EMITTANCE FACTORS FOR INFRARED THERMOMETERS USED FOR WOOD PRODUCTS[1]

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ABSTRACT

Most infrared thermometers and pyrometers require that an emissivity factor be set for the proper prediction of temperature. During this series of experiments, emittance values were measured for both solid wood and wood-based composites of various colors and surface textures. After establishing the correct values of emittance for the samples, temperature measurements were done at three temperature levels using two infrared thermometers. The thermometers were first tested using the suggested emissivity values from the manufacturer and then reset with the measured emittances. When compared, little difference between the temperature values measured with the infrared thermometers and the actual temperature values were found at room temperature, regardless of the emissivity setting. At nominal temperatures of 100 and zero Celsius, the differences in actual temperature and the temperature measured with the infrared thermometers were significant regardless of the emissivity settings.

Keywords: Emittance factor, infrared thermometers.

INTRODUCTION

The use of non-contact infrared (IR) thermometers and pyrometers for monitoring temperature is becoming increasingly important in the forest products industry. The most common measurements for infrared thermometers involve drying operations for solid wood products. Non-contact thermometers are also used to investigate kiln wall energy losses and to monitor equipment such as steam traps and piping. The approach is both rapid and, with proper attention to detail, can be quite accurate. This article discusses some of the critical aspects of determining the accuracy and precision of infrared thermometers. Also presented are some measurements of emittance that can be used to adjust infrared-based measuring devices. Emittance or emissivity, discussed in detail below, is the most critical field adjustment for infrared thermometers. It is a measure of the reflectance properties of the body being measured compared to those of a perfect absorber/emitter known as a blackbody. The purpose of this research was to establish the emittance values for a variety of wood products having differing reflectivities and surface textures. As an adjunct, data were taken at three temperature levels using two non-contact infrared thermometers to show the practical effect of the adjustment.

Materials can absorb, reflect, emit (radiate), or transmit energy. Under normal conditions, any body containing thermal energy (i.e., above absolute zero) radiates energy, and the magnitude of the radiant energy is in proportion to its temperature. Nearly all of the thermal radiation is within the range of wavelengths between 0.1 μm and 100 μm, a band known as the thermal radiation region (Childs 2001). A classification of the entire infrared region is shown in Table 1, revealing that the thermal radiation range is only a portion of the band (Smith et al. 1968). Nearly all infrared thermometers operate at wavelengths between 0.7 and 20 μm or at the lower end of the IR spectrum. Because of the range of thermal ra-

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TABLE 1. *Classification of the infrared spectrum (after Smith et al. 1968).*

Wavelength (μm)	Classification
0.75–1.5	Near infrared
1.5–15	Intermediate infrared
15–100	Far infrared
100–1000	Very far infrared

diation, it is common to neglect reflected light that is not in the infrared region because only infrared radiation derives from thermal energy. In addition, some "atmospheric windowing" or selective filtering is used in more sophisticated infrared detectors to minimize the effects of water vapor or other contaminants in air. For example, the wavelengths between 5.3 μm and 8 μm are sometimes excluded (Anon. 2003). As a rule, a spectral response close to 0.7 μm is desirable because the effective emissivity is highest at shorter wavelengths, and the effects of surface characteristics are minimized (Anon. 2003).

Few data are available that list the emissivities of wood and other building materials. Childs (2001) reports the emissivity of wood to be between 0.8 and 0.9, and ASHRAE (2001) cites a value of 0.9 for planed white oak.

Energy that radiates from surfaces is usually measured in units of power. The sum of reflected energy and emitted energy is properly termed *exitance* and is usually measured as the rate of transfer of radiant power per unit surface area. Most authors use less formal terminology, although infrared thermometers sense both reflected and emitted energy. Since the radiation from a surface occurs in all directions, the term *hemispherical* is often added, and the mathematics often reflects the solid angles over which radiation is measured. However, because the radiation does not reflect evenly in all directions from real surfaces, the preferred method is to measure the radiation normal or nearly normal to the surface of interest (Dewitt and Nutter 1988). The emissivity values used for most common infrared thermometers are based on near-normal radiation measurements.

When dealing with radiation from bodies, it is common to use as a reference an ideal radiation absorber and emitter. Such ideal absorbers and emitters are known as blackbodies. In practice, they consist of cavities or spheres with the interior painted flat black.

The term *spectral* is used to identify the radiation at a particular wavelength or, more commonly, across a limited range of wavelengths. The relationship between the spectra1 radiation intensity, temperature, and wavelength is defined by Plank's law (Michalski et al. 2001):

$$W_{b\lambda} = \frac{c_1 \lambda^{-5}}{\exp\left(\frac{c_2}{\lambda T}\right) - 1} \tag{1}$$

where $W_{b\lambda}$ is the spectral radiant intensity of a blackbody; λ is the wavelength, T is the absolute temperature, and c_1 and c_2 are constants.

Integrating Eq. (1) over the entire spectrum of wavelengths leads to the Stefan-Boltzmann law for the total radiant power or intensity (W_0) of a blackbody. The equation shows the strong dependence of radiation on the temperature (Michalski et al. 2001):

$$W_0 = \int_0^\infty W_{b\lambda} d\lambda = \sigma_0 T^4 \tag{2}$$

where $\sigma_0$is the Stefan-Boltzman constant.

Most radiating bodies are not blackbodies, and common materials that are not translucent are termed *graybodies.* The ratio of the total radiation from a graybody to that of a blackbody at the same temperature is called the total emissivity of the material. The term *emissivity* is sometimes reserved to describe radiation from an optically smooth material. When used in that manner, emissivity is a material property. When a distinction is made, the term *emittance* is used for a particular sample and allows for imperfections such as surface roughness and a non-planar surface (Dewitt and Nutter 1988). More commonly, the term emissivity is used to describe the radiative properties of a class of materials, such as brick or wood, without any distinction for particular samples. The total emissivity is expressed as:

$$\varepsilon = \frac{W}{W_0} \tag{3}$$

where W is the radiant power from a graybody. At a specific wavelength, the spectral emissivity is defined as follows:

$$\varepsilon_\lambda = \frac{W}{W_{0\lambda}} \tag{4}$$

A number of techniques for measuring emissivity are reviewed by Dewitt and Nutter (1988). A common approach is to measure the reflected infrared radiation and compare the reflectance to that of a perfect reflector or blackbody. The law of conservation of energy requires that the transmission (t_λ), reflection (ρ_λ), and emission/absorption (a_λ) of energy sum to unity (Barton 2003):

$$t_\lambda + \rho_\lambda + \alpha_\lambda = 1 \tag{5}$$

For a blackbody, the emissivity equals the absorptivity; a relationship known as Kirchoff's law:

$$\varepsilon_\lambda = \alpha_\lambda \tag{6}$$

Also, for an opaque material, the transmission is zero and Eqs. (5) and (6) can be combined:

$$\varepsilon_\lambda = 1 - \rho_\lambda \tag{7}$$

The particular method used to measure emittance during these experiments is based on reflectance and is described as Method A in ASTM E 408 (ASTM 2003) and in more detail by Nelson et al. (1966). Only the rudiments will be described here.

The instrument, a Geir-Dunkle DB 100 infrared reflectrometer, consists of two semicylinders maintained at different temperatures, labeled hot and cold. The cylinders are rotated past an aperture over which the nearly flat sample being measured is placed. As the cavities rotate, the sample is irradiated with infrared radiation from the cavity at the higher temperature and then from the one at the lower temperature. The total reflected energy is sensed with a thermocouple. Following Eq. (2), the net blackbody infrared radiation from the two rotating cylinders is:

$$KW_{0h-c} = \int_0^\infty W_{h\lambda}\,d\lambda - \int_0^\infty W_{c\lambda}\,d\lambda = \sigma T_h^4 - \sigma T_c^4 \tag{8}$$

where K is an adjustment factor for the amplifier within the instrument. With a sample in place, the reflectance, ρ, from the graybody is a fraction of the reflectance from a blackbody as defined above:

$$KW_{\lambda h-c} = \int_0^\infty \rho_\lambda W_{h\lambda}\,d\lambda - \int_0^\infty \rho_\lambda W_{c\lambda}\,d\lambda \tag{9}$$

The measured reflectance ratio, ρ_m, is the ratio of Eq. (9) to Eq. (8):

$$\rho_m = \frac{\int_0^\infty \rho_\lambda W_{h\lambda}\,d\lambda - \int_0^\infty \rho_\lambda W_{c\lambda}\,d\lambda}{\sigma T_h^4 - \sigma T_c^4} \tag{10}$$

Additional details are discussed under the Materials and Methods section.

Infrared sensors, often called *infrared* or *radiation detectors,* produce a signal that corresponds to the amount of infrared radiation that strikes the detector. The classification of infrared temperature-measuring devices is sometimes confusing, and the literature provided by manufacturers is often vague. One classification defines two main types (Fraden 1999). The first type are spectral thermometers that measure radiance over a fairly narrow band and constitute the vast majority of infrared temperature-measuring devices. They are also known as single-wave band, narrow-wave band, or monochromatic thermometers. Typically, they consist of a lens, a filter, an aperture, a detector, an amplifier with emissivity adjustment and display electronics.

Of critical importance in a spectral thermometer is the detector, which can be divided into two categories: quantum and thermal. Quantum detectors, also known as photon or photoelectric detectors, measure the conduction generated by incident photoelectrons. They are broken down further by whether current or voltage is measured and can be classified as photoemissive, photoconductive, or photovoltaic. Photon detectors are more sensitive and have a faster response than thermal detectors. Many quantum detectors are highly nonlinear (Fraden 1999).

The second type of device is a thermal detector. Thermal detectors convert absorbed energy from a radiating body into heat causing a rise in the temperature of the detector. The rise in temperature can be sensed by a change in electrical resistance (bolometers), thermoelectric electromotive force, as measured by thermocouples and thermopiles (thermocouples in series), or electrical polarization (AC pyroelectic detectors). Thermal detectors measure across a wide spectrum of wavelengths. They respond slowly (e.g., 10–100 milliseconds for a bolometer) but are very good for low temperature measurements (Fraden 1999).

METHODS AND MATERIALS

The mathematical basis for the Geir-Dunkle DB 100 reflectometer was described above. The instrument is calibrated before use using a flat black disk and a gold disk, chosen to mimic blackbodies and highly reflective surfaces. By calibrating the instrument with a blackbody sample and a highly reflective sample, the limits of the numerator in Eq. (10) are electronically set between zero and one. The actual reflectance for a particular sample is then measured using a millivoltmeter circuit, and the emittance is calculated using Eq. (7). To insure that drift had not occurred during the measurements, the instrument was periodically recalibrated. There were four recalibrations done during testing at intervals of 15–20 min. Little drift was found.

Although infrared thermometers are inherently color blind, light and dark materials absorb and reflect differently. Accordingly, light and dark samples were chosen. Also, because surface texture is an important determinant of radiation, the samples had both rough and smooth surfaces. A listing of the samples with a brief characterization of their surfaces (rough, planed, heartwood, sapwood, etc.) is shown in Table 2.

Most samples measured at least 75 mm long by 75 mm wide. The sample surfaces were gen-

TABLE 2. *Sample characteristics and average emittance values.*

Sample	Calibration #	ε
Red oak (*Quercus,* spp) heartwood, planed, sample #1	1	0.91
Red oak (*Quercus,* spp) heartwood, planed, sample #2	3	0.91
Red oak (*Quercus,* spp) heartwood, planed, sample #2	4	0.90
Black cherry *(Prunus* serotina) heartwood, planed	1	0.90
White oak (*Quercus,* spp) rift sawn, heartwood, planed	1	0.90
White oak (*Quercus,* spp) rift sawn, heartwood, planed sample #2	3	0.90
Soft maple *(Acer,* spp) sapwood, planed	1	0.90
Soft maple *(Acer,* spp) sapwood, planed	2	0.90
Walnut *(Juglans* nigra) heartwood, planed	1	0.91
Sugar maple *(Acer* saccharum), sapwood, planed	3	0.90
European beech (*Fagus,* spp) heartwood, planed	2	0.90
Spruce (*Picea,* spp), heartwood, planed	1	0.89
Spruce *(Picea,* spp), heartwood, rough sawn	2	0.90
Eastern white pine *(Pinus* strobus) heartwood, planed	3	0.89
Eastern white pine *(Pinus* strobus) heartwood, rough	3	0.91
Eastern white pine *(Pinus* strobus) heartwood, quartersawn, planed	3	0.89
Medium density fiberboard, (PF bond)	3	0.90
Particleboard (PF bond) 80% softwood, 20% hardwood	3	0.91
Hardboard, smooth surface	3	0.90
SYP earlywood*	1	0.90
SYP latewood	1	0.92
SYP earlywood/latewood boundary	1	0.91
Kiln panel, bright, textured aluminum	1	0.43
Kiln panel, smooth aluminum	4	0.45

*Southern yellow pine.

erally flat, cleaned of dust and dirt, and were dry (EMC of about 8%). The circular port over the rotating cylinders measured 23 mm in diameter allowing multiple measurements for each sample. The thickness of the samples was not important since the measurement of emittance is a surface phenomenon. After some initial testing to determine stability of the measurements, at least three measurements of emittance were taken across the surfaces from each sample and the data were averaged.

As an adjunct to the principal experiments measuring emittance, two infrared thermometers with different brand names were tested at three different temperatures. At each temperature, each instrument was set to the emissivity recommended by the manufacture, and the temperature of the sample was measured after allowing the instrument to stabilize. The emissivity was then changed to the value determined using the Gier-Dunkle DB-100 reflectometer, and the temperature measurement was repeated. The time between the initial measurement and the second measurement at each emissivity setting was usually less than one minute. Summary specifications for the instruments are shown in Table 3.

Measurements were made on a subset of the original sample group, first at room temperature (about 23.3°C/74°F), and then through a side wall port in a Tenney T11-RS environmental chamber. The nominal chamber setting for the elevated temperature tests was 100°C (212°F), while the setting for the reduced temperature tests was zero Celsius (32°F). To verify the temperature setting, a recently calibrated Vaisala HM70 recording temperature meter with an HMP 76 probe (accuracy: +/–.2°C) was used to monitor the temperature directly adjacent to the sample position. The average measured temperature in the vicinity of the samples was 97.3°C (207.1°F) for the elevated temperature tests and 1.4°C (34.6°F) for the reduced temperature tests. Three readings were taken at each emissivity setting after the meters settled. The reported data are averages. Readings were taken normal to the surface and at a distance of about 150 mm.

RESULTS AND DISCUSSION

Summary data from the emittance measurements are shown in Table 2. Groupings include hardwoods of various surface textures and color, softwoods of various surface textures and color, and composite materials. Also included in the table are data from two different types of kiln panel surfaces.

Emittance data from the wood products are clearly grouped with the average calculated emittance of 0.90. Some variation exists, such as both samples of the dark, planed, red oak heartwood (0.91), and the light spruce heartwood (0.89). As expected, the highest emittance values were generated by dull-dark or rough surfaces. For example, the SYP heartwood with an emittance value of 0.92 was the highest of all the measurements. The rough, dark eastern white pine was also high at 0.91. Conversely, the smooth-surfaced, lighter-colored eastern white pine heartwood was below the mean at 0.89. The perceived color difference was the result of natural heartwood color variation and reflectance caused by the smooth surface.

Some of the values of Table 2 may appear anomalous. For example, the dark, planed, walnut heartwood has an emittance value of 0.91, but the dark, smooth surface of hardboard was lower at 0.90. The difference lies in the texture of the surface. The hardboard is much smoother and more reflective than the walnut sample used for these tests.

TABLE 3. *Characteristics of the infrared thermometers.*

Instrument	Spectral responses (μm)	Range of temperature (°C)	Emissivity range (.01 increment)	Emissivity setting for wood	Instrument accuracy	
1	8–14	–32 to 760	0.1 to 1.0	0.94	<23°C: +/– 2°C	>23°C: +/– 1°C
2	7–18	–32 to 500	0.3 to 1.0	0.94	<25°C: +/– 2°C	>25°C: +/– 1°C

Two types of kiln panel surfaces were included in the measurements. Manufacturers of infrared thermometers recommend that specular surfaces, such as polished aluminum, be coated with masking tape or a similar substance before measuring the temperature of the surface. The effect of the coating is to reduce the reflectance of the metal. For these measurements, the surfaces were not coated because the emittance of the surface was the desired measurement. Measurement error increases when highly reflective surfaces are measured, and caution should be observed when using the kiln panel data with IR thermometers.

Some of the practical effects of emissivity changes are shown in Table 4. The data were taken at three temperatures using a subset of the samples in Table 2. The measurements taken at room temperature were close to each other regardless of whether the corrected (measured) emissivity or uncorrected (general recommendation by manufacturer) emissivity setting was used. All of the data were within the manufacturer's tolerances (Table 3). At room temperature, both instruments settled quickly to a specific reading and remained stable.

At a nominal temperature of 100°C, the differences between the corrected and uncorrected temperature values were substantial. Variation from the expected temperature was consistently less from instrument one than from instrument two, regardless of whether the emissivity was corrected or uncorrected. Instrument one settled quickly and remained stable, while instrument two tended to drift and require about 30 s to stabilize. Neither instrument was very accurate, although using the factory recommendation for the emissivity setting yielded values closer to the actual temperature. Only three readings from instrument one were within the stated limits of accuracy. All other readings were out of tolerance.

The pattern found at a nominal temperature of zero Celsius was similar to that at elevated temperatures. Using the uncorrected emissivity, the variation from the expected values was about twice as large for instrument two as for instrument one. Drift and stability problems were again encountered with instrument two. When the data were compared to the expected limits of accuracy, only four temperature readings from instrument one, all using uncorrected emissivity

TABLE 4. *Percent variation from actual temperature as measured in the immediate vicinity of the samples.*

		Room temperature (23.3°C)		Elevated Temp. (97.3°C)		Reduced Temp. (1.4°C)	
Sample	Instrument	Uncorrected	Corrected	Uncorrected	Corrected	Uncorrected	Corrected
Medium density fiberboard (PF bond)	1	2.1	1.4	0.3	2.1	1.8	6.4
	2	3.1	1.4	2.2	5.3	6.2	10.2
Eastern white pine–heartwood, quartersawn, planed	1	1.5	1.5	0.7	3.6	2.9	7.7
	2	1.8	1.8	2.8	7.0	4.4	12.7
Walnut–heartwood, planed	1	2.8	2.3	1.6	3.3	3.7	6.3
	2	2.4	2.4	3.2	5.7	7.8	11.2
Eastern white pine–heartwood, rough	1	1.2	1.4	1.3	3.1	4.4	6.4
	2	0.8	0.8	2.8	5.6	8.2	13.5
Red oak–heartwood, planed, sample #2	1	1.5	0.9	0.5	2.8	4.1	6.4
	2	2.8	0.9	2.2	5.4	9.8	14.1
Hardboard, smooth surface	1	0.7	0.3	2.1	4.3	5.1	8.8
	2	1.8	0.3	3.3	6.2	9.1	13.8
Southern yellow pine plywood (EW)	1	1.5	0.5	1.8	4.2	4.2	7.6
	2	2.6	0.4	3.3	6.7	8.6	13.5
Southern yellow pine plywood (LW)	1	2.0	1.8	2.1	3.3	4.4	5.4
	2	2.0	1.9	3.8	4.9	10.0	12.5
White oak–rift sawn, heartwood, planed, sample #2	1	1.8	1.9	1.9	2.8	4.3	7.4
	2	0.9	0.8	3.6	6.1	8.8	12.7

values, were within the manufacturer's specified tolerances.

CONCLUSIONS

The data show that emittance values for common wood products are generally within the range between 0.89 and 0.92 and are in line with previously reported values, but they are well below the commonly recommended value of 0.94–0.95 given by many IR thermometer manufacturers. The emissivity correction was not generally noticeable when data were taken at room temperature but will have a significant effect at common kiln and steam piping temperatures or when measuring cold or frozen wood. A limited amount of data derived from two noncontact IR thermometers shows the importance of verifying the accuracy of the instruments when measuring reduced or elevated temperatures.

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