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URBAN HEAT ISLAND MITIGATION AND LIFE CYCLE CO_2 REDUCTION BY INSTALLATION OF URBAN HEAT ISLAND COUNTERMEASURES

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1. INTRODUCTION

1.1 *Background*

In Japan, the air temperature in big cities has been increasing rapidly since the 1980s. This phenomenon is referred to as the “urban heat island (UHI) phenomenon.” UHI is an environmental problem that results in increases in energy consumption due to the increased cooling demand, and in unfavorable conditions for human health. Various local activities against UHI have been promoted after the enactment of the Outline of Countermeasures to Urban Heat Island in March 2004.

Many countermeasures against UHI have been developed so far in order to decrease the air temperature. If such countermeasures are installed, the air temperature during summer will decrease, and therefore the energy consumption required for cooling will also decrease. On the other hand, if such countermeasures are installed, the air temperature during winter will decrease, and therefore the energy consumption for heating will increase. In addition, a lot of energy will be consumed for the construction and the operation of such countermeasures. Thus, the installation of countermeasures can cause an increase in CO_2 emissions.

Global warming is also one of the most important environmental issues. The Japanese government has enacted the Goals of the Kyoto Protocol Target Achievement Plan in April 2005. In order to meet the goal, even when UHI countermeasures are installed, it is required that there should be no significant increase in CO_2 emissions. From the viewpoint of global warming, it is very important to evaluate not only changes in CO_2 emissions for air-conditioning demand of the building by UHI countermeasures but also increases in CO_2 emissions for the construction and the operation of UHI countermeasures.

1.2 *Objectives*

This study evaluated both the changes in the urban air temperature and life cycle CO_2 ($LCCO_2$) emissions resulting from the installation of various UHI countermeasures.

2. METHODOLOGY

The purpose of this study is calculation of $LCCO_2$ change and UHI mitigation by installation of UHI countermeasures. We set an evaluation scope of $LCCO_2$ to production and operation stages of countermeasures and change in air conditioning in the buildings where UHI countermeasures were installed. The disposal stage of UHI countermeasures was excluded from the evaluation scope because they are disposed with scrapping of the buildings (Fig. 1).

$LCCO_2$ change and UHI mitigation are evaluated using annual meteorological and building energy models (AIST-CBM, this is a part of AIST-MCBM ver.2) and the life cycle inventory analysis (LCI). AIST-CBM calculates CO_2 emissions change by the building air-conditioning change and UHI mitigation. LCI calculates the production and operation stages of the countermeasures.

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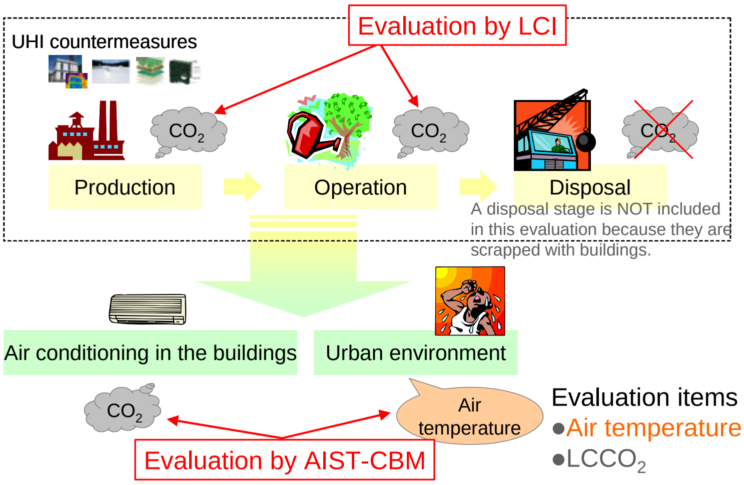

Fig. 1: Methodology of this study

AIST-CBM (Fig. 2) is a model developed by combining the 1D canopy meteorological model and the building energy use model (Ihara *et al*, 2007). This model can evaluate the year-round air temperature and annual energy consumption.

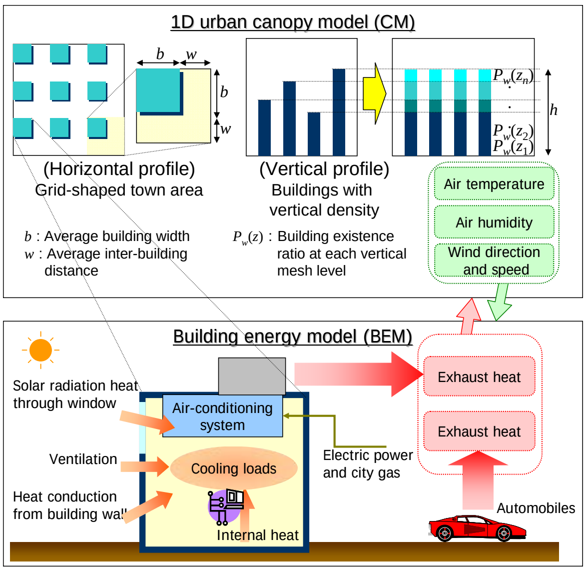

Fig. 2: Overview of AIST-CBM

LCI is a life cycle assessment (LCA) methodology to calculate the environmental emissions from each stage of products or services and evaluate their total emissions. We used AIST-LCA ver.4 as an LCI calculation software in this study. AIST-LCA ver.4 was one of most popular LCA software in Japan. It can execute the inventory analysis (LCI) and the impact assessment (LCIA). AIST-LCA ver.4 was developed by AIST and it is marketed as JEMAI-LCA Pro by Japan Environmental Management Association for Industry (JEMAI) (JEMAI, 2006).

3. EVALUATION SCENARIO

3.1 *UHI countermeasures*

Today we have various countermeasures against UHI. However, our previous study showed that countermeasures which have significant UHI mitigation effects are limited (Ihara *et al*, 2007).

In our previous study, only photocatalytic coating with watering, solar reflective paint (SRP) and ground source heat pump (GSHP) have significant effects. Other countermeasures, particularly building energy-saving measures such as insulation, adoption of high-efficiency appliances and lightings, high-efficiency air-conditioning systems have very small effect or opposite effect for UHI mitigation.

In this study three major UHI countermeasures such as photocatalytic coating, SRP, and greening (rooftop and sidewall greening) were selected. We did not evaluate other countermeasures such as energy-saving technologies, since these countermeasures have few UHI mitigation effects.

Evaluation conditions of them were shown below.

The lifetime of photocatalytic coating is set to 10 years. Coated area is watering only between 8:00 and 18:00 of from May to September. It can be installed to 50% of sidewalls of the building other than windows.

SRP has the same CO_2 emissions from production stage and the same lifetime as conventional paint. It can be installed to rooftops and sidewalls other than windows.

There are various greenings and they have different UHI mitigation effects. One rooftop greening and one sidewall greening were selected here from the standpoint of significant UHI mitigation.

Grass & flowers type greening with watering was selected as rooftop greening for the evaluation. The lifetime is 10 years. It can be installed to 50% of rooftops.

Unit type greening with watering was selected as sidewall greening. The lifetime is 30 years. It can be installed to 50% of sidewalls other than windows.

In addition, we used installation effects per installation area (1 m^2) as a function unit of UHI countermeasures. It is general to make equal function units in comparison in LCA.

3.2 *Evaluation conditions*

Nihombashi area was selected for a case study area in this study. This area is a typical office area in Tokyo.

The simulation period was one year—0000LST June 1st, 2002 to 0000LST June 1st, 2003 (LST means local standard time).

4. SIMULATION BY AIST-CBM

4.1 *Urban heat island mitigation*

Average air temperature in August was selected as an index of UHI mitigation effect because daytime air temperature is important in office areas. Simulation results are shown as Fig. 3.

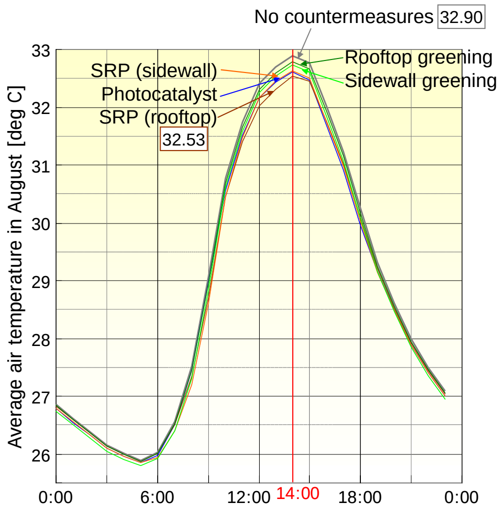

Fig. 3: Air temperature change by countermeasures

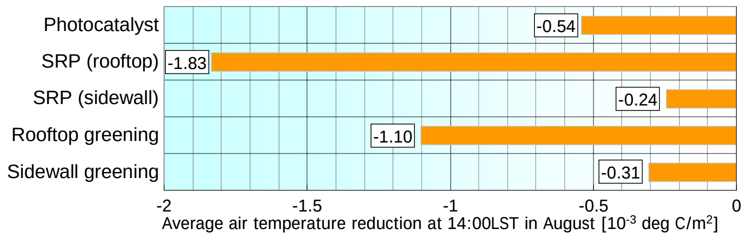

Fig. 4: Air temperature reduction by UHI countermeasures

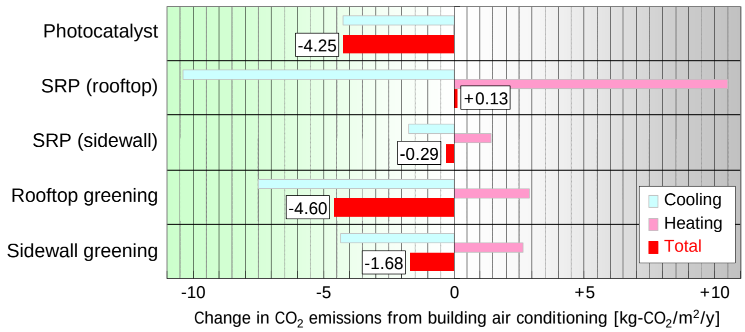

Fig. 5: Change in CO_2 emissions from building air conditioning by UHI countermeasures

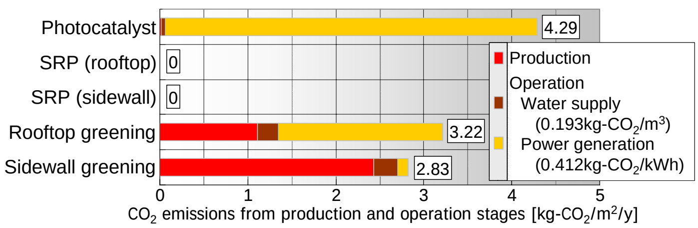

Fig. 6: CO_2 emissions from production and operation stages of UHI countermeasures

Each countermeasure in Fig. 3 has different installation area. To make equal their function units, their air temperature reductions are divided by their installation areas. In the results, all the countermeasures mitigated the urban air temperature during summer. The averaged air temperature at 1400LST in August was decreased by -0.54 × 10^{-3} °C/m^2 in the unit of installation area by installation of photocatalysts to sidewalls of buildings. Similarly, it was decreased by -1.83, -0.24, -1.10, and -0.31 by SRP (rooftop), SRP (sidewall), rooftop greening, and sidewall greening, respectively (Fig. 4).

4.2 *Urban heat island mitigation*

The change in the annualized CO_2 emission from air conditioning of the buildings was -4.25 kg-CO_2/y/m^2 by installation of photocatalysts. Similarly, those of SRP (rooftop), SRP (sidewall), rooftop greening, and sidewall greening were 0.13, -0.29, -4.60, and -1.68, respectively (Fig. 5).

5. INVENTORY ANALYSIS BY AIST-LCA VER.4

Annualized $LCCO_2$ emissions in the unit of installation area were also calculated. The annualized $LCCO_2$ from the construction and the operation of photocatalysts (sidewall) was 4.29 kg-CO_2/y/m^2. Similarly, those of rooftop greening and sidewall greening were 3.22 and 2.82, respectively (Fig. 6).

6. CONCLUSIONS

We evaluated $LCCO_2$ change and UHI mitigation effects by installation of UHI countermeasures simultaneously. This methodology is useful to find UHI countermeasures to contribute for global warming and UHI mitigation.

6.1 *Air temperature reduction and $LCCO_2$*

- SRP (rooftop) has overwhelming air temperature reduction effect. Rooftop greening is next. Effects by installation to sidewall is not large so mach per installation area.
- Only rooftop greening and SRP (sidewall) are not against prevention of global warming.
- However, calculation of latent heat transportation has many assumptions. It needs detailed checking.

6.2 *Discussion and future work*

- Existence of difference of installation effects in different installation height is predicted from the difference between rooftop and sidewall. Calculation by installation height is needed for evaluation by installation area of sidewalls.
- It is considered that both air temperature reduction and $LCCO_2$ vary by installation town blocks.
- The following are expected
    - Large installation height increases pumping power and $LCCO_2$ of countermeasures using latent heat transportation such as photocatalysts and greenings.
    - Small installation height reduces solar radiation received by sidewall and air temperature reduction by SRP.
- In particular, information of heat transportation about greening is few. We need to have more survey and experiment

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