	67.52 (-12.4%)
Naha	1990s	-	96.44 (-28.3%)	96.44 (-28.3%)
	2040s	-	109.85 (-18.3%)	109.85 (-18.3%)
	2090s	-	122.52 (-8.9%)	122.52 (-8.9%)

Fig 5.7 Heating/cooling loads and percentage change by improved lighting and equipment compared to the 1990s base model

(2) Relaxation of the indoor air quality target

It has been proven that at present relaxing the target temperature could save on the total heating/cooling loads significantly in all locations (Fig 5.8). However, in the future in Tokyo and Naha the amount of load reduction will be compensated by the increase in cooling loads from climate change, and in the 2090s the total loads will increase largely compared to the 1990s base model. Only in Sapporo the total loads will be constant in the future. On the other hand, saving energy by relaxing the target relative humidity would be a negligible quantity.

		Air-conditioning loads (kWh/m^2/year) and percentage change compared to the 1990s base model		
		Heating loads	Cooling loads	Total loads
Sapporo	1990s	33.54 (-12.7%)	26.17 (-25.0%)	59.71 (-18.6%)
	2040s	25.74 (-33.0%)	35.74 (+2.4%)	61.48 (-16.2%)
	2090s	19.74 (-48.6%)	41.22 (+18.1%)	60.95 (-16.9%)
Tokyo	1990s	2.59 (-34.9%)	62.03 (-15.2%)	64.62 (-16.2%)
	2040s	0.49 (-87.8%)	76.18 (+4.2%)	76.67 (-0.6%)
	2090s	0.40 (-90.1%)	85.50 (+16.9%)	85.90 (+11.4%)
Naha	1990s	-	122.40 (-9.0%)	122.40 (-9.0%)
	2040s	-	136.03 (+1.1%)	136.03 (+1.1%)
	2090s	-	148.90 (+10.7%)	148.90 (+10.7%)

Fig 5.8 Heating/cooling loads and percentage change by relaxation of the target temperature by 1-2 ℃ compared to the 1990s base model

(3) Building envelope improvement (Improvement of glazing, walls and the roof)

Fig 5.9-5.10 show that in all locations and all periods a lower U-value could bring lower energy use. Thus in this study a combination of double glazing with low-e coating and quadrupled insulation was selected for the improved model. Trends in the total heating/cooling load change of this strategy are similar to that of the temperature target relaxation. Only in Sapporo the total loads will be relatively constant in the future.

Double clear glazing & Doubled insulation (50 mm)		Air-conditioning loads (kWh/m^2/year) and percentage change compared to 1990s base model		
		Heating loads	Cooling loads	Total loads
Sapporo	1990s	32.72 (-14.9%)	33.97 (-2.7%)	66.69 (-9.1%)
	2040s	25.60 (-33.4%)	43.87 (25.7%)	69.46 (-5.3%)
	2090s	19.89 (-48.2%)	49.39 (+41.5%)	69.28 (-5.5%)
Tokyo	1990s	2.81 (-29.5%)	70.46 (-3.7%)	73.27 (-5.0%)
	2040s	0.63 (-84.3%)	84.89 (+16.1%)	85.52 (+10.9%)
	2090s	0.52 (-86.8%)	93.36 (+27.7%)	93.89 (+21.7%)
Naha	1990s	-	128.14 (-4.7%)	128.14 (-4.7%)
	2040s	-	140.73 (+4.6%)	140.73 (+4.6%)
	2090s	-	152.58 (+13.4%)	152.58 (+13.4%)

Fig 5.9 Heating/cooling loads and percentage change by improved windows and insulation 1 (double clear glazing & doubled insulation (50 mm)) compared to the 1990s base model

Double glazing with low-e coating & quadrupled insulation (100 mm)		Air-conditioning loads (kWh/m^2/year) and percentage change compared to the 1990s base model		
		Heating loads	Cooling loads	Total loads
Sapporo	1990s	35.93 (-6.5%)	29.82 (-14.6%)	65.75 (-10.3%)
	2040s	28.75 (-25.2%)	39.16 (+12.2%)	67.91 (-7.4%)
	2090s	22.73 (-40.8%)	44.27 (+26.8%)	67.00 (-8.6%)
Tokyo	1990s	3.66 (-8.1%)	63.23 (-13.5%)	66.90 (-13.3%)
	2040s	0.97 (-75.6%)	77.05 (+5.4%)	78.02 (+1.2%)
	2090s	0.86 (-78.5%)	84.69 (+15.8%)	85.55 (+10.9%)
Naha	1990s	-	119.40 (-11.2%)	119.40 (-11.2%)
	2040s	-	131.15 (-2.5%)	131.15 (-2.5%)
	2090s	-	142.65 (+6.1%)	142.65 (+6.1%)

Fig 5.10 Heating/cooling loads and percentage change by improved windows and insulation 2 (double glazing with low-e coating & quadrupled insulation (100 mm)) compared to the 1990s base model

(4) Overhangs

Fig 5.11 indicates that in Tokyo and Naha installing overhangs could decrease the total heating/cooling loads in every month. On the other hand, from January to April and in November and December (six months) in Sapporo, this strategy could increase the total loads. Thus, it is assumed that in Sapporo overhangs are removed during the six months (shaded in Fig 5.11). As a result, the total loads and percentage change are seen in Fig 5.12. Overall, it has been proved that the effect of installing overhangs in windows with blinds would be limited in every location in terms of reducing the air-conditioning loads.

Sapporo (1990s)	Heating loads	Cooling loads	Total loads
Jan	0.2%	-	0.2%
Feb	0.2%	-	0.2%
Mar	0.4%	-	0.4%
Apr	1.0%	-2.1%	0.4%
May	3.2%	-1.1%	-1.0%
Jun	3.8%	-0.6%	-0.5%
Jul	-	-0.4%	-0.4%
Aug	-	-0.3%	-0.3%
Sep	-	-0.4%	-0.4%
Oct	2.1%	-0.7%	-0.7%
Nov	0.3%	-1.9%	0.2%
Dec	0.2%	-	0.2%

Tokyo (1990s)	Heating loads	Cooling loads	Total loads
Jan	0.5%	-1.8%	0.0%
Feb	0.6%	-3.5%	-0.1%
Mar	0.6%	-1.7%	-0.6%
Apr	1.3%	-0.6%	-0.6%
May	-	-0.4%	-0.4%
Jun	-	-0.3%	-0.3%
Jul	-	-0.2%	-0.2%
Aug	-	-0.2%	-0.2%
Sep	-	-0.2%	-0.2%
Oct	-	-0.3%	-0.3%
Nov	22.9%	-0.5%	-0.5%
Dec	0.9%	-0.8%	-0.4%

Naha (1990s)	Heating loads	Cooling loads	Total loads
Jan	-	-0.3%	-0.3%
Feb	-	-0.3%	-0.3%
Mar	-	-0.3%	-0.3%
Apr	-	-0.3%	-0.3%
May	-	-0.3%	-0.3%
Jun	-	-0.3%	-0.3%
Jul	-	-0.3%	-0.3%
Aug	-	-0.3%	-0.3%
Sep	-	-0.3%	-0.3%
Oct	-	-0.3%	-0.3%
Nov	-	-0.2%	-0.2%
Dec	-	-0.2%	-0.2%

Fig 5.11 1990s monthly reduction rates of heating/cooling loads by overhangs on east/west façades compared to the 1990s base model

		Air-conditioning loads (kWh/m^2/year) and percentage change compared to the 1990s base model		
		Heating loads	Cooling loads	Total loads
Sapporo	1990s	38.44 (0.0%)	34.74 (-0.5%)	73.18 (-0.2%)
	2040s	30.22 (-21.4%)	45.12 (+29.3%)	75.34 (+2.7%)
	2090s	23.79 (-38.1%)	51.04 (+46.2%)	74.83 (+2.0%)
Tokyo	1990s	4.01 (+0.6%)	72.88 (-0.4%)	76.88 (-0.3%)
	2040s	1.15 (-71.1%)	87.41 (19.5%)	88.56 (+14.8%)
	2090s	0.96 (-76.0%)	96.85 (+32.4%)	97.81 (+26.8%)
Naha	1990s	-	134.14 (-0.3%)	134.14 (-0.3%)
	2040s	-	147.84 (+9.9%)	147.84 (+9.9%)
	2090s	-	160.75 (+19.5%)	160.75 (+19.5%)

Fig 5.12 Heating/cooling loads and percentage change by overhangs on east/west façades compared to the 1990s base model

(5) Night cooling

Fig 5.13-5.14 show that in all locations and all periods the base model (lightweight building) with night cooling could reduce more of the heating/cooling loads than a heavyweight building with night cooling. Additionally, heavyweight materials are characterised by having higher embodied energy. Thus, in this study additions of thermal mass were not adopted. Moreover, it is shown that heavyweight buildings in Naha could lead to increases in the 1990s total load. This means that building constructions (thermal mass) should be considered carefully because inappropriate construction could have the reverse effect. Fig 5.13 shows that in the future in Tokyo and Naha the amount of load reduction from the 1990s base model by night cooling would be compensated by an increase in the cooling loads due to climate change, and in the 2090s the total loads would increase significantly compared to the 1990s base model.

Night cooling (lightweight building)		Air-conditioning loads (kWh/m^2/year) and percentage change compared to the 1990s base model		
		Heating loads	Cooling loads	Total loads
Sapporo	1990s	31.92 (-17.0%)	32.13 (-7.9%)	64.05 (-12.7%)
	2040s	24.67 (-35.8%)	41.56 (+19.1%)	66.23 (-9.7%)
	2090s	18.96 (-50.7%)	46.93 (+34.5%)	65.89 (-10.2%)
Tokyo	1990s	2.29 (-42.4%)	69.39 (-5.1%)	71.69 (-7.0%)
	2040s	0.42 (-89.5%)	83.78 (+14.6%)	84.20 (+9.2%)
	2090s	0.31 (-92.2%)	92.53 (+26.5%)	92.84 (+20.4%)
Naha	1990s	-	126.87 (-5.7%)	126.87 (-5.7%)
	2040s	-	141.15 (+4.9%)	141.15 (+4.9%)
	2090s	-	154.52 (+14.9%)	154.52 (+14.9%)

Fig 5.13 Heating/cooling loads and percentage change by night cooling for lightweight buildings compared to the 1990s base model

Night cooling & Thermal mass (heavyweight building)		Air-conditioning loads (kWh/m^2/year) and percentage change compared to the 1990s base model		
		Heating loads	Cooling loads	Total loads
Sapporo	1990s	38.71 (+0.7%)	30.63 (-12.2%)	69.34 (-5.5%)
	2040s	30.38 (-20.9%)	40.17 (+15.1%)	70.55 (-3.8%)
	2090s	23.90 (-37.8%)	45.87 (+31.4%)	69.77 (-4.9%)
Tokyo	1990s	3.90 (-2.1%)	71.29 (-2.5%)	75.19 (-2.5%)
	2040s	1.12 (-71.8%)	87.23 (+19.3%)	88.35 (+14.6%)
	2090s	0.94 (-76.5%)	102.68 (+40.4%)	103.62 (+34.4%)
Naha	1990s	-	147.75 (+9.9%)	147.75 (+9.9%)
	2040s	-	183.84 (+36.7%)	183.84 (+36.7%)
	2090s	-	221.20 (+64.5%)	221.20 (+64.5%)

Fig 5.14 Heating/cooling loads and percentage change by night cooling for heavyweight buildings compared to the 1990s base model

(6) Zonal analysis

The differences in the effects between east side areas and west side areas in each of the introduced strategies are analysed. Fig 5.15 shows that only in Tokyo improved lighting/equipment and improved glazing/insulation could make large differences (over 5 %) in the heating loads between the two office zones. However, the impact of the heating loads on the total loads in Tokyo is small (Fig 5.2, p.41). Thus, in every location and period there is no clear difference in the reduction rates between the west office zone and the east office zone. This suggests that there is no need to consider different measures for areas located on the east or the west side in the building model used, either now or in the future.

Lighting and equipment improvements (reducing internal heat gains)

		Heating loads				Cooling loads			
		East office	West office	EVhall	Total	East office	West office	EVhall	Total
Sapporo	1990s	58.7%	56.8%	12.8%	45.8%	-47.3%	-46.9%	-43.8%	-47.0%
	2040s	29.9%	28.0%	-7.3%	19.3%	-26.6%	-25.9%	7.2%	-25.8%
	2090s	7.7%	6.6%	-19.7%	0.0%	-14.3%	-13.6%	63.0%	-12.8%
Tokyo	1990s	368.3%	322.4%	38.5%	149.4%	-37.3%	-37.1%	-23.5%	-36.7%
	2040s	31.8%	23.9%	-37.8%	-14.1%	-25.1%	-25.0%	-0.6%	-24.3%
	2090s	18.5%	13.3%	-44.2%	-22.4%	-13.5%	-13.3%	33.0%	-11.9%
Naha	1990s	-	-	-	-	-29.0%	-28.8%	-16.6%	-28.3%
	2040s	-	-	-	-	-19.7%	-19.4%	5.0%	-18.3%
	2090s	-	-	-	-	-10.8%	-10.6%	25.4%	-8.9%

Target temperature relaxation (1-2℃)

		Heating loads				Cooling loads			
		East office	West office	EVhall	Total	East office	West office	EVhall	Total
Sapporo	1990s	-13.6%	-13.1%	-11.0%	-12.7%	-24.6%	-24.1%	-68.0%	-25.0%
	2040s	-16.4%	-15.9%	-11.4%	-14.8%	-20.3%	-20.2%	-62.2%	-21.1%
	2090s	-19.5%	-18.8%	-12.4%	-17.1%	-18.9%	-18.6%	-51.9%	-19.5%
Tokyo	1990s	-43.8%	-44.4%	-29.6%	-34.9%	-14.6%	-14.3%	-38.3%	-15.2%
	2040s	-67.6%	-70.1%	-54.1%	-57.2%	-12.4%	-12.2%	-35.9%	-13.1%
	2090s	-71.3%	-74.7%	-55.0%	-58.2%	-11.3%	-11.1%	-30.6%	-12.0%
Naha	1990s	-	-	-	-	-8.4%	-8.3%	-21.6%	-9.0%
	2040s	-	-	-	-	-7.7%	-7.6%	-17.9%	-8.2%
	2090s	-	-	-	-	-7.1%	-7.1%	-15.4%	-7.6%

Double glazing with low-e coating & quadrupled insulation (100 mm)

		Heating loads				Cooling loads			
		East office	West office	EVhall	Total	East office	West office	EVhall	Total
Sapporo	1990s	-4.2%	-5.8%	-10.7%	-6.5%	-13.6%	-14.3%	-53.4%	-14.6%
	2040s	-24.5%	-25.7%	-25.5%	-25.2%	12.9%	12.1%	-6.5%	12.2%
	2090s	-42.3%	-43.0%	-35.9%	-40.8%	27.1%	26.3%	34.5%	26.8%
Tokyo	1990s	-5.9%	-11.8%	-7.4%	-8.1%	-12.2%	-13.5%	-33.3%	-13.5%
	2040s	-89.3%	-89.4%	-67.8%	-75.6%	6.8%	5.0%	-10.3%	5.4%
	2090s	-92.7%	-92.4%	-70.4%	-78.5%	16.8%	14.8%	15.3%	15.8%
Naha	1990s	-	-	-	-	-10.3%	-10.6%	-26.2%	-11.2%
	2040s	-	-	-	-	-2.0%	-2.4%	-8.3%	-2.5%
	2090s	-	-	-	-	6.1%	5.7%	9.9%	6.1%

Overhangs on east/west façades

		Heating loads				Cooling loads			
		East office	West office	EVhall	Total	East office	West office	EVhall	Total
Sapporo	1990s	0.0%	0.0%	0.1%	0.0%	-0.5%	-0.4%	-1.5%	-0.5%
	2040s	-23.1%	-22.9%	-16.9%	-21.4%	28.3%	29.0%	68.4%	29.3%
	2090s	-41.9%	-41.1%	-28.7%	-38.1%	44.6%	45.3%	129.1%	46.2%
Tokyo	1990s	0.9%	0.7%	0.5%	0.6%	-0.3%	-0.3%	-0.6%	-0.4%
	2040s	-82.6%	-83.7%	-64.3%	-71.1%	19.9%	18.6%	27.3%	19.5%
	2090s	-88.2%	-88.9%	-68.8%	-76.0%	32.0%	30.7%	64.9%	32.4%
Naha	1990s	-	-	-	-	-0.3%	-0.2%	-0.5%	-0.3%
	2040s	-	-	-	-	9.2%	9.3%	23.0%	9.9%
	2090s	-	-	-	-	18.2%	18.2%	45.2%	19.5%

Night cooling

		Heating loads				Cooling loads			
		East office	West office	EVhall	Total	East office	West office	EVhall	Total
Sapporo	1990s	-15.1%	-14.6%	-22.8%	-17.0%	-7.9%	-6.3%	-64.2%	-7.9%
	2040s	-35.8%	-35.3%	-36.6%	-35.8%	18.5%	20.9%	-24.6%	19.1%
	2090s	-52.7%	-51.7%	-46.4%	-50.7%	33.3%	35.9%	25.0%	34.5%
Tokyo	1990s	-36.8%	-39.2%	-44.9%	-42.4%	-4.7%	-4.2%	-26.1%	-5.1%
	2040s	-91.8%	-93.1%	-87.8%	-89.5%	15.5%	14.7%	-0.9%	14.6%
	2090s	-95.0%	-95.9%	-90.3%	-92.2%	26.7%	26.1%	30.5%	26.5%
Naha	1990s	-	-	-	-	-5.3%	-5.1%	-15.3%	-5.7%
	2040s	-	-	-	-	4.6%	4.9%	8.7%	4.9%
	2090s	-	-	-	-	14.0%	14.1%	31.0%	14.9%

Fig 5.15 Zonal percentage change of heating/cooling loads by each strategy compared to the 1990s base model

(7) Comparative analysis

Fig 5.16-5.17 show the potential for heating/cooling load reductions by each energy-saving measure introduced in the present and in the future.

It is clear that in Sapporo relaxing the target temperature could save the largest air-conditioning loads both now and in the future. Night cooling and improved glazing/insulation could also decrease the heating/cooling loads largely both now and in the future. The reduction rates would be constant in the future. Improved lighting/equipment could have a larger reduction rates in the future than the present.

In Tokyo and Naha improved lighting and equipment could reduce the largest air-conditioning loads. Additionally, only this measure could decrease total heating/cooling loads both in the 2040s and 2090s compared to the 1990s base model against climate change. Relaxing the target temperature, improved glazing/insulation, and night cooling could reduce the total heating/cooling loads compared to the 1990s base model and these trends in the total load change would be similar. However, the effects of night cooling might be much less than the other two strategies.

In all locations, overhangs could decrease the smallest air-conditioning loads.

These results mean that the effect of each strategy for reducing the heating/cooling requirements could fluctuate significantly due to the climate characteristic of each location both currently and in the future.

Strategy	Sapporo			Tokyo			Naha		
	1990s	2040s	2090s	1990s	2040s	2090s	1990s	2040s	2090s
Improved lighting and equipment (reducing internal heat gains)	1.6%	-2.1%	-6.1%	-27.1%	-23.7%	-12.4%	-28.3%	-18.3%	-8.9%
Target temperature relaxation	-18.6%	-16.2%	-16.9%	-16.2%	-0.6%	11.4%	-9.0%	1.1%	10.7%
Double glazing with low-e coating and quadrupled insulation (100 mm)	-10.3%	-7.4%	-8.6%	-13.3%	1.2%	10.9%	-11.2%	-2.5%	6.1%
Overhangs on east/west façades	-0.2%	2.7%	2.0%	-0.3%	14.8%	26.8%	-0.3%	9.9%	19.5%
Night cooling	-12.7%	-9.7%	-10.2%	-7.0%	9.2%	20.4%	-5.7%	4.9%	14.9%

Fig 5.16 Percentage change of the total heating/cooling loads by each strategy compared to the 1990s base model

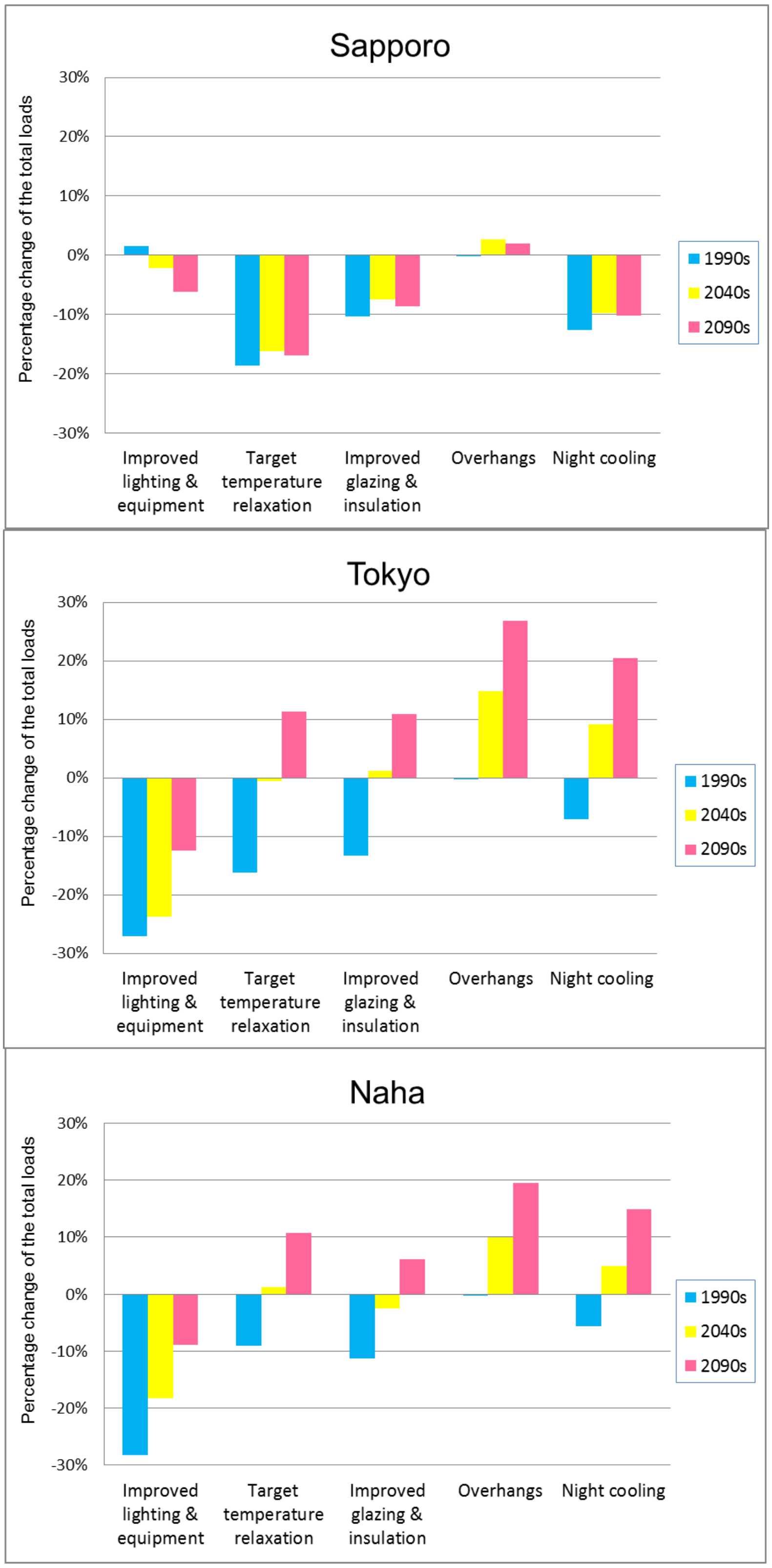


Fig 5.17 Percentage change of the total heating/cooling loads by each strategy compared to the 1990s base model

5.2.2. Cumulative effect of all the strategies

The cumulatively improved model, in which all the effective strategies were introduced concurrently, can be seen in Fig 5.18-5.19. They show that with these measures in Sapporo, the total heating/cooling loads could be decreased from the 73.34 kWh/m^2/year from the 1990s base model to 47.86 kWh/m^2/year in the 1990s, 44.55 kWh/m^2/year in the 2040s, and 41.51 kWh/m^2/year in the 2090s, respectively. Thus, despite the projected climate change, Sapporo could reduce its total loads by 39.3 % in the 2040s and by 43.4 % in the 2090s compared to the 1990s base model.

On the other hand, with these measures in Tokyo and Naha the total heating/cooling loads would increase in the future. For example, in Tokyo at present (1990s) the total loads would decrease by 58.6 % compared to the 1990s base model, but by 53.9 % in the 2040s and by 45.0 % in the 2090s. Similarly, the total loads in Naha could drop by 50.2 % in the 1990s, but by 41.0% in the 2040s and by 32.3 % in the 2090s. This means that in the future additional strategies should be considered at both locations to get the same amount of heating/cooling load reduction as in the 1990s.

Overall, effective strategies and their effects for reducing the heating/cooling requirements would be completely different depending on the regional climate characteristics and the period.

		Air-conditioning loads (kWh/m^2/year)					
		Cumulatively improved model (Percentage change compared to the 1990s base model)			1990s base model		
		Heating loads	Cooling loads	Total loads	Heating loads	Cooling loads	Total loads
Sapporo	1990s	40.84 (+6.3%)	7.02 (-79.9%)	47.86 (-34.7%)	38.43	34.91	73.34
	2040s	33.23 (-13.5%)	11.32 (-67.6%)	44.55 (-39.3%)			
	2090s	27.16 (-29.3%)	14.35 (-58.9%)	41.51 (-43.4%)			
Tokyo	1990s	5.09 (+27.8%)	26.80 (-63.4%)	31.89 (-58.6%)	3.98	73.13	77.12
	2040s	1.12 (-71.9%)	34.41 (-53.0%)	35.53 (-53.9%)			
	2090s	0.98 (-75.5%)	41.40 (-43.4%)	42.38 (-45.0%)			
Naha	1990s	-	66.96 (-50.2%)	66.96 (-50.2%)	-	134.50	134.50
	2040s	-	79.33 (-41.0%)	79.33 (-41.0%)			
	2090s	-	91.07 (-32.3%)	91.07 (-32.3%)			

Fig 5.18 Heating/cooling loads and percentage change of the cumulatively improved model and the 1990s base model

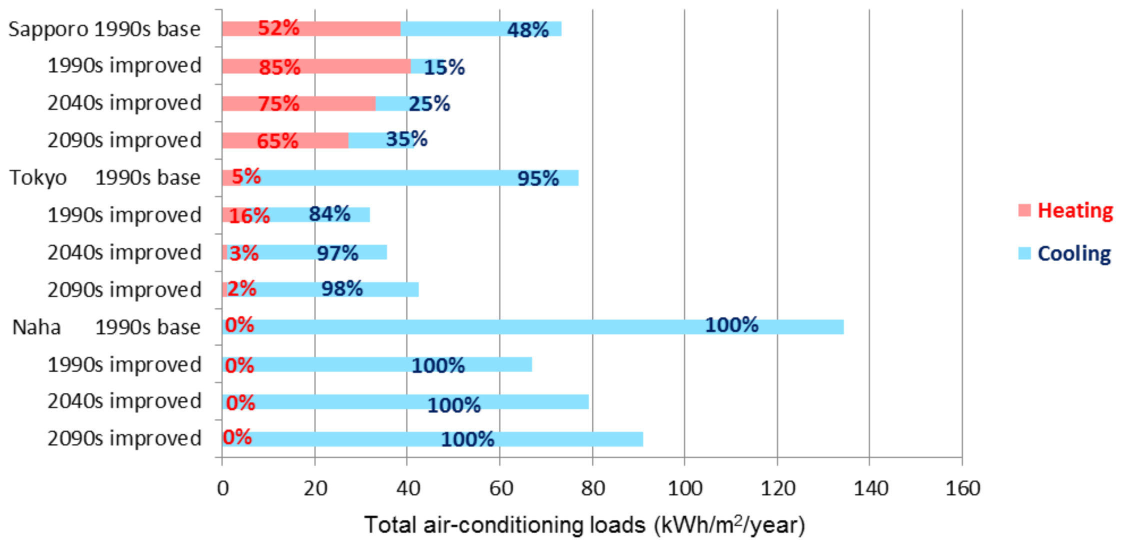


Fig 5.19 Heating/cooling load comparison between the cumulatively improved model and the 1990s base model

As a zonal analysis, only the heating load in Tokyo in the 1990s has large differences (over 5 %) between the east office zone and the west office zone (Fig 5.20); however, the amount of heating load in Tokyo is much smaller than that for the cooling. Additionally, the heating/cooling loads profile in both office zones would be similar (Fig 5.21-5.22, Appendix 14-16). Thus, on the cumulatively improved model as well as the base model (Fig 5.3-5.5, p.42-44), the difference was considered to be unimportant.

		Heating loads				Cooling loads			
		East office	West office	EVhall	Total	East office	West office	EVhall	Total
Sapporo	1990s	19.6%	17.8%	-27.9%	6.3%	-79.9%	-79.3%	-100.0%	-79.9%
	2040s	-2.5%	-4.2%	-41.7%	-13.5%	-67.5%	-66.6%	-100.0%	-67.6%
	2090s	-21.2%	-22.2%	-50.4%	-29.3%	-58.8%	-57.8%	-97.2%	-58.9%
Tokyo	1990s	146.0%	123.1%	-32.7%	27.8%	-62.8%	-62.6%	-83.7%	-63.4%
	2040s	-48.8%	-52.4%	-84.0%	-71.9%	-52.2%	-52.1%	-77.4%	-53.0%
	2090s	-55.4%	-58.3%	-86.1%	-75.5%	-42.7%	-42.8%	-62.7%	-43.4%
Naha	1990s	-	-	-	-	-49.4%	-49.4%	-66.5%	-50.2%
	2040s	-	-	-	-	-40.5%	-40.5%	-50.7%	-41.0%
	2090s	-	-	-	-	-32.2%	-32.2%	-34.4%	-32.3%

Fig 5.20 Percentage change of heating/cooling loads compared to the 1990s base model by all the strategies by zone

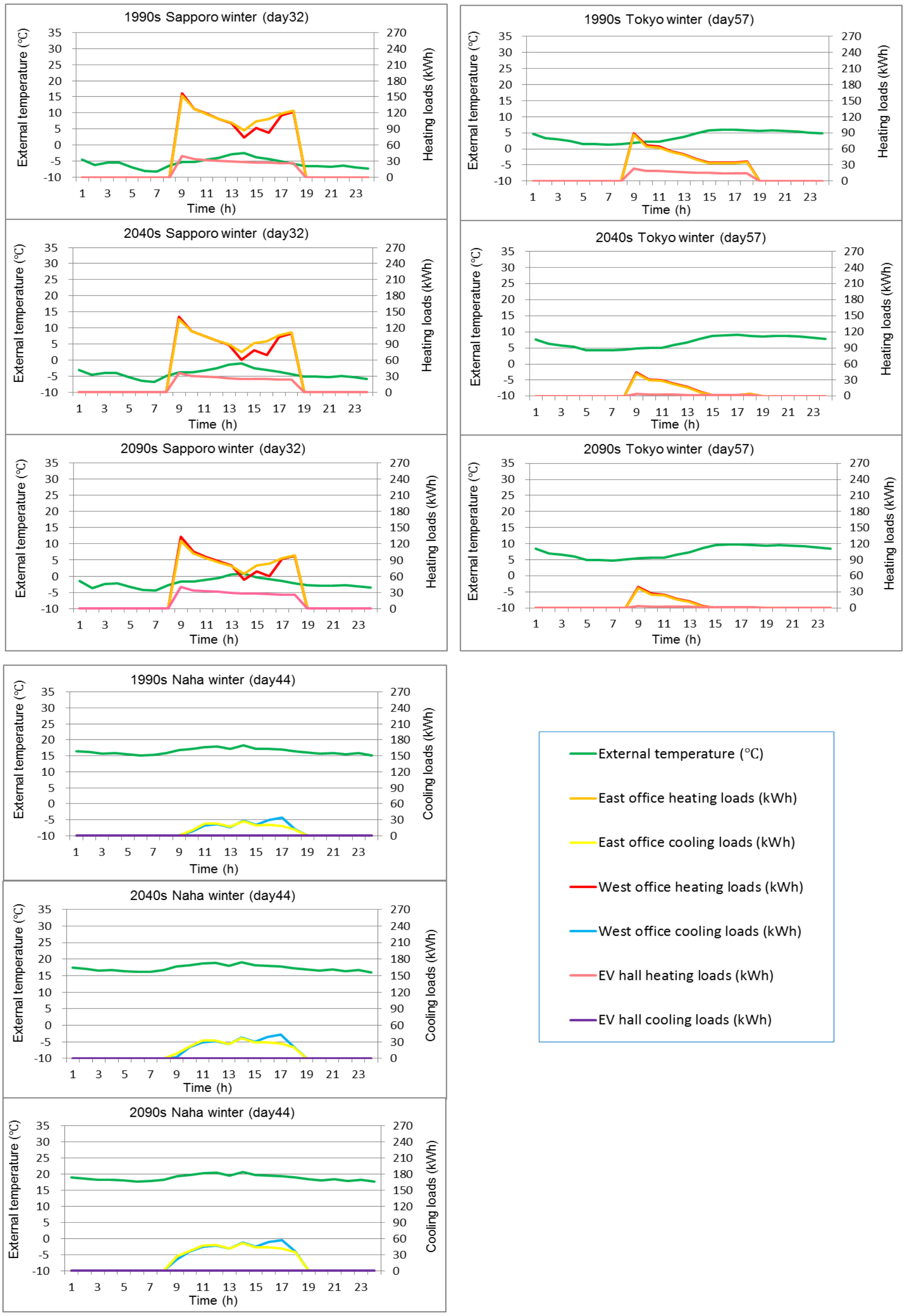


Fig 5.21 Heating/cooling loads profile of the cumulatively improved model on a typical winter day

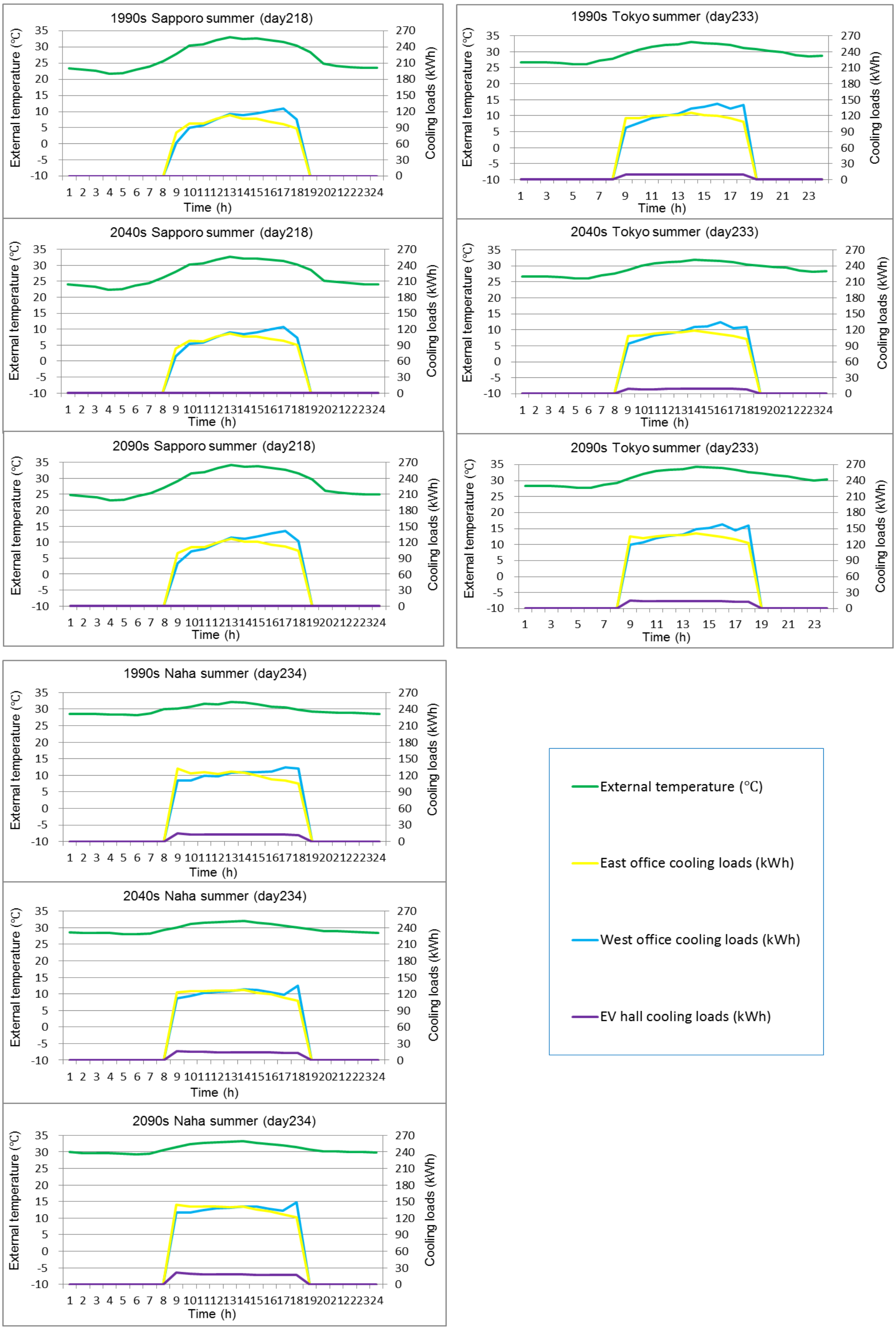


Fig 5.22 Cooling loads profile of the cumulatively improved model on a typical summer day

Fig 5.23 indicates that the monthly trends in the heating/cooling load in each location would be almost the same over every period as along with the base model (Fig 5.6, p.45) (Appendix 17).

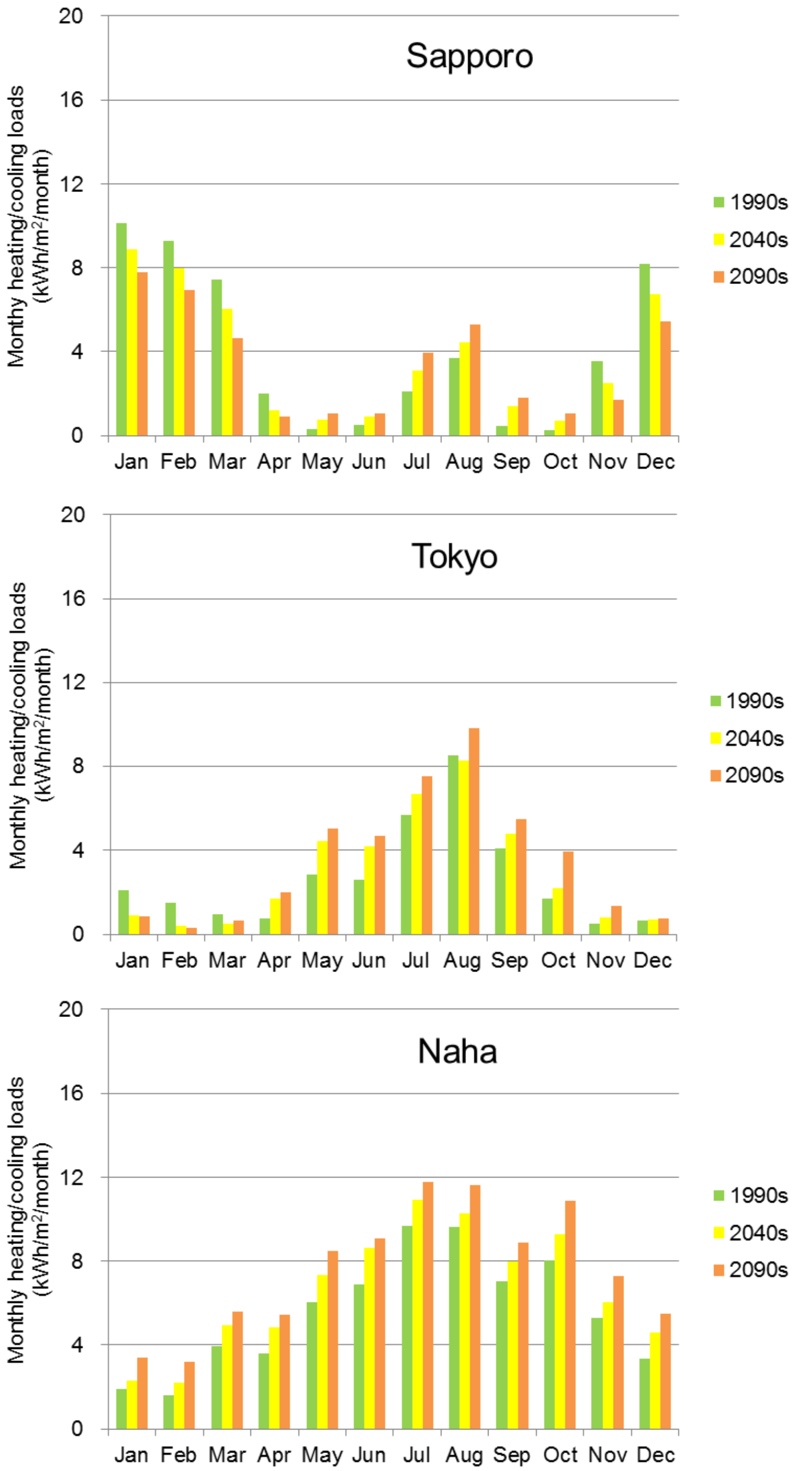


Fig 5.23 Monthly heating/cooling load of the cumulatively improved model

5.3. Electric Energy Consumption and Carbon Dioxide Emissions

In Japanese offices cooling and heating are usually provided by electricity much more often than by gas (ACENR 2007). In this study, both heating and cooling provided by only electricity was assumed for the calculations.

A Coefficient of Performance (COP) of an all air distribution system (air-source heat pumps) was assumed to be 2.7 in the 1990s since this value is based on previous research, which shows the average COP of typical air-conditioning installed in Japanese commercial buildings as 2.7 in 1997 (ACENR 2007). On the other hand, 5.7 was used as the future value (Annual Performance Factor (APF)) since this value is the best target figure of manufacturers in 2015 (ACENR 2009). This means that in this study, future technological innovation after 2015 was ignored. Electric energy required for transporting cooling (fans, pumps, and controls) was also ignored.

Meanwhile, an electricity conversion factor of 0.376 $kgCO_2/kWh$ was used for the calculations in the 1990s since this factor is based on data measured in 1990 in Japan (FEPC 2011). On the other hand, two future electricity conversion factors of 0.559 $kgCO_2/kWh$ and 0.699 $kgCO_2/kWh$ were estimated. As mentioned before, recently there have been discussions about reduced dependency on nuclear power in the future wherever possible. These values are based on current energy conservation codes in Japan (MOE 2012) and the proposed options about the amount of electricity generated by nuclear power; 20-25 % (similar to the current 30.8 %, Fig 2.11, p.10) and 0 %. 0.559 $kgCO_2/kWh$ is based on the estimate that dependency on nuclear power is 20-25 % and that the reduction of nuclear power can be offset by other low-CO_2-emitting energies such as wind, while 0.699 $kgCO_2/kWh$ is based on the assumption that nuclear power will disappear and electricity conversion factors will increase by 25 % since this disappearance cannot be offset and trends in other primary energy supply are constant.

Fig 5.24 shows that in all locations electricity consumption for air-conditioning can be reduced by around 70 % in the future. This means that installing all the strategies introduced here could lead to meeting the national energy consumption reduction target, which is to reduce energy demand by 40 % (relative to the 2000 value) in the commercial sector to achieve the proposed 70 % CO_2 emissions reductions by 2050 (" 2050 Japan Low-Carbon Society" scenario team 2008). However, Fig 5.25 suggests that in all locations the related CO_2 emissions cannot be reduced by 70 % in the future even if electricity conversion factors remain unchanged (0.559 $kgCO_2/kWh$). Additionally, there are clear differences between the reduction rates of each location.

Overall, in order to meet the national CO_2 emissions reduction target, additional effective strategies for buildings that consider regional climate differences should be completed. Otherwise, electricity conversion factor improvements from increases in the dependence on nuclear power or technological progress, such as improved new energy efficiency, or further improvements of air-conditioning units should be completed.

	Electricity consumption for heating/cooling ($kWh/m^2/year$) and reduction rates compared to 1990s base model (%)			
	1990s base model (COP 2.7)	1990s improved model (COP 2.7)	2040s improved model (APF 5.7)	2090s improved model (APF 5.7)
Sapporo	27.2	17.7 (-34.7%)	7.8 (-71.2%)	7.3 (-73.2%)
Tokyo	28.6	11.8 (-58.6%)	6.2 (-78.2%)	7.4 (-74.0%)
Naha	49.8	24.8 (-50.2%)	13.9 (-72.1%)	16.0 (-67.9%)

Fig 5.24 Electricity consumption for heating/cooling and reduction rates compared to the 1990s base model

	CO_2 emissions for heating/cooling ($CO_2kg/m^2/year$) and reduction rates compared to 1990s base model (%)					
	1990s base model	1990s improved model	2040s improved model		2090s improved model	
	(0.376 CO_2kg/kWh)	(0.376 CO_2kg/kWh)	(0.559 CO_2kg/kWh)	(0.699 CO_2kg/kWh)	(0.559 CO_2kg/kWh)	(0.699 CO_2kg/kWh)
Sapporo	10.2	6.7 (-34.7%)	4.4 (-57.2%)	5.5 (-46.5%)	4.1 (-60.1%)	5.1 (-50.2%)
Tokyo	10.7	4.4 (-58.6%)	3.5 (-67.6%)	4.4 (-59.4%)	4.2 (-61.3%)	5.2 (-51.6%)
Naha	18.7	9.3 (-50.2 %)	7.8 (-58.5%)	9.7 (-48.1%)	8.9 (-52.3%)	11.2 (-40.4%)

Fig 5.25 CO_2 emissions for heating/cooling and reduction rates compared to the 1990s base model

5.4. Economic Analysis

First, in order to analyse the cost effectiveness of each strategy, the expected additional costs to install the strategies was calculated in Fig 5.26 (Appendix 18).

The additional costs for glazing/insulation improvements and overhangs were divided by their estimated life (20 years) to calculate the annual additional costs for convenience's sake, though originally the initial capital costs would all be in year zero. Additionally, the time value of money was not considered since in Japan recently O/N Call Rate Target (corresponding to the Current Bank Rate of the UK) has been approximately zero (Gaitame.Com Co.,Ltd. 2012, Appendix 19) and the Consumer Price Index (CPI) has been constant (MIC 2012, Appendix 20).

The additional costs for lighting and equipment improvements were estimated to be zero since this strategy comes from technological progress by mainly manufacturers, and so changes in the price were ignored in this study. The additional costs for relaxing temperature settings and for night cooling were also estimated to not cost anything. Because the base model assumed that the internal and external temperatures are controlled in a central control room, and that control panels have already been installed.

Fig 5.16-5.17 (p.55-56) and 5.26 indicate that the effect from overhangs on energy savings is limited and that this strategy is not effective compared to the costs incurred. As a result, in this economic analysis, the effect from overhangs for reducing cooling/heating loads was ignored and it was assumed that all overhangs were excluded.

	Additional costs (A) (JPY)	The life (B) (year)	Annual additional costs (A/B) (JPY/year)
Lighting and equipment improvements	-	-	-
Relaxation of the indoor air quality target	-	-	-
Double glazing with low-e coating & quadrupled insulation in the roof and external walls	13.6M	20	0.7M
Overhangs	32.3M	20	1.6M
Night cooling	-	-	-
Total			2.3M
Total (excluding overhangs)			0.7M*
			* around 5,400 GBP

Fig 5.26 Annual additional costs for the effective strategies

Next, the cost effectiveness for reducing electricity consumption with the effectve strategies was examined in Fig 5.27.

It is clear that the electricity rate is much higher than the expected costs from reducing electricity usage via the effective strategies. Considering the recent rise in the electricity rate over the Tokyo Metroporitan Area (Tokyo Electric Power Company Co.,Ltd. service area, ANRE 2012), the rate might rise nationwide in the near future.

It is also clear that the expected costs for the effective strategies could be competitive with the nuclear power generating costs. Since nuclear power does not emit CO_2 in the process of generating power (ANRE 2010), both of these are considered to be measures to reduce CO_2 emissions effectively. It is important to note that nuclear power generating costs are the minimum and it is highly likely that the costs will be more expensive (EEC 2011).

Overall, the costs for reducing heating/cooling loads in office buildings could be lower than not only the electricity rate but also that for nuclear power generation, which is known for being an economical generation system, in all locations, especially in the future.

Cost effectiveness for electricity consumption reduction by effective strategies (JPY/▲kWh)				Electricity rate (JPY/kWh)		Minimum nuclear power generating cost (JPY/kWh)
	1990s	2040s	2090s	Industrial, business use (high tension voltage)	Home use (low tension voltage)	
Sapporo	13.8	6.7	6.5	14.8	21.3	8.9*
Tokyo	7.8	5.8	6.2			
Naha	5.2	3.6	3.8			
						*0.071 GBP

Fig 5.27 Cost comparison between electricity consumption reductions by the effective strategies and electricity rate and nuclear power generation (EEC 2011, ANRE 2011b)

5.5. Summary

First, the simulations of the base model showed that heating/cooling loads can be changed significantly due to regional climate characteristic even if the construction elements and internal conditions are the same. In the future, cooling loads will increase and heating loads will decrease due to higher external temperatures. As a result, in the future in Sapporo the total energy requirements for heating/cooling will be constant, while a distinct increasing trend could potentially be observed for both Tokyo and Naha, which are locations where cooling is dominant.

Second, the simulations of the improved models showed that effective strategies could decrease the total loads in office buildings significantly. In all locations, replacing single glazing with double glazing that has low-e coating and adding insulation to roofs and external walls can reduce the total loads largely. Additionally, improved lighting and equipment, relaxing the temperature target, and the availability of passive cooling in the form of natural night ventilation without adding thermal mass could reduce the total loads effectively and economically. This means that non-fabric strategies are as important as fabric improvements in order to reduce the total loads in office buildings efficiently. It is important to note that the expected reduction rates in each location would be clearly different.

Finally, it was explained that electricity consumption and related CO_2 emissions for space heating/cooling are greatly infuenced by the efficiency of air-conditioning units and electricity conversion factors. In other words, sufficient electricity use reduction does not always lead to sufficient CO_2 emissions reductions. It was also explained that the strategies introduced here can be cost-effective measures with proper consideration from medium and long-term perspectives.

6. CONCLUSIONS

This dissertation reviewed the recent policies, rules, regulations, and measures which can contribute to reducing energy usage in office buildings in Japan. In addition, the potential impacts of climate change on the cooling and heating energy requirements for offices were investigated by means of thermal analysis simulations and hourly reference weather years over three periods; 1981-2000 (1990s), 2031-2050 (2040s), and 2081-2100 (2090s). Over a series of computational studies, a multistorey office building in three locations with improved building envelope components and internal heat gains, relaxed targets for indoor air quality, a fixed infiltration rate, and a fixed window area fraction of 30 % was considered.

This study quantified how such measures could have a direct effect on the total heating/cooling loads in both current and future offices. It also revealed that under the IPCC's A2 carbon emission scenario, substantial reductions of energy consumption are expected in all locations over all periods if the full measures and technologies that are currently available were to be implemented, while bearing in mind that other types of buildings and other climate change scenarios might react differently to changing conditions. However, the reduction rates can change significantly in each location and each period due to regional climate characteristics and climate change. In Sapporo, despite climate change the expected reduction rate of the total load from the 1990s base model would be better in the future; 34.7 % in the 1990s, 39.3 % in the 2040s, and 43.4 % in the 2090s. In contrast, in Tokyo and Naha it will be worse in the future; 58.6 % and 50.2 % in the 1990s, 53.9 % and 41.0 % in the 2040s, and 45.0 % and 32.3 % in the 2090s, respectively.

Additionally, sufficient reductions in the heating/cooling loads and energy consumption do not necessarily mean that the CO_2 emissions reduction targets set by the Japanese government will be achieved. This is because electricity conversion factors could be worse due to revisions of the national energy plan triggered by the Fukushima nuclear accident would reduce the dependency on nuclear power in the future. Thus, in order to attain the national target further energy reduction measures, on both the supply and demand sides, should be considered. What is particularly important is decarbonising the grid. The findings of this study would help building designers, engineers, urban planners, energy and environmental policy makers, utilities, and other stakeholders to consider the impact of climate change on energy production, distribution, and consumption. They have traditionally assumed an unchanging external climate. Confronted with climate change, this approach should be revised and necessary measures must be taken.

As a result, more attention should be paid to regional and global impact of climate change in building energy codes. For example, the standards of office's heating/cooling loads in perimeter zones could vary by each location, and could more closely reflect the total loads increases in the future. Moreover, efficient building envelopes, as well as lighting, appliances, and HVAC systems with higher efficiency would need to be developed. A series of more efficient strategies (e.g. triple glazing with argon gas) could be simulated to determine at which level the added efficiency will need to compensate for the heating/cooling demand increases from climate change. Furthermore, some supports, policy implications, suitable suggestions, and political and awareness-raising activities should be proposed for end-users in order to change their activities, such as by relaxing the indoor air quality targets.

Meanwhile, around one-third of the office building stock in the chief cities of Japan dates from before 1981 (JREI 2011). This means that Japan still has a vast quantity of old offices without sufficiently effective energy measures. In addition, the measures introduced in the study are typical and popular, and not very specific. Moreover, technological improvements in the future (e.g. effective lighting, better COP/AFP of air-conditioning units) were not fully considered. With more specific and up-to-date technologies, much greater energy reductions could be completed more effectively and efficiently. Furthermore, a brief economic analysis suggested that these measures could be competitive with nuclear power generation, especially in the future.

In conclusion, office buildings in Japan have enormous potential to reduce energy requirements and related CO_2 emissions without resorting to nuclear power generation. In other words, reducing nuclear dependency could be covered by promoting effective energy saving measures in building sectors in terms of both CO_2 emissions and economical aspects.

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APPENDICES

Appendix 1	Essential features of the Standards of Judgment for Buildings on Rational Use of Energy (ECCJ 2011b)
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Appendix 1. Essential features of the Standards of Judgment for Buildings on Rational Use of Energy (ECCJ 2011b)

(1) Prevention of heat loss through external walls, windows, etc. of the buildings	i) Orientation of the external walls, layouts of rooms, and other matters should be considered in planning site and floor.
	ii) Thermal insulation materials for external walls, roofs, floors, windows, and openings should be used.
	iii) Solar radiation load should be reduced by adopting a system capable of properly controlling solar radiation through windows, planting trees, or taking other measures.
(2) Efficient use of energy by air-conditioning equipment	i) Air conditioning load characteristics of rooms and other factors should be considered in designing air conditioing systems.
	ii) Heat retention plans should be made to minimize energy loss in air ducts, piping, and others.
	iii) A proper control system should be adopted.
	iv) A heat source system with high energy efficiency should be adopted.
(3) Efficient use of energy by mechanical ventilation equipment other than air-conditioning equipment	i) A plan should be made to minimize energy loss in air ducts and others.
	ii) A proper control system should be adopted.
	iii) Mechanical ventilation equipment with high energy efficiency and a proper capacity for the required ventilation volume should be introduced.
(4) Efficient use of energy by lighting fixtures	i) Lighting fixtures with high lighting efficiency should be introduced.
	ii) A proper control system should be adopted.
	iii) Lighting fixtures should be installed in a manner that facilitates easy maintenance and management.
	iv) Lighting fixtures, set illuminance, and select room shape and interior finishes should be properly laid out.
(5) Efficient use of energy by hot water supply equipment	i) Shorter piping, thermal insulation of piping, etc. should be considered in planning proper piping.
	ii) A proper control system should be adopted.
	iii) An energy-efficient heat source system should be adopted.
(6) Efficient use of energy by vertical transportation	i) A proper control system should be adopted.
	ii) A drive system with high energy efficiency should be adopted.
	iii) A proper installation plan for the required transport capacity should be adopted.

Appendix 2. Main criteria of CASBEE for New Construction (JSBC 2010)

Built Environmental Quality (Q)	Q1: Indoor Environment	sonic environment, thermal comfort, lighting & illumination, air quality
	Q2 Quality of Service	service ability, durability & reliability, flexibility & adaptability
	Q3: Outdoor Environment On-Site	conservation & creation of biotope, townscape & landscape, local characteristics & outdoor amenity
Building Environmental Load Reduction (LR)	LR1: Energy	building thermal load, natural energy utilization, efficiency in building service system, efficient operation
	LR2: Resources & Material	water resources, reducing usage of non-renewable resources, avoiding the use of materials with pollutant content
	LR3: Off-Site Environment	consideration of global warming, consideration of local environment, consideration of surrounding environment

Appendix 3. Energy conservation facilities in Japan (ECCJ 2011b)

<table>
<tr><th>Target recipiets</th><th>Available funds</th><th>Financing percentage*</th></tr>
<tr><td>Enterprises installig energy conservation equipment (including those which lease or rent this equipment)</td><td>Funds required to acquire 52 pieces of energy conservation equipment such as heat pump type heat source equipment, waste heat boilers and cogeneration systems, etc.</td><td rowspan="2">Up to 270M JPY**
<special interest rate Ⅱ>

Over 270M JPY**
<standard rate></td></tr>
<tr><td>The leasing enterprises or rental companies which purchase energy conservation equipment</td><td>Funds required to acquire 11 pieces of mechanical self-running equipment for works such as excavating machines etc.</td></tr>
<tr><td>Enterprises which plan to install specific high-performance energy consumption equipment</td><td>(1)Funds required to install specific high-performance furnace and boiler
(2)Funds required to install specific additional equipment which enhances the performance of the current equipment to the level of a high-performance furnace or boiler</td><td>Up to 270M JPY**
<special energy conservation rate B>

Over 270M JPY**
<standard rate></td></tr>
<tr><td colspan="2">*Financing percentage is the rate defined by Japan Finance Corporation.</td><td>**around 2.1M GBP</td></tr>
</table>

Appendix 4. Subsidy programme in Japan (ECCJ 2011b)

<table>
<tr><th rowspan="2">Implementing Organization</th><th rowspan="2">Project name</th><th colspan="4">Granted persons</th></tr>
<tr><th>Local public authority</th><th>NPO etc.</th><th>Companies</th><th>Indivisuals etc.</th></tr>
<tr><td rowspan="5">New Energy and Inductrial Technology Development Organization (NEDO)</td><td>Projects for formulating visions of regional energy conservation etc.</td><td>✓</td><td>✓</td><td>✓</td><td></td></tr>
<tr><td>Projects for supporting business operators promoting the rational utilization of energy</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Projects for supporting the introduction of energy conservation measures</td><td></td><td>✓</td><td>✓</td><td></td></tr>
<tr><td>Projects for promoting the introduction of high-efficiency energy systems (e.g. BEMS, water heaters) into homes and buildings</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Projects for promoting the energy supplier-led collaboration of comprehensive energy conservation (for buildings)</td><td>✓</td><td></td><td>✓</td><td></td></tr>
<tr><td rowspan="2">Japan Electro-Heat Centre</td><td>Projects for promoting the introduction of high-efficiency water heaters (Eco Cute)</td><td colspan="4">All types of industries (including household)</td></tr>
<tr><td>Projects for promoting the introduction of high-efficiency air conditioning equipment</td><td colspan="4">Private business operators (commercial sector) etc. (including local governments)</td></tr>
<tr><td rowspan="3">Toshi-gas Shinko Centre</td><td>Support projects for promoting natural gasification of energy-intensive facilities</td><td colspan="4">All types of industries</td></tr>
<tr><td>Projects for disseminating the introduction of high-efficiency water heaters (town gas)</td><td colspan="4">Individuals and private business operators, etc.</td></tr>
<tr><td>Model projects for the introduction of area energy network of natural gas type</td><td colspan="4">Business operators (including local governments)</td></tr>
<tr><td>The Conference of LP Gas Associated Organizations</td><td>Projects for supporting the introduction of high-efficiency water heaters (LP Gas)</td><td colspan="4">Individuals and private business operators, etc.</td></tr>
<tr><td>Petroleum Association of Japan (PAJ)</td><td>Subsidy system for supporting the introduction of high-efficiency water heaters (Eco Feel)</td><td colspan="4">Individuals and private business operators, etc.</td></tr>
</table>

Appendix 5. Method for developing reference weather year (Soga and Akasaka 2004)

To start with, months that have peculiar values for the three parameters (air temperature, absolute humidity, and solar radiation) which influence energy consumption in buildings were removed. Next, since two parameters (wind speed and rainfall) are considered to be more frequently used in architectural and engineering fields than three other parameters (atmospheric radiation, wind direction, and sunshine duration), months that have peculiar values for the two parameters were removed. The requirements of removing the two parameters are relaxed compared to the former three parameters. Each requirement for candidate months are seen in Fig A5.1. SW in the table are standard deviation in the L years ($SW0 = \sqrt{\sum^{L} FS_{y,m}^{2} iL}$), and FS is an index of frequency inclination and is calculated by using the equation A5.1-A5.2.

Step	Selection requirements for candidate months
1	Monthly mean air temperature is within $\pm SW$
2	Monthly mean horizontal diffuse radiation is within $\pm SW$
3	Monthly mean absolute humidity is within $\pm SW$
4	Monthly mean rainfall is within $\pm 1.5SW$
5	Monthly mean wind speed is within $\pm 1.5SW$
6	FS of daily mean air temperature is within $+SW0$
7	FS of daily mean horizontal diffuse radiation is within $+SW0$
8	FS of daily mean absolute humidity is within $+SW0$
9	FS of daily mean rainfall is within $+1.5SW0$
10	FS of daily mean wind speed is within $+1.5SW0$

Fig A5.1 Candidate months requirements for reference weather year

$$FS_{y,m} = \frac{1}{n}\sum_{i=1}^{n} \delta_{y,m,i} \quad (A5.1)$$

$$\delta_{y,m,i} = \left|CDF_{y,m,i} - CDF_{m,i}\right| \quad (A5.2)$$

Where

e: parameters (1: air temperature [℃], 2: absolute humidity [g/kg'], 3: solar radiation [MJ/m^{2}d])

m: month (1-12)

y: year (1-L)

L: the number of years

$W_{e,m,y}$*: mean of e in m month in y year*

$W_{e,m}$*: mean of e in m month in y year in L years*

n: the number of days in the month

$CDF_{y,m,i}$*: cumulative frequency function of m month in y year*

$CDF_{m,i}$*: cumulative frequency function of m month in L years*

When there are multiple candidate months satisfying all of the requirements in Fig A5.1, the month which has a minimum DM in equation A5.3 is selected as the candidate month.

$$DM_{m,y} = DW_{1,m,y} + k_2 DW_{2,m,y} + k_{3,m} DW_{3,m,y} \quad (A5.3)$$

$$DW_{e,m,y} = W_{e,m,y} - W_{e,m} \quad (A5.4)$$

Where

k_2*: weighting coefficient of absolute humidity to air temperature*

$k_{3,m}$*: weighting coefficient of solar radiation to air temperature*

Appendix 6. Method for developing future weather files (Soga 2011)

(1) Method for calculating one day's worth of horizontal global radiation

Soga constructed statistical functions to calculate one day's worth of horizontal global radiation I_{Gd} from air temperature, absolute humidity, amount of precipitation, and degree of cloudiness as follows. Equation A6.2 indicates that global radiation expotentially decreases as cloudiness increases. Equation A6.3-A6.4 show that clearness index decreases according to precipitable water (when there is no rainfall) or rainfall intensity (when there is rainfall). Coefficient values in equation A6.3-A6.4 are calculated from past weather data observed in 11 Japanese meteorological offices between 2001 and 2007 by using the least-squares method. He compared weather predictions by equation A6.1 and past weather data observed by JMA to research the precision of the equation, and it was confirmed that weather predictions by the equation are largely precise.

$$I_{Gd} = K_{Td} \times I_{0d} \quad (A6.1)$$

$$K_{Td} = 1 - a \times exp\left[b \times \left(\frac{N}{10}\right)\right] \quad (A6.2)$$

$$a = \begin{cases} -0.4725RW^2 + 0.5864RW + 0.0972, & PA = 0 \\ 0.2565PA^{0.012}, & PA > 0 \end{cases} \quad (A6.3)$$

$$b = \begin{cases} 1.5011RW^2 - 1.3117RW + 0.9263, & PA = 0 \\ 0.9992PA^{0.0376}, & PA > 0 \end{cases} \quad (A6.4)$$

$$I_{od} = \int_{t1}^{t2} \left[I_0 \left(\frac{d_0}{d}\right)^2 \times sin\,\gamma\right] dt \quad (A6.5)$$

Where

I_{Gd}*: one day amount of horizontal global radiation [MJ/(*$m^2 d$*)]*

K_{Td}*: clearness index (*I_{Gd}/I_{0d}*)*

I_{0d}*: one day amount of horizontal extra-terrestrial solar radiation [MJ/(*$m^2 d$*)]*

N: daily mean degree of cloudiness (0 to 10)

PA: one day amount of precipitation [mm/d]

W: daily mean precipitable water [cm]

SW: saturate precipitable water [cm]

RW: daily mean relative precipitable water (RW=W/SW)(0 to 1)

I_0*: solar constant (4.9212) [MJ/m^2 h]*

γ*: solar altitude [°]*

t1: sunrise time

t2: sunset time

d: distance between the sun and the earth

d_0*: mean distance between the sun and the earth*

(2) Method for calculating atmospheric radiation

Atmospheric radiation L_d was calculated statistically by using functions (equation A6.6-A6.8) developed by Kondo et al. (1991). In this study, the maximum degree of cloudiness was chosen from three types of values (upper-air, middle-air, and lower-air observations).

$$L_d = \sigma T^4 \left\{1 - \left(1 - \frac{L_{df}}{\sigma T^4}\right) C\right\} \quad (A6.6)$$

$$\frac{L_{df}}{\sigma T^4} = 0.74 + 0.19\, log_{10} SW + 0.07(log_{10} SW)^2 \quad (A6.7)$$

$$\begin{cases} C = 0.826\left(\frac{N_J}{N_0}\right)^3 - 1.234\left(\frac{N_J}{N_0}\right)^2 + 1.135\frac{N_J}{N_0} + 0.298, & 0 < N_J/N_0 \leq 1 \\ C = 0.2235, & N_J/N_0 = 0 \end{cases} \quad (A6.8)$$

Where

L_d*: one day amount of atmospheric radiation [MJ/(m^{2}d)]*

σ*: Stefan-Boltzmann constant (= 5.67×10^{-8} [$\frac{W}{m^2K^4}$])*

T: daily mean air temperature [°C]

L_{df}*: one day amount of atmospheric radiation in fine weather [MJ/(m^{2}d)]*

C: effect of degree of cloudiness on daily mean atmospheric radiation

SW: saturate precipitable water [cm]

N_J/N_0*: percentage of possible sunshine calculated by using past weather data obserbed by JMA*

(3) Method to for generating hourly future weather data

Since the weather data made by RCM20 and the other supplementary data (horizontal global radiation and atmospheric radiation) are future predictions, these data have systematic errors peculiar to the software. Thus, these data cannot be directly utilized as future weather data. Additionally, as the weather data made by RCM20 are daily values, they must be transformed to hourly values as below.

As air temperature, absolute humidity and atmospheric radiation, current daily values were changed to future daily ones (equation A6.9-A6.11) and then they were changed to future hourly ones (equation A6.12). On the one hand, since there are future daily maximums and minimums for air temperature, the stretch coefficient of the standard deviation of hourly values to daily one was considered by caluculating $\alpha Wh_{\Delta y,m}$ (equation A6.9). On the other hand, since there are no future predictions about absolute humidity and atmospheric radiation, $\alpha Wh_{\Delta y,m}$ was estimated to be zero.

For solar radiation, wind speed, and the amount of precipitation, current hourly values were changed to future hourly ones (equation A6.14) considering the future change rate of the monthly average value βWm (equation A6.15).

$$W_{d_{p,y+\Delta y,m,d}} = W_{d_{r,y,m,d}} + \Delta WM_{\Delta y,m} + \alpha Wd_{\Delta y,m}\left(Wd_{r,y,m,d} - WM_{r,b,m}\right) \quad \textit{(A6.9)}$$

$$\Delta WM_{\Delta y,m} = WM_{p,f,m} - WM_{p,b,m} \quad \textit{(A6.10)}$$

$$\alpha Wd_{\Delta y,m} = \left(SDWM_{p,f,m} - SDWM_{p,b,m}\right)/SDWM_{r,b,m} \quad \textit{(A6.11)}$$

$$Wh_{p,y+\Delta y,m,d,h} = Wd_{p,y+\Delta y,m,d} + \left(1 + \alpha Wh_{\Delta y,m}\right)\left(Wh_{r,y,m,d,h} - Wd_{r,y,m,d}\right) \quad \textit{(A6.12)}$$

$$\alpha Wh_{\Delta y,m} = \begin{cases} \dfrac{(TMAXM_{p,f,m} - WM_{p,f,m}) - (TMAXM_{p,b,m} - WM_{p,b,m})}{TMAXM_{r,b,m} - WM_{r,b,m}}, & Wh_{r,y,m,d,h} \geq Wd_{r,y,m,d} \\ \dfrac{(WM_{p,f,m} - TMINM_{p,f,m}) - (WM_{p,b,m} - TMINM_{p,b,m})}{WM_{r,b,m} - TMINM_{r,b,m}}, & Wh_{r,y,m,d,h} < Wd_{r,y,m,d} \end{cases} \quad \textit{(A6.13)}$$

$$Wh_{p,y+\Delta y,m,d,h} = \beta Wm_{\Delta y,m} \times Wh_{r,y,m,d,h} \quad \textit{(A6.14)}$$

$$\beta Wm_{\Delta y,m} = 1 + \Delta WM_{\Delta y,m}/WM_{r,b,m} \quad \textit{(A6.15)}$$

Where

N: years of base period or future period

Wh: hourly weather data

Wd: daily weather data

WM: monthly mean value in N years

TMAXM: monthly mean value of daily maximum air temperature in N years [℃]

TMINM: monthly mean value of daily minimum air temperature in N years [℃]

△WM: amount of future change of monthly mean value

SDWM: monthly standard deviation of daily weather data in N years

αWh: stretch coefficient of standard deviation of hourly value to daily one

αWd: stretch coefficient of standard deviation of daily value to monthly mean one

$\beta Wm_{\Delta y,m}$*: rate of future change of monthly mean value*

r: observation value in base period

p: future prediction value

y: base period year (1981-2000)

△y: future year (difference between base period and future period)

b: base period

f: future period

m: month (1-12), d: date (1-365), h: hour (1-24)

Appendix 7. Monthly mean external air temperature

Mean air temperature (℃)	Sapporo			Tokyo			Naha		
	1990s	2040s	2090s	1990s	2040s	2090s	1990s	2040s	2090s
Jan	-2.8	-1.4	-0.3	5.8	8.7	8.7	17.1	17.7	19.4
Feb	-3.5	-2.0	-0.4	6.5	9.9	9.9	16.9	17.8	19.3
Mar	0.3	1.8	3.5	8.9	12.3	12.3	19.0	20.3	21.1
Apr	6.7	9.1	10.6	15.0	18.0	18.3	21.3	23.0	23.7
May	12.4	15.2	16.1	18.8	21.1	21.6	23.8	25.0	26.2
Jun	16.1	18.6	18.7	21.7	23.9	24.2	26.9	28.6	29.1
Jul	20.5	22.0	22.8	25.3	26.4	27.2	28.7	29.8	30.6
Aug	22.3	23.3	24.1	27.3	27.1	28.4	28.4	28.9	30.2
Sep	17.5	19.4	19.9	23.7	25.0	25.6	27.5	28.5	29.5
Oct	11.7	13.5	14.8	17.9	19.1	21.0	24.9	26.1	27.5
Nov	5.1	6.7	8.2	13.2	15.0	16.2	22.4	23.2	24.5
Dec	-0.9	0.8	2.3	9.0	12.2	12.3	18.6	20.4	21.4

Appendix 8. Monthly mean external relative humidity

Mean RH (%)	Sapporo			Tokyo			Naha		
	1990s	2040s	2090s	1990s	2040s	2090s	1990s	2040s	2090s
Jan	64.6	67.7	73.3	50.7	59.5	53.0	71.7	72.4	73.1
Feb	70.2	72.3	71.8	48.3	55.3	47.6	73.9	74.9	73.7
Mar	63.8	64.9	60.7	62.3	69.7	61.7	74.1	74.3	74.3
Apr	63.4	61.1	57.0	56.7	63.7	56.4	77.4	78.1	77.6
May	65.7	65.3	62.1	62.7	69.4	63.5	78.6	80.6	79.9
Jun	74.5	75.3	75.0	74.8	80.3	74.2	86.2	83.2	85.4
Jul	78.3	81.3	79.2	76.8	80.4	77.6	81.4	81.7	82.4
Aug	79.0	82.3	79.5	73.0	78.6	73.8	79.1	83.1	82.9
Sep	72.0	72.5	71.0	77.7	84.3	77.8	74.9	75.5	75.4
Oct	71.6	72.5	72.1	70.1	79.2	71.2	68.5	69.1	70.4
Nov	67.1	70.4	67.5	62.5	70.5	63.9	75.4	77.1	76.8
Dec	67.8	69.0	67.0	52.0	62.3	53.3	65.4	68.3	68.0

Appendix 9. Building elements for the base model for typical 1990s type office buildings

Costructions	U-value ($W/m^2/K$)	Description
Roof	0.428	acoustic tile (12 mm), plaster board (9 mm), cavity, concrete (150 mm), asphalt (10 mm), polystyrene expanded sheet (25 mm), lightweight concrete (60 mm)
External wall	0.624	plaster board (12 mm), cavity, glass fibre insulation (25 mm), concrete (150 mm), concrete screed(20 mm), acoustic tile (8 mm)
Internal wall	2.330	concrete screed (20 mm), concrete (120 mm), concrete screed (20 mm)
Window	5.731	clear glass (6 mm), cavity, medium blind (1 mm)
Frame	3.844	aluminium frame (25 mm)
Door	1.309	steel (1 mm), cavity, steel (1 mm)
Upper floor	1.036	acoustic tile (12 mm), plaster board (9 mm), cavity, concrete (150 mm), plastic tile (3 mm)
Ground floor	0.270	carpet (5 mm), concrete screed (50 mm), concrete (125 mm), crushed brick aggregate (75 mm), dry sand (1,000 mm)

Appendix 10. Heating/cooling loads profile of the base model on a typical winter and summer day in Sapporo

Sapporo Winter (day32)

Time (h)	1990s External temperature (℃)	1990s East office heating loads (kWh)	1990s West office heating loads (kWh)	1990s EV hall heating loads (kWh)	2040s External temperature (℃)	2040s East office heating loads (kWh)	2040s West office heating loads (kWh)	2040s EV hall heating loads (kWh)	2090s External temperature (℃)	2090s East office heating loads (kWh)	2090s West office heating loads (kWh)	2090s EV hall heating loads (kWh)
1	-4.6	0.0	0.0	0.0	-3.1	0.0	0.0	0.0	-1.5	0.0	0.0	0.0
2	-6.2	0.0	0.0	0.0	-4.6	0.0	0.0	0.0	-3.6	0.0	0.0	0.0
3	-5.5	0.0	0.0	0.0	-4.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0
4	-5.5	0.0	0.0	0.0	-4.1	0.0	0.0	0.0	-2.3	0.0	0.0	0.0
5	-6.9	0.0	0.0	0.0	-5.4	0.0	0.0	0.0	-3.4	0.0	0.0	0.0
6	-8.0	0.0	0.0	0.0	-6.5	0.0	0.0	0.0	-4.2	0.0	0.0	0.0
7	-8.3	0.0	0.0	0.0	-6.8	0.0	0.0	0.0	-4.4	0.0	0.0	0.0
8	-6.4	0.0	0.0	0.0	-5.0	0.0	0.0	0.0	-2.7	0.0	0.0	0.0
9	-5.3	150.7	157.4	55.7	-3.9	131.3	137.9	49.6	-1.7	120.6	133.6	57.4
10	-5.3	119.5	119.9	47.5	-3.9	103.2	103.5	42.2	-1.7	92.5	96.7	48.8
11	-4.6	107.4	107.8	45.3	-3.2	91.4	91.7	40.3	-1.1	81.1	85.0	46.4
12	-3.9	95.8	95.6	43.4	-2.5	80.3	80.1	38.6	-0.5	70.3	73.5	44.4
13	-2.8	88.6	87.4	41.6	-1.5	74.0	72.7	37.0	0.5	63.6	65.5	42.4
14	-2.4	64.0	37.7	39.4	-1.1	49.1	22.3	35.0	0.8	39.7	16.1	40.1
15	-3.8	89.8	64.9	38.7	-2.5	74.5	47.7	34.4	-0.4	63.3	40.0	39.2
16	-4.4	93.4	44.4	37.5	-3.0	78.5	28.9	33.3	-0.9	66.9	20.6	37.8
17	-5.1	110.2	105.6	36.7	-3.7	95.5	90.8	32.7	-1.5	83.0	81.0	36.9
18	-5.8	115.8	112.7	35.8	-4.4	101.0	97.8	31.9	-2.2	88.2	87.7	35.8
19	-6.5	0.0	0.0	0.0	-5.1	0.0	0.0	0.0	-2.8	0.0	0.0	0.0
20	-6.6	0.0	0.0	0.0	-5.2	0.0	0.0	0.0	-2.9	0.0	0.0	0.0
21	-6.7	0.0	0.0	0.0	-5.3	0.0	0.0	0.0	-3.0	0.0	0.0	0.0
22	-6.4	0.0	0.0	0.0	-5.0	0.0	0.0	0.0	-2.7	0.0	0.0	0.0
23	-6.9	0.0	0.0	0.0	-5.4	0.0	0.0	0.0	-3.2	0.0	0.0	0.0
24	-7.3	0.0	0.0	0.0	-5.8	0.0	0.0	0.0	-3.5	0.0	0.0	0.0

Sapporo Summer (day218)

Time (h)	1990s External temperature (℃)	1990s East office cooling loads (kWh)	1990s West office cooling loads (kWh)	1990s EV hall cooling loads (kWh)	2040s External temperature (℃)	2040s East office cooling loads (kWh)	2040s West office cooling loads (kWh)	2040s EV hall cooling loads (kWh)	2090s External temperature (℃)	2090s East office cooling loads (kWh)	2090s West office cooling loads (kWh)	2090s EV hall cooling loads (kWh)
1	23.4	0.0	0.0	0.0	24.0	0.0	0.0	0.0	24.8	0.0	0.0	0.0
2	23.0	0.0	0.0	0.0	23.6	0.0	0.0	0.0	24.4	0.0	0.0	0.0
3	22.6	0.0	0.0	0.0	23.2	0.0	0.0	0.0	24.0	0.0	0.0	0.0
4	21.7	0.0	0.0	0.0	22.4	0.0	0.0	0.0	23.1	0.0	0.0	0.0
5	21.9	0.0	0.0	0.0	22.6	0.0	0.0	0.0	23.3	0.0	0.0	0.0
6	23.0	0.0	0.0	0.0	23.6	0.0	0.0	0.0	24.4	0.0	0.0	0.0
7	23.9	0.0	0.0	0.0	24.4	0.0	0.0	0.0	25.3	0.0	0.0	0.0
8	25.7	0.0	0.0	0.0	26.0	0.0	0.0	0.0	27.0	0.0	0.0	0.0
9	27.8	211.5	166.6	15.5	27.9	211.2	174.0	19.4	29.0	236.6	190.2	25.2
10	30.4	201.1	181.1	14.8	30.2	201.2	184.3	18.1	31.5	220.7	199.9	23.1
11	30.8	196.0	186.0	14.9	30.5	196.3	187.8	18.0	31.9	214.6	204.2	22.9
12	32.2	203.6	197.9	15.3	31.8	203.5	198.6	18.3	33.3	221.6	215.6	23.0
13	33.1	209.2	210.8	15.6	32.6	208.8	210.1	18.4	34.2	226.7	228.3	23.1
14	32.5	200.4	212.2	15.4	32.0	200.3	209.9	18.1	33.6	217.4	229.5	22.6
15	32.6	199.1	217.4	15.4	32.1	198.4	213.3	18.1	33.7	215.6	234.6	22.5
16	32.1	189.2	232.3	15.3	31.7	189.3	225.7	17.9	33.2	205.3	249.0	22.1
17	31.6	183.3	242.8	15.2	31.3	183.4	237.9	17.7	32.7	199.0	259.1	21.8
18	30.4	173.9	208.2	14.9	30.2	174.0	202.0	17.3	31.5	189.2	224.6	21.3
19	28.5	0.0	0.0	0.0	28.5	0.0	0.0	0.0	29.7	0.0	0.0	0.0
20	24.8	0.0	0.0	0.0	25.2	0.0	0.0	0.0	26.1	0.0	0.0	0.0
21	24.2	0.0	0.0	0.0	24.7	0.0	0.0	0.0	25.5	0.0	0.0	0.0
22	23.8	0.0	0.0	0.0	24.3	0.0	0.0	0.0	25.2	0.0	0.0	0.0
23	23.6	0.0	0.0	0.0	24.1	0.0	0.0	0.0	25.0	0.0	0.0	0.0
24	23.5	0.0	0.0	0.0	24.0	0.0	0.0	0.0	24.9	0.0	0.0	0.0

Appendix 11. Heating/cooling loads profile of the base model on a typical winter and summer day in Tokyo

Tokyo Winter (day57)

Time (h)	1990s External temperature (℃)	1990s East office heating loads (kWh)	1990s West office heating loads (kWh)	1990s EV hall heating loads (kWh)	2040s External temperature (℃)	2040s East office heating loads (kWh)	2040s West office heating loads (kWh)	2040s EV hall heating loads (kWh)	2090s External temperature (℃)	2090s East office heating loads (kWh)	2090s West office heating loads (kWh)	2090s EV hall heating loads (kWh)
1	4.7	0.0	0.0	0.0	7.7	0.0	0.0	0.0	8.4	0.0	0.0	0.0
2	3.4	0.0	0.0	0.0	6.4	0.0	0.0	0.0	7.0	0.0	0.0	0.0
3	2.9	0.0	0.0	0.0	5.8	0.0	0.0	0.0	6.5	0.0	0.0	0.0
4	2.5	0.0	0.0	0.0	5.4	0.0	0.0	0.0	6.0	0.0	0.0	0.0
5	1.4	0.0	0.0	0.0	4.3	0.0	0.0	0.0	4.9	0.0	0.0	0.0
6	1.4	0.0	0.0	0.0	4.3	0.0	0.0	0.0	4.9	0.0	0.0	0.0
7	1.3	0.0	0.0	0.0	4.2	0.0	0.0	0.0	4.8	0.0	0.0	0.0
8	1.5	0.0	0.0	0.0	4.4	0.0	0.0	0.0	5.0	0.0	0.0	0.0
9	1.9	76.9	82.4	31.7	4.8	32.4	36.9	12.1	5.4	26.0	30.4	12.1
10	2.2	48.7	52.4	26.6	5.1	12.9	15.8	9.9	5.7	6.8	9.7	9.9
11	2.2	45.4	48.8	25.6	5.1	10.8	13.5	9.6	5.7	4.5	7.2	9.6
12	3.0	34.8	38.1	24.4	5.9	1.7	4.2	9.1	6.6	0.0	0.0	9.1
13	3.7	28.9	32.0	23.4	6.7	0.0	0.0	8.7	7.3	0.0	0.0	8.7
14	4.9	19.4	22.2	22.3	7.9	0.0	0.0	8.1	8.6	0.0	0.0	8.1
15	5.7	12.4	15.0	21.3	8.8	0.0	0.0	7.6	9.5	0.0	0.0	7.6
16	5.9	13.6	16.3	20.5	9.0	0.0	0.0	7.3	9.7	0.0	0.0	7.3
17	6.0	15.2	17.8	19.9	9.1	0.0	0.0	7.0	9.8	0.0	0.0	7.0
18	5.7	17.7	20.1	19.3	8.8	0.0	0.0	6.9	9.5	0.0	0.0	6.9
19	5.5	0.0	0.0	0.0	8.6	0.0	0.0	0.0	9.3	0.0	0.0	0.0
20	5.7	0.0	0.0	0.0	8.8	0.0	0.0	0.0	9.5	0.0	0.0	0.0
21	5.6	0.0	0.0	0.0	8.7	0.0	0.0	0.0	9.4	0.0	0.0	0.0
22	5.4	0.0	0.0	0.0	8.5	0.0	0.0	0.0	9.2	0.0	0.0	0.0
23	5.1	0.0	0.0	0.0	8.1	0.0	0.0	0.0	8.8	0.0	0.0	0.0
24	4.8	0.0	0.0	0.0	7.8	0.0	0.0	0.0	8.5	0.0	0.0	0.0

Tokyo Summer (day233)

Time (h)	1990s External temperature (℃)	1990s East office cooling loads (kWh)	1990s West office cooling loads (kWh)	1990s EV hall cooling loads (kWh)	2040s External temperature (℃)	2040s East office cooling loads (kWh)	2040s West office cooling loads (kWh)	2040s EV hall cooling loads (kWh)	2090s External temperature (℃)	2090s East office cooling loads (kWh)	2090s West office cooling loads (kWh)	2090s EV hall cooling loads (kWh)
1	26.7	0.0	0.0	0.0	26.6	0.0	0.0	0.0	28.4	0.0	0.0	0.0
2	26.7	0.0	0.0	0.0	26.6	0.0	0.0	0.0	28.4	0.0	0.0	0.0
3	26.7	0.0	0.0	0.0	26.6	0.0	0.0	0.0	28.4	0.0	0.0	0.0
4	26.5	0.0	0.0	0.0	26.4	0.0	0.0	0.0	28.2	0.0	0.0	0.0
5	26.1	0.0	0.0	0.0	26.1	0.0	0.0	0.0	27.8	0.0	0.0	0.0
6	26.1	0.0	0.0	0.0	26.1	0.0	0.0	0.0	27.8	0.0	0.0	0.0
7	27.2	0.0	0.0	0.0	27.0	0.0	0.0	0.0	28.8	0.0	0.0	0.0
8	27.7	0.0	0.0	0.0	27.5	0.0	0.0	0.0	29.3	0.0	0.0	0.0
9	29.2	231.0	192.4	31.2	28.8	220.3	188.5	30.0	30.8	249.1	213.3	36.7
10	30.6	211.7	190.8	27.9	30.0	203.9	186.2	26.8	32.1	227.9	208.4	32.7
11	31.6	210.9	200.8	27.6	30.8	203.2	194.3	26.5	33.0	226.7	217.3	32.2
12	32.1	209.8	205.0	27.3	31.2	202.3	197.9	26.2	33.5	225.8	221.4	31.7
13	32.2	208.4	210.5	26.8	31.3	201.1	202.5	25.8	33.6	224.2	226.2	31.1
14	33.0	210.5	225.8	26.7	32.0	203.0	215.4	25.6	34.4	226.1	240.6	30.8
15	32.7	203.2	233.6	26.2	31.7	196.4	219.6	25.2	34.1	219.1	246.5	30.2
16	32.5	199.4	244.7	25.8	31.5	190.5	233.4	24.8	33.9	213.7	259.6	29.7
17	32.1	193.0	228.0	25.4	31.2	185.4	211.9	24.4	33.5	207.5	239.1	29.2
18	31.1	184.6	246.2	24.8	30.4	177.5	220.7	23.9	32.6	199.4	261.8	28.5
19	30.8	0.0	0.0	0.0	30.1	0.0	0.0	0.0	32.3	0.0	0.0	0.0
20	30.3	0.0	0.0	0.0	29.7	0.0	0.0	0.0	31.8	0.0	0.0	0.0
21	29.9	0.0	0.0	0.0	29.4	0.0	0.0	0.0	31.4	0.0	0.0	0.0
22	28.9	0.0	0.0	0.0	28.5	0.0	0.0	0.0	30.5	0.0	0.0	0.0
23	28.5	0.0	0.0	0.0	28.2	0.0	0.0	0.0	30.1	0.0	0.0	0.0
24	28.8	0.0	0.0	0.0	28.4	0.0	0.0	0.0	30.4	0.0	0.0	0.0

Appendix 12. Heating/cooling loads profile of the base model on a typical winter and summer day in Naha

Naha Winter (day44)

	1990s				2040s				2090s			
Time (h)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)
1	16.5	0.0	0.0	0.0	17.4	0.0	0.0	0.0	19.0	0.0	0.0	0.0
2	16.2	0.0	0.0	0.0	17.1	0.0	0.0	0.0	18.7	0.0	0.0	0.0
3	15.7	0.0	0.0	0.0	16.6	0.0	0.0	0.0	18.2	0.0	0.0	0.0
4	15.8	0.0	0.0	0.0	16.7	0.0	0.0	0.0	18.3	0.0	0.0	0.0
5	15.5	0.0	0.0	0.0	16.4	0.0	0.0	0.0	18.0	0.0	0.0	0.0
6	15.2	0.0	0.0	0.0	16.1	0.0	0.0	0.0	17.7	0.0	0.0	0.0
7	15.3	0.0	0.0	0.0	16.2	0.0	0.0	0.0	17.8	0.0	0.0	0.0
8	15.8	0.0	0.0	0.0	16.7	0.0	0.0	0.0	18.3	0.0	0.0	0.0
9	16.8	47.4	36.6	0.0	17.7	65.3	51.5	0.0	19.3	85.1	72.7	0.0
10	17.2	55.8	53.2	0.0	18.1	66.9	65.0	0.0	19.7	82.6	81.3	0.0
11	17.7	71.7	65.5	0.0	18.6	83.4	76.8	0.0	20.2	97.3	92.4	0.0
12	18.0	68.3	67.4	0.0	18.9	79.4	78.5	0.0	20.5	93.7	93.0	0.0
13	17.1	61.1	60.4	0.0	18.0	71.7	71.2	0.0	19.6	86.2	85.5	0.0
14	18.2	74.3	76.0	0.0	19.1	83.6	86.0	0.0	20.7	99.3	100.9	0.0
15	17.2	64.0	66.5	0.0	18.1	73.6	76.3	0.0	19.7	88.9	91.4	0.0
16	17.1	64.9	83.1	0.0	18.0	74.3	94.2	0.0	19.6	89.8	110.2	0.0
17	16.9	61.5	91.1	0.0	17.8	70.6	102.3	0.0	19.4	86.1	119.9	0.2
18	16.4	50.3	51.9	0.0	17.3	59.7	60.6	0.0	18.9	75.2	76.9	0.1
19	16.0	0.0	0.0	0.0	16.9	0.0	0.0	0.0	18.5	0.0	0.0	0.0
20	15.6	0.0	0.0	0.0	16.5	0.0	0.0	0.0	18.1	0.0	0.0	0.0
21	15.9	0.0	0.0	0.0	16.8	0.0	0.0	0.0	18.4	0.0	0.0	0.0
22	15.4	0.0	0.0	0.0	16.3	0.0	0.0	0.0	17.9	0.0	0.0	0.0
23	15.8	0.0	0.0	0.0	16.7	0.0	0.0	0.0	18.3	0.0	0.0	0.0
24	15.1	0.0	0.0	0.0	16.0	0.0	0.0	0.0	17.6	0.0	0.0	0.0

Naha Summer (day234)

	1990s				2040s				2090s			
Time (h)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)
1	28.6	0.0	0.0	0.0	28.6	0.0	0.0	0.0	29.9	0.0	0.0	0.0
2	28.6	0.0	0.0	0.0	28.5	0.0	0.0	0.0	29.7	0.0	0.0	0.0
3	28.5	0.0	0.0	0.0	28.4	0.0	0.0	0.0	29.6	0.0	0.0	0.0
4	28.4	0.0	0.0	0.0	28.4	0.0	0.0	0.0	29.6	0.0	0.0	0.0
5	28.3	0.0	0.0	0.0	28.1	0.0	0.0	0.0	29.4	0.0	0.0	0.0
6	28.2	0.0	0.0	0.0	28.0	0.0	0.0	0.0	29.2	0.0	0.0	0.0
7	28.7	0.0	0.0	0.0	28.3	0.0	0.0	0.0	29.5	0.0	0.0	0.0
8	30.0	0.0	0.0	0.0	29.4	0.0	0.0	0.0	30.6	0.0	0.0	0.0
9	30.2	248.6	197.7	33.8	30.1	224.7	202.1	35.5	31.4	251.3	219.4	40.7
10	30.8	218.1	189.4	29.9	31.2	215.8	198.2	31.5	32.4	234.4	211.4	36.0
11	31.6	216.3	199.7	29.4	31.5	213.2	204.5	30.8	32.7	230.0	217.9	35.1
12	31.4	208.9	199.8	28.8	31.7	212.0	207.5	30.2	32.9	227.8	220.7	34.4
13	32.1	211.0	205.8	28.5	31.9	209.0	207.1	29.7	33.1	225.2	221.1	33.8
14	31.9	206.8	209.8	28.0	32.0	210.6	212.6	29.3	33.2	225.5	226.1	33.2
15	31.4	198.2	213.6	27.4	31.5	202.5	213.9	28.6	32.7	216.7	228.2	32.4
16	30.7	189.3	219.5	26.8	31.2	198.2	205.6	28.1	32.4	212.8	219.8	31.7
17	30.6	185.7	235.3	26.4	30.6	188.2	201.0	27.4	31.9	203.3	217.2	31.0
18	29.8	178.0	233.7	25.8	30.1	180.5	236.7	26.9	31.4	195.5	250.5	30.4
19	29.3	0.0	0.0	0.0	29.5	0.0	0.0	0.0	30.7	0.0	0.0	0.0
20	29.1	0.0	0.0	0.0	29.0	0.0	0.0	0.0	30.2	0.0	0.0	0.0
21	28.9	0.0	0.0	0.0	28.9	0.0	0.0	0.0	30.1	0.0	0.0	0.0
22	28.9	0.0	0.0	0.0	28.8	0.0	0.0	0.0	30.0	0.0	0.0	0.0
23	28.7	0.0	0.0	0.0	28.6	0.0	0.0	0.0	29.9	0.0	0.0	0.0
24	28.6	0.0	0.0	0.0	28.5	0.0	0.0	0.0	29.8	0.0	0.0	0.0

Appendix 13. Monthly heating/cooling loads of the base model

Sapporo

	1990s			2040s			2090s		
	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)
Jan	10.18	0.00	10.18	8.64	0.00	8.64	7.42	0.00	7.42
Feb	9.08	0.00	9.08	7.46	0.00	7.46	6.30	0.00	6.30
Mar	6.69	0.00	6.69	5.03	0.00	5.03	3.53	0.03	3.56
Apr	1.37	0.37	1.74	0.81	1.00	1.81	0.48	1.65	2.13
May	0.09	2.19	2.28	0.01	4.26	4.27	0.00	5.05	5.05
Jun	0.05	4.73	4.78	0.00	6.78	6.78	0.00	6.97	6.97
Jul	0.00	8.62	8.62	0.00	9.79	9.79	0.00	10.88	10.88
Aug	0.00	11.15	11.15	0.00	11.92	11.92	0.00	13.09	13.09
Sep	0.00	5.13	5.13	0.00	6.73	6.73	0.00	7.29	7.29
Oct	0.05	2.64	2.69	0.00	4.47	4.47	0.00	5.47	5.47
Nov	2.99	0.08	3.06	2.04	0.33	2.37	1.29	0.75	2.04
Dec	7.93	0.00	7.93	6.22	0.01	6.23	4.77	0.04	4.81

Tokyo

	1990s			2040s			2090s		
	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)
Jan	1.58	0.47	2.05	0.63	1.45	2.08	0.57	1.47	2.04
Feb	1.14	0.27	1.40	0.33	1.69	2.02	0.25	1.75	2.00
Mar	0.81	0.91	1.73	0.14	2.78	2.92	0.11	3.05	3.17
Apr	0.06	3.89	3.95	0.00	5.98	5.99	0.00	6.41	6.41
May	0.00	8.17	8.17	0.00	10.11	10.11	0.00	10.88	10.88
Jun	0.00	8.83	8.83	0.00	10.52	10.52	0.00	11.33	11.33
Jul	0.00	12.43	12.43	0.00	13.50	13.50	0.00	14.46	14.46
Aug	0.00	16.52	16.52	0.00	16.08	16.08	0.00	17.79	17.79
Sep	0.00	9.71	9.71	0.00	10.37	10.37	0.00	11.25	11.25
Oct	0.00	6.89	6.89	0.00	7.40	7.40	0.00	9.84	9.84
Nov	0.00	3.77	3.77	0.00	4.92	4.92	0.00	5.70	5.70
Dec	0.40	1.27	1.67	0.04	2.87	2.92	0.01	3.19	3.20

Naha

	1990s			2040s			2090s		
	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)
Jan	0.00	5.07	5.07	0.00	5.60	5.60	0.00	7.11	7.11
Feb	0.00	4.84	4.84	0.00	5.60	5.60	0.00	6.85	6.85
Mar	0.00	8.01	8.01	0.00	9.36	9.36	0.00	10.14	10.14
Apr	0.00	8.68	8.68	0.00	10.25	10.25	0.00	10.94	10.94
May	0.00	11.99	11.99	0.00	13.36	13.36	0.00	14.51	14.51
Jun	0.00	13.99	13.99	0.00	15.83	15.83	0.00	16.22	16.22
Jul	0.00	17.49	17.49	0.00	18.76	18.76	0.00	19.59	19.59
Aug	0.00	17.74	17.74	0.00	18.15	18.15	0.00	19.58	19.58
Sep	0.00	13.50	13.50	0.00	14.49	14.49	0.00	15.42	15.42
Oct	0.00	14.67	14.67	0.00	15.94	15.94	0.00	17.54	17.54
Nov	0.00	11.12	11.12	0.00	11.94	11.94	0.00	13.29	13.29
Dec	0.00	7.41	7.41	0.00	8.91	8.91	0.00	9.93	9.93

Appendix 14. Heating/cooling loads profile of the cumulatively improved model on a typical winter and summer day in Sapporo

Sapporo Winter (day32)

	1990s				2040s				2090s			
Time (h)	External temperature (℃)	East office heating loads (kWh)	West office heating loads (kWh)	EV hall heating loads (kWh)	External temperature (℃)	East office heating loads (kWh)	West office heating loads (kWh)	EV hall heating loads (kWh)	External temperature (℃)	East office heating loads (kWh)	West office heating loads (kWh)	EV hall heating loads (kWh)
1	-4.6	0.0	0.0	0.0	-3.1	0.0	0.0	0.0	-1.5	0.0	0.0	0.0
2	-6.2	0.0	0.0	0.0	-4.6	0.0	0.0	0.0	-3.6	0.0	0.0	0.0
3	-5.5	0.0	0.0	0.0	-4.0	0.0	0.0	0.0	-2.4	0.0	0.0	0.0
4	-5.5	0.0	0.0	0.0	-4.1	0.0	0.0	0.0	-2.3	0.0	0.0	0.0
5	-6.9	0.0	0.0	0.0	-5.4	0.0	0.0	0.0	-3.4	0.0	0.0	0.0
6	-8.0	0.0	0.0	0.0	-6.5	0.0	0.0	0.0	-4.2	0.0	0.0	0.0
7	-8.3	0.0	0.0	0.0	-6.8	0.0	0.0	0.0	-4.4	0.0	0.0	0.0
8	-6.4	0.0	0.0	0.0	-5.0	0.0	0.0	0.0	-2.7	0.0	0.0	0.0
9	-5.3	152.5	156.3	39.7	-3.9	136.4	140.2	35.5	-1.7	125.2	132.8	39.7
10	-5.3	127.4	127.8	33.8	-3.9	113.6	113.9	30.1	-1.7	102.2	104.9	33.7
11	-4.6	118.1	118.3	32.3	-3.2	104.5	104.7	28.8	-1.1	93.6	96.0	32.1
12	-3.9	109.0	109.1	31.0	-2.5	95.8	95.8	27.6	-0.5	85.3	87.3	30.8
13	-2.8	101.5	100.9	29.6	-1.5	89.1	88.4	26.4	0.5	78.3	79.6	29.4
14	-2.4	87.3	73.6	28.2	-1.1	74.8	60.7	25.1	0.8	64.9	52.9	28.0
15	-3.8	104.6	91.5	27.9	-2.5	91.9	77.9	24.9	-0.4	80.5	68.6	27.5
16	-4.4	108.2	82.7	27.1	-3.0	95.4	69.5	24.2	-0.9	83.7	59.8	26.7
17	-5.1	119.0	115.9	26.7	-3.7	106.3	103.2	23.9	-1.5	93.8	92.2	26.1
18	-5.8	123.9	122.0	26.2	-4.4	111.2	109.3	23.4	-2.2	98.5	98.1	25.6
19	-6.5	0.0	0.0	0.0	-5.1	0.0	0.0	0.0	-2.8	0.0	0.0	0.0
20	-6.6	0.0	0.0	0.0	-5.2	0.0	0.0	0.0	-2.9	0.0	0.0	0.0
21	-6.7	0.0	0.0	0.0	-5.3	0.0	0.0	0.0	-3.0	0.0	0.0	0.0
22	-6.4	0.0	0.0	0.0	-5.0	0.0	0.0	0.0	-2.7	0.0	0.0	0.0
23	-6.9	0.0	0.0	0.0	-5.4	0.0	0.0	0.0	-3.2	0.0	0.0	0.0
24	-7.3	0.0	0.0	0.0	-5.8	0.0	0.0	0.0	-3.5	0.0	0.0	0.0

Sapporo Summer (day218)

	1990s				2040s				2090s			
Time (h)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)
1	23.4	0.0	0.0	0.0	24.0	0.0	0.0	0.0	24.8	0.0	0.0	0.0
2	23.0	0.0	0.0	0.0	23.6	0.0	0.0	0.0	24.4	0.0	0.0	0.0
3	22.6	0.0	0.0	0.0	23.2	0.0	0.0	0.0	24.0	0.0	0.0	0.0
4	21.7	0.0	0.0	0.0	22.4	0.0	0.0	0.0	23.1	0.0	0.0	0.0
5	21.9	0.0	0.0	0.0	22.6	0.0	0.0	0.0	23.3	0.0	0.0	0.0
6	23.0	0.0	0.0	0.0	23.6	0.0	0.0	0.0	24.4	0.0	0.0	0.0
7	23.9	0.0	0.0	0.0	24.4	0.0	0.0	0.0	25.3	0.0	0.0	0.0
8	25.7	0.0	0.0	0.0	26.0	0.0	0.0	0.0	27.0	0.0	0.0	0.0
9	27.8	80.9	62.2	0.0	27.9	83.5	69.3	0.0	29.0	99.0	80.6	0.0
10	30.4	97.7	90.2	0.0	30.2	98.0	92.1	0.0	31.5	111.2	103.1	0.0
11	30.8	97.3	94.4	0.0	30.5	97.4	95.0	0.0	31.9	110.8	107.2	0.0
12	32.2	106.2	105.2	0.0	31.8	105.8	104.8	0.0	33.3	120.0	118.1	0.0
13	33.1	112.8	115.0	0.0	32.6	112.1	113.7	0.0	34.2	126.8	128.4	0.0
14	32.5	106.7	112.9	0.0	32.0	106.3	111.2	0.0	33.6	120.8	126.8	0.0
15	32.6	107.0	116.2	0.0	32.1	106.5	114.0	0.0	33.7	121.2	130.7	0.3
16	32.1	101.2	121.7	0.0	31.7	101.5	119.2	0.0	33.2	115.4	136.9	0.4
17	31.6	97.1	125.6	0.0	31.3	97.9	124.6	0.0	32.7	111.4	141.2	0.5
18	30.4	89.1	105.7	0.0	30.2	90.4	104.4	0.0	31.5	103.3	121.4	0.4
19	28.5	0.0	0.0	0.0	28.5	0.0	0.0	0.0	29.7	0.0	0.0	0.0
20	24.8	0.0	0.0	0.0	25.2	0.0	0.0	0.0	26.1	0.0	0.0	0.0
21	24.2	0.0	0.0	0.0	24.7	0.0	0.0	0.0	25.5	0.0	0.0	0.0
22	23.8	0.0	0.0	0.0	24.3	0.0	0.0	0.0	25.2	0.0	0.0	0.0
23	23.6	0.0	0.0	0.0	24.1	0.0	0.0	0.0	25.0	0.0	0.0	0.0
24	23.5	0.0	0.0	0.0	24.0	0.0	0.0	0.0	24.9	0.0	0.0	0.0

Appendix 15. Heating/cooling loads profile of the cumulatively improved model on a typical winter and summer day in Tokyo

Tokyo Winter (day57)

Time (h)	1990s External temperature (℃)	1990s East office heating loads (kWh)	1990s West office heating loads (kWh)	1990s EV hall heating loads (kWh)	2040s External temperature (℃)	2040s East office heating loads (kWh)	2040s West office heating loads (kWh)	2040s EV hall heating loads (kWh)	2090s External temperature (℃)	2090s East office heating loads (kWh)	2090s West office heating loads (kWh)	2090s EV hall heating loads (kWh)
1	4.7	0.0	0.0	0.0	7.7	0.0	0.0	0.0	8.4	0.0	0.0	0.0
2	3.4	0.0	0.0	0.0	6.4	0.0	0.0	0.0	7.0	0.0	0.0	0.0
3	2.9	0.0	0.0	0.0	5.8	0.0	0.0	0.0	6.5	0.0	0.0	0.0
4	2.5	0.0	0.0	0.0	5.4	0.0	0.0	0.0	6.0	0.0	0.0	0.0
5	1.4	0.0	0.0	0.0	4.3	0.0	0.0	0.0	4.9	0.0	0.0	0.0
6	1.4	0.0	0.0	0.0	4.3	0.0	0.0	0.0	4.9	0.0	0.0	0.0
7	1.3	0.0	0.0	0.0	4.2	0.0	0.0	0.0	4.8	0.0	0.0	0.0
8	1.5	0.0	0.0	0.0	4.4	0.0	0.0	0.0	5.0	0.0	0.0	0.0
9	1.9	87.1	89.3	22.7	4.8	42.0	44.9	3.7	5.4	36.6	39.5	3.3
10	2.2	65.0	66.5	19.0	5.1	29.6	31.4	3.0	5.7	24.6	26.3	2.6
11	2.2	62.7	64.0	18.3	5.1	28.5	30.1	2.9	5.7	23.5	25.0	2.6
12	3.0	54.3	55.6	17.5	5.9	21.5	22.9	2.6	6.6	15.9	17.1	2.2
13	3.7	48.7	49.9	16.7	6.7	16.0	17.3	2.4	7.3	11.1	12.2	2.0
14	4.9	39.8	40.9	15.8	7.9	7.8	9.0	2.0	8.6	2.4	3.2	1.6
15	5.7	33.4	34.4	15.1	8.8	1.6	2.5	1.7	9.5	0.0	0.0	1.3
16	5.9	33.2	34.2	14.6	9.0	1.2	2.2	1.6	9.7	0.0	0.0	1.2
17	6.0	33.6	34.6	14.1	9.1	1.5	2.5	1.5	9.8	0.0	0.0	1.1
18	5.7	35.6	36.6	13.8	8.8	3.8	4.7	1.6	9.5	0.0	0.0	1.2
19	5.5	0.0	0.0	0.0	8.6	0.0	0.0	0.0	9.3	0.0	0.0	0.0
20	5.7	0.0	0.0	0.0	8.8	0.0	0.0	0.0	9.5	0.0	0.0	0.0
21	5.6	0.0	0.0	0.0	8.7	0.0	0.0	0.0	9.4	0.0	0.0	0.0
22	5.4	0.0	0.0	0.0	8.5	0.0	0.0	0.0	9.2	0.0	0.0	0.0
23	5.1	0.0	0.0	0.0	8.1	0.0	0.0	0.0	8.8	0.0	0.0	0.0
24	4.8	0.0	0.0	0.0	7.8	0.0	0.0	0.0	8.5	0.0	0.0	0.0

Tokyo Summer (day233)

Time (h)	1990s External temperature (℃)	1990s East office cooling loads (kWh)	1990s West office cooling loads (kWh)	1990s EV hall cooling loads (kWh)	2040s External temperature (℃)	2040s East office cooling loads (kWh)	2040s West office cooling loads (kWh)	2040s EV hall cooling loads (kWh)	2090s External temperature (℃)	2090s East office cooling loads (kWh)	2090s West office cooling loads (kWh)	2090s EV hall cooling loads (kWh)
1	26.7	0.0	0.0	0.0	26.6	0.0	0.0	0.0	28.4	0.0	0.0	0.0
2	26.7	0.0	0.0	0.0	26.6	0.0	0.0	0.0	28.4	0.0	0.0	0.0
3	26.7	0.0	0.0	0.0	26.6	0.0	0.0	0.0	28.4	0.0	0.0	0.0
4	26.5	0.0	0.0	0.0	26.4	0.0	0.0	0.0	28.2	0.0	0.0	0.0
5	26.1	0.0	0.0	0.0	26.1	0.0	0.0	0.0	27.8	0.0	0.0	0.0
6	26.1	0.0	0.0	0.0	26.1	0.0	0.0	0.0	27.8	0.0	0.0	0.0
7	27.2	0.0	0.0	0.0	27.0	0.0	0.0	0.0	28.8	0.0	0.0	0.0
8	27.7	0.0	0.0	0.0	27.5	0.0	0.0	0.0	29.3	0.0	0.0	0.0
9	29.2	114.8	97.3	9.4	28.8	108.5	94.2	9.1	30.8	136.0	119.6	15.0
10	30.6	115.3	106.2	8.9	30.0	109.9	102.2	8.6	32.1	132.6	123.9	13.7
11	31.6	119.2	115.1	9.1	30.8	113.2	109.6	8.8	33.0	135.8	131.9	13.7
12	32.1	121.1	119.5	9.3	31.2	114.8	113.3	8.9	33.5	137.6	136.1	13.8
13	32.2	121.2	122.8	9.3	31.3	114.9	116.1	8.9	33.6	137.4	138.9	13.7
14	33.0	125.5	133.4	9.5	32.0	118.9	125.3	9.1	34.4	141.5	149.0	13.8
15	32.7	121.4	136.4	9.4	31.7	115.0	126.6	9.0	34.1	137.2	151.0	13.6
16	32.5	119.4	142.6	9.4	31.5	112.0	133.9	9.0	33.9	134.4	158.0	13.5
17	32.1	115.3	133.4	9.3	31.2	108.8	122.7	8.9	33.5	130.2	146.9	13.3
18	31.1	108.3	140.2	9.1	30.4	102.8	125.4	8.7	32.6	123.7	156.2	13.0
19	30.8	0.0	0.0	0.0	30.1	0.0	0.0	0.0	32.3	0.0	0.0	0.0
20	30.3	0.0	0.0	0.0	29.7	0.0	0.0	0.0	31.8	0.0	0.0	0.0
21	29.9	0.0	0.0	0.0	29.4	0.0	0.0	0.0	31.4	0.0	0.0	0.0
22	28.9	0.0	0.0	0.0	28.5	0.0	0.0	0.0	30.5	0.0	0.0	0.0
23	28.5	0.0	0.0	0.0	28.2	0.0	0.0	0.0	30.1	0.0	0.0	0.0
24	28.8	0.0	0.0	0.0	28.4	0.0	0.0	0.0	30.4	0.0	0.0	0.0

Appendix 16. Heating/cooling loads profile of the cumulatively improved model on a typical winter and summer day in Naha

Naha Winter (day44)												
	1990s				2040s				2090s			
Time (h)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)
1	16.5	0.0	0.0	0.0	17.4	0.0	0.0	0.0	19.0	0.0	0.0	0.0
2	16.2	0.0	0.0	0.0	17.1	0.0	0.0	0.0	18.7	0.0	0.0	0.0
3	15.7	0.0	0.0	0.0	16.6	0.0	0.0	0.0	18.2	0.0	0.0	0.0
4	15.8	0.0	0.0	0.0	16.7	0.0	0.0	0.0	18.3	0.0	0.0	0.0
5	15.5	0.0	0.0	0.0	16.4	0.0	0.0	0.0	18.0	0.0	0.0	0.0
6	15.2	0.0	0.0	0.0	16.1	0.0	0.0	0.0	17.7	0.0	0.0	0.0
7	15.3	0.0	0.0	0.0	16.2	0.0	0.0	0.0	17.8	0.0	0.0	0.0
8	15.8	0.0	0.0	0.0	16.7	0.0	0.0	0.0	18.3	0.0	0.0	0.0
9	16.8	0.0	0.0	0.0	17.7	8.2	1.5	0.0	19.3	27.1	20.8	0.0
10	17.2	11.0	8.5	0.0	18.1	21.0	19.9	0.0	19.7	37.1	36.2	0.0
11	17.7	22.3	19.2	0.0	18.6	32.0	28.7	0.0	20.2	47.3	44.9	0.0
12	18.0	22.8	22.1	0.0	18.9	32.1	31.5	0.0	20.5	47.5	47.1	0.0
13	17.1	16.9	16.4	0.0	18.0	26.0	25.6	0.0	19.6	41.2	41.0	0.0
14	18.2	27.5	28.2	0.0	19.1	36.3	37.4	0.0	20.7	51.6	52.6	0.0
15	17.2	19.8	21.0	0.0	18.1	28.7	30.1	0.0	19.7	43.6	45.0	0.0
16	17.1	20.4	29.5	0.0	18.0	29.3	39.3	0.0	19.6	43.8	53.5	0.0
17	16.9	18.4	33.9	0.0	17.8	27.1	43.5	0.0	19.4	41.5	56.9	0.2
18	16.4	11.4	12.6	0.0	17.3	19.9	21.3	0.0	18.9	34.6	35.8	0.1
19	16.0	0.0	0.0	0.0	16.9	0.0	0.0	0.0	18.5	0.0	0.0	0.0
20	15.6	0.0	0.0	0.0	16.5	0.0	0.0	0.0	18.1	0.0	0.0	0.0
21	15.9	0.0	0.0	0.0	16.8	0.0	0.0	0.0	18.4	0.0	0.0	0.0
22	15.4	0.0	0.0	0.0	16.3	0.0	0.0	0.0	17.9	0.0	0.0	0.0
23	15.8	0.0	0.0	0.0	16.7	0.0	0.0	0.0	18.3	0.0	0.0	0.0
24	15.1	0.0	0.0	0.0	16.0	0.0	0.0	0.0	17.6	0.0	0.0	0.0

Naha Summer (day234)												
	1990s				2040s				2090s			
Time (h)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)	External temperature (℃)	East office cooling loads (kWh)	West office cooling loads (kWh)	EV hall cooling loads (kWh)
1	28.6	0.0	0.0	0.0	28.6	0.0	0.0	0.0	29.9	0.0	0.0	0.0
2	28.6	0.0	0.0	0.0	28.5	0.0	0.0	0.0	29.7	0.0	0.0	0.0
3	28.5	0.0	0.0	0.0	28.4	0.0	0.0	0.0	29.6	0.0	0.0	0.0
4	28.4	0.0	0.0	0.0	28.4	0.0	0.0	0.0	29.6	0.0	0.0	0.0
5	28.3	0.0	0.0	0.0	28.1	0.0	0.0	0.0	29.4	0.0	0.0	0.0
6	28.2	0.0	0.0	0.0	28.0	0.0	0.0	0.0	29.2	0.0	0.0	0.0
7	28.7	0.0	0.0	0.0	28.3	0.0	0.0	0.0	29.5	0.0	0.0	0.0
8	30.0	0.0	0.0	0.0	29.4	0.0	0.0	0.0	30.6	0.0	0.0	0.0
9	30.2	132.5	110.1	14.4	30.1	123.1	111.9	16.5	31.4	144.5	130.0	21.2
10	30.8	123.1	110.5	12.9	31.2	124.7	116.5	14.8	32.4	140.8	130.3	18.9
11	31.6	126.1	118.7	13.0	31.5	125.4	121.3	14.7	32.7	140.5	134.9	18.6
12	31.4	122.6	118.5	12.8	31.7	126.1	123.9	14.6	32.9	140.6	137.3	18.3
13	32.1	126.5	124.2	12.9	31.9	125.7	124.7	14.4	33.1	140.2	138.4	18.1
14	31.9	124.2	125.5	12.7	32.0	127.1	127.9	14.3	33.2	140.9	141.2	17.9
15	31.4	118.8	125.7	12.5	31.5	122.1	127.3	14.0	32.7	135.4	140.8	17.5
16	30.7	112.5	126.4	12.2	31.2	119.2	122.7	13.8	32.4	132.6	136.1	17.2
17	30.6	110.7	134.4	12.1	30.6	112.7	118.9	13.5	31.9	126.6	133.6	16.8
18	29.8	104.6	132.0	11.8	30.1	107.5	134.9	13.2	31.4	121.2	148.3	16.5
19	29.3	0.0	0.0	0.0	29.5	0.0	0.0	0.0	30.7	0.0	0.0	0.0
20	29.1	0.0	0.0	0.0	29.0	0.0	0.0	0.0	30.2	0.0	0.0	0.0
21	28.9	0.0	0.0	0.0	28.9	0.0	0.0	0.0	30.1	0.0	0.0	0.0
22	28.9	0.0	0.0	0.0	28.8	0.0	0.0	0.0	30.0	0.0	0.0	0.0
23	28.7	0.0	0.0	0.0	28.6	0.0	0.0	0.0	29.9	0.0	0.0	0.0
24	28.6	0.0	0.0	0.0	28.5	0.0	0.0	0.0	29.8	0.0	0.0	0.0

Appendix 17. Monthly heating/cooling loads of the cumulatively improved model

Sapporo

	1990s			2040s			2090s		
	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)
Jan	10.13	0.00	10.13	8.86	0.00	8.86	7.76	0.00	7.76
Feb	9.29	0.00	9.29	7.97	0.00	7.97	6.95	0.00	6.95
Mar	7.44	0.00	7.44	6.02	0.00	6.02	4.62	0.00	4.62
Apr	1.98	0.00	1.98	1.11	0.09	1.20	0.67	0.21	0.88
May	0.08	0.21	0.29	0.00	0.73	0.73	0.00	1.05	1.05
Jun	0.17	0.34	0.52	0.01	0.91	0.92	0.00	1.04	1.04
Jul	0.00	2.08	2.08	0.00	3.08	3.08	0.00	3.92	3.92
Aug	0.00	3.67	3.67	0.00	4.44	4.44	0.00	5.30	5.30
Sep	0.00	0.45	0.46	0.00	1.39	1.39	0.00	1.78	1.78
Oct	0.01	0.25	0.25	0.00	0.69	0.69	0.00	1.04	1.04
Nov	3.55	0.00	3.55	2.51	0.00	2.51	1.70	0.01	1.71
Dec	8.18	0.00	8.18	6.74	0.00	6.74	5.46	0.00	5.46

Tokyo

	1990s			2040s			2090s		
	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)
Jan	2.09	0.02	2.10	0.72	0.20	0.92	0.65	0.19	0.85
Feb	1.49	0.00	1.49	0.30	0.09	0.40	0.23	0.10	0.33
Mar	0.90	0.07	0.97	0.06	0.44	0.50	0.08	0.59	0.67
Apr	0.05	0.69	0.73	0.00	1.69	1.69	0.00	2.00	2.00
May	0.00	2.84	2.84	0.00	4.45	4.45	0.00	5.02	5.02
Jun	0.00	2.61	2.61	0.00	4.19	4.19	0.00	4.68	4.68
Jul	0.00	5.66	5.66	0.00	6.67	6.67	0.00	7.51	7.51
Aug	0.00	8.54	8.54	0.00	8.26	8.26	0.00	9.82	9.82
Sep	0.00	4.08	4.08	0.00	4.78	4.78	0.00	5.47	5.47
Oct	0.00	1.71	1.71	0.00	2.20	2.20	0.00	3.95	3.95
Nov	0.01	0.47	0.48	0.00	0.79	0.79	0.00	1.35	1.35
Dec	0.55	0.11	0.66	0.03	0.65	0.69	0.02	0.72	0.74

Naha

	1990s			2040s			2090s		
	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)	Heating loads ($kWh/m^2/month$)	Cooling loads ($kWh/m^2/month$)	Total loads ($kWh/m^2/month$)
Jan	0.00	1.91	1.91	0.00	2.31	2.31	0.00	3.40	3.40
Feb	0.00	1.62	1.62	0.00	2.21	2.21	0.00	3.18	3.18
Mar	0.00	3.92	3.92	0.00	4.94	4.94	0.00	5.59	5.59
Apr	0.00	3.57	3.57	0.00	4.85	4.85	0.00	5.45	5.45
May	0.00	6.03	6.03	0.00	7.31	7.31	0.00	8.47	8.47
Jun	0.00	6.90	6.90	0.00	8.64	8.64	0.00	9.08	9.08
Jul	0.00	9.66	9.66	0.00	10.90	10.90	0.00	11.74	11.74
Aug	0.00	9.64	9.64	0.00	10.26	10.26	0.00	11.64	11.64
Sep	0.00	7.04	7.04	0.00	7.99	7.99	0.00	8.90	8.90
Oct	0.00	8.04	8.04	0.00	9.30	9.30	0.00	10.87	10.87
Nov	0.00	5.30	5.30	0.00	6.03	6.03	0.00	7.30	7.30
Dec	0.00	3.34	3.34	0.00	4.60	4.60	0.00	5.46	5.46

Appendix 18. Estimated costs for each strategy (Kanpou Co.,Ltd. 2010, 2012a, 2012b, Sugita Ace Co.,Ltd. 2011)

Glazing*

	Unit price (A)	Quantity (B)	Total price (A×B)	Reference
Single clear glazing (C)	36,730 (JPY/unit)	256 (unit)	9,402,880 (JPY)	Kanpou Co.,Ltd. 2010, 2012a, 2012b
Double glazing with low-e (D)	58,680 (JPY/unit)	256 (unit)	15,022,080 (JPY)	
Additional costs (C-D)			5,619,200 (JPY) (44,865 (GBP))	

Insulation**

	Unit price (A)	Quantity (B)	Total price (A×B)	Reference
Thickness 25 mm (C)	1,030 (JPY/m^2)	4,202 (m^2)	4,328,060 (JPY)	Kanpou Co.,Ltd. 2012b
Thickness 100 mm (D)	2,940 (JPY/m^2)	4,202 (m^2)	12,353,880 (JPY)	
Additional costs (C-D)			8,025,820 (JPY) (63,824 (GBP))	

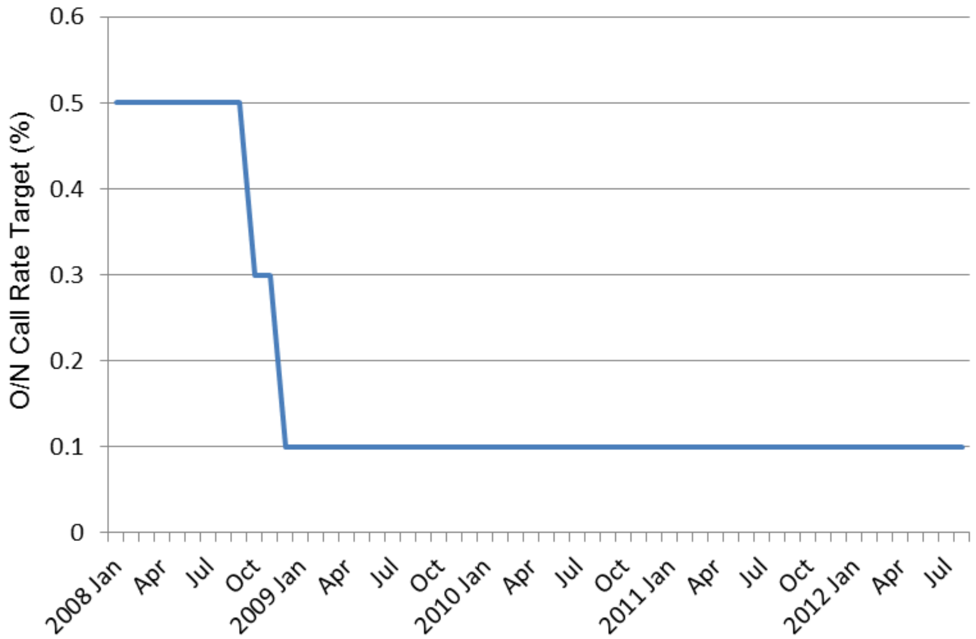
Overhang

	Unit price (A)	Quantity (B)	Total price (A×B)	Reference
Material costs (C)	296,000 (JPY/unit)	108 (unit)	31,968,000 (JPY)	Sugita Ace Co.,Ltd. 2011
Construction costs (D)	13,800 (JPY/person/day)	24 (person×day)	331,200 (JPY)	Kanpou Co.,Ltd. 2010
Additional costs (C+D)			32,299,200 (JPY) (256,852 (GBP))	

* Difference between construction costs for single glazing and double glazing with low-e was estimated to be 0.

** Difference between construction costs for 25 mm insulation and 100 mm insulation was estimated to be 0.

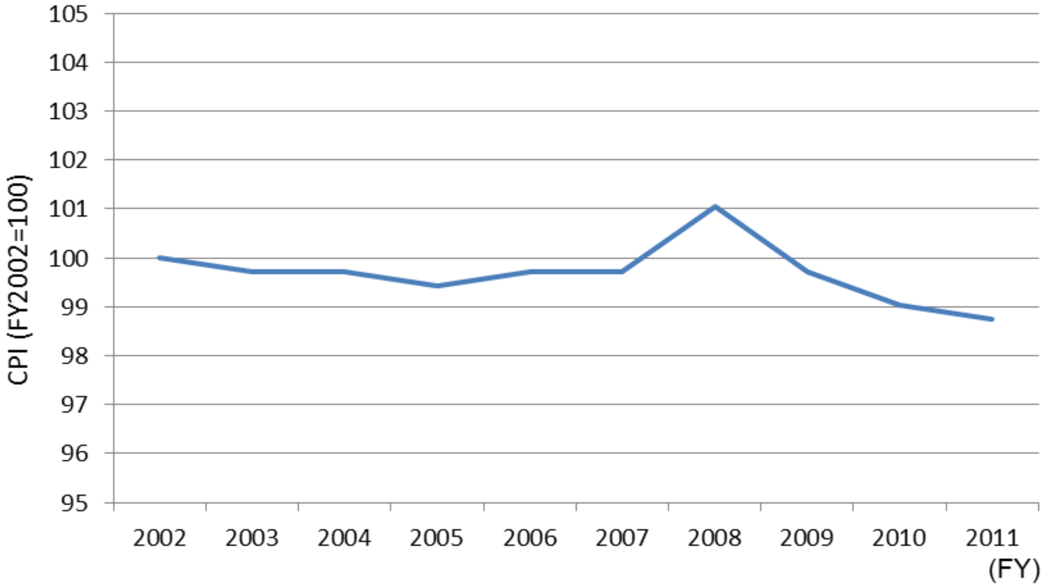
Appendix 19. Trends in O/N Call Rate Target of Japan (Gaitame.Com Co.,Ltd. 2012)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.30%	0.30%	0.10%
2009	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
2010	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%*	0.10%*	0.10%*
2011	0.10%*	0.10%*	0.10%*	0.10%*	0.10%*	0.10%*	0.10%*	0.10%*	0.10%*	0.10%*	0.10%*	0.10%*
2012	0.10%*	0.10%*	0.10%*	0.10%*	0.10%*	0.10%*	0.10%*	0.10%*				

* 0.00-0.10%

Appendix 20. Trends in CPI of Japan (MIC 2012)



FY	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
CPI (FY2002=100)	100.0	99.7	99.7	99.4	99.7	99.7	101.1	99.7	99.0	98.7