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Determining the emissivity and temperature of building materials by infrared thermometer

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HIGHLIGHTS

- A technique to determine the emissivity and temperature of construction materials.
- The technique use an infrared thermometer and two contact thermometers.
- The mean emissivity of seven materials was determined.
- The range of emissivity we determined was similar to that in the literature.
- The precision of the measurement is acceptable for practical application.

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ABSTRACT

An infrared thermometer can be used to detect the temperature of materials not in-contact, *in situ* and in real-time measurement. The set emissivity is key to obtaining the accurate measurement. In this study, we investigated a novel technique to determine the emissivity and temperature of construction materials by using an infrared thermometer and two contact thermometers. These measured values were transformed into true temperatures by calibration equations to improve their measurement accuracy, then the emissivity and temperature of the materials were determined by regression analysis. The mean emissivity of seven materials was 0.937, 0.942, 0.944, 0.804, 0.802, 0.902 and 0.911 for black plastic, polyethylene plate, red brick, paper, cotton cloth, wood and flat glass, respectively. The range of emissivity we determined was similar to that in the literature. The precision of the measurement is acceptable for practical application. The method we developed is easy and inexpensive and could be used for other materials.

1. Introduction

The infrared (IR) thermography is a useful technique to access building performance. It is used to access the insulation and leakage of heat and vapor loss through windows and leakage. The measurement values are then used to evaluate energy conservation or mold development [1,2]. The two approaches for measuring IR thermography are qualitative and quantitative. Accurate measurement concerns the quantitative method. Two important parameters for quantitative measurement are the surface temperature and emissivity of building materials. Avdelidis and Moropoulou [3] introduced the use of the IR thermography for building diagnostics and illustrated the importance of emissivity for quantitative results. Barreira et al. [4] evaluated factors affecting IR thermography of building materials and found that emissivity, environmental factors and surface conditions needed to be considered.

Two standard methods of emissivity determination are recommended by the American Society for Testing and Materials (ASTM) [5]. In the contact thermometer method, the target temperature of the emissivity is measured with a contact thermometer and the emissivity of an IR thermometer is adjusted until both thermometers have the same temperature. In the non-contact thermometer method, the surface-modifying material (SMM) is adhered to the surface of the specimen to determine the emissivity. The emissivity value of this SMM is set to the IR thermometer, then the temperature of the SMM is measured. The IR thermometer is focused on the adjacent SMM and the emissivity of the IR thermometer is adjusted until the temperature of the adjacent position is same as that of the SMM. In this condition, the indicated emissivity is considered as

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the measured emissivity. Both methods are simple. However, besides the emissivity of the target and emissivity setting of the instrument, the accuracy is affected by surrounding temperature, detector temperature, and radiation reflection [6–8]. Moropoulou et al. [9] tested the emissivity of building materials with the ASTM standard [4] and the Madding empirical method [10] and found significantly different results with the two methods. Ciocia and Marinetti [11] proposed a new method to determine the emissivity of several construction materials with three types of boundary tapes and two kinds of cameras with different wave-length bands. However, the authors did not compare the performance of emissivity measurement with that in the literature. Recently, some novel techniques have been proposed. Smetana and Reicher [12] used a laser beam to produce a heat flow and induced in a test body to correlate with the emissivity of the body surface. Berini et al. [13] measured the radiation energy that was a function of emissivity and surface temperature detected by an IR camera. Ianiro and Cardone [14] proposed IR thermography with a multi-wave length principle by using two IR cameras and measured the emissivity and surface temperature of samples simultaneously. Albatici et al. [15] suggested an IR thermovision technique to measure the emissivity of six building materials. Monchau et al. [16] reviewed three methods for emissivity measurements: calorimetric method, reflectometry and a special integrating sphere for reflectometry and then constructed a new device to measure the emissivity of building materials by using a modulated IR source and camera. Araujo et al. [17] used the Monte Carlo method to estimate the measurement uncertainty of the emissivity detected by dual spectral IR radiometry at room temperature and found that narrow and short wave-length bands provided the smallest uncertainty.

Saunders [18] derived a serious of equations to consider factors affecting the target temperature measurement by an IR thermometer at ambient temperature; the factors included the emissivity of the target, the emissivity setting on the IR thermometer, the detector temperature, the ambient (background) temperature and the spectral responsiveness of the IR thermometer.

Recently, the performance of the commercial IR thermometer and contact thermometer has improved. The accuracy of these thermometers could be improved significantly with temperature calibrator and adequate calibration equation [19,20]. The previous equations of emissivity measurement [18] included system and random errors. The system errors from the detector and ambient temperature could be measured and serve as variables in these measurement equations. The random errors could be assessed by regression analysis. This measurement and statistical technique provides an opportunity to simultaneously determine the emissivity and surface temperature.

In this study, we developed a novel and simple technique to determine the emissivity of seven construction materials by using a commercial IR thermometer and two contact thermometers. The determination emissivity were compared with those in the literature.

2. Material and methods

2.1. Theoretical background

The measurement equations were developed by the heat transfer principle.

$S(T_i)$ is the response blackbody radiation at temperature T_i for the detector. Because the measurement target is not the perfect blackbody, the actual signal of the measurement, S_{meas} written as follows [18]:

$$S_{meas} = S(T_s) + (1-\varepsilon_s)S(T_w) - S(T_d) \quad (1)$$

where ε_s is the target emissivity, T_s the target temperature in K, T_w the surrounding temperature in K; and T_d the detector temperature in K.

Saunders [18] proposed a modified equation by considering the effect of the emissivity setting of the instrumentation on measurement temperature,

$$S_{meas} = [S(T_{meas}) - S(T_d)] \quad (2)$$

where T_{meas} is the measurement temperature of IR meter in K.

Combining Eqs. (1) and (2),

$$S(T_{meas}) = S(T_s) + \frac{1-\varepsilon_d}{\varepsilon_d}[S(T_w) - S(T_d)] + \left(\frac{\varepsilon_s - \varepsilon_d}{\varepsilon_d}\right)[S(T_s) - S(T_w)] \quad (3)$$

where ε_d is the setting emissivity value of the detector.

From the definition of heat radiation,

$$S(T_s) = \sigma T_s^4 \quad (4)$$

Combining Eqs. (3) and (4),

$$\sigma T_{meas}^4 = \sigma T_s^4 + \left(\frac{1-\varepsilon_d}{\varepsilon_d}\right)(\sigma T_w^4 - \sigma T_d^4) + \left(\frac{\varepsilon_s - \varepsilon_d}{\varepsilon_d}\right)(\sigma T_s^4 - \sigma T_w^4) \quad (5)$$

In this study, ε_d was adjusted in test procedures and was not a constant, T_{meas}, T_w and T_d were measured by using the IR thermometer and other thermometers.

$$Y = \sigma T_{meas}^4 \quad (6)$$

$$A = \sigma T_s^4 \quad (7)$$

$$X_1 = \varepsilon_d \quad (8)$$

$$X_2 = \sigma T_w^4 \quad (9)$$

$$X_3 = \sigma T_d^4 \quad (10)$$

Rearranging Eqs. (5)–(10),

$$Y - \frac{1}{X_1}(X_2 - X_3) - X_3 = A/X_1 - \frac{X_2}{X_1} \quad (11)$$

Let $K_1 = \varepsilon_s A$ and $K_2 = -\varepsilon_s$

$$Y - \frac{1}{X_1}(X_2 - X_3) - X_3 = K_1/X_1 + K_2\frac{X_2}{X_1} \quad (12)$$

For the *i* measurement, Eq. (11) was denoted as follows:

$$Y_i - \frac{1}{X_{1i}}(X_{2i} - X_{3i}) - X_{3i} = K_1/X_{1i} + K_2\frac{X_{2i}}{X_{1i}} \quad (13)$$

$$\text{Let } Y_i' = Y_i - \frac{1}{X_{1i}}(X_{2i} - X_{3i}) - X_{3i} \quad (14)$$

Eq. (13) can be rewritten as follows:

$$Y_i' = K_1/X_{1i} + K_2\frac{X_{2i}}{X_{1i}} \quad (15)$$

Eq. (15) can be treated as a regression equation; the dependent value is Y_i' and two independent variables $1/X_{1i}$ and $\frac{X_{2i}}{X_{1i}}$. That is, Eq. (15) is an equation without an intercept and includes two unknown constants: K_1 and K_2.

In this experiment, the emissivity (X_{1i}) of the IR thermometer was adjusted from 0.45 to 0.99, T_{meas}, T_w and T_d values were measured by thermometers and numeric values of X_{2i} , X_{3i} and Y_i^{prime} were computed, then K_1 and K_2 could be obtained by regression