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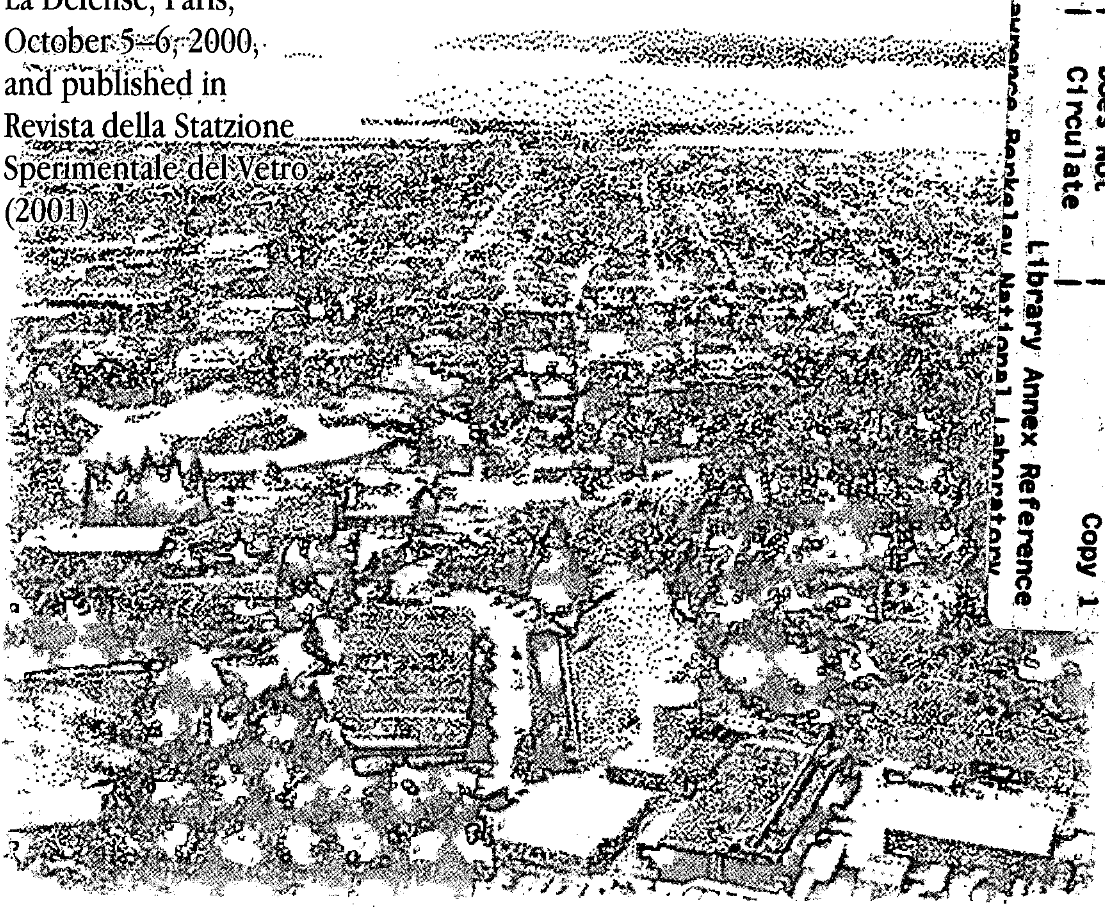

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Optical Properties of Glazing Materials at Normal Incidence

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Summary

Measurements of spectral transmittance *T* and reflectance *R* at normal incidence continue to be the most common and accurate source of energy performance data for glazing materials. Prediction of these radiometric properties from more fundamental materials data is often confounded by the complexity and uncertainty of coating structures. Angle-dependent radiometric properties of coated glazing will probably be predicted from normal-incidence data rather than being measured at many angles. The general error level demonstrated in round-robin tests is on the order 1-2%; it is often necessary to achieve better levels of performance. Based on results obtained following the round-robin tests, it is expected that accuracy of better than 0.5% can be generally achieved. A new type of absolute standard reference is described and tested with promising results.

1. Introduction

At present there are no practical substitutes for measurements or transmittance and reflectance of coated glazing materials at normal incidence. A new generation of spectroscopic ellipsometers can determine the optical indices of the coating layers, which in principle can be used to calculate any radiometric property at any angle of incidence. In practice, however, this data requires some knowledge of the coating structure, which is often not available or not reliable. Furthermore, ellipsometers are less common, more expensive and more difficult to operate than standard spectrophotometers.

Angle-dependent optical properties of glazing materials are needed to properly characterize the performance of windows in buildings. Angle dependent measurements can be made directly, using attachments to commercial spectrometers or specialized scanning instruments. There are several problems with this approach: oblique measurements have additional sources of error, calibrated reference materials are not yet available, and the amount of data to collect is 10 times greater than at normal incidence alone. All of this indicates continued use of normal-incidence measurements with oblique properties being calculated from this data.

In this paper, some of the results of a recent round robin are discussed, focussing on the data at normal incidence only. Potential sources of error are analysed. A new type of absolute standard is introduced. Preliminary test results using this standard are presented.

2. Round Robin Results and Analysis of Errors

A round robin was conducted to test the state of angle-dependent measurements. Although not the primary purpose, normal-incidence data were also measured. In the first stage, 5 types of commercial glazing material were sent to 15 laboratories (A-T) in Europe and the U.S. Each laboratory received a unique set of samples. An additional 3 sample sets were circulated among 9 labs in the US (V1-W4). In this case, more than one lab measured the same samples. Let us consider a single example for now: the transmittance of the Amiram antireflection coating made by Schott Glass.

Figure 1 shows the transmittance of the sample measured at 500 nm. . This is actually a relatively good example with most results clustered around what we must assume to be the true value of 0.97. There are a few points however, that are about one percentage point below this consensus value. **Figure 2** shows the transmittance for the same material at 1500 nm. The transmittance seems to be about 0.65 based on most of the measurements, but in this case there are some deviations of 1-2 percentage points. Greater deviations are to be expected in the infrared measurements for various reasons including the smaller size of the detector area. Also, this particular value of transmittance is much farther from the 100% reference line in the infrared than in the visible so that linearity may be more of a problem.

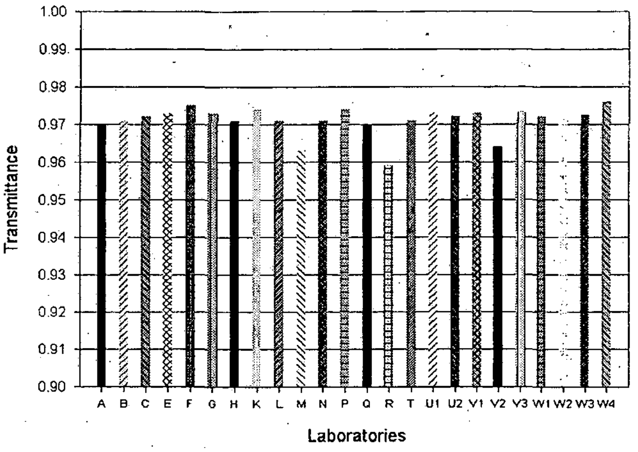

Figure 1. Transmittance of Amiram antireflection coating on glass at 500 nm as measured by 24 laboratories.

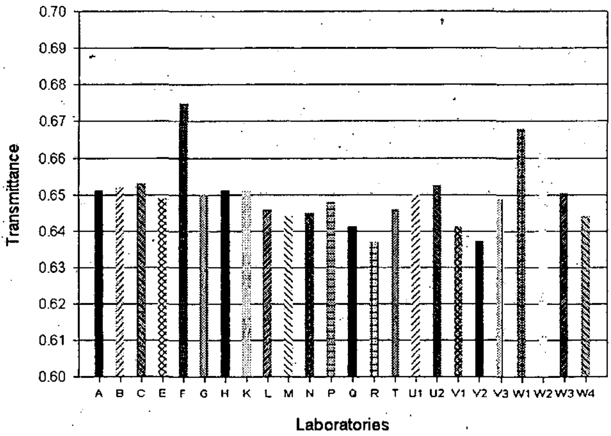

Figure 2. Transmittance of Amiram antireflection coating on glass at 1500 nm as measured by 24 laboratories.

Standard deviations of 0.003 and 0.004 were calculated for transmittance values integrated over the visible and solar spectrum, respectively [1]. The accuracy of these measurements was described as "reasonable." While true for many purposes, this assertion bears closer examination. First, the use of a standard deviation implies that the errors are random. Examination of the trends in the data however indicates that systematic errors are present. As noted above, some of these errors are large compared to the standard deviation. For purposes of rating and labelling window performance, we must diagnose and eliminate these systematic errors from all providers of data in order to maintain a fair rating system. Also, calculations involving extraction of fundamental optical parameters [2] require consistently high accuracy, wavelength by wavelength. For example, an error of less than 1% in transmittance of a laminated glazing can result in a predicted transmittance for the interlayer to become non-physical at that wavelength.

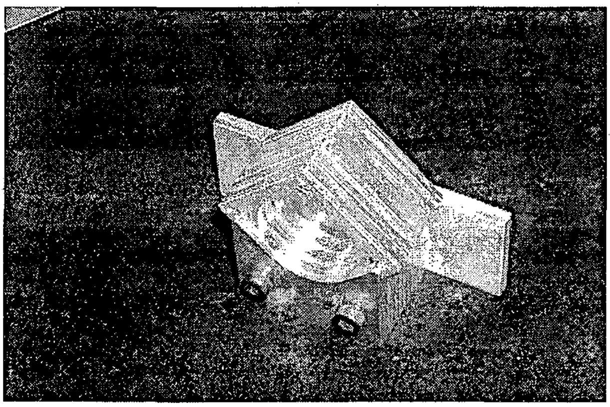

Figure 3: This absolute transmittance standard can hold up to six silica disks.

The aggregate results of the round robin indicate, but do not clearly identify, the actual transmittance of the samples because of systematic errors. An absolute standard for both transmittance and reflectance was needed. We obtained the thinnest silica plates that we could find (0.5mm) and constructed a special sample holder to allow them to be easily handled and stacked (**Figure 3**). Silica has a well-known index of refraction [3] and the transmittance of one or more disks can be calculated [2]. The transmittance was measured on three instruments; two were Perkin-Elmer Lambda 19 spectroradiometers equipped with Labsphere RSA-PE-19 integrating spheres; the third instrument was a new Perkin-Elmer Lambda 900 also with a Labsphere integrating sphere.

Figure 4 shows the measured and calculated transmittance of up to six silica disks. The excellent results of a single disk are not too surprising considering the similarity of clear silica to the unblocked sample beam. A more stringent test on linearity of the systems would utilize several disks to produce a range of transmittance. Figure 4 shows that the results are just as good as for a single disk. Thus, neither cumulative absorption nor reflection would seem to present a problem. All results are within a few tenths of a percentage point of the theoretical value except near regions where water absorption is present. The newer more advanced Lambda 900 is even closer in the infrared region where the Lambda 19s have systematically higher transmittance.

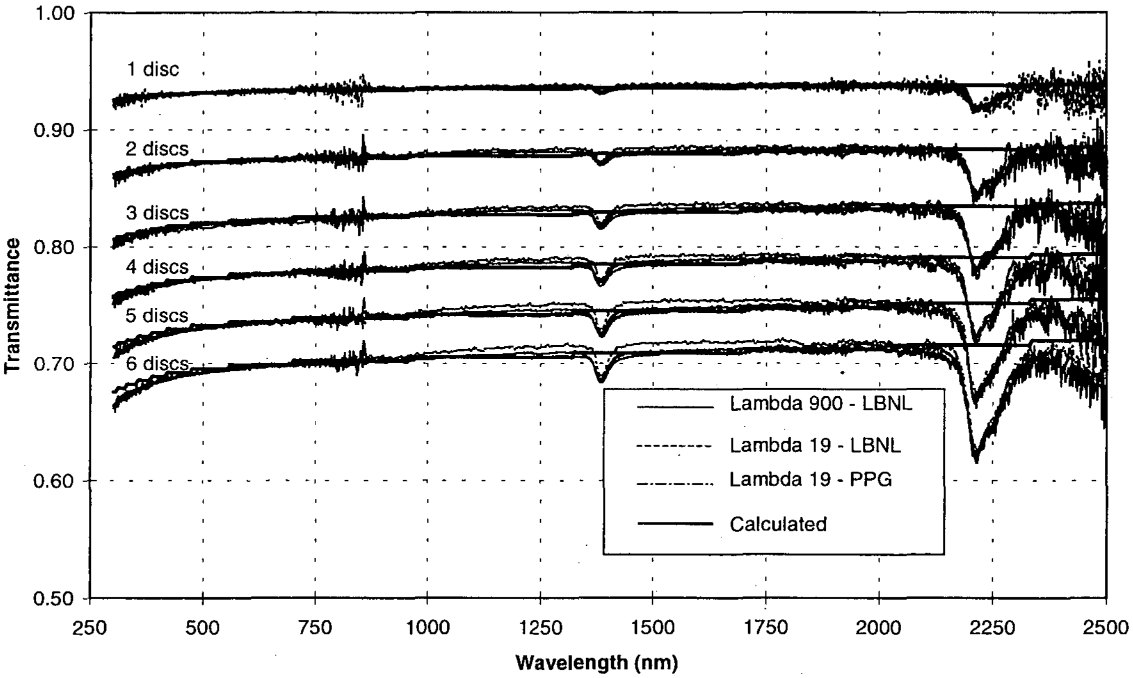

Figure 4: Spectral transmittance of silica disks measured on three different instruments.

Although our small sampling of similar instruments has not identified any problems yet, we believe that there should be special emphasis on corrections for zero line and 100% line. The correction equations in ASTM 903 [4], for example, could be used for this purpose. Both the Lambda 19 and Lambda 900 have automatic corrections for 100% line, but other types of instruments especially older models may not. At PPG it has been found that the zero-line is primarily important for transmittance in the infrared range and reflectance in the visible range, and sometimes for reflectance in the IR range. For reflectance, the zero-line correction for one PPG's older instruments has increased over time. It may be due to mirrors getting dirty resulting in more "haloing" of the light. Also, on the same instrument, alignment of the light after replacement, even though they are supposed to be pre-aligned, is important to reduce the zero line since the beam nearly fills the exit port of the sphere. Even so, proper zero-line correction minimizes the effect.

There are many other potential sources of error, some of which may prove to be significant in isolated cases. Some of our colleagues have reported and quantified specific problems. For example, variations of 0.002 with laboratory temperature were observed in a long-term series of experiments. A light trap was found to have a reflectivity of 0.004. Fingerprints on a sample caused an error of 0.005. Modern instruments have internal wavelength calibrations against a line in the deuterium lamp output. We found that this is not always fail-safe and should be checked periodically with a holmium oxide filter, for example.

3. Conclusions

Our tests using an absolute transmittance standard indicate that measurements of transmittance accurate to a fraction of a percentage point should be achievable using standard equipment and no special precautions. It is recommended that international standards be upgraded to include specific statements about checks and corrections on the zero and 100% levels and on linearity. A new round robin should be conducted with these additional controls in place.

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