Window and External Optics Transmittance

By R. Danjoux

This technical publication aims at helping the thermographers understand what is meant by transmittance, how to estimate it.

Definition of transmittance according to the ISO 80000-7:2008 standard.

$$\tau = \Phi_t / \Phi_m$$

Where Φ_t is the transmitted radiant flux, and Φ_m is the radiant flux.

A radiant flux is the radiant energy emitted, transmitted or received during a time interval of the duration dt.

The unit for a flux is watt, symbol W.

Transmittance being a ratio of terms expressed with an identical unit, it is unit less.

Note that two approved French translations for transmittance are also mentioned in the standard:

- Facteur de transmission
- Transmittance.

When and why do you have to consider external optics in thermography?

An external optic can be anything situated between the front lens and the object:

1. a physical solid window in a material such as BaF_2, CaF_2, ZnSe, Sapphire,
2. an attenuating atmosphere that cannot be taken into account by the settings in the software, with parameters such as distance, temperature and relative humidity (LOW TRAN or MODTRAN or other).

Because it is located outside the camera body, it cannot be considered during the stabilization, compensation, uniformization and calibration factory processes.

Failure in recognizing its radiometric influences may lead to measurement errors.

How can you estimate the transmittance?

Several methods are available.

<table>
<tr><td colspan="2">ASTM E1897-97 (2010) Standard Test Methods for Measuring and Compensating for Transmittance of an Attenuating Medium Using Infrared Imaging Radiometers</td></tr>
<tr><td colspan="2">1) Set the emissivity to 1.00 and the distance at 0 m.
2) Measure and set the reflected apparent temperature.
3) With the emissivity still set to 1.00, measure the apparent temperature of a hot radiation source.
4) Place the test specimen in between the radiation source and the camera and freeze the image.
5) Change the “emissivity” until the temperature equals the apparent temperature of the hot radiation source.
6) This value is the transmittance.
7) Multiply your target true emissivity by the window transmittance you have obtained, and consider a “global equivalent emissivity”.</td></tr>
<tr><td>Advantages and limitations</td><td>• You need a calibrated camera.
• The window temperature shall be the same as the original reflected apparent temperature (prevalent before the window is applied).
• The technique does not take into account two possible environmental conditions (atmospheric temperature and reflected apparent temperature) on each side of the window.</td></tr>
<tr><td colspan="2">Note: This standard is also a normative reference for ISO18434-1.</td></tr>
</table>

Extrapolation of ASTM E1896-97 (2010) for systems featuring a transmittance value input in the settings.	
1) Set the emissivity to 1.00 and the distance at 0 m. 2) Measure and set the reflected apparent temperature. 3) With the emissivity still set to 1.00, measure the apparent temperature of a hot radiation source. 4) Place the test specimen in between the radiation source and the camera and freeze the image. 5) Change the transmittance until the temperature equals the apparent temperature of the hot radiation source. 6) Enter the transmittance value you have obtained in your settings. Do not forget the window temperature (assuming that the transmittance is unchanged at this temperature). This method first assumes that the window temperature and the original reflected apparent temperature (prevalent before the window is applied) are the same. If this changes, and provided that the environmental conditions on both side of the windows are the same, it is possible to take into account the window temperature. Note that, although this indeed brings an improvement, it is also limited! It is applicable for a window of rather good transmittance, and therefore low absorbance and low emissivity, placed rather far from the target to observe so that it does not cover too much of a solid angle.	
Advantages and limitations	• You need a calibrated camera. • Not as easy as it appears!

Extrapolation of ASTM E1896-97 (2010) for systems featuring a transmittance value input in the settings. Refined method.	
A more refined solution exists in the radiometric settings and, again, it is not universal. Firstly it consists in assuming that the window is at the temperature of the atmosphere situated close to the thermal scene. From this, you admit that it is also very close to the reflected apparent temperature in the immediate vicinity of the thermal scene. Then, you are able to measure the reflected apparent temperature in front of the window. To finish with, you know the transmittance of the window at its current temperature. These three conditions being verified, in the system settings: 1) Adjust the window transmittance to 1.00. 2) Put window transmission, in lieu of the atmospheric transmission. 3) Put the reflected apparent temperature in the immediate vicinity of the object, in lieu of the reflected apparent temperature. 4) Put the reflected apparent temperature of the external side of the window, in lieu of the atmospheric temperature.	
Advantages and limitations	• You need a calibrated camera. • Not as easy as it appears!

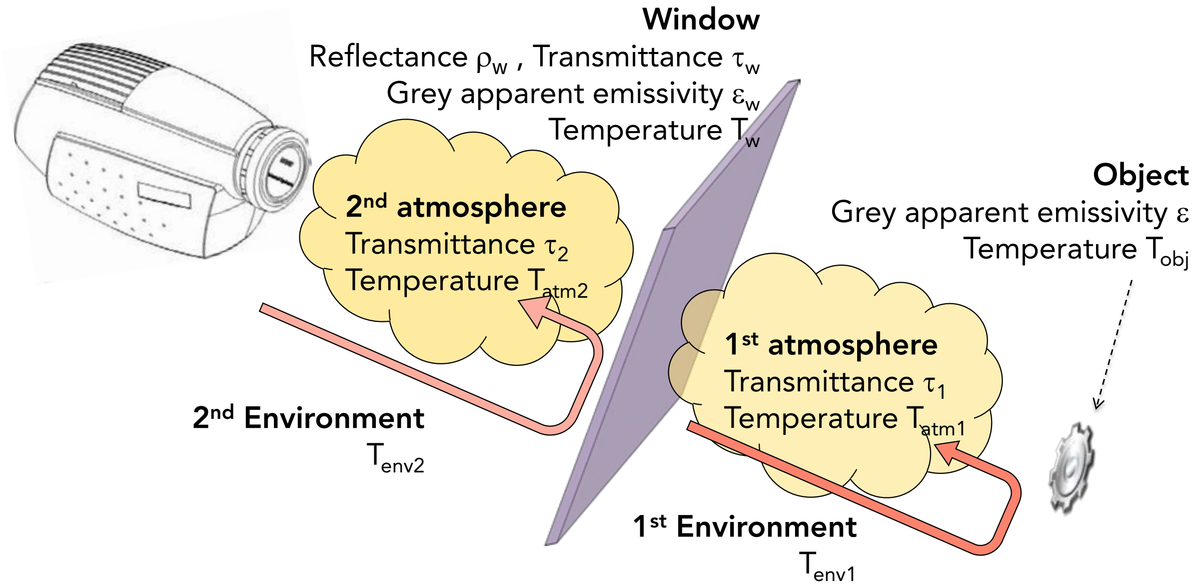
Window and External Optics Transmittance

By R. Danjoux

Section reserved for math aficionados and lab-goers

When you insert a solid window in the optical path, the radiometric toll is modified:

- The window will absorb the radiation coming from the object, but, it will also emit its own radiation in the directions of both the object and the camera.
- Because of the radiative contribution of the window, two environments and two atmospheres will possibly exist; between the object and the window, and between the window and the camera.



The radiance received by the camera is made up by six components:

1. What is emitted by the object, and is then affected by the transmittance of the first atmosphere, then the window, then the second atmosphere.
2. What is reflected by the object from the first environment, and is then affected by the transmittance of the window and of the second atmosphere.
3. What is emitted by the first atmosphere, and is then affected by the transmittance of the window and of the second atmosphere.
4. What is emitted by the window, and then affected by the transmittance of the second atmosphere.
5. What is reflected by the window's outer surface from the second environment.
6. The contribution of the emitting second atmosphere.

The mathematical expressions of these six radiances are:

1	$\varepsilon \cdot \tau_1 \cdot \tau_w \cdot \tau_2 \cdot R_{Tobj}$	4	$\varepsilon_w \cdot \tau_2 \cdot R_{Tw}$
2	$(1 - \varepsilon) \cdot \tau_1 \cdot \tau_w \cdot \tau_2 \cdot R_{Tenv1}$	5	$\rho_W \cdot \tau_2 \cdot R_{Tenv2}$
3	$(1 - \tau_1) \cdot \tau_w \cdot \tau_2 \cdot R_{Tatm1}$	6	$(1 - \tau_2) \cdot R_{Tatm2}$

What can be assessed at this point of the demonstration?

- The original object's emissivity ε is still present, and unchanged.
- There is an equivalent *global* transmittance from the object to the camera. It characterizes the combined effects of both atmospheres and the window. Its value is $\tau_1 \cdot \tau_w \cdot \tau_2$.

We have to admit that this is complicated. Unless some simplification hypothesizes are suggested, it is unlikely that anybody could solve it!

The following simplifications are sometimes possible:

- Assuming that the distances between the object to the window, and between the window and the camera, are small, both atmosphere transmittances equal unity.
- Ultimately, the window, and both environments could be at the same unique temperature (this may not always be realistic though). In this case, we simply have: $R_{Tenv1} = R_{Tenv2} = R_{Tw} = R_{Tenv}$

  Hence, the measured radiance rewrites:

$$R_{measured} = \varepsilon\tau_w R_{Tobj} + (1-\varepsilon)\tau_w R_{Tenv} + \varepsilon_w R_{Tenv} + \rho_w R_{Tenv}$$

  Having $1 = \varepsilon_w + \rho_w + \tau_w$ (conservation of energy)

  The final expression of the measured radiance is:

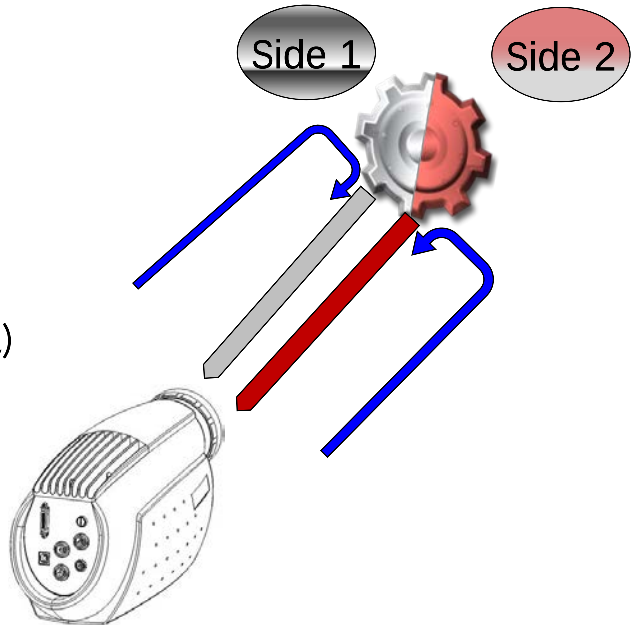
$$R_{measured} = \varepsilon\tau_w R_{Tobj} + (1-\varepsilon\tau_w) R_{Tenv}$$

Again, the hypotheses leading to this equation may not always be verified in the real life. In a laboratory type of environment, with a rather stabilized environment, it is possible. In that case, we can propose an easy method to estimate the transmittance of the window. It consists in looking at a contrasted thermal scene, in direct and through the window, and then compute. Note that you need a thermographic system displaying values in radiance or any other unit proportional to radiance (at FLIR- DLs, Counts, OS). Because of the usage of such a unit, you do not need your camera to be necessarily temperature calibrated.

- Step 1 - direct

- $R_1 = \varepsilon_1 R_{Tobj} + (1-\varepsilon_1) R_{Tenv}$
- $R_2 = \varepsilon_2 R_{Tobj} + (1-\varepsilon_2) R_{Tenv}$

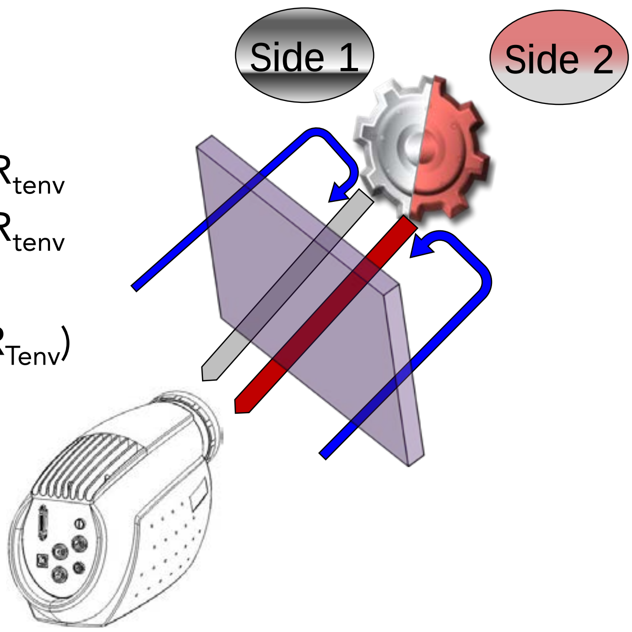
- $R_1 - R_2 = (\varepsilon_1 - \varepsilon_2)(R_{Tobj} - R_{Tenv})$



- Step 2 - with window

- $R'_1 = \varepsilon_1 \cdot \tau_w \cdot R_{Tobj} + (1 - \varepsilon_1 \cdot \tau_w) \cdot R_{tenv}$
- $R'_2 = \varepsilon_2 \cdot \tau_w \cdot R_{Tobj} + (1 - \varepsilon_2 \cdot \tau_w) \cdot R_{tenv}$

- $R'_1 - R'_2 = \tau_w(\varepsilon_1 - \varepsilon_2)(R_{Tobj} - R_{Tenv})$



- Step 3

- Direct $R_1 - R_2 = (\varepsilon_1 - \varepsilon_2)\,(R_{Tobj} - R_{Tenv})$
- With window $R'_1 - R'_2 = \tau_w(\varepsilon_1 - \varepsilon_2)\,(R_{Tobj} - R_{Tenv})$

- Conclusion $$\tau_w = \frac{(R'_1 - R'_2)_{with\ window}}{(R_1 - R_2)_{direct}}$$

There are points to always keep in mind:

- Like the emissivity, the transmittance you input in your calculator is context dependent.
- The transmittance may vary with the temperature of the window.
- Because the emission of objects shifts towards shorter wavelengths when the temperature increases, the transmittance may vary with the temperature of the object you look at!
- The transmittance may vary with ageing of the window.
- Environments on both sides of the window may not always be of identical temperatures.
- Atmospheres on both sides of the window may not always be non-influential.
- Because the transmittance of a window follows a negative exponential law with its thickness, be careful in looking through in oblique. The optical infrared rays may be affected by a variable transmittance depending on the position of the pixel in the image!

A thorough and accurate calculation may be sometimes impossible, just because the context forbids you to perform an estimation of all parameters. In this case, you have to remain humble, honest and accept the limitations.