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# The effect of climate change on office building energy consumption in Japan

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ABSTRACT

Global climate change is making the mild Japanese climate significantly warmer, which is expected to have a substantial impact on building energy consumption. 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, 2031–2050, and 2081–2100.

This study reveals that under the IPCC's A2 carbon emission scenario, substantial reductions of energy consumption are expected if the full measures reviewed here are implemented. These rates differ in each location and each period due to regional climate characteristics and climate change. $CO_2$ emissions reduction targets will depend on future electricity conversion factors which could worsen due to revisions of the national energy plan triggered by the Fukushima nuclear accident.

Japan still has a vast quantity of energy inefficient old offices (pre-1981). With more specific and up-to-date technologies than those reviewed here, even greater energy reductions could be completed. A brief economic analysis suggests that these measures could be competitive with nuclear power generation.

Overall, office buildings in Japan have enormous potential to reduce energy requirements and related $CO_2$ emissions without resorting to nuclear power generation.



## 1. Introduction

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 [1]. 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 [2].

In Japan in recent years, energy consumption in the commercial sector has increased, especially in office buildings for heating and cooling [3,4]. 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 on space heating and cooling. 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 in 2011, laid bare the risks associated with nuclear power and exposed the vulnerabilities of and strains on Japan's energy supply system. The revisions of the national energy plan triggered by the Fukushima nuclear accident will reduce dependence on nuclear power in the future, in 2011 around 30% of electricity was generated by nuclear power [3]. Discussions on Japan's future energy policy place priority on the supply side [5]. We suggest it is also very important to consider the demand side, and in particular attempts to reduce energy consumption in office buildings.

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. While some researchers have studied the effects of global warming on total energy consumption in office buildings, few have shown the most effective measures and their impact to get the target reduction

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of $CO_2$ in future Japanese offices. In Japan, three hourly weather datasets representing each of the periods; current, 2040's and 2090's [1981–2000] have been constructed by Soga and Akasaka [6] and these were utilized in this study. The future weather datasets were based on the A2 climate change scenario of the IPCC, Kubota and Soga [7]. In this study, these latest current and future weather data were utilized, which leads to more reliable calculation in future cooling/heating loads.

This paper presents 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. The aim of the paper 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 60–80% by the year 2050.

## 2. Methodology

The study simulated an office with typical construction, heat gains, and operational patterns with Thermal Analysis Software (TAS) [8]. The Japanese weather files mentioned previously were utilized. Several strategies for reducing heating/cooling demand are described and analysed.

### 2.1. Weather files

#### 2.1.1. Reference weather year

Weather data in Japan is acquired by the Automated Meteorological Data Acquisition System (AMeDAS) of the Japan Meteorological Agency (JMA). Weather data for the current period developed as Expanded AMeDAS (EA weather data) [9]. EA weather data are hourly data obtained from 842 stations throughout Japan over 20 years [1981–2000]. EA weather data was reformatted considering not only equality of the monthly mean of each weather parameter but also equality of the frequency of each day's value [6]. As a result, a reference weather year (Standard EA weather data) was constructed.

#### 2.1.2. Future weather files

JMA [10] produced two types of future weather data for Japan: 2031–2050 (2040s) and 2081–2100 (2090s). There are 46 variables including; daily 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 for each of 11,881 nodes whose 20 km apart. These data based on AMeDAS data, were made by a 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 are daily, not hourly.

Soga [11] developed two types of hourly future weather data (2040s, 2090s) available for building energy calculations. He chose 833 nodes from which to use as base data, which are located nearest to the sites observed by JMA (AMeDAS). He calculated horizontal global solar radiation and atmospheric radiation using statistical functions. As a result, the new weather data were considered to be predicted values of air temperature, absolute humidity, solar radiation quantity, and wind direction and velocity.

#### 2.1.3. Site selection

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.

**Table 1**
Latitude and longitude of the three locations selected in Japan.

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

As a result, Sapporo (cold zone), Tokyo (ordinary zone), and Naha (tropical zone) were selected (Fig. 1 and Table 1). Fig. 2 and Table 2 show that in each site air temperature increases at each period relative to the previous period. For relative humidity, no clear change was indicated between the periods.

### 2.2. Office building model

#### 2.2.1. 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 [12]. The office building oriented with the longer sides facing north-south. Around one-third of the office building stock in the chief cities of Japan dates from before 1981 [13], 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 6612 $m^2$, of which the air-conditioned floor area is 5250 $m^2$ (east and west office zones and EV hall zone, Fig. 3).

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 [14]. 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 but also the related unpleasant glare. Thus blinds should be utilized effectively, especially on south façades. A typical wall construction was used and windows were single glazed with 30% glazing ratio in office zones. The building has no insulation and single skin block construction type walls and thus can be considered to be a lightweight building.

The occupant density in office zones and EV hall zones are estimated to be 0.2 and 0.03 person/$m^2$, respectively [12] (EV = elevator, or lift). For the office area of the base floor for example, the size of one office area is $12.3 \times 24.6 \times 3.6$, for area = 302.6 $m^2$ and volume = 1089.3 $m^3$. For the given occupant density, $302.6 \times 0.2 \fallingdotseq 60$ people, the fresh air requirement is 600 L/s, hence the air change rate is $600 \times 3.6/1089.3 \fallingdotseq 2$ ach. The air change rate for EV hall zones was calculated to be 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 an assumed infiltration rate of 0.25 ach, were fixed (Table 3). Note typical 1990s type office buildings in Japan had no heat recovery [12].

The internal heat gains and the target temperature and relative humidity were defined using data from reference (12, Appendix 1); note that it was typical to work saturday mornings in 1990, but current and future trends mean that this is now an outdated practice and a 5 day working week is normal (Appendix 2).

#### 2.2.2. Improved model

A series of simulations with different measures or improvements applied were carried out. In the following figures, the improved factors are shown in red ink.

*2.2.2.1. Lighting and equipment improvements (reducing internal heat gains).* Recently the efficiency of office appliances has improved significantly by technological innovations, and efficiency