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An Estimation Method on Thermophysical Properties of the Building Surface Based on Multispectral Remote Sensing and Surface Energy Balance Simulation

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Abstract— **A time- and labor-saving estimation method is proposed to obtain the near actual thermophysical properties, coupling the use of multi-spectral remote sensing and numerical simulation.**

I. INTRODUCTION

Surface energy balance (SEB) models are widely used to explore the heat and radiative exchange between buildings and the atmosphere at the surface layer. The selection of thermophysical properties is important to the simulation quality, but the thermal properties (e.g., heat capacity and thermal conductivity) of urban surfaces are usually assumed and generalized. The current methods (e.g. the theoretical method, in-situ method, and etc.) that most widely used to obtain thermal properties of walls cannot be well adopted on an urban block or neighborhood. To bridge this gap, a new estimation method is proposed to obtain the actual thermophysical properties, coupling the use of multi-spectral remote sensing and numerical simulation. This estimation method can shorten the measurement period, extent the study scale (e.g., block and neighborhood), and reduce some requirements of the current in-situ methods for assessing the thermal transmittance of walls, such as the many pieces of equipment, strict operation, certain times of the day and etc.

II. METHODOLOGY

A. Study area

The case study was carried out on a university campus in Yokohama city, Japan. The test areas are about 120 [m] × 100 [m], which can be regarded as a repeated unit within the school (Fig. 1).

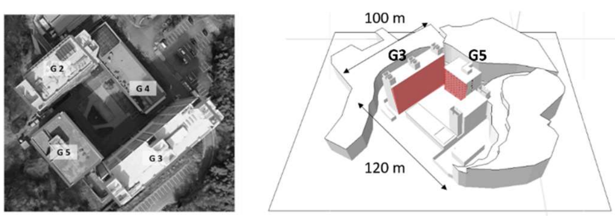


FIG.1. STUDY AREA

B. Multi-spectral remote sensing

1) *Narrowband albedo:* By using a multispectral camera (Rededge-M, MicaSense Inc., USA) and a reference panel with the known albedo of 4 narrow bands (i.e., blue, green, red and near infrared (NIR)), the multispectral images of study wall surfaces were captured and calibrated into the albedo of 4 narrow bands.

2) *Radiant temperature:* The hourly infrared images for each façade were captured from sunrise to sunset and at around midnight by using a thermal infrared camera (InfReC Thermo GEAR, Nippon Avionics Co., Ltd., Japan) on August 1, 2018, which is a typical summer day with the clear-sky conditions.

C. Simulation

1) *Simulation model:* The THERMORender model developed by Asawa et al. (2008) was applied[1].

2) *Simulation conditions:* The physical properties except for the thermal properties of the building surfaces to reproduce the actual material in the study area (Table 1), in which the input values of the albedo were derived from section 3.1. The meteorological data on August 1, 2018 were input into the simulation model.

TABLE 1. PHYSICAL PROPERTIES OF TEST AREA

	Floor [-]	Wall δ [mm]	α / material [-]	ε [-]
G2	**11**	**200**	**0.350 / Concrete**	**0.95**
G3 (study)	**11**	**200**	**0.569 / Concrete**	**0.95**
G4	**2**	**200**	**0.363 / Concrete**	**0.95**
G5 (study)	**9**	**200**	**0.366 / Tile**	**0.95**
Ground	**-**	**1130**	**0.3**	**0.90**

3) *Simulation cases:* The input thermal properties were determined from the typical combinations of thermal properties based on a database for existing buildings in urban Japan [2]. Before conducting the K-means clustering for the database, the Elbow method was carried out to figure out the optimal number of clusters (K value). As shown in Fig.2 (left), both the mean and maximum standard deviations sharply decrease as the cluster number increasing until the number of 14; while the reduction turns gentle after that. Therefore, the number of 14 was selected. The mean and maximum standard deviation in each cluster under being clustered by 14 is shown in Fig.2 (right). The centres of 14 clusters, typical combinations of wall thermal properties, were thus selected to be simulated.

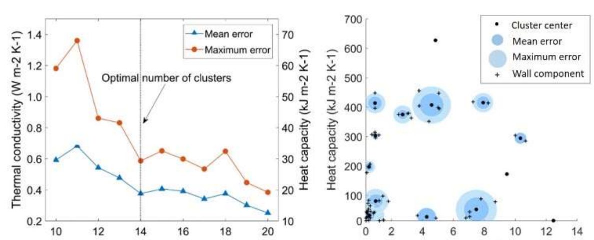


FIG.2. OPTIMAL NUMBER OF CLUSTERS BY ELBOW METHOD (LEFT), AND MEAN AND MAXIMUM STANDARD DEVIATION IN EACH CLUSTER UNDER BEING CLUSTERED BY THE OPTIMAL NUMBER OF 14 (RIGHT).

D. ESTIMATION

1) *Estimation on total shortwave albedo:* The conversion from the narrowband albedo obtained by multispectral camera to the total shortwave albedo can be achieved by their relation. In my study, the target wall surface materials are classified as concrete (G3) and tile (G5). 18 different concretes and 5 different tiles measured by using a spectroradiometer (ASD FieldSpec4, ASD Inc., USA) were studied to analyse the narrow-to-broadband conversion. Within a single class, the relation between the narrowband and broadband demonstrates the linear trends. Hence the conversion formulas were given:

$$\alpha_{visible\ g3} = 0.465B + 0.160G + 0.311R + 0.00168 \quad (1)$$

$$\alpha_{NIR\ g3} = 0.961NIR + 0.01404 \quad (2)$$

$$\alpha_{visible\ g5} = 0.375B + 0.276G + 0.304R - 0.00476 \quad (3)$$

$$\alpha_{NIR\ g5} = 0.977NIR + 0.01219 \quad (4)$$

The solar albedo of the target building wall is calculated as the weighted mean of the reflectance of the visible and near infrared band [Eq. (5)], where the weight is proportional to solar spectral irradiances of visible and NIR band, respectively [Eq. (6,7)].

$$\alpha = w_{visible}\ \alpha_{visible} + w_{NIR}\ \alpha_{NIR} \quad (5)$$

$$w_{visible} = \int_{350}^{700} R(\lambda_i)\, d\lambda / \int_{350}^{2200} R(\lambda_i)\, d\lambda = 0.47 \quad (6)$$

$$w_{NIR} = \int_{700}^{2200} R(\lambda_i)\, d\lambda / \int_{350}^{2200} R(\lambda_i)\, d\lambda = 0.53 \quad (7)$$

As shown in Fig.3, regression equations are fitting well.

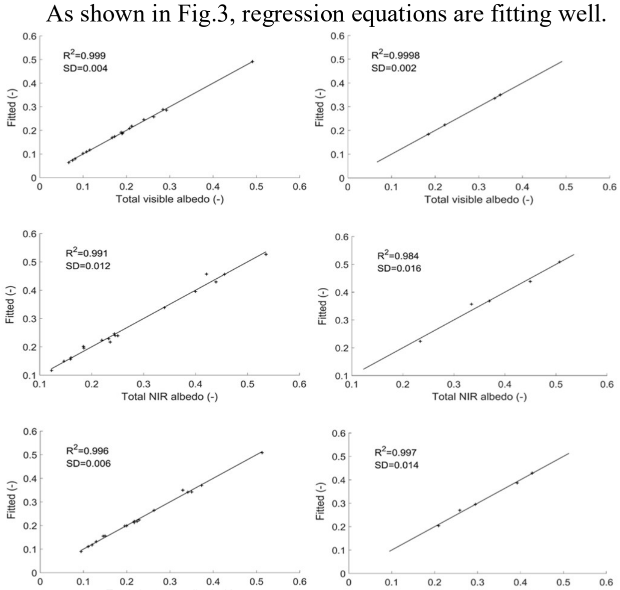


FIG. 3. MEASURED BROADBAND ALBEDOS AND THE ESTIMATED ONES FOR CONCRETE (LEFT) AND TILE (RIGHT)

2) *Estimation on thermal properties:* A comparison was carried out to figure out the difference between each simulation case and measured results. The thermal properties in the case which result showed most consistent to the measured infrared data were the ones closest to actual thermal properties of the target wall surfaces among 14 typical cases. The estimated values of thermal properties obtained by our method here were validated by a theoretical method based on ISO 6946 [3], with the known composition and thermal properties of layers for the target wall surfaces according to a reliable technical document.

III. RESULT

A. Estimated albedo and its validation

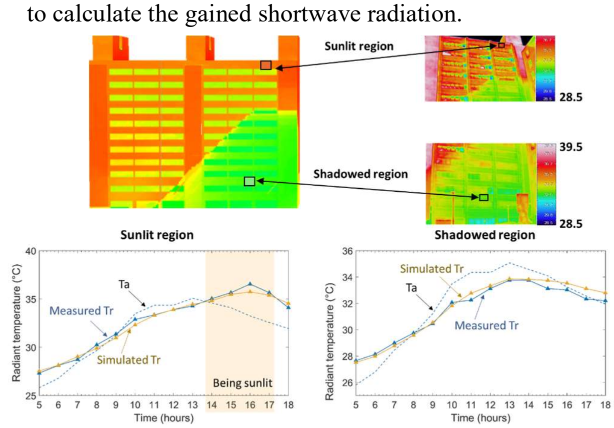
Based on the obtained narrowband albedos and Eq. (1-7), the albedo was estimated and validated by a comparison with the continues spectral reflectance measured by using a spectroradiometer (Table.2). The estimated albedos are overestimated of only 0.005 and 0.006 for G3 and G5 wall surface, respectively, demonstrating that the performance of this estimation method based on narrowband albedo obtained by a multispectral camera is sufficient.

TABLE 2. ESTIMATION-TO-MEASUREMENT COMPARISON ON ALBEDO

	G3 wall surface	G5 wall surface
Estimated albedo [-]	0.575	0.368
Measured albedo [-]	0.564	0.360
Standard deviation [-]	0.011	0.008
Relative SD [%]	1.9	2.4

B. Estimated thermal properties and its validation

Two representative small regions, one was being sunlit in the afternoon while the other was always being shadowed during the measurement day, on the G3 northwest-oriented wall surface were selected to carry out a primary validation (Fig.4). The simulated results, as shown in Fig.4, indicate a fairly good agreement to the measured surface radiant temperature with a generally low error as shown in the table of Fig.4, which demonstrates that the proposed method is fundamentally applicable for the estimation of thermal properties. However, the simulated peak values are underestimated in sunlit region while the afternoon data are a bit overestimated in shadowed region. It may be caused by the insufficient accuracy of the regression equation used to calculate the gained shortwave radiation.



	MAE [°C]	RMSE [°C]	RMSEs [°C]	RMSEu [°C]	r2
Sunlit	0.284	0.095	0.047	0.082	0.988
Shadowed	0.316	0.104	0.073	0.074	0.984

FIG.4. COMPARISON OF SIMULATED AND MEASURED SURFACE RADIANT TEMPERATURE OF G3 SOUTHEAST-ORIENTED WALL SURFACE

IV. CONCLUSTION

The estimation method proposed in this study is time-, equipment-, and labor-saving compared to current in-situ measurement methods for assessing building surface thermal properties. To integrate with the vehicle or unmanned aerial vehicle, this estimation method is allowed to obtain the near actual thermophysical properties of urban surfaces. It has the potential to collect data in the field of urban thermal environment improvement, building energy efficiency, and urban disaster management.

REFERENCES

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