Optimization of the building façade based on the spectral measurement

Masayuki Ichinose
Tokyo University of Science, Assistant Professor, Dr. Eng. Japan

Abstract

It is evaluated that reduction potential of the CO2 exhaust in an architectural field is the maximum in IPCC the fourth report WG3 (2007). It is important to examine the strategy that decreases the energy consumption of the buildings, though attention has gathered in groping for alternative energy to the fossil fuel. Moreover, it is also needed to pay attention to the outside environment around the buildings. For example, the heat island phenomenon brought by the accumulation of the buildings became conspicuous at the region with a warm climate. Therefore, the coupled evaluation that includes the buildings and the outside micro climate is necessary, instead of developing the efficiency improvement independently at the buildings.

One of the effective strategies includes control of spectral selectivity and directivity against solar radiation on the building envelope. For the building internal space, appropriate visible solar radiation is effective, because utilization of daylight contributes to the reduction of the electricity for the lighting and the air-conditioning cooling load. Therefore, it is preferable that the opening has an optical performance with highly transparent in the visible region against infrared region. On the other hand, for the outside space around the buildings, accumulation of solar radiation that is reflected by the building envelope causes getting worse of the thermal environment at the urban street.

This paper presents that the research about the optimization of the building façade based on the spectral measurement and evaluation at the inside and outside of the buildings.

1. Introduction

1-1. Potential of CO2 reduction and influence on earth environment of the buildings

It is evaluated that reduction potential of the CO2 exhaust in an architectural field is the maximum in IPCC the fourth report WG3 (2007). In such the circumstances, the use of natural energy resources that include solar photovoltaic power generation and wind-power generation, and alternative energy has been sought. But actually, almost of them have problems including reliability and economic efficiency.

Energy of solar radiation on the whole of earth is said to be equivalent in about ten thousand times of energy consumption by human beings. However, in the urban region where most of energy is consumed on the earth, buildings covering surface of the ground are inappropriate to solar radiation. The defect of envelope and building service system cause excessive energy consumption for air conditioning and heat-island phenomenon. So, it is important to present the method to utilize the solar radiation maximally on the whole of buildings and urban region. Especially, in Asian countries that have the potential for economic development, if the buildings are constructed without any action against the solar radiation, global environment will be affected considerably. It is necessary to establish and spread actual and effective technology of utilizing solar energy as quickly as possible.

1-2. Selective utilization of the solar energy in the architectural area

Practical method of the solar energy utilization includes solar photovoltaic power generation, solar hot-water supply, solar heating and daylighting. Because electricity for the lighting accounts for 30 percent of the building energy consumption and daylight can be got directly from the solar radiation without complicated equipment, daylighting is the most of the actual and effective way to reduce energy consumption of the buildings in these methods.

On the other hand, shielding the solar radiation is also important for environment of the internal space and the energy conservation. The method of solar shielding includes solar shielding window, shading device, high reflectivity paint, rooftop greening and so on. Solar shielding at window has large effect for energy conservation of the office buildings that tend to have cooling load whole year. High reflectivity paint and rooftop greening can reduce sensible heat flux from surface of the buildings to regional urban atmosphere and decrease regional warmer temperatures.

So, it is apparent that important element for utilization of the solar energy is the selective transmission of visible solar radiation at window and selective reflection of near-infrared solar radiation at window and wall. Figure 1 shows diagram of the influence of the building on energy and environment. This paper presents a part of my research that I've ever done concerning to spectral measurement.

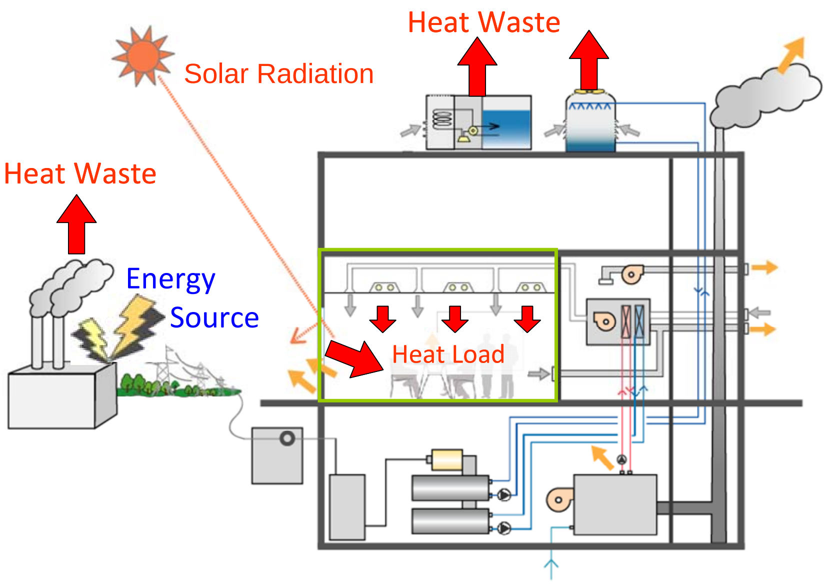


Figure 1 Diagram of relationship between buildings and environment

2. Spectral characteristics of the typical architectural materials

Figure 2 shows the spectral transmissivity of the typical glasses available commercially in Japan. For the buildings, it is preferable that the glass transmit more visible light without heat gain. The most typical clear glass is transparent to all wavelength regions, but the high-performance Low-E glass has highly spectral selectivity to the solar radiation. These characteristics influence greatly on the energy efficiency of the buildings.

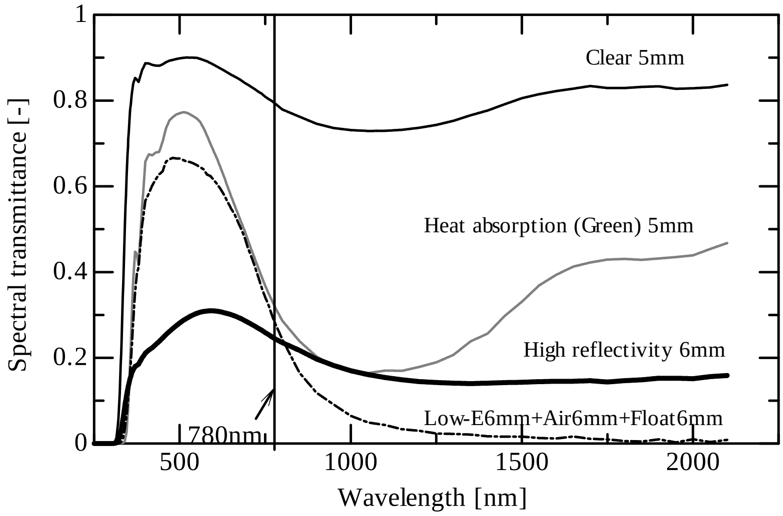


Figure 2 Spectral transmittance of the glasses available commercially

Figure 3 shows the spectral reflectivity of the typical architectural materials. The reflectivity tends to indicate highly in the near-infrared region. Especially, high-reflectivity paint indicates significantly.

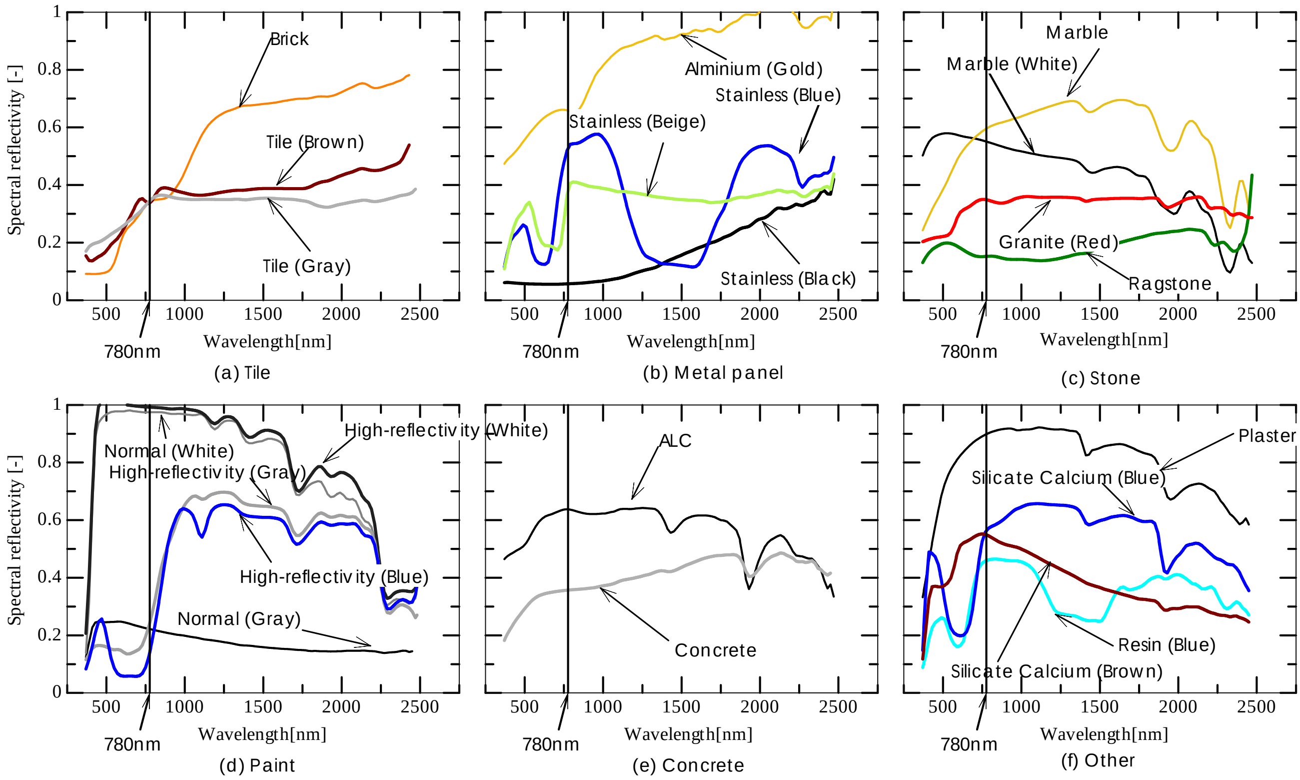


Figure 3 Spectral reflectivity of the architectural materials

3. Spectral measurement in the urban space

3-1. Application method of the spectrometer

The actual measurement includes the spectral reflectivity of the building envelope, the spectral irradiance and global distribution of the spectral radiance at the ground level. Because the survey is on site, the spectral reflectivity is easily estimated by the normal radiance using the white reference as shown in figure 4. Global distribution of the spectral radiance is measured by the combination of the 1 degree FOV and the newly developed mechanical platform as shown figure 6. The rotation axes of the platform are optimized for the 1 degree FOV. The platform is based on the technology for the accurate angle control of the professional movie camera, and it can be controlled by the RS232 protocol. We set the motion of the platform to scan 270 points over the global. From the results of the distribution of the spectral radiance, spectral irradiance from each element of the surfaces to the human body is estimated.

3-2. Spectral reflectivity of the building envelope

Figure 5 is the subset of the measuring spectral reflectivity on site. These include many types of the architectural materials under the actual conditions; for example soiling, degradation and so on. Figure 5 (a) indicates that the reflectivity of the near-infrared region is high. Based on the whole measured data, figure 5 (b) presents the correlation of the reflectivity between the ultra violet and visible region (UV+V) and the near infrared region (NIR). The reflectivity of NIR is higher than UV+V. From the results of the spectral reflectivity on site, the solar radiation in the space of the urban street is supposed to have the larger NIR radiation than under the natural condition.

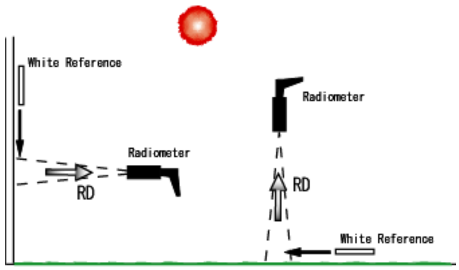
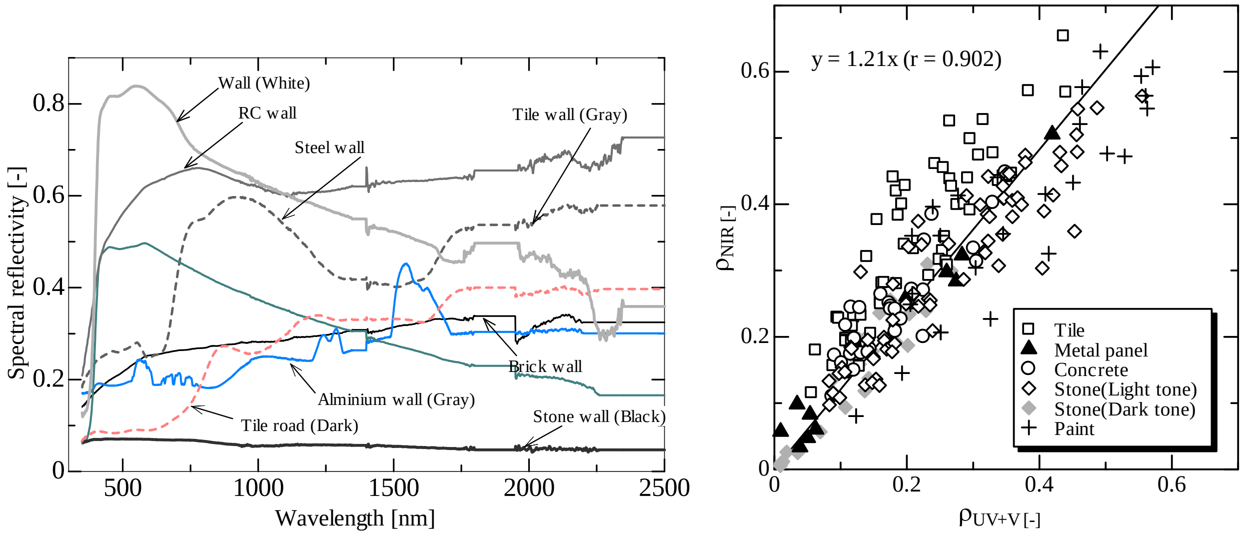


Figure 4 Diagram of measuring spectral reflectivity in the actual condition

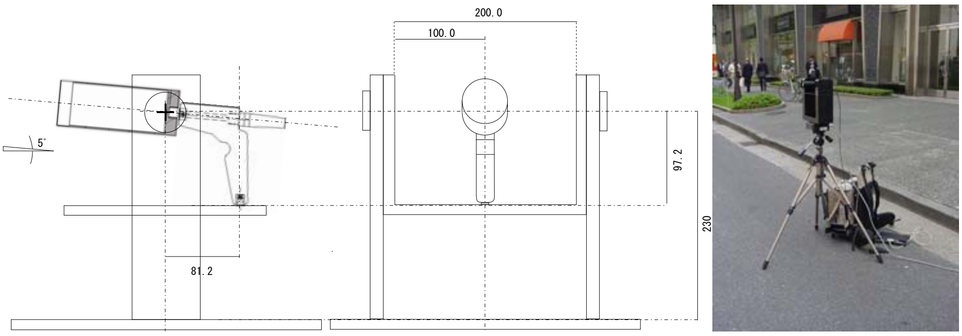


(a) Spectral reflectivity (b) Correlation of the waveband reflectivity

Figure 5 Spectral reflectivity in the actual condition (343 samples)

3-3. Radiant environment nearby the buildings

Figure 8 shows spectral irradiance on human body at the different two spaces. The characteristics of the spaces are bellowed; a) surrounded by the lower buildings, b) surrounded by higher buildings equipped with high reflectivity glazing, as shown in figure 7. In figure 8 b), element of the wall indicates clearly that the spectral reflectivity of the building façade. It is obvious that the solar radiation in the space nearby the buildings is different from natural spectral irradiance.

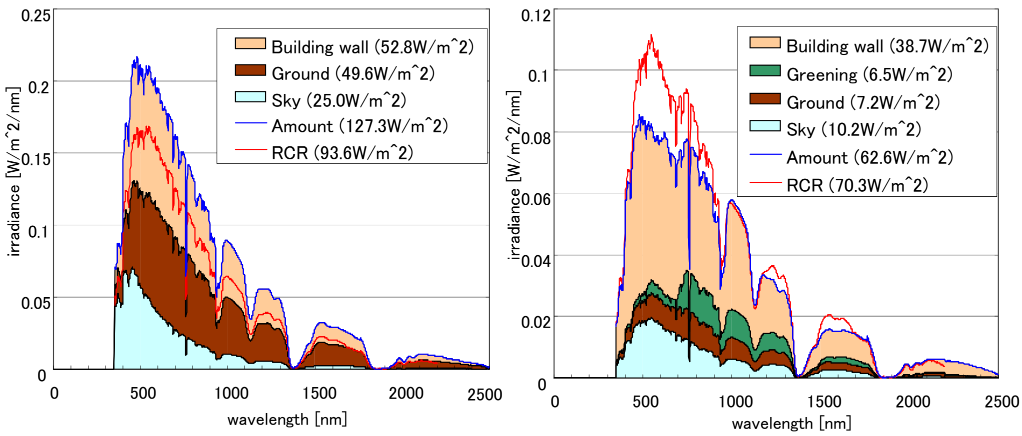


(a) Side view (b) Front view (c) Photo

Figure 6 Diagram of the mechanical platform for 1 degree FOV

(a) Surrounded by low buildings (b) Surrounded by high buildings

Figure 7 Different situations for measuring influence of the building



(a) Surrounded by low buildings (b) Surrounded by high buildings

Figure 8 Irradiance of the different spaces separated by the elements

Irradiance from each surface element to the human body is estimated by equation (1).

$$I_{(i)} = F_{H(i)} \cdot \pi \cdot RD_{(i)} \quad (1)$$

$I_{(i)}$ Irradiance from the surface element (i) [W/m^2]

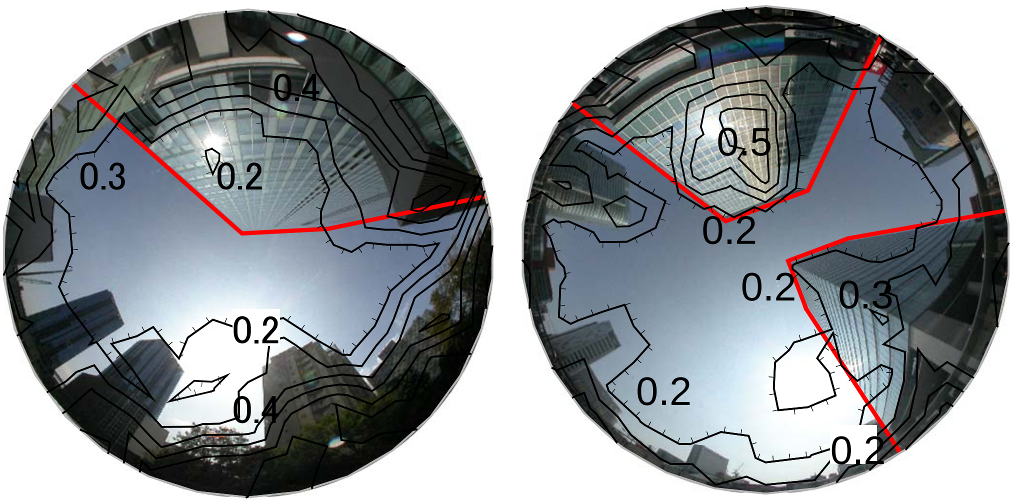
$F_{H(i)}$ Form factor from human body to surface element (i) [-]

$RD_{(i)}$ Radiance from surface element (i) to human body [W/m^2/sr]

Figure 10 shows distribution of spectral radiance and ratio of NIR radiation in the upper sphere from the urban street nearby the different buildings. These buildings have different type of glazing; a) Low-E glass, b) clear glass, as shown figure 9. It is measured in the equivalent weather condition and orientation. In the figure 10 a), radiance from the Low-E glass facade that reflect direct solar radiation indicates high NIR characteristics. In the figure 10 b), radiance from the clear glass façade indicates equivalent to sky radiation. There is an obvious difference in the spectral radiance attributed to characteristics of glazing.

(a) Clear glass (b) Low-E glass

Figure 9 Different situation for measuring influence of the glass



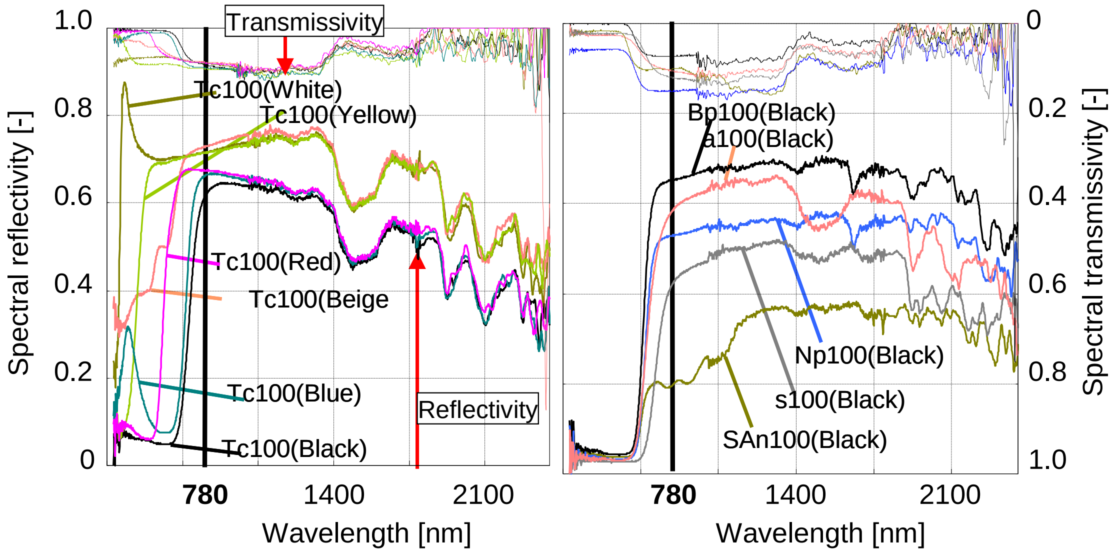
(a) Clear glass (b) Low-E glass

Figure 10 Ratio of the near infrared region in the spectral radiance; spatial distribution on the sphere

3-4. Evaluation of the sensory temperature of the human body

It is presented that the solar irradiance near-by the buildings include higher rate of the NIR than natural solar radiation. If the NIR solar radiation is absorbed by the surface of the human body, sensory temperature may increase without recognizing visible radiation. Spectral characteristics of the human skin are previously investigated many times. But characteristics of the clothes are not well-investigated despite almost of the human wearing clothes when they are in the outside.

Figure 11 shows spectral reflectivity and transmissivity of the typical clothes; a) variant colors of 100% cotton clothes, b) variant fabric of black colors. These indicate that the typical clothes have lowly transmissivity and absorptivity in NIR region.



(a) Variant color of the 100% cotton (b) Variant fabric of the black

Figure 11 Spectral reflectivity and transmissivity of the clothes

Based on the spectral characteristics of the clothes, influence of the clothes on the operative temperature is studied. The operative temperature describes sensation of radiant and convective heat of the human. Figure 12 shows the difference of operative temperature between typical clothes. Not only the color but also NIR absorptivity of the clothes has a significant impact. By considering NIR characteristics of the clothes, the influence of reflected solar radiation from the building façade can be assumed smaller.

Operative temperature of the human body is estimated by equation (2).

$$OT = \frac{\alpha_{HC} \cdot t_A + \alpha_{HR} \cdot t_R + a_H \cdot I}{\alpha_{HC} + \alpha_{HR}} \qquad (2)$$

α_{HC} Convective heat transfer coefficient [W/m^2/K]

α_{HR} Radiative heat transfer coefficient [W/m^2/K]

t_A Air temperature [degrees C]

t_R Mean radiant temperature [degrees C]

a_H Absorptivity of the human body [-]

I Irradiance on the human body [W/m^2]

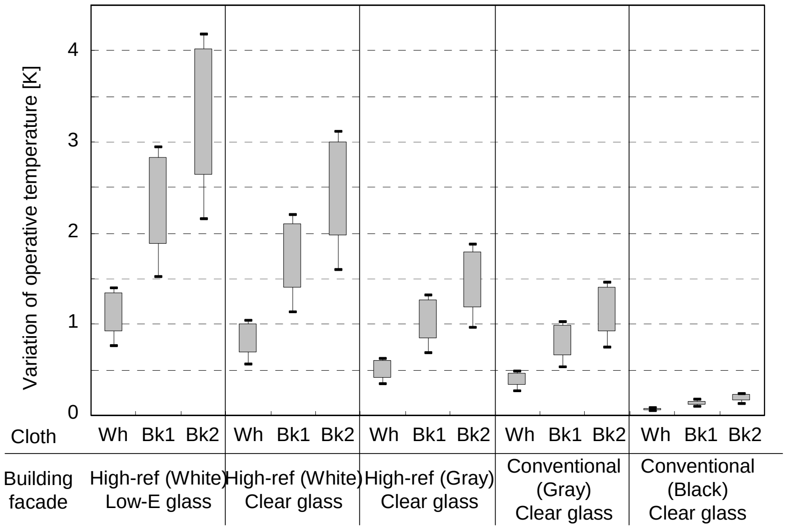
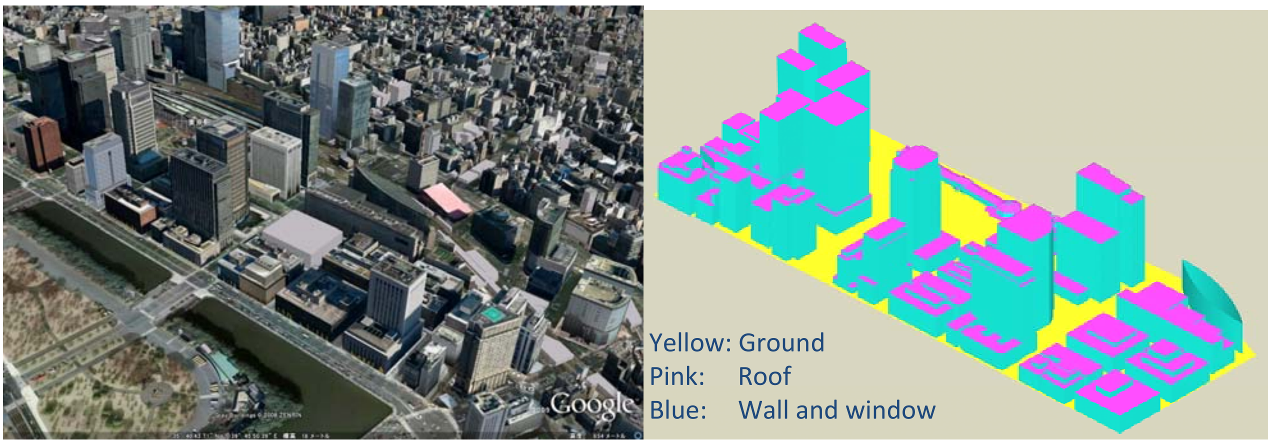


Figure 12 Spectral reflectivity and transmissivity of the clothes

4. Effect of improving reflectivity of the building façade to the urban climate and energy consumption

4-1. Irradiated surface of the solar radiation

To evaluate effect of improving reflectivity of the building façade, heat balance analysis of the urban regional climate is made. The 3 dimensional geometry of the urban area is based on Google Map and Google Earth that is available to the public on the Web. Figure 13 (a) is the computer graphic from the view point of infinite distance to the center of Tokyo. This graphic describes the urban city as seen from the sun. Figure 13 (b) shows the component of the surfaces in 3 different colors; red is building roof, blue is building wall, yellow is ground. This color-coded graphic obviously indicates that most of direct solar radiation irradiate to the building wall. By applying the graphics to counting number of different color of pixels, ratio of the irradiated surfaces in the city block is estimated. Figure 14 shows the fluctuation of the ratio on seasonal typical days. When the sun is southing, roof and ground have the higher rate in the summer, but window and wall is the highest in the other period of time.



(a) 3D graphic (b) Color-coded component of the surfaces

Figure 13 3D geometry of the center of Tokyo

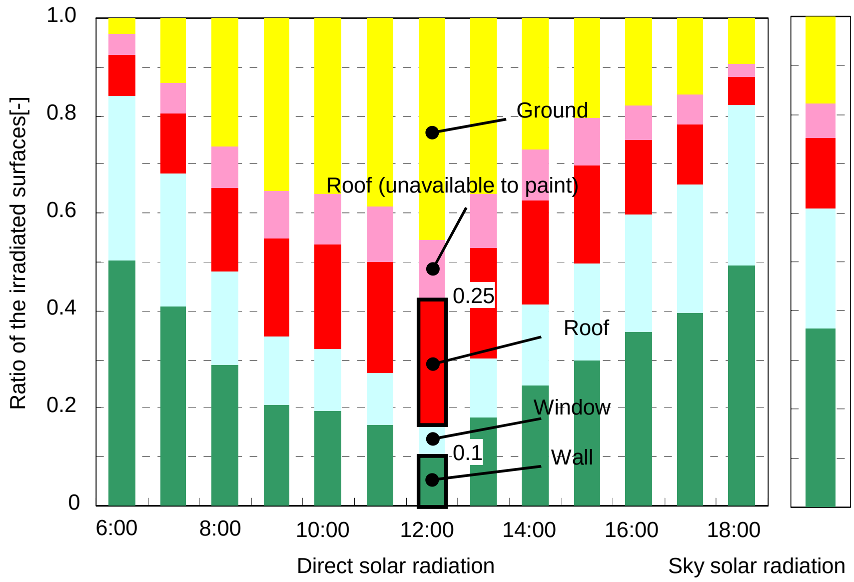
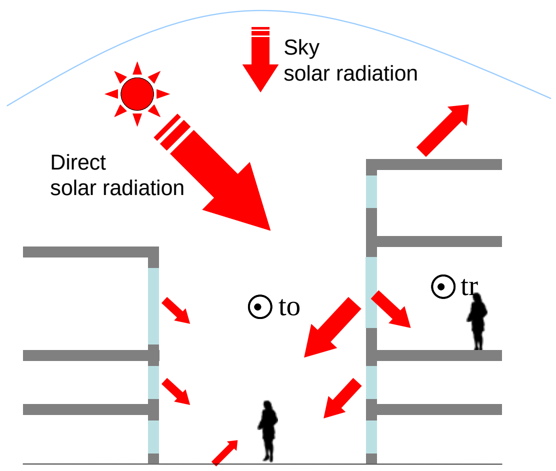


Figure 14 Ratio of the irradiated surfaces in the city

4-2. Heat balance of the urban area

Based on the estimated primary irradiated solar radiation, heat balance model is structured. Figure 15 shows conceptual diagram of this model that including interreflection of solar and long-wave radiation, convection and unsteady conductive heat flux. Stream of air is simply dealt. Figure 16 shows the reduction possibility of the energy consumption of the buildings and the sensible heat flux from the building surface to the regional urban atmosphere that causes heat island phenomenon. Because the building façade has the highest rate of the square and ratio of the irradiated solar radiation, improving reflectivity of glazing and wall is the most effective to the heat balance of the urban area.



$$q_C + q_{RS} + q_{RL} + q_T = 0 \qquad (3)$$

Convection $\quad q_C = \alpha_C * (t_A - t_S)$

Shortwave radiation $\quad q_{RS} = a_S * I_S$

Longwave radiation $\quad q_{RL} = \varepsilon_S * (L_\downarrow - \sigma T_S{}^4)$

Conduction $\quad q_T = \sum_{j=1}^{N_j} Y_{(j)} * T_{ref\,(k-j)} - \sum_{j=1}^{N_j} Z_{(j)} * T_{ref\,(k-j)}$

α_c : *Convective heat transfer coefficient*[W/m^2/K] $\quad t_A$: *Air temperature*[°C] $\quad t_S, T_S$: *Surface temperature*[°C],[K]

a_S : *Absorptivity of shortwave radiation*[−] $\quad I$: *Irradiance*[W/m^2] $\quad \varepsilon_S$: *Emissivity of longwave radiation*[−]

$L_\downarrow$: *Atmospheric longwave radiation*[W/m^2] $\quad \sigma$: *Stefann Bolzmann const.*

$Y_{(j)}, Z_{(j)}$: Re*sponse factor*[W/m^2/K] $\quad T_{ref}$: Re *fference temperature*[°C] $\quad N_j$: *Number of terms*[−]

Figure 15 Diagram of the heat balance model of the urban canopy

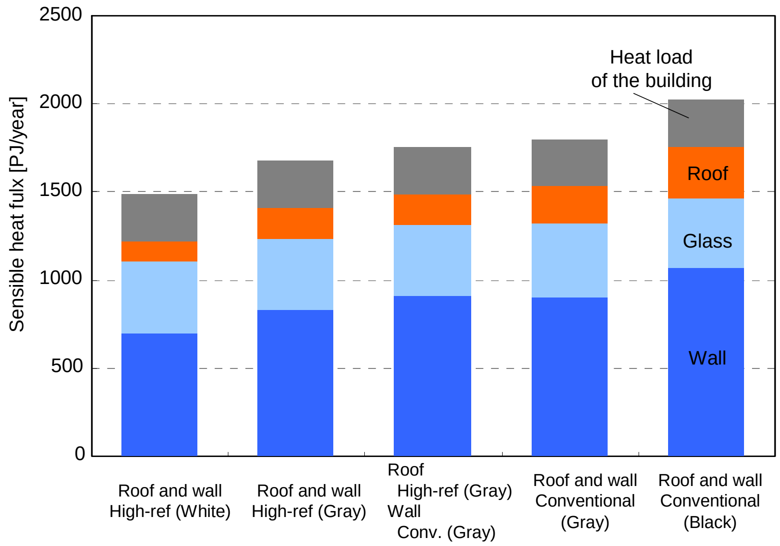


Figure 16 Sensible heat flux from surface of the building to urban atmosphere

5. Conclusion

This paper presents significance of the energy conservation and reduction of the heat waste on the buildings. Advanced spectral measurement for the buildings is suggested and examined. Based on the spectral measurement, calculation model of the heat balance at the urban area is built. From the result of the dynamic heat balance simulation, effect of improving reflectivity of the building façade is obviously presented. To maximize efficiency of the solar energy utilization whole of the urban city, improving NIR reflectivity of the building façade is one of the actual and effective ways.

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