ENVIRONMENTAL IMPACT ASSESSMENT OF URBAN AIR TEMPERATURE INCREASE BASED ON ENDPOINT-TYPE LIFE CYCLE IMPACT (PART 2) – QUANTIFICATION OF ENVIRONMENTAL IMPACT IN TOKYO

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Abstract

The urban air temperature rise has various environmental impacts on our society. We developed a framework to assess environmental impact based on endpoint-type life cycle impact assessment methodology. We used our developed framework and assessed impacts on five category endpoints, namely heat stress including hyperthermia, cold stress, energy consumption in hot/cold, and sleep disturbance, caused by recent 30-years air temperature increase in Tokyo. The result showed that the damage on sleep disturbance is the most remarkable, while we obtain merit from reduction in cold stress from October to May.

Key words: Urban heat island, Environmental impact, Life cycle assessment

1. INTRODUCTION

The air temperature of Tokyo has been rising by about 3 °C over recent 100 years. It is considered that it is due to urban heat island (UHI) and global warming, particularly UHI. The air temperature rise is actually bringing various serious damages to our society. Meanwhile, the effects of UHI countermeasures, which are air temperature reduction measures, vary by time and area. In order to reduce environmental impacts totally by installation of UHI countermeasure, it is required to grasp magnitude of various impacts varied by time and area. For the purpose, we reported development of a framework to assess various impacts in the previous paper (Genchi and Ihara, 2009). In this paper, we use the framework and assess magnitude of various impacts by air temperature increase.

2. CONDITIONS FOR ASSESSMENT

2.1. Category endpoints

As mentioned before, UHI phenomenon has environmental impacts on various category endpoints. However, there are few category endpoints which have explicitly quantitative relation with air temperature/air humidity/wind direction/wind velocity. In this study, we assessed four category endpoints, namely heat-related disease including hyperthermia, cold-related disease, and energy consumption for heating/cooling which are considered to be large and quantifiable. The previous survey showed that sleep disturbance is recognized to be the most significant problem caused by warming air temperature among Japanese residents (NIES, 2003). Therefore, we added sleep disturbance as the fifth category endpoint. Generally in the environmental impact assessment field, damage of heat/cold-related disease is called heat/cold stress. In this paper, they are also described heat/cold stress.

2.2. Impact categories

Changes in various meteorological elements pose the environmental impacts on our society, but available time-series meteorological data are limited. In this study, we took only an air temperature as an impact category.

2.3. Temporal scope and spatial scope

UHI phenomena have different impacts depending on temporal condition and spatial condition. Therefore, the assessment requires defining a temporal scope and a spatial scope.
We set the whole area of the 23 special wards of Tokyo as the spatial scope because it has much statistics and is significantly affected by UHI. Regarding the temporal scope, we assess environmental impacts by month.

2.4. Single index

Single index defined in LIME ver.1 (Itsubo and Inaba, 2005) is used. Four endpoints which are human health, social assets, biodiversity, and primary production are calculated to the single index in LIME ver.1. Its unit is Yen. Fig. 1 shows our environmental impact assessment model quantified in this study.

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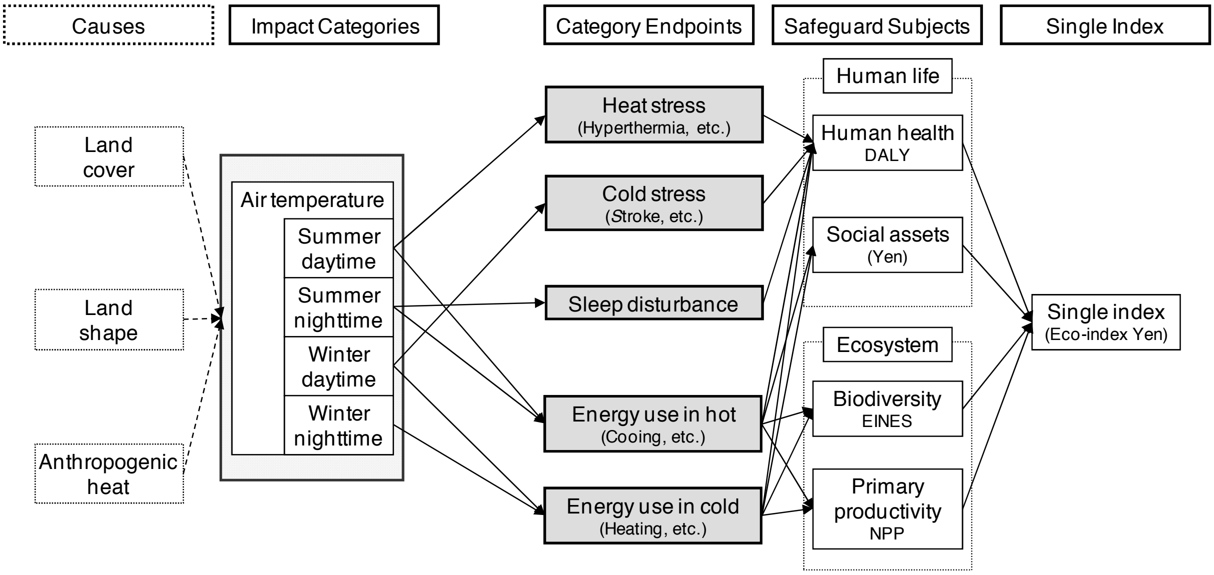

Fig. 1 Environmental impact assessment model quantified in this study

3. ENVIRONMENT IMPACT ASSESSMENT ACCORDING TO CATEGORY ENDPOINTS

3.1. Heat/cold stress (aged 65 and over)

LIME, which is the basis of our framework, assesses an impact on human health using disability-adjusted life year (DALY). DALY is defined to be the sum of years of life lost (YLL) and years lived with disability (YLD). In this study, only YLL is assessed because it is hard to obtain statistics on YLD and YLD is considered to be small.
The relationship between a daily maximum air temperature and an increase in deaths among people aged 65 and over in Tokyo was calculated based on the research about the relationship between a daily maximum air temperature and mortality rate for people aged 65 and over (Honda el al, 1998) and the research about cold stress (Kunst et al, 1993). The result is shown as Fig. 2.
We assumed that 2 years of life would be lost by heat/cold stress as well the estimation of those caused by global warming (Itsubo and Inaba, 2005). The impacts are expressed as a function of air temperature difference from the optimum daily maximum air temperature in Tokyo. 1 DALY is estimated as 9.76 million Yen in LIME. Therefore, the impacts y [Yen/d] were assessed as the following equation.

$$y = \begin{cases} -3.04 \times 10^7 (x - 28) & (x < 28) \\ 6.09 \times 10^7 (x - 33) & (x > 33) \end{cases}$$

Here, x is daily maximum air temperature [°C].

3.2. Heat/cold stress (under 65: only hyperthermia)

It is considered that heat/cold stress mostly occurs in elderly people but less occurs in not elderly. However, half of deaths by hyperthermia, which is one of typical impacts by UHI, are people under 65. Therefore, half of deaths by hyperthermia are not included above assessment. We analyze impact about hyperthermia on people under 65.
Ono (2009) analyzed mortality by hyperthermia according to daily maximum air temperature in Tokyo from 1972 to 1996. Ono also summarized a number of deaths by hyperthermia according to year, sex, and age group from 1972 to 1993. We made relationship between a daily maximum air temperature and deaths by hyperthermia among people under 65 from these data. The result is shown as Fig. 3.
From statistics of population in Tokyo and Ono, YLL of an average person under 65 who died by hyperthermia is estimated to be 47.8 years. The impact by hyperthermia y [Yen/d] was assessed as the following equation as well as heat/cold stress.

$$y = 1.32\exp(0.536x)$$

Here, x is daily maximum air temperature [°C].

3.3. Energy consumption

Narumi et al (2007) analyzed the rate of change in the secondary energy consumption in commercial and residential sectors in Tokyo by monthly average air temperature from 1999 to 2003. Using a number of family and total floor area in Tokyo, we assessed the amount of energy consumption by change in air temperature.
Increase in energy consumption poses increases in exhaustible resource including oil and coal. It also poses increases in emission of environmental burden including CO_2, SO_X, and NO_x. These events have impacts on our

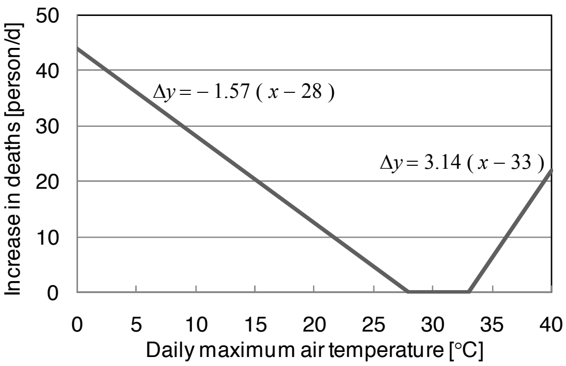

Fig. 2 Relationship between daily maximum air temperature and death risk of people aged 65 and over in Tokyo

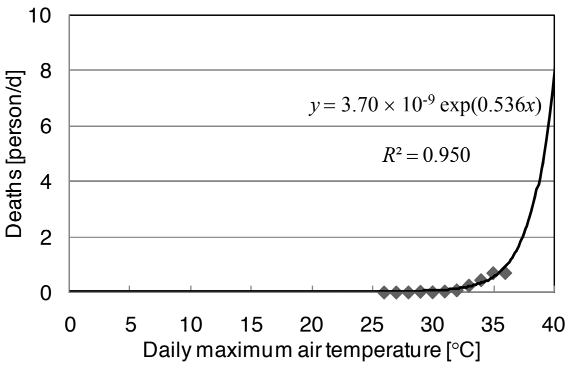

Fig. 3 Relationship between daily maximum air temperature and deaths by hyperthermia of people under 65 in Tokyo

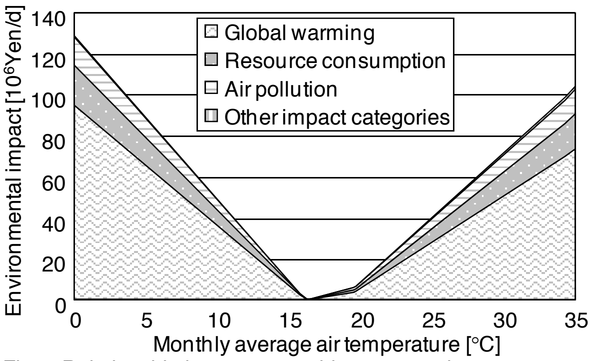

Fig. 4 Relationship between monthly average air temperature and impacts by energy use in Tokyo

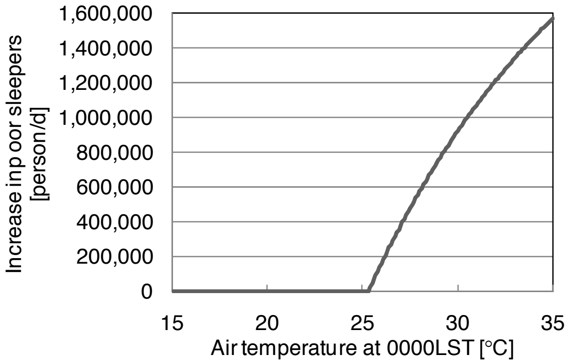

Fig. 5 Relationship between air temperature at 0000LST and poor sleepers in Tokyo

society such as depletion of resources, global warming, air pollution, and so on. We analyzed the environmental impact by energy consumption using life cycle inventory (LCI) analysis and life cycle impact assessment (LCIA) on AIST-LCA ver.4, which mounts LIME as an LCIA calculating method and is the most widely used in Japan (its commercial version is JEMAI-LCA Pro (JEMAI, 2007)). The impact on energy consumption y [Yen/d] was assessed as the following equation.

$$y = \begin{cases} -8.04 \times 10^6 (x - 15.7) + 3.20 \times 10^6 & (x < 15.7) \\ -5.70 \times 10^6 (x - 16.3) & (15.7 \le x < 16.3) \\ 1.82 \times 10^6 (x - 16.3) & (16.3 < x \le 19.5) \\ 3.18 \times 10^7 (x - 19.5) + 5.87 \times 10^6 & (19.5 < x \le 19.7) \\ 6.80 \times 10^6 (x - 19.7) + 6.34 \times 10^6 & (19.7 < x \le 34.3) \\ 1.47 \times 10^8 (x - 34.3) + 9.91 \times 10^7 & (34.3 < x) \end{cases}$$

Here, x is monthly average air temperature [°C]. The result according to impact categories is shown as Fig. 4.

3.4. Sleep disturbance

We developed a questionnaire for daily sleep quality with reference to the Japanese version of the Pittsburgh Sleep Quality Index (PSQI-J) (Doi et al, 2000) and measured daily sleep quality of Tokyo residents during 10 days of the summer in 2007 (Okano et al, 2008). From the analysis, we found that about 2 % more people become “poor” sleepers for each 1 °C increase in outdoor air temperature at 0000LST over 25.3 °C. The detailed result of the relationship between a nighttime air temperature and sleep disturbance is shown as Fig. 5.

Calculating YLD requires duration and severity of sleep disturbance. We set these values to 1 day and 0.05, respectively. The impact by sleep disturbance y [Yen/d] was assessed to 0 when $x < 25.3$, 1.22×10^9 when $x = 30$, and 2.08×10^9 when $x = 35$ (The model is complicated and cannot be expressed with a simple equation). Here, x is air temperature at 0000LST [°C].

4. ENVIRONMENT IMPACT ASSESSMENT BY INCREASE IN AIR TEMPERATURE IN TOKYO

4.1. Duration for assessment

The air temperature of Tokyo has been rising over 100 years. However, available meteorological data in the past is limited. The environmental impacts caused by air temperature increase during 30 years from 1973 to 2003 are assessed. In addition, we use 11-year average meteorological data in order to remove the short-term effect.

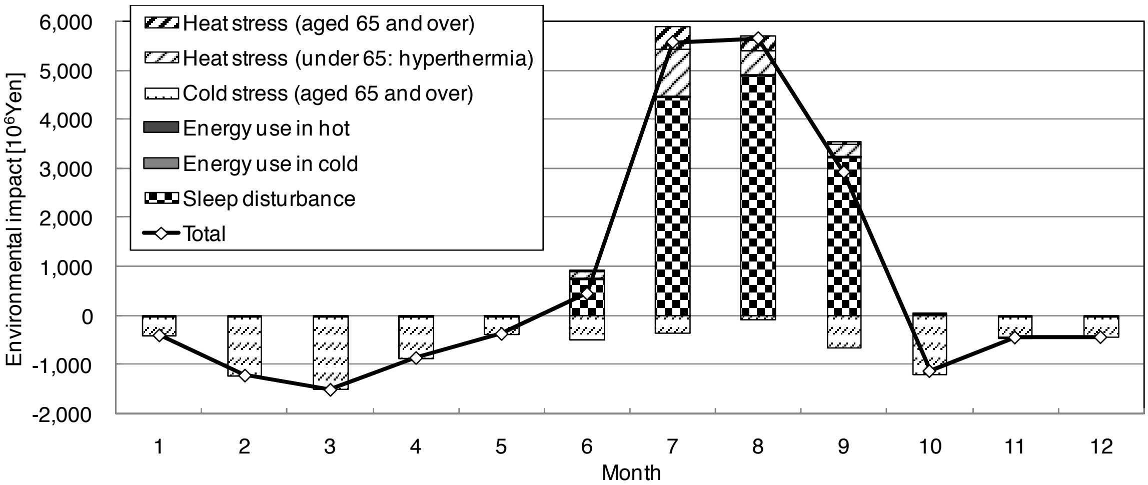

Fig. 6 Monthly environmental impact assessment by air temperature increase in Tokyo during 30 years from 1973 to 2003

4.2. Annual and monthly assessment

The quantified result is shown as Fig. 6. We found that the air temperature increase in Tokyo during recent 30 years brought 8.43×10^8 Yen damage on heat stress of people aged 65 and over, 1.87×10^9 Yen on heat stress of people under 65 (hyperthermia), -7.86×10^9 Yen on cold stress (only people aged 65 and over), 3.28×10^7 Yen on energy use in hot, -5.87×10^7 Yen on energy use in cold, 1.35×10^{10} Yen on sleep disturbance (Negative values mean merits). Total damage is 8.31×10^9 Yen. The damage on sleep disturbance is the most remarkable, while we obtain merit from reduction in cold stress from October to May.

5. CONCLUSION

We assessed environmental impacts by air temperature increase in Tokyo during recent 30 years using our developed framework. We found that sleep disturbance, which is small per capita but wide-spread in our society, has had large impact on our society. From the result, it can be said that UHI countermeasures to reduce nighttime air temperature but not to reduce air temperature in winter is effective for our society. However, this study assessed only five category points, so our findings are limited. The assessment about fatigue, torrential rain, and biota, which are considered to have large impacts, are the future tasks.

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