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IMPACT ASSESSMENT AND PREDICTION OF HUMAN HEALTH AND ENERGY CONSUMPTION CAUSED BY URBAN CLIMATE CHANGE

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1. INTRODUCTION

1.1 *Background*

The air temperature in Tokyo has increased by 3.0 °C for the past 100 years and it seems to continue to increase by global warming in the future. This urban air temperature increase poses various environmental impacts in our society, such as hyperthermia, increase in the use of air conditioning, and so on.

An air temperature reduction measure is positioned as a countermeasure against urban heat islands and is also positioned as an adaptation measure for global warming. Our society has been developing many kinds of countermeasures such as green roofs, cool roofs which are rooftops with coating reflective paint, heat pump water heaters, ground source heat pumps and so on. However, their air temperature reduction effects are varied by time. For example, trees or green roofs should be installed for decreasing daytime air temperature, but heat pump water heaters should be installed for decreasing nighttime air temperature (Yamaguchi *et al*, 2009). Similarly, cool roofs & cool walls decrease the air temperature in summer and winter, but ground source heat pumps decrease the air temperature in summer and increase the one in winter (Ihara *et al*, 2008).

In order to reduce the environmental impacts reasonably and totally, first we need to grasp magnitude of various impacts varied by time in the past and the future with the same criteria.

1.2 *Objectives*

In this study, we aim at developing a framework for evaluating various environmental impacts caused by urban air temperature increase with the same criteria. Using the developed framework, we evaluate the actual environmental impacts in Tokyo in the past and in the future. Furthermore, from the result, we also investigate what air temperature reduction measure should be installed there in order to reduce the environmental impact on our society totally.

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2. LIFE CYCLE IMPACT ASSESSMENT (LCIA) OF URBAN CLIMATE CHANGE

2.1 *Life cycle impact assessment (LCIA)*

Life cycle impact assessment (LCIA) is one of methodologies in life cycle assessment (LCA), which assesses environmental impacts on our society caused by environmental burdens emitted from human activities. In particular, the endpoint-type LCIA methodology can quantitatively calculate environmental impacts on a few previously-defined safeguard subjects which we have to protect eventually. Additionally, it also provides that the assessed damage on the safeguard subjects can be converted to economical values based on our values. Therefore, by using the endpoint-type LCIA methodology, we can evaluate various environmental impacts with single economical index.

Life cycle Impact assessment Method based on Endpoint modeling 1 (LIME 1) (Itsubo and Inaba, 2005) is one of the endpoint-type LCIA methodologies and the only model in Japan. LIME 1 has four kinds of safeguard subjects which are human health, social assets, biodiversity, and primary productivity. Every safeguard subject has their own indexes which are disability-adjusted life year (DALY) (WHO, 2011), Yen (cost), extinct species, and kg (dry weight). They can be converted to single index (Yen).

2.2 *Framework of environmental impacts caused by urban climate change*

Many previous studies have pointed out relationships between meteorological elements and environmental issues caused by urban climate change. We referred to those studies and LIME 1 to develop a framework of environmental impacts caused by urban climate change based on LIME 1 (Ihara and Genchi, 2008). The framework is shown as Fig. 1.

Here, we dealt with urban meteorological elements by time which is season and hour because the effects by urban climate change are varied by season and hour. The category endpoints mean so-called environmental impacts (or environmental issues). We included all environmental impacts mentioned in previous researched and drew relationship between the impact categories and them, and them and the safeguard subjects. The safeguard subjects and the single index are the same as LIME 1.

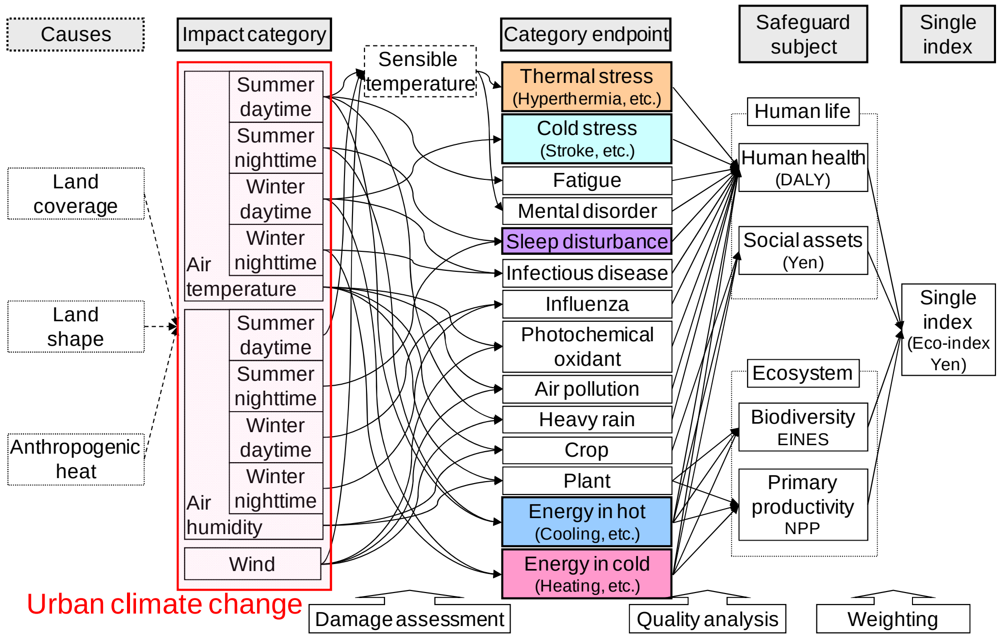

Fig. 1: Framework for LCIA of urban climate change based on LIME

2.3 *Damage assessment and quality analysis (in Tokyo)*

Next, we have to develop damage assessment functions and quality analysis functions in the framework so that we can quantify environmental impacts caused by urban climate change.

There are many unknown relationships in the framework. This time, we took up four kinds of impacts, 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 impact.

The relationships among thermal/cold stress (including severe hyperthermia), sleep disturbance, and energy consumption with diurnal and nocturnal air temperature were quantified within the developed model as follows:

- Thermal/cold stress expressed among people of aged 65 and over was based on a previous research about the relationship between mortality rate and daily maximum air temperature by Honda *et al* (1998). The relationship in Tokyo is shown as Fig. 2. We assumed that the years of life lost (YLL) by heat/cold stress would be 2 years as well the estimation of those caused by global warming (Itsubo and Inaba, 2005). 1 disability-adjusted life year (DALY) was estimated as 9.76 million Yen in LIME.
- There are no previous studies on thermal/cold stress among people under 65. But only severe hyperthermia which results in death was analyzed by Ono (2009). The relationship in Tokyo is shown as Fig. 3. In this study, only severe hyperthermia among people under 65 was evaluated as thermal/cold stress among people under 65. YLL of an average person under 65 who died by hyperthermia was estimated to be 47.8 years.
- There are no available statistics about sleep disturbance caused by air temperature increase. With reference to the Japanese version of the Pittsburgh Sleep Quality Index (PSQI-J) (Doi *et al*, 2000), we surveyed relationship between quantitative sleep quality and nocturnal air temperature (Okano *et al*, 2008). The relationship in Tokyo is shown as Fig. 4. Calculating years lived with disability (YLD) requires disability weight and average duration (of the case until remission or death) of sleep disturbance (WHO, 2011). We assumed 1 day and 0.05 as these values, respectively.
- The relationship between various energy consumption and air temperature were referred to Narumi *et al* (2007). Those various energy consumptions also pose increases in emission of environmental burden including CO_2, SO_x, and NO_x. These events have impacts on our 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 LCIA on AIST-LCA ver.4, which mounts LIME as an LCIA calculating method and is the most widely used LCA software in Japan (JEMAI, 2007). The result in Tokyo is shown as Fig. 5.

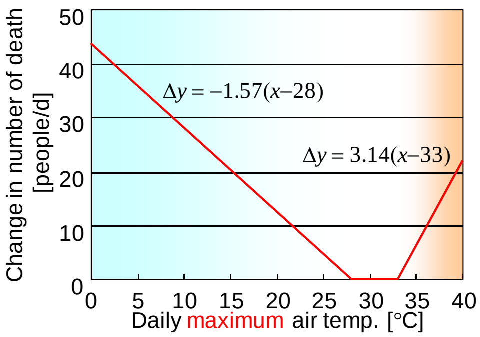

Fig. 2: Relationship between air temperature and thermal/cold stress among people of aged 65 and over in Tokyo

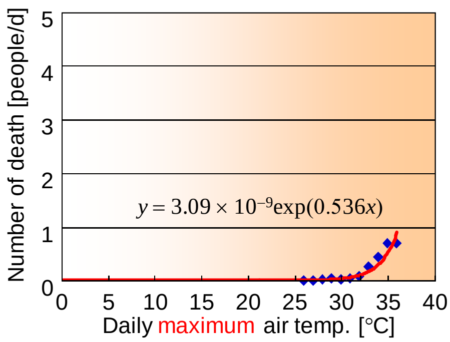

Fig. 3: Relationship between air temperature and thermal/cold stress for under 65 (only hyperthermia) in Tokyo

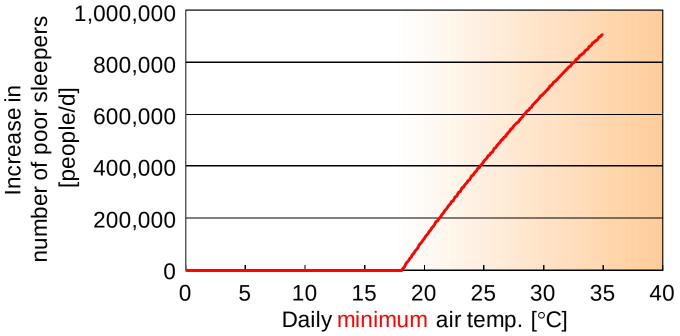

Fig. 4: Relationship between air temperature and sleep disturbance in Tokyo

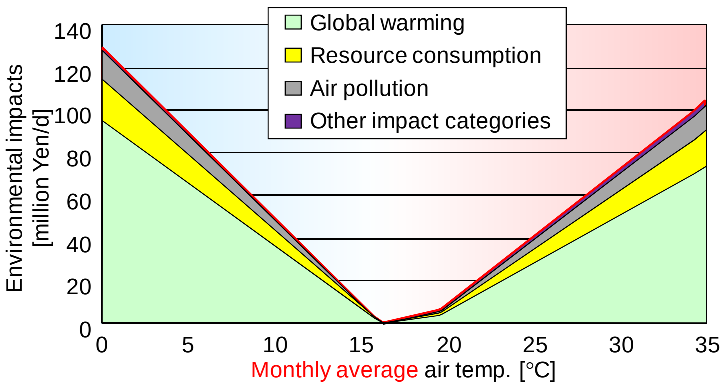

Fig. 5: Relationship between air temperature and environmental impacts from energy consumption in Tokyo

3. TOTAL ENVIRONMENTAL IMPACT IN THE PRESENT

3.1 *30-year urban climate change (1973→2003, in Tokyo)*

The meteorological observation data by Japan Meteorological Agency (JMA, 2011), which can use for the evaluation in this study, are available in only the past 30 years.

We evaluated total environmental impacts caused by 30-year urban climate change in Tokyo. 30-year urban climate change in Tokyo is defined as air temperature increase from 1973 to 2003 here. As 1973 data, 11-year average between 1968 and 1978 are used, as 2003 data, 11-year average between 1998 and 2008 are used.

3.2 *Total impact of 30-year urban climate change (in Tokyo)*

Using the above LCIA model and the air temperature data in Tokyo in the past, the environmental impacts by the increase in air temperature in Tokyo were evaluated. The result is shown as Fig. 6

From the result, we found that sleep disturbance, which is small impact per capita but wide-spread in our society, has had large impact on our society. The air temperature increase in Tokyo during the recent 30

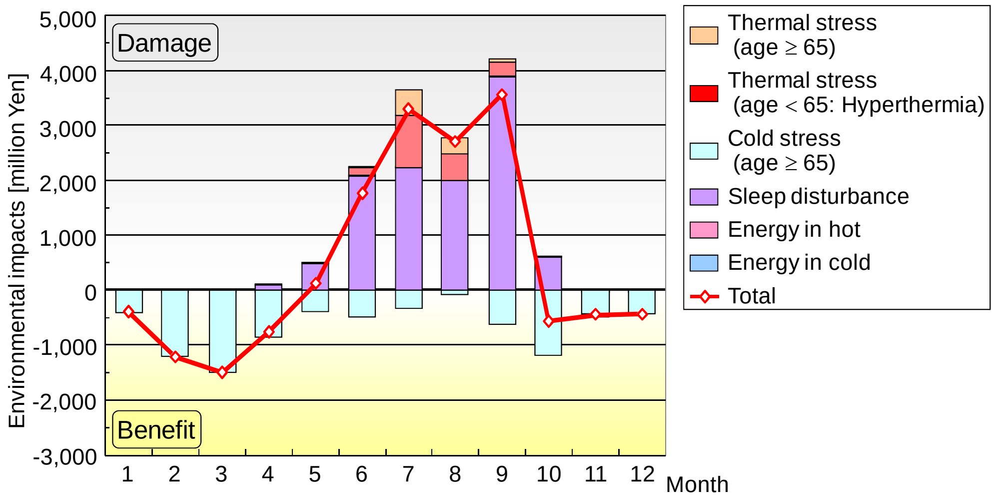

Fig. 6: Total impact of 30-year urban climate change (in Tokyo)

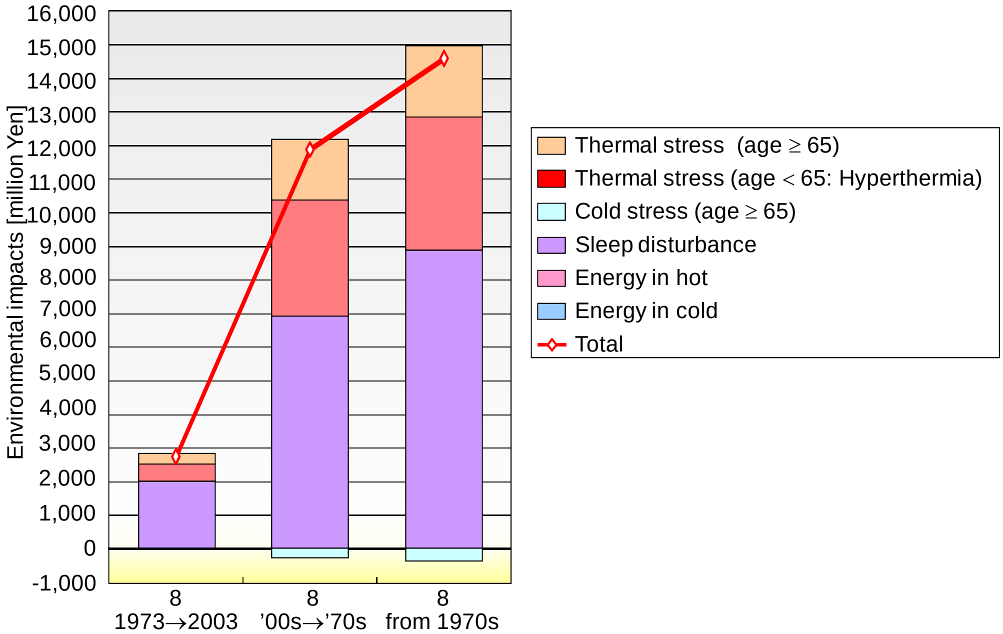

Fig. 7: Total impact of future 70-year urban climate change (in Tokyo, under IPCC SRES A2 scenario)

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), 1.35×10^{10} Yen on sleep disturbance, 3.28×10^7 Yen on energy use in hot, -5.87×10^7 Yen on energy use in cold (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.

4. TOTAL ENVIRONMENTAL IMPACT IN THE FUTURE

4.1 *70-year urban climate change (2000s→2070s, in Tokyo)*

We redicted air temperature in Tokyo in the next 70 years under IPCC SRES A2 scenario with pseudo global warming technique (Kimura and Kitoh, 2007) from a global circulation model (GCM)'s future prediction (Nozawa *et al*, 2007).

4.2 *Total impact of future 70-year urban climate change (in Tokyo)*

We found that the next 70-year air temperature increase will give about five times more damage on our society than the present (Fig. 7). Particularly, because diurnal air temperature will also increase while nocturnal air temperature largely increased in the past, heat stress including severe hyperthermia will significantly increase. Concretely, the air temperature increase of August in the future 70 years under IPCC SRES A2 scenario brought 1.80×10^9 Yen damage on heat stress of people aged 65 and over (while the past 30-year air temperature increase brought 2.99×10^8 Yen), 3.48×10^9 Yen (4.95×10^8 Yen) on heat stress of people under 65, -3.12×10^8 Yen (-6.58×10^7 Yen) on cold stress (only people aged 65 and over) , 6.89×10^9 Yen (1.99×10^9 Yen) on sleep disturbance, 2.14×10^7 Yen (4.15×10^6 Yen) on energy use in hot. Total damage is 4.99×10^9 Yen (7.32×10^8 Yen).

5. CONCLUSION

5.1 *Summary*

We evaluated environmental impacts caused by urban climate change based on the endpoint-type LCIA methodology quantitatively and showed usefulness and necessity of the endpoint-type LCIA methodology.

We found that mild but broad human health impacts (sleep disturbance, fatigue, etc.) can become more serious than other problems in our society. If IPCC SRES A2 scenario realizes, health impact damages may increase remarkably.

From the evaluation, it can be said that air temperature reduction measures to reduce nocturnal air temperature except reduction of air temperature in winter is effective for our society in the past and for the future. However, the impacts caused by diurnal air temperature increase may become more serious in the future.

5.2 *Future tasks*

This study showed that mild but broad human impacts are important. However, some assumptions including calculation of DALY were used in the evaluation. Additionally, other similar impacts such as fatigue and hyperthermia which does not result in death have not been evaluated. They should be considered in the future. Other impacts excluding human health and energy consumption, which are torrential rain, biota, and so on, are similar.

Furthermore, more detailed urban climate prediction is needed because the impacts depend on seasonal and diurnal change of air temperature.

REFERENCES

Doi Y, Minowa M, Uchiyama M, Okawa M, Kim K, Shibui K, Kamei Y (2000): Psychometric assessment of subjective sleep quality using the Japanese version of the Pittsburgh Sleep Quality Index (PSQI-J) in psychiatric disordered and control subjects, Psychiatry Research, 165-172.

Honda Y, Ono M, Sasaki A, Uchiyama I (1998): Shift of the short-term temperature-mortality relationship by a climate factor-some evidence necessary to take account of in estimating the health effect of global warming, Journal of Risk Research, 1(3), 209-220.

Ihara T, Kikegawa Y, Asahi K, Genchi Y, Kondo H (2008): Changes in year-round air temperature and annual energy consumption in office building areas by urban heat island countermeasures and energy-saving measures, Applied Energy, 85(1), 12-25.

Ihara T, Genchi Y (2008): Environmental impact assessment of urban heat island phenomena based on endpoint-type life cycle impact assessment methodology, Journal of Environmental Engineering, Architectural Institute of Japan, 73(634), 1407-1415. [in Japanese with English Abstract]

Itsubo N, Inaba A (eds.) (2005): Lifecycle Impact Assessment Method – LIME-LCA, assessment method and database for environmental accounting and eco-efficiency, Japan Environmental Management Association for Industry. [in Japanese]

Japan Environmental Management Association for Industry (JEMAI) (2007): JEMAI-LCA Pro. [in Japanese]

Japan Meteorological Agency (JMA) (2011): Climate Statistics. http://www.jma.go.jp/jma/menu/report.html. [in Japanese]

Kimura F, Kitoh A (2007): Downscaling by pseudo global warming method, The Final Report of the ICCAP, Research Institute for Human and Nature.

Okano Y, Ihara T, Genchi Y (2008): Evaluation of environmental impacts on disturbed sleep by nighttime urban heat island phenomena using surveys via the Internet, Journal of Heat Island Institute International, 3, 22-33. [in Japanese with English Abstract]

Ono M (2009): Hyperthermia in Japan, IGES-WHO International Symposium on climate change and health. [in Japanese]

Narumi D, Hashimoto S, Shimoda Y, Mizuno M (2007): Regional characteristics of the effect of temperature upon the energy consumption, Energy and Resources, 28(6), 395-402. [in Japanese with English abstract]

Nozawa T, Nagashima T, Ogura T, Yokohata T, Okada N, Shiogama H (2007): Climate change simulations with a coupled ocean-atmosphere GCM called the model for interdisciplinary research on climate: MIROC, CGER's Supercomputer Monograph Report 12, Center for Global Environmental Research, National Institute for Environmental Studies.

National Institute for Environmental Studies (NIES) (2003): Inquiry Survey on Warming Air Temperature (conducted in 2003FY).

http://www.nies.go.jp/impact/jp_quest.html. [in Japanese]

Yamaguchi K, Ihara T, Kikegawa Y, Genchi Y, Endo Y (2009): Thermal environment and energy evaluation for heat island - Countermeasure in different residential areas, The 7th International Conference on Urban Climate Proceedings, International Association for Urban Climate. http://www.ide.titech.ac.jp/~icuc7/extended_abstracts/pdf/384689-1-090520161321-003.pdf.

World Health Organization (WHO) (2011): Metrics: Disability-Adjusted Life Year (DALY). http://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/index.html.