291 **Performance Evaluation of the Architectural Countermeasures against UHI and GW upon the Heat Release and Energy Consumption**

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1. INTRODUCTION

Recently, increasing urban temperatures due to the urban heat islands (UHI) and global warming (GW) have been remarkable around the world. Especially in Japan, during the last century, annual average temperature has increased about 1K all over Japan, and this is seen as the influence of GW. In addition to the influence of GW, high temperatures in the summer have increased about 1 K to 2K, and low temperatures in the winter have increased about 3K to 6K in some metropolises. These extreme temperature rises in some metropolises result from UHI and GW, and it is easy to imagine that the temperature rise will continue for some time into the future.

Under such circumstances, it is highly desirable that measures be effective for both UHI and GW relaxation at the same time. However, there are cases that measures taken against UHI can impact energy consumption negatively. For example, increasing the albedo of a building mitigates UHI but offsets annual energy consumption reduction by increasing the winter heating load in some areas [1]. Placing shade trees adjacent to a building can have the same effect [2]. For this reason, when introducing UHI measures, it is necessary to understand both the UHI countermeasure's effectiveness against UHI and its impact on energy consumption. Similarly, it is important to ensure that measures taken to address GW do not increase the UHI effect, as they can negatively impact heat release. For this reason, when introducing GW measures, it is necessary to understand both a GW countermeasure's effectiveness against energy consumption and also its impact on heat release. Therefore, studies must compare how much heat and energy consumption reduction effect can be achieved by using countermeasures mainly targeted to UHI (UHI countermeasure) versus those using countermeasures mainly targeted to GW (GW countermeasure). In this study we used a simulation model to quantify the effect of UHI and GW countermeasures upon heat release and energy consumption, respectively, and investigated features of various countermeasures related to building.

In general, many UHI and GW research has only examined the effects of UHI and GW countermeasures individually, even though these measures will change both the amount of heat release and energy consumption. Therefore, to successfully implement urban and regional planning measures to address these issues, it is important to examine the potential adverse effects of these countermeasures, and to use the same model to compare heat release and energy consumption on an equal footing.

2. METHOD

2.1 Simulation model

In this study, the SCIENCE-Outdoor model was used to evaluate UHI and GW countermeasures. The SCIENCE-Outdoor model is based on the computational fluid dynamics (CFD) SCIENCE model by Onishi et al. [3] that can evaluate thermal and fluid conditions inside building. Habara et al. [4] modified the SCIENCE model to the SCIENCE-Vent model by expanding the fluid and radiant analysis outside building and by adding an indoor climate control behavior model [5]. The SCIENCE-Vent model can predict energy consumption of air conditioning (AC), and it also considers the relationship between the inside and outside environments, as well as occupant indoor thermal environment control behavior (e.g., cross-ventilation by opening windows and AC use). In this study, we modified the SCIENCE-Vent model to the SCIENCE-Outdoor model by adding outside heat release analysis and by omitting fluid analysis. Because the SCIENCE-Outdoor model was developed based on the CFD model, this model can evaluate the thermal condition of building surfaces both inside and outside at each detailed mesh. As shown in Figure 1, the SCIENCE-Outdoor model consists of the three sub-models: (1) radiant, (2) inside thermal environment, and (3) outside heat release. In this study, the total of the sensible heat release derived from the building outer surface and the equipment described above is defined as the whole sensible heat release discharged from the building. Figure 2 shows the image of the heat release defined in this study.

2.2 Building and weather condition

This simulation used the standard detached house model by AIJ (Architectural Institute of Japan) [6]. Total floor area of the house is about 125 square meters (m^2), and roughly, has a living room, a dining room, and three individual rooms. Figure 3 shows the plan view of this house model.

Table 1 shows the computational condition. As for the building condition, two kinds of building structures were set: wooden and reinforced concrete (RC). Three levels ("LV1", "LV2", and "LV3") were set to represent

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Table 1. Outline of the computational condition

Setup Item		Computational Condition
Outdoor	Climate condition	Expanded AMeDAS weather data : standard year (Osaka city, Japan)
	Ground albedo	0.16
Building	House model	Standard residential house model by AIJ
	Structure	Wooden or reinforced concrete
	Insulation	3 levels: No insulation (LV1), Low insulation equivalent to the old 1980 Japanese energy-saving code (LV2), High insulation equivalent to the next-generation 1999 Japanese energy-saving code (LV3)
	Wall albedo	0.20 (Base condition)
	Space conditioning unit	Air cooled type heat pumps, Cooling capacity (living room, bedroom: 3.6kW, other individual room: 2.2kW)
Occupant	Household	two adults (one employed outside the home, the other a homemaker) and two schoolchildren
	Preset temp. and relative humidity	27 °C and 60% (for summer), 22 °C and humidity was not contolled (for winter)
	Opening pattern	Inner door: close, Outerwall window: depend on the condition (by the indoor climate control behavior model)
	Schedule of occupancy and heat generation	Set by applying the automatic setup scheduling program SCHEDULE

Table 2. Outline of the evaluated countermeasures

Countermeasures	Main target	Computational condition
High albedo roof (HAR)	UHI	･Raising albedo of rooftop from 0.20 to 0.60
Roof greening (RG)	UHI	･Improving evaporation efficiency of rooftop from 0.0 to 0.3 and albedo of rooftop to 0.25, ･Adding a greening and soil layer on rooftop surface, ･Setting for the Reinforced concrete structure only, ･Setting the condition for withering during winter
Roof water showering (RWS)	UHI	･Setting evaporation efficiency of rooftop at 0.7 from 0.0 when the rooftop surface temperature exceeds 40 °C in the daytime until 5pm, ･Evaporation efficiency will be gradually decreasing in the nighttime
Dry fog jetting (DFJ)	UHI	･Improving indoor thermal comfort by spraying dry fog jet, ･Cooling effect is equivalent to -1 K of SET*, ･Jetting will be stopped when it judged AC is required by behavior model, ･Installing only in the air-conditioned room—9 pieces in the living room and the main bedroom, and 4 pieces in the child's bedroom, ･The amount of water used per piece was 1.34 liters per minute (L/min)
Condensing water heaters (CWH)	GW	･Improving the efficiency from 0.78 to 0.95
Heat pump water heaters (HPH)	GW	･Setting rated generation output of the hot water at 4.5 kW, ･Improving in efficiency, ･Absorbing heat from the ambient atmosphere, ･Changing the COP due to outside air temperature
Gas engine cogeneration systems (GECS)	GW	･Setting rated power generation output at 1.0kW and rated power generation efficiency at 20%, ･Heat exhaust efficiency at 57%, ･Operating in accordance with the heat demand, ･Number of operation per day is unlimited but excessive start / stop is restricted
Solid oxide fuel cells (SOFC)	GW	･Setting rated power generation output at 0.7kW and rated power generation efficiency at 45%, ･Heat exhaust efficiency at 36% (depend on the load), ･Setting hourly power generation as for fitting electricity load without start / stop
Photovoltaic power generation (PV)	GW	･Setting rated power generation efficiency at 13%, ･Considering influence of decreasing the albedo on the rising temperature of the rooftop surface and increasing heat release

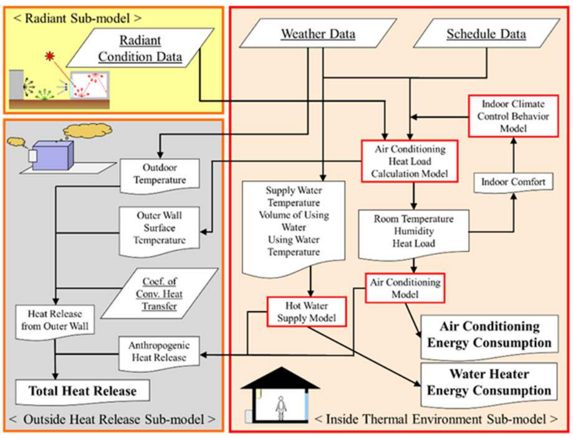

Figure 1. Outline of the SCIENCE-Outdoor model.

insulation performance: 1) LV1: no insulation, 2) LV2: insufficient insulation equivalent to the old 1980 Japanese energy-saving code, and 3) LV3: sufficient insulation equivalent to the current 1999 Japanese energy-saving code. Electric AC was set at living room (3.6kW), bedroom (3.6kW) and both child room (2.2kW).

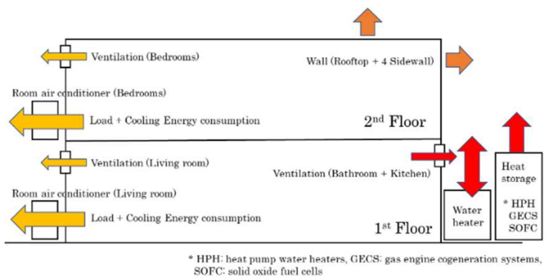

Figure 2. Image of the heat release defined in this study (summer)

The rate of solar reflectance of outer wall for the base condition was set at 0.2.

As for the occupant, the household was considered to be a family of four: husband (employed), wife (housewife), and two children (a boy and girl, both at school). The schedule of occupancy and heat generation were set by applying "SCHEDULE" [7], which was an automatic setup scheduling program. Electric AC was used for cooling and heating, and the preset temperature and humidity were set at 27°C and 60%, respectively, for summer, and 22°C for winter. In winter, humidity was not controlled.

Expanded AMeDAS weather data [8] were used for the climate condition. The targeted area was set in Osaka, the second largest city in Japan, located near the center of the country. Osaka has very severe weather conditions in the summer, and is one of the hottest metropolises in Japan.

2.3 Countermeasures

Table 2 outlines the countermeasures evaluated in this study. For this research, the countermeasures for UHI and GW that are expected to become common in the near future were selected. High albedo roof (HAR), roof greening (RG), roof water showering (RWS), and dry fog jetting (DFJ) were selected as the UHI countermeasures. Condensing water heaters (CWH) and heat pump water heaters (HPH), gas engine cogeneration systems (GECS), solid oxide fuel cells (SOFC), and photovoltaic power generation (PV) were selected as the GW countermeasures.

3. RESULTS

3.1 Base condition (no countermeasure)

Figure 3 shows the sensible heat release from each path on a representative sunny summer day (August 5th) for the wooden structure with LV2. Here, the heat from AC is the total value of the AC load and the consumption energy for AC; it is equivalent to the amount of heat release to the outside through the outdoor unit, as shown in Figure 2. The heat from HW equals the total amount of heat released to the outside through the HW and inside the house at the time of using hot water.

The maximum value of sensible heat release during the daytime reached up to 180 W/m^2. The daily heat from the wall surface was by far the largest proportion, accounting for about 87% of the total. The anthropogenic heat was very slight; the AC accounted for 12% and the HW accounted for only 1%. However, when the heat from the wall surface decreased in the evening, the proportion of anthropogenic heat became much greater than it was in the daytime. Because on the representative hot summer days the indoor climate control behavior model showed the AC being used for almost the entire day, the heat from the AC system occurred even at midnight. The exhaust heat from the HW rose temporarily around 9 pm because of hot water needed for bathing. As the sky radiation cooled, the heat release from the wall surface showed a negative value from 12 midnight until dawn.

3.2 Variation of the heat release by applying the countermeasures

Figure 4 (upper) shows the effectiveness of countermeasures influencing the heat from the wall surface for the summer season. Compared with the base condition, heat release from the wall surface of the RC structure decreased for HAR, RG, and RWS, but

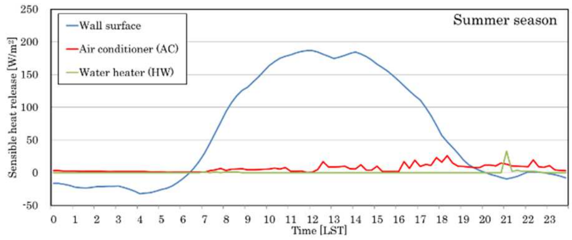

Figure 3. Sensible heat release from each path on a representative sunny summer day (Wooden, LV2)

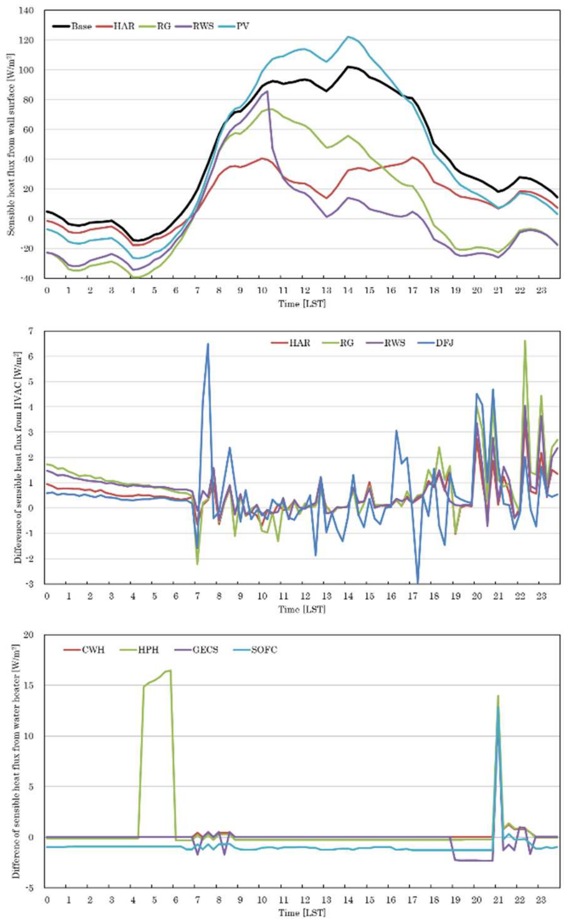

Figure 4. Time series of the average difference of a sensible heat release from HW, average on a summer sunny day (upper: wall surface, center: AC, lower: HW)

increased for PV. The reduction rate for the whole day became larger, with RWS providing the largest reductions, then RG, then HAR in declining order. When looking at daytime reduction alone, the reduction rate was largest RWS, then HAR, and then RG. In contrast, at nighttime, the reduction rate was largest with RG, then RWS, then HAR. When comparing the wooden structure with LV2 to the RC structure, there was no

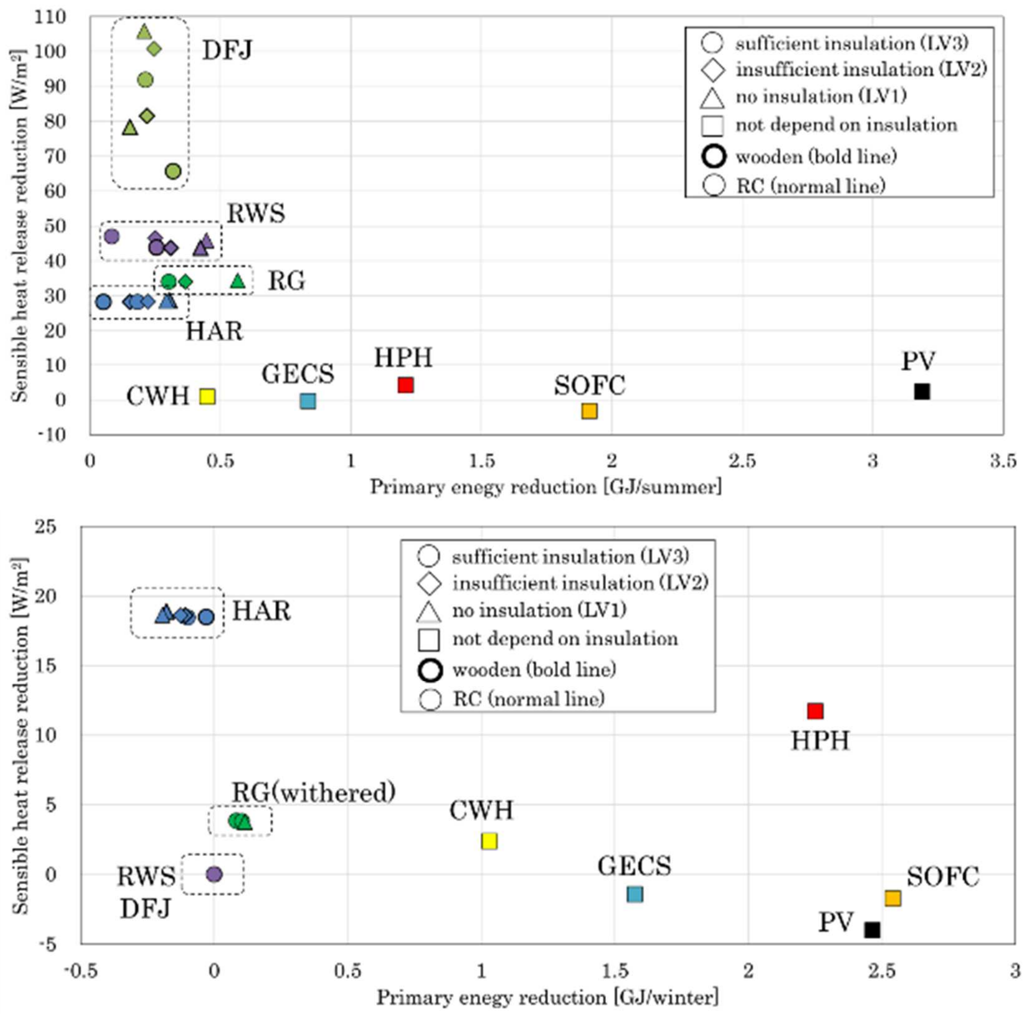

Figure 5. Reduction of heat release and energy consumption by applying each countermeasure (upper: summer, lower: winter)

significant difference in results; the reduction rate for whole day was largest with RWS, and then HAR.

Figure 4 (center) shows the effectiveness of countermeasures influencing the heat from AC system during the summer season. Compared with the base condition, the heat release from AC decreased for all countermeasures used with the RC structure. The reduction rate for whole day became largest with RG, then RWS, DFJ, and HAR in declining order. The reduction rate for whole day for the wooden structure with LV2 became largest with DFJ, then RWS, and then HAR.

Figure 4 (lower) shows the results of the effectiveness of countermeasures influencing the heat from HW for the summer season. Compared with the base condition, heat release from the HW decreased for HPH and CWH. The reduction rate for the whole day was larger for HPH than for CWH. Since the heat pump absorbs and accumulates heat from the atmosphere, clearly a large reduction was seen around dawn, but slight heat release from the hot water tank increased during the day. CWH always reduced heat loss by improving efficiency, but the effect was minimal.

3.3 Performance evaluation concerning the heat release and energy consumption

(a) Summer season

Figure 5 (upper) shows the relationship between the sensible heat release reduction and the energy consumption reduction by applying each countermeasure for the summer season. This graph is helpful when considering UHI and GW adaptation, as it offers the chance to examine both the amount of heat release and the amount of energy consumption, using the same model. The reduction of sensible heat release (vertical axis) shows a total value from the wall, AC, and HW per building area, and that is the time average value of a sunny day in August. For the energy consumption (horizontal axis), UHI countermeasures evaluate the reduction of AC energy only, and GW countermeasures evaluate the whole of energy reductions reduced by atmospheric heat absorption, power generation, waste heat utilization, and other factors. That shows the reduction of total primary energy volume during the summer season (from July to September). For PV, all of the generated electric power can be available, and it is evaluated on the premise that the same amount of system power supply can be reduced.

Based on the results, the plots were roughly classified into two technology groups: (1) effective for heat release reduction, and (2) effective for energy consumption reduction. As mentioned above, DFJ contributed to the reduction of heat release most, then RWS, RG, and HAR. However, no GW countermeasure contributed considerably to heat release reduction. Although DFJ contributed most to reduce the amount of time the AC was used, the building structure and the insulation level also influenced the result significantly, because the amount of heat release reduction was dependent on the AC time and load.

Among the GW countermeasures, PV contributed most to reduce energy consumption, followed by SOFC, HPH, GECS, and CWH, in order of reductions. Among the UHI countermeasures, RG (LV1) reduced energy consumption the most, although the reduction was almost the same compared with the middle between GECS and CWH. Regarding the UHI countermeasures, heat insulation and building structure somewhat influenced the energy consumption reductions, but they had no considerable influence on reducing heat release. Meanwhile, although some GW countermeasures (e.g., HPH) reduced the heat release, the amount of change was very small, and it was less than HAR, which was the least effective in UHI countermeasures. Some GW countermeasures (e.g., SOFC) increased the heat release, but the amount of change was very small as well.

(b) Winter season

Figure 5 (lower) shows the relationship between the sensible heat release reduction and the energy consumption reduction by applying each countermeasure for the winter season. The reduction of sensible heat release (vertical axis) shows an average value of sunny day in February. The energy consumption (horizontal axis) shows the total reduction volume during the winter season (from December to February). Others are the same as the summer season.

Based on the results, the plots were roughly classified into two groups: (1) effective for heat release reduction, and (2) effective for energy consumption reduction, just as they were for the summer season. But only HPH had effects for both heat release reduction and for energy consumption reduction. HAR contributed to the reduction of heat release the most, then HPH, RG (withered), CWH in order of reductions. Moreover, HAR increased energy consumption due to an increase in heating load. Since RWS and DFJ stopped operation in the winter season, they had no influence on heat release or energy consumption during the winter. Since the hot water demand was greater in the winter, the HW systems had greater influence in the winter than in summer. Some GW countermeasures (e.g., PV) increased the heat release. Since the overall trend is the same as in summer, the result of separating during the daytime and the nighttime in the winter season is omitted.

3.4 Recommendations for countermeasures

Based on the results obtained in 3.3, we developed some guidelines for designing building that considers the benefits and impacts of both UHI and GW. For the summer season, it is desirable to introduce measures to achieve both heat release reduction and energy conservation, but this study did not identify any measures that were effective in both areas. Therefore, it was necessary to apply countermeasures for each purpose individually. It was shown that countermeasures using an evaporative cooling effect, such as DFJ and RWS, are desirable to reduce heat release, and countermeasures such as PV and SOFC are effective in reducing energy consumption.

For the winter season, only HPH had effects on both heat release reduction and energy consumption reduction, so HPH is positioned as an effective countermeasure when viewed from the same viewpoint as the summer. However, it is necessary to consider the implications of reducing heat release during the winter. It has been shown that temperature rise during the winter in Japan contributes to reduced energy consumption and adverse health impacts [9][10]. To maintain these indirect benefits, it is not desirable to reduce the amount of heat release during the winter. HPH is effective in reducing energy, it is counterproductive to reduce heat release in winter season. Moreover, HAR will be positioned as a countermeasure to avoid in Japan because it increases annual AC energy consumption. In this regard, countermeasures using water, such as DFJ and RWS, can stop during the winter, so there is an advantage in that they do not affect the amount of heat release and energy consumption in the winter at all.

Based on these results, it is necessary to introduce water-using UHI countermeasures that can only provide benefits in the summer season, to plan for UHI and GW considerations in the mild, temperate areas of Japan. However, since their effect on reducing energy consumption is not very significant, it is desirable to introduce GW countermeasures such as SOFC and PV that significantly effect energy consumption reduction.

4. CONCLUSION

In this study, through an examination using the SCIENCE-Outdoor simulation model, we quantified the effect of urban heat islands (UHI) and global warming (GW) countermeasures upon heat release and energy consumption, and investigated various features of countermeasures related to building. This study's purpose was to evaluate various technologies for their potential to mitigate UHI and conserve energy, and then to propose their proper implementation. The results of this research are described below.

1) We constructed the SCIENCE-Outdoor model for evaluating UHI and GW countermeasures. This model can evaluate the thermal condition of building surfaces, both inside and outside, at each detailed mesh and consists of the three sub-models: (1) radiant, (2) inside thermal environment, and (3) outside heat release.

2) An example of the result for the base condition (no countermeasure) for the summer, evaluating a wooden detached house with insufficient insulation (LV2), the maximum heat release during the day reached up to 180 W/m^2. The breakdown of the cumulative daily heat was almost all from the wall surface and accounted for about 87% of the total. The anthropogenic heat was very slight; the air conditioning (AC) accounted for 12% and the water heater system (HW) accounted for only 1%.

3) Concerning the effectiveness of countermeasures influencing the heat from wall surface, the reduction rate of heat release for whole day was largest with roof water showering (RWS), then roof greening (RG), and then high albedo roof (HAR) in the summer season.

4) The effectiveness of countermeasures influencing the heat from AC, the reduction rate for whole day was largest with RG, then RWS, then dry fog jetting (DFJ), and then HAR in the summer season. In the winter, the amount of absorbed heat through the AC increased at the HAR slightly.

5) The effectiveness of countermeasures influencing the heat from HW decreased for heat pump water heaters (HPH) and condensing water heaters (CWH), but increased for gas engine cogeneration systems (GECS) and solid oxide fuel cells (SOFC) in the summer. For the winter season, the demand of hot water rose, to HW had a greater influence than in summer season.

6) As the result of evaluating the relationship between the heat release reduction and the energy consumption reduction and by applying each countermeasure for the summer season, the plots were roughly classified into two technology groups: those effective for heat release reduction and those for energy consumption reduction.

7) From the same relationship for the winter season, the plots were roughly classified into the same two groups as for the summer season, but only HPH was found to effect heat release reduction and energy consumption reduction.

8) The results showed that it is the best choice to introduce water-using countermeasures (DFJ and RWS) that can provide benefits only in the summer season, to plan for UHI and GW considerations in the mild, temperate areas of Japan. However, since their effect on reducing energy consumption is not very significant, it is desirable to introduce GW countermeasures such as SOFC and PV that significantly effect energy consumption reduction.

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