Application Note
Radiometric Temperature: Concepts and Solutions

Several factors can lead to differences between a blackbody's temperature as measured by a thermometer ("thermometric temperature") and its temperature as measured by a radiometer ("radiometric temperature", or "effective temperature") . These factors affect both absolute and differential temperatures.

There are two principal sources for these errors. The first is attenuation of the radiant output of the IR source, because of blackbody emissivity limitations, optical losses, or atmospheric attenuation. The second source of these errors comes from the fact that radiance is not a linear function of temperature.

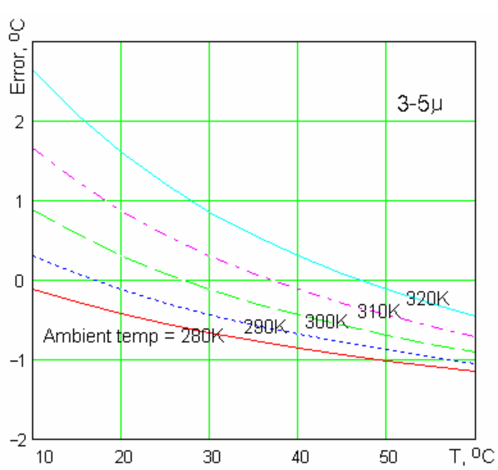
Let's look at the first of these sources. If the output of a blackbody is less than its ideal value (that is, its emissivity is less than 100%), it will appear to the radiometer to be at a lower temperature. This can be compensated for by increasing the blackbody's setpoint slightly, so that the net output is correct. Determining just how much to boost the setpoint is where things get more complex.

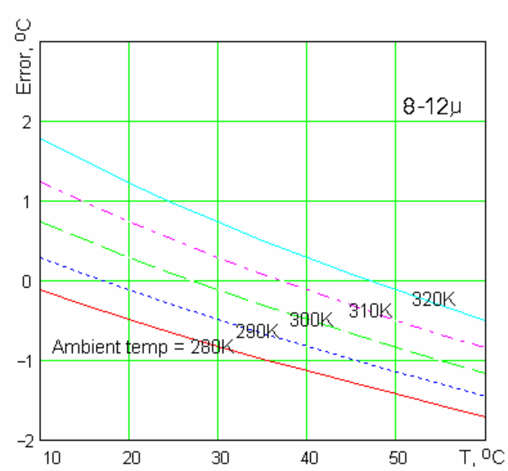
Take a simple case – a blackbody with emissivity of 96%. It will emit 96% of the flux that an ideal blackbody would emit. Additionally, it will reflect 4% of the flux incident on the blackbody surface from the environment. That's the complicating factor: the correction to the blackbody setpoint will depend on how much energy the environment supplies. Usually, it's practical to treat the environment as a blackbody at room temperature.

One way to look at this is that a 25°C blackbody in a 25°C room would require no correction, regardless of its emissivity. That is, its radiometric temperature is equal to its thermometric temperature. Similarly, a 40°C blackbody in a 40°C room would require no correction. But a 40°C blackbody in a 25°C room would have a radiometric temperature of less than 40°C.

Note that this error will be wavelength dependent. In the example above, the reflected energy will be a different fraction of the total flux in the 3-5μ band than in the 8-12μ band.

The errors may or may not be significant, depending on the user's application. The graphs below show errors at different ambient temperatures for a blackbody with emissivity = 96%, as that blackbody's temperature varies between 10 and 60°C. Note that, as discussed earlier, error is zero when ambient temperature equals blackbody temperature.

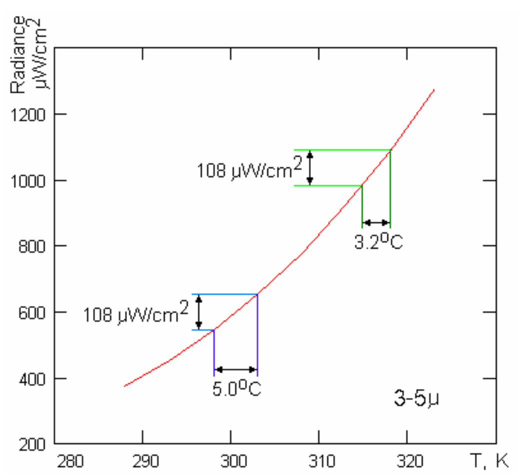


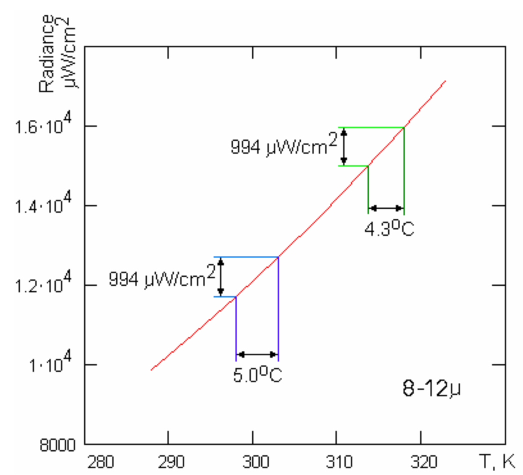


Some commercial blackbodies attempt to compensate for radiometric losses by inserting a gain or offset correction into the temperature setpoint. But the ambient temperature dependence and wavelength dependence discussed above make this correction an uncertain approximation at best. Santa Barbara Infrared's blackbodies are available with a more sophisticated radiometric correction option, which measures ambient temperature and automatically computes and applies a true wavelength-compensated adjustment. As an alternative to such a blackbody, a user can, using spectral data, ambient temperature and Planck's Law, compute a correction and add it to the blackbody's setpoint, updating that setpoint as ambient temperature changes. Beware of simpler solutions!

The above discussion dealt with absolute temperature errors, but radiometric attenuation is also a source of differential temperature errors. Since the two temperatures that comprise the ΔT are each at a different distance from ambient temperature, each will require its own correction. Frequently, one of the temperatures is floating at ambient and needs no correction. Be aware though – if a differential blackbody's target is heated above ambient by its proximity to the blackbody, then its temperature will need correction.

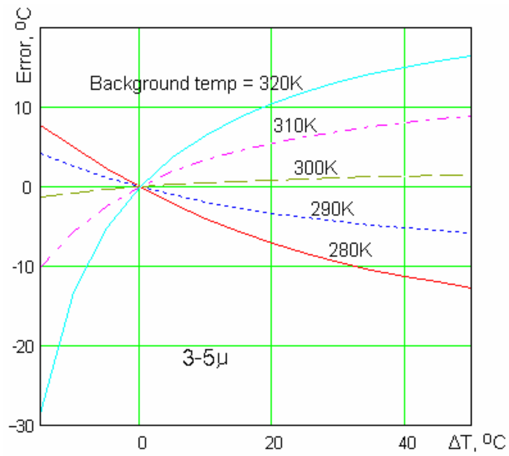
The other source of radiometric temperature errors is more subtle, and exists even in an ideal blackbody source (emissivity = 100%). The cause of this error, which affects only differential temperatures, is that blackbody radiance is not a linear function of temperature. So a given temperature difference will not always yield the same radiance difference. A ΔT of 3°C (23°C to 26°C), for example, will yield a different radiance contrast than a ΔT of 3°C (24°C to 27°C). The graph below (a plot of in-band blackbody radiance as a function of temperature) can be helpful in visualizing why this happens. A differential blackbody typically allows one temperature (the target plate) to float with ambient, and controls the temperature difference referred to this ambient target. You can see that at a 298K ambient, a ΔT of 5°C will generate a radiance contrast of 108 $\mu W/cm^2$ (3-5µ), but at 313K a ΔT of only 3.2°C is needed to generate the same contrast. So, if the blackbody is set to 5°C ΔT, it will yield a higher radiance contrast, and thus a higher apparent ΔT, if room temperature rises.

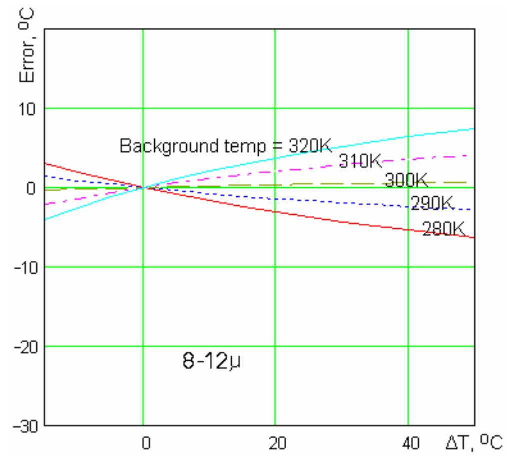




This is a problem in infrared testing because an imaging system responds to *radiance* contrast, while a blackbody is typically controlling *temperature* contrast. One way to accommodate this difference is to consider a quantity called Radiometric Temperature Difference (RΔT), defined as "the same radiance contrast, integrated over the waveband of interest, which would be generated by a blackbody at 298K and a second blackbody at a temperature of RΔT above 298K". Note that, although RΔT is expressed in units of temperature, it actually defines a radiance contrast. To use the example from the previous paragraph: for a 3-5µ sensor, an RΔT of 5°C could be generated by a pair of blackbodies at 298K and 303K, or by a pair of blackbodies at 313K and 316.2K, etc. This phenomenon is wavelength-dependent. To an 8-12µ sensor, 298K and 303K would still generate the desired RΔT (by definition), but 313K and 316.2K would no longer yield RΔT = 5°C; 313K and 317.3K would create this contrast.

While a 313K (40°C or 104°F) ambient temperature is unlikely in a laboratory, it could be encountered in a field testing environment. Even the more benign temperature variations seen in a lab could cause significant errors, though. The graphs below show ΔT errors at different background temperatures. Note that 3-5µ errors particularly can grow quite large: 50% or more error at high background temperatures.





Again, this phenomenon is *not* due to emissivity being less than 100% or to some other limitation of the blackbody, but is simply a consequence of Planck's Law. Indeed, to get an accurate radiance contrast, both emissivity correction and linearity correction must be performed. This further reduces the utility of the simplistic gain-and-offset correction for radiometric temperature. The user must either compute the correction off-line, or use a blackbody controller such as SBIR's that computes and applies true radiometric corrections.