BRIGHTNESS MEASUREMENT

ISO brightness of fluorescent papers and indoor whiteness—proposal for illuminant

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ABSTRACT

The appearance of any object depends on the illuminating and viewing conditions. The International Lighting Commission (CIE) has defined relative power distributions of various standard illuminants. Hitherto, the measurement of paper whiteness has been linked to the D65 illuminant, although the UV content of this illuminant is higher than that of a normal indoor environment. This may lead to unrealistic whiteness values for papers containing large quantities of fluorescent whitening agents in relation to papers in which whiteness is achieved in other ways. This paper proposes that indoor whiteness be defined in relation to the CIE illuminant C. It also proposes that the definition of ISO brightness be ridigly linked to the C illuminant so that the ISO brightness of a paper containing FWA can be unambiguously measured .

Application:

Adoption of the proposal of the authors would improve measurement of whiteness and brightness of papers.

WE WISH TO PROPOSE A solution to the problem of selecting an illuminant for the measurement of indoor whiteness. This illuminant should be the CIE illuminant C.* The measurement of indoor whiteness should be based on an adjustment of the ultraviolet (UV) content through reference standards traceable to a two-monochromator system analogous to that proposed in ISO/FDIS 11475 for the determination of D65 whiteness.

We also propose that this adjustment of the UV content in the instrument illumination be included in a precise definition of the conditions under which ISO brightness of materials containing fluorescent whitening agents (FWA) should be measured.

Both issues----the definition of conditions for measuring indoor whiteness and the definition of conditions for measuring ISO brightness----are matters of increasing urgency, due to the development of new instrumentation and the increasing use of FWA in white papers. Since a greater degree of precision is necessary in a brightness value than in a whiteness value, we propose that the adjustment of the UV content in the instrument illumination should use a fluorescent reference standard having an assigned ISO brightness level rather than an assigned CIE (C/2°) whiteness value. After considering the relevant facts, we think this proposal is the most suitable and also the easiest to adopt.

The CIE whiteness equation was developed using the CIE illuminant D65. We suggest that the similarity between the C and D65 illuminants within the visible region and the closeness of their correlated color temperatures justifies using the analogous whiteness equation with the CIE illuminant C.

The senior author is the convener of ISO/Technical Committee 6/Working group 3 (ISO/TC6/WG3), which is the working group for the optical properties of pulps, papers, and boards. The working group supports this proposal. The authors are also responsible for the optical calibration service at the Swedish Pulp and Paper Research Institute (STFI). This is an ISO/TC6 authorized laboratory for issuing ISO reference standards of level 3 (IR3) according to ISO 2469 and the provisions of ISO 4094.

BACKGROUND

A task facing ISO/TC6/WG3 for a long time has been the need for a method of measuring "indoor whiteness," i.e. a whiteness value that ranks papers according to their normal appearance in an indoor environment *(1)*. The method for determining CIE whiteness (D65/10°), that is now virtually approved as an international standard designated ISO/FDIS 11475, is a valuable step forward in this field of standardization. A problem is however that the standard may rank papers unrealistically if they are to be used in an indoor environment where the UV content of the illumination is much less than that in the D65 illuminant.

To draft a method for indoor conditions is easy in so far as it parallels the work in the preparation of ISO/FDIS 11475. Such a draft method is now undergoing balloting as ISO/DIS 11476. Two problems have however delayed the task:

- The need to define an illuminant that is relevant to the measurement of whiteness under indoor conditions
- The need to decide upon a routine for adjusting the relative UV content of the illumination in the sphere.

The appearance on the market of

*CIE: Commission Internationale d'Eclairage several new instruments and the need to unite several different requirements in a unified routine has led to a situation where it has become clear that the measurement of an indoor whiteness property can advantageously be linked to the CIE whiteness (C/2°) function. It has also become clear that ISO brightness can be approximately defined as the value obtained with a UV setting associated with the CIE illuminant C.

This document describes experiments designed to investige the impact of this proposal, but first it lists the various constraints that have led to the conclusion that this is the best proposal that can be made.

CONSTRAINTS ON DEVELOPING THE SYSTEM

There is no agreed definition of an indoor illuminant, and it cannot be expected that CIE will agree on any such definition. There is nevertheless an urgent need in the paper industry to define an illuminant representing the indoor conditions under which paper is sold, bought, and used. This is particularly important for the assessment of paper whiteness where the emphasis is on the evaluation of different papers to rank them correctly regarding their appearance under conditions of use. The difficulty is associated with the use of FWAs which contribute to whiteness to an extent dependent on the UV content of the light source. There is also a need to compare and correctly rank papers that rely to different extents on added FWA, bleaching, or dyes for their white appearance.

Jordan and O'Neill *(2)* have provided experimental evidence based on perceptual judgements to indicate that the best correlation between visual experience in an indoor situation and data derived from instrumental measurement may be obtained using a quartz-tungsten-halogen (QTH) light source, such as that in the Technidyne Micro-TB-1C.

Industry wants to measure not only whiteness but also the traditional ISO brightness. Confusion exists about ISO brightness *(3)*. A reliable method for measuring this property in the presence of FWA is necessary. Although ISO 2470 that defines ISO brightness has always contained a warning against measuring brightness when FWA is present, ISO brightness is historically linked to the Zeiss Elrepho with a lamp close to the A illuminant which does excite some fluorescence. This lamp corresponds to the QTH light source. There is thus a historical link between ISO brightness and the conditions appropriate to indoor whiteness. The concept of ISO brightness is also linked to ISO 2469 and to the normative requirement of calibration with an IR3 supplied by a laboratory authorized ISO/TC6.

When the Datacolor Elrepho 2000 instrument first became available almost a decade ago, approximate agreement with the older Zeiss Elrepho for papers containing FWA could be achieved by setting the GG395 UV adjustment filter at UV = 0. Although several persons made comparisons suggesting that a setting of approximately 30 would give better agreement, no method of standardizing this adjustment was possible. The suggestion to use UV = 0 was the only unambiguous advice that could be offered.

The preliminary version of the Technidyne ColorTouch assumes that the user needs to measure a brightness value corresponding to that given by the Micro-TB-1C. A facility is provided that permits the UV adjustment filter to be set at a position that enables the instrument to give such a QTH brightness value. This means that the user requires from an authorized laboratory a reference standard IR3 to which an official, so-called QTH brightness value has been assigned. The authorized laboratory therefore requires new routines defining exactly how to establish the traceability of a QTH brightness value.

Setting the position of the UV adjustment to measure QTH brightness as a step towards creating a basis for measuring an indoor whiteness level as advocated by Jordan and O'Neill *(2)* introduces a major problem. The fluorescence emission of the FWA relates to the actual illumination on the sample. If an instrument is adjusted so that the illumination matches a given illuminant, the only whiteness value that can logically be calculated is the whiteness value associated with that illuminant. If an instrument is adjusted to agree with a QTH illuminant, calculating the CIE whiteness (C/2°) or CIE whiteness (D65/10°) gives nonsensical information. The only whiteness that is logically acceptable is QTH whiteness, and this requires standardization of a QTH illuminant.

Now that the Datacolor Elrepho 3000 is available, paper mills are asking for calibration standards with an assigned value that will bring the Datacolor 3000 into agreement with the Elrepho 2000 at UV = 0. This would be a standard with an assigned brightness value or whiteness value which is not rigorously defined. It is not possible for an authorized laboratory to issue reference standards using a poorly defined traceability to a particular E2000 instrument with undefined characteristics at a UV = 0 setting.

Mills now require reference standards to bring an E3000 instrument into agreement with an E2000, reference standards with a brightness value to bring a ColorTouch instrument into agreement with a Micro-TB-1C, and reference standards to bring an Elrepho 3000 into agreement with a ColorTouch. For an authorized laboratory to agree to this demand and to support the proliferation of a host of different standards would be detrimental to the task of standardization and outside the scope of its authorization. We make an important step forward if we realize that all these desires represent a need for the same thing—a single reference standard that permits adjustment of the UV content of the illumination reaching the sample in the instrument so that it is possible to measure both ISO brightness and indoor whiteness.

A system for the preparation of reference standards must be fully traceable to unambiguous and internationally defined and approved sources. It is not possible to build up an international calibration system based on a UV = 0 setting in an arbitrary instrument of the E2000 type or a QTH brightness value obtained in an arbitrary instrument of the Micro-TB-1C type.

Traceable calibration can best be achieved using total radiance factor data for a fluorescent transfer standard computed for a given illuminant function from data derived in a two-monochromator system. Such equipment is available at Bundesanstalt fur Materialforschung und prufung (BAM) *(4)*, National Physical Laboratory (NPL), and National Research Council of Canada (NRC) *(5)*.

The illuminant function that corresponds most closely to the QTH source and the UV = 0 condition in the E2000 appears to be the CIE illuminant C. The adoption of the C illuminant as the basis for setting the instruments to measure ISO brightness and indoor whiteness should be readily acceptable within the paper industry. It appears similar to the situation that became familiar in the Zeiss Elrepho. Although the ISO brightness function relates to a filter and an incandescent lamp source and does not specifically involve any illuminant or observer function, mill personnel have often mistakenly been convinced that brightness as measured in the Zeiss Elrepho is a C/2° function. In the Micro-TB-1C, the whiteness value given is the C/2° whiteness, the argument being that the filters in cooperation with the lamps, etc, represent C/2° conditions although the QTH source is closer to the A illuminant. Similarly, the only whiteness value that can logically be computed from Zeiss Elrepho data is C/2° whiteness because of the FMX/C, FMY/C, and FMZ/C filters.

Sample F1	Whiteness, W	Tint, T_W	Brightness
C/2°	107.2	-0.64	90.6
A/2°	100.9	-1.90	94.3
D50/2°	120.7	-0.43	98.4
D65/10°	136.6	-0.32	104.8

I. Whiteness, tint, and brightness values for sample F1

FLUORESCENT TRANSFER STANDARDS

Recent trials at STFI used two-monochromator data provided by BAM *(6)*. Samples were sent to BAM for evaluation, and the total radiance factor data at 10 nm intervals were supplied corresponding to the A, C, D50, and D65 illuminants. From the data for sample F1 after appropriate adjustment (x 0.977) for the difference in photometric level between BAM and STFI (traceable to Physikalische-Technische Bundesanstalt, PTB), the whiteness values given in **Table I** were calculated using the CIE whiteness equation and tristimulus values calculated using table 6 of ASTM E308-95. The brightness values were calculated using the values of the ISO brightness function given in the latest draft version of ISO/DIS 2470. No adjustment was made for any anisotropy in sample F1.

These whiteness values were used to adjust the Elrepho 2000 to various levels *(6)*. Note that the use of the CIE whiteness function with the A/2° and D50/2° radiance factor data is a question of establishing an operative routine. It should not be interpreted as meaning that the values indicate the perceptual whiteness of sample F1 in these different environments.

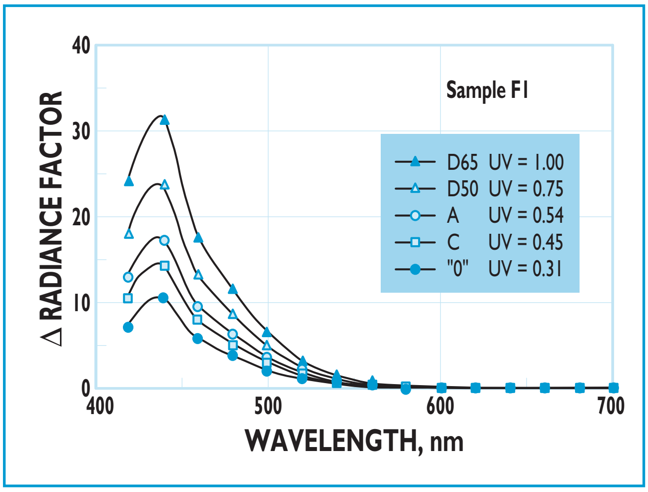
COMPARISON OF DIFFERENT ELREPHO 2000 SETTINGS

Fourteen samples with different whiteness and brightness levels were measured in different instruments under different conditions as follows:

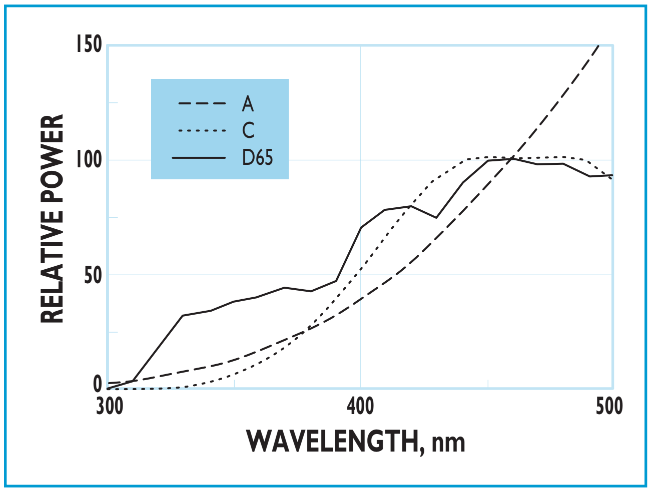
(a) The STFI reference Zeiss Elrepho instrument
(b) An E2000 instrument with setting UV = 0
(c) A Micro-TB-1C instrument
(d) E2000 instrument using F1 to adapt to C/2° whiteness (UV filter = 24.0)
(e) An E2000 instrument using F1 to adapt to A/2° whiteness (UV filter = 31.0)
(f) An E2000 instrument using F1 to adapt to D50/2° whiteness (UV filter = 44.0)
(g) An E2000 instrument using F1 to adapt to D65/10° whiteness (UV filter = 64.5).

Note that the UV adjustment filter operates so that the filter settings can in no sense be interpreted as representing the percentage of the UV radiation entering the sphere. The relationships between the UV contents of the different settings are better given by an analysis of the spectral radiance factor data for sample F1 in these different settings.

Figure 1 shows the fluorescence component of the radiance factor spectra, i.e., the difference between the spectral radiance factor curve at the stated setting and the spectral radiance factor curve when the fluorescence is eliminated using a GG420 filter. When this filter is used, no measured value can be obtained at 400 nm. The curves therefore begin at 420 nm.



1. Fluorescence component of spectral radiance curves for UV settings corresponding to different illuminants in the E2000 instrument



2. Relative power distributions of the A, C, and D65 illuminants normalized with respect to power at 460 nm

The relative UV contents in these different situations have been assessed by a simple numerical integration of the areas under these curves. The values in the table are given in relation to the D65 setting that has been set at 1.00. Note that the proportion of the UV radiation required to meet the conditions for the A illuminant is higher than the proportion required to meet the requirements for the C illuminant.

This may seem surprising, but the spectral power curves traditionally shown in all textbooks are misleading in this respect. They are relative distribution curves that arbitrarily intersect at 550 nm. When these curves are redrawn to intersect at the wavelength of 460 nm at which brightness is measured, the relationships between them in the UV region are very different as **Fig. 2** shows. It is then easier to understand the results presented in Fig. 1.

Note also that the UV content of the D50 illuminant is approximately midway between the contents associated with the C and the D65 illuminants. This emphasizes the fact that the UV component of the D50 illuminant is much too large to justify the choice of this illuminant as a representation of an indoor illuminant.

The E2000 was controlled by an external computer. All photometric calibrations were made using a Japanese opal designated ST20060. Depending on the translucence and surface characteristics of the material, there are always problems in achieving a reliable photometric transfer between different instruments. We usually recommend that the transfer between instruments should use paper rather than an opal or other tablet. The use of the opal was motivated in this case by STFI's status as an ISO/TC6 authorized laboratory, which means that it is necessary to consider what happens with different instruments when they are calibrated with an ISO reference standard of level 2 (IR2) from PTB or NRC. The Japanese opal used here was a secondary working standard based on a PTB calibration and not the primary PTB standard. Sample A19 is an STFI non-fluorescent paper reference standard. The constancy of the data for this sample in the various tables indicates that there is no great problem associated with the opal.

The adjustments were made using whiteness values calculated according to table 6 of ASTM E308-95, and the measured values were calculated using the same tables.

CIE whiteness

Table II shows the whiteness values obtained. In the last four columns, the whiteness values have been calculated using illuminant functions corresponding to the illuminant to which the illumination has been adjusted. In the E2000 with setting UV = 0, the weighting functions corresponding to the C/2° conditions have been used. The whiteness values given by the Micro-TB-1C are also related to C/2° conditions. The data are single values only.

In each column, data are presented for F1 at the beginning and end of the series to show the stability of the instrument during each measurement series. In this series of samples, A19 was the only nonfluorescent paper. E00 was a semi- glossy carton board. All other samples were matte fluorescent papers.

Determination of brightness

In this study, the brightness was a vital point of interest. **Table III** shows the results. These values were calculated using the ISO function that has an effective wavelength of 457 nm and a width at half height of 44 nm. Three features in this table are worth mentioning:

- Brightness values in the Micro-TB-1C instrument are slightly higher than those obtained with the Zeiss Elrepho. This indicates that the UV content in the Technidyne lamps is slightly higher than that in the Elrepho lamps.

Sample	E2000 UV = 0	Micro-TB-1C	E2000 C/2°	E2000 A/2°	E2000 D50/2°	E2000 D65/10°
F1	99.2	102.4	107.1	101.0	120.8	136.4
E00	64.1	64.2	66.4	75.0	72.6	74.5
624	75.3	79.0	82.1	86.7	94.9	107.1
622	74.6	77.8	80.6	85.6	91.2	101.3
D7	77.9	81.3	84.6	88.3	96.7	109.2
597	85.1	88.0	89.7	89.3	97.7	106.4
620	82.6	86.3	90.0	90.8	102.7	116.7
B9	83.4	86.7	91.9	92.4	106.8	122.3
F3	88.1	90.8	94.1	91.7	103.7	115.2
621	87.3	90.8	96.4	95.2	111.9	128.3
F40	91.7	95.3	98.6	94.8	109.1	122.4
A19	81.4	81.6	81.4	87.9	89.5	81.4
E7	93.2	97.0	102.2	99.0	117.2	134.7
X19	110.2	113.2	119.9	107.2	134.3	152.4
Z19	95.3	97.0	98.5	96.4	103.4	109.7
F1	99.0	102.5	107.1	101.0	120.8	136.4

II.CIE whiteness values

Sample	Zeiss Elrepho	E2000 UV = 0	Micro-TB-1C	E2000 C/2°	E2000 A/2°	E2000 D50/2°	E2000 D65/10°
F1	91.4	90.2	92.7	92.6	94.4	98.4	103.5
E00	75.6	75.6	75.9	76.1	76.6	77.5	78.6
624	82.8	81.8	83.4	83.7	85.1	88.0	91.6
622	83.1	81.9	83.4	83.6	84.6	87.0	90.1
D7	84.8	83.7	85.4	85.6	86.9	89.7	93.5
597	85.2	84.5	85.6	85.8	86.7	88.7	91.2
620	85.9	84.8	86.7	86.9	88.3	91.6	95.6
B9	86.2	84.9	87.1	87.3	89.2	92.9	97.8
F3	86.2	85.5	86.8	87.1	88.3	90.9	94.2
621	87.4	85.9	88.3	88.5	90.5	94.5	99.7
F40	87.4	86.4	88.3	88.3	89.7	92.6	96.4
A19	89.4	89.6	89.7	89.6	89.5	89.5	89.5
E7	91.2	89.9	92.3	92.5	94.5	98.8	104.2
X19	93.1	91.7	94.4	94.7	96.9	101.5	107.3
Z19	93.4	93.1	94.4	94.1	94.7	96.2	98.1
F1	91.4	90.1	92.7	92.6	94.4	98.4	103.5

III. Brightness values

Sample	E2000 UV = 0	Micro-TB-1C	E2000 C/2°	E2000 D50/2°	E2000 D65/10°
F1	-1.76	-2.39	-1.87	-1.41	-1.37
E00	-2.30	-2.75	-2.32	-3.08	-1.87
624	-2.73	-3.33	-2.80	-3.14	-2.53
622	-2.65	-3.19	-2.76	-3.21	-2.49
D7	-2.58	-3.09	-2.68	-2.89	-2.63
597	-0.28	-0.76	-0.40	-0.35	-0.19
620	-1.81	-2.36	-1.92	-1.87	-1.99
B9	-1.88	-2.56	-1.97	-1.70	-1.76
F3	-1.25	-1.68	-1.34	-1.11	-1.30
621	-2.24	-2.94	-2.36	-2.17	-1.99
F40	-2.42	-2.93	-2.47	-2.52	-2.17
A19	-1.33	-1.41	-1.32	-1.92	-1.16
E7	-1.69	-2.27	-1.84	-1.36	-1.90
X19	-1.96	-2.64	-2.05	-1.30	-1.50
Z19	0.16	-0.26	0.09	0.41	0.07
F1	-1.77	-2.37	-1.88	-1.41	-1.37

IV. CIE tint values

Sample	B_F	Filter adjustment based on CIE whiteness E2000	E3000	Color Touch	Micro-TB-1C	Filter adjustment based on ISO brightness E2000	E3000	Color Touch
C2X	10,3	96.0	95.8	96.9	95.1	97.0	96.9	97.0
E00	1,8	76.3	75.6	76.0	75.8	76.5	75.9	76.0
624	7,0	84.2	83.6	84.8	83.2	84.9	84.6	85.0
622	5,9	84.4	84.0	85.0	83.8	85.0	84.9	85.2
D7	7,3	86.7	86.3	87.3	85.9	87.5	87.4	87.7
597	4,8	86.5	86.1	86.8	85.9	87.1	86.9	87.2
620	7,9	87.9	87.5	88.7	87.0	88.8	88.8	89.0
B9	9,7	88.6	88.0	89.6	87.5	89.7	89.6	90.1
F3	6,7	88.0	87.7	88.6	87.4	88.8	88.7	88.8
621	10,7	89.9	89.4	91.1	88.7	91.1	91.0	91.6
F40	7,9	89.3	88.8	90.1	88.7	90.2	89.8	90.4
A19	0,0	89.9	89.7	89.7	89.9	89.9	89.7	89.8
E7	10,8	93.8	93.4	94.9	92.7	94.9	95.0	95.5
X19	12,1	95.8	95.4	96.9	94.5	97.1	97.1	97.5
Z19	4,8	94.6	94.2	95.2	94.8	95.0	94.6	95.3
C2X	10,3	96.0	95.8	96.9	95.1	97.0	96.9	97.1

V. Brightness values

Sample	W_F	Filter adjustment based on CIE whiteness E2000	E3000	Color Touch	Micro-TB-1C	Filter adjustment based on ISO brightness E2000	E3000	Color Touch
F1	30.5	112.3	112.3	112.4	105.9	115.30	113.55	112.71
E00	8.7	66.8	65.4	65.1	64.4	67.80	65.65	65.57
624	23.4	83.7	83.1	83.6	78.4	86.40	84.93	84.53
622	19.5	82.8	82.3	82.6	78.6	85.20	83.88	83.50
D7	23.0	87.9	87.6	87.7	82.9	90.80	89.86	89.22
597	15.2	91.6	91.4	91.1	88.5	93.60	92.75	92.31
620	24.8	93.1	92.9	93.1	87.3	96.30	94.78	94.56
B9	30.0	95.4	94.6	95.5	87.9	99.10	97.67	97.30
F3	21.0	96.7	96.4	96.5	91.9	99.20	98.29	97.60
621	32.9	100.2	99.3	100.7	92.0	104.10	102.35	102.35
F40	25.4	101.4	100.6	100.9	96.3	104.20	102.31	102.31
A19	0.1	81.9	81.8	81.4	82.2	81.80	81.57	81.83
E7	32.1	105.8	105.6	106.2	98.2	109.60	108.45	108.09
X19	35.4	122.8	122.1	122.7	113.2	126.80	124.76	124.56
Z19	15.2	99.8	98.5	99.4	97.6	101.20	98.78	99.97
F1	30.5	112.3	112.3	112.3	105.9	115.30	113.60	112.92

VI. CIE whiteness values

- Values for the Micro-TB-1C and for the E2000 adjusted to C/2° conditions are very similar. They are also close to those for the Zeiss Elrepho.
- In the last four columns, brightness increases as expected with increasing UV content in the illumination. The values are in all cases much higher than the traditional Zeiss Elrepho and Micro-TB-1C values. This provides a strong indication that an adjustment to A or D50 illuminant conditions would not be an acceptable way of simulating indoor conditions.

These data strongly suggest that a setting closely corresponding to the QTH situation can be achieved by adjusting the UV content of the radiation with respect to the CIE whiteness (C/2°) value to correspond to the C illuminant.

CIE tint values

Table IV shows the tint values corresponding to the CIE whiteness values in Table II. The tint values for the A illuminant are absent because the software available lacked this function. There is systematic pattern in the shifts among the first three columns.

Sample	$T_{W(F)}$	Filter adjustment based on CIE whiteness E2000	E3000	Color Touch	Micro-TB-1C	Filter adjustment based on ISO brightness E2000	E3000	Color Touch
C2X	-0.28	-1.00	-0.30	-0.46	-1.64	-1.13	-0.97	-0.10
E00	0.08	-2.46	-1.80	-2.26	-2.87	-2.49	-1.21	-1.73
624	-0.08	-2.91	-2.30	-2.53	-3.44	-2.99	-2.12	-2.07
622	-0.13	-2.73	-2.11	-2.38	-3.28	-2.80	-1.89	-1.90
D7	-0.17	-2.61	-2.07	-2.29	-3.05	-2.67	-1.94	-1.78
597	-0.19	-0.38	0.27	-0.15	-0.94	-0.44	-0.03	0.33
620	-0.25	-1.95	-1.38	-1.52	-2.38	-2.04	-1.28	-1.06
B9	-0.05	-1.92	-1.36	-1.42	-2.47	-1.98	-1.46	-0.92
F3	-0.21	-1.30	-0.70	-0.96	-1.67	-1.36	-1.00	-0.46
621	-0.61	-2.34	-1.68	-1.82	-2.94	-2.42	-1.97	-1.35
F40	-0.23	-2.40	-1.74	-1.95	-2.99	-2.49	-2.10	-1.52
A19	-0.04	-1.26	-0.70	-1.27	-1.46	-1.26	-0.34	-0.73
E7	-0.24	-1.82	-1.24	-1.32	-2.35	-1.88	-1.59	-0.82
X19	-0.17	-1.97	-1.28	-1.30	-2.55	-2.07	-2.26	-0.93
Z19	-0.14	0.12	0.75	0.43	-0.27	0.07	0.57	0.90
C2X	-0.29	-1.00	-0.29	-0.47	-1.61	-1.14	-1.00	-0.11

VII. CIE tint values

Intermediate conclusions

Adjustment using the C illuminant is not perfect. Apart from the variations among the first three columns in Table III, reference to Table I shows that adjustment to the C illuminant with respect to CIE whiteness does not give the true ISO brightness value obtained by direct calculation based on the BAM radiance factor data. Since industry wants accuracy and high precision when measuring ISO brightness, we therefore consider that a better solution might be to adjust the UV content of the illumination not with a CIE whiteness value but with a brightness value calculated from the primary spectrofluorimetric data for the C illuminant. Part of the problem is that we have only one degree of freedom with which to make adjustments, e.g., either a whiteness value or a brightness value. We cannot therefore achieve full agreement on all the tristimulus values. Although it may be possible to trim the light sources more, the use of a sphere geometry and the interaction between sample emission and source within the sphere may mean that full agreement is indeed theoretically impossible.

MEASUREMENTS WITH NEW GENERATION INSTRUMENTS

The vital question is how good is the agreement among the new generation of instruments when the UV adjustment is made in this manner. As a continuation of this study, we made measurements on the Datacolor Elrepho 3000 and on the Technidyne ColorTouch. Neither the Nippon Denshoku PF10 nor the Conrex Autoelrepho that are advertised as conforming to ISO 2469 were available for this study. In contrast to the earlier study, this comparison was made after the change in UV adjustment level announced by STFI in late 1997.

Instrument calibration was carried out with the same Japanese opal (ST20060). UV adjustment was made using sample C2X having a calculated CIE whiteness (C/2°) value of 112.3 and a calculated brightness (C/2°) value of 97.0.

The values for the CIE whiteness (C/2°), W, were calculated using the equation:

$$W = Y + 800(x_n - x) + 1700(y_n - y) \quad (1)$$

where

Y = tristimulus y-value for the sample for C/2° conditions

x, y = chromaticity coordinates for the sample

x_n, y_n = chromaticity coordinates of the perfect reflecting diffuser under the illumination and observer conditions specified (for C/2° conditions, x_n = 0.3101 and y_n = 0.3162).

The green/red tint value, T_W, was calculated as

$$T_W = 1000(x_n - x) - 650(y_n - y) \quad (2)$$

The limiting conditions for the material to be white are here assumed the same as those published for the D65/10° conditions:

$$40 < W < (5Y - 280) \quad (3)$$

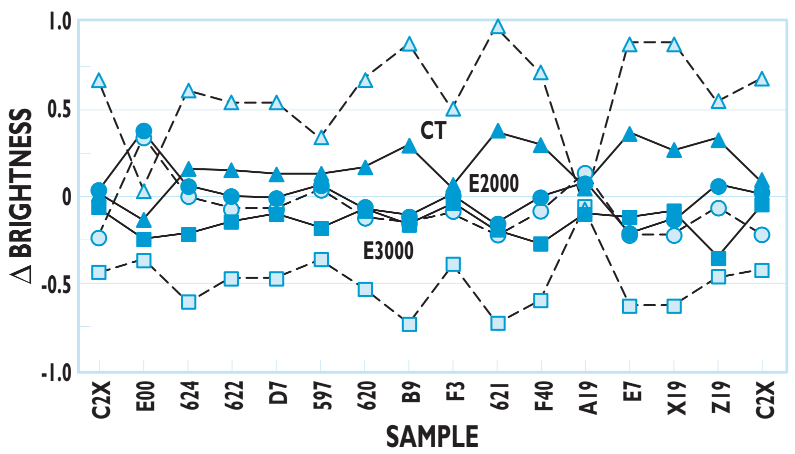
and

$$-3 < T_W < 3 \quad (4)$$

Since neither of the instruments used was then programmed to adjust the filter using a C/2° whiteness value or a brightness value, the adjustment used parameters that these instruments recognized until the correct setting resulted.

Sample	ΔW (CT - E3)	ΔW (E3 - E2)	ΔW (CT - E2)	ΔB (CT - E3)	ΔB (E3 - E2)	ΔB (CT - E2)
C2X	-0.8	-1.8	-2.6	0.1	-0.1	0.0
E00	-0.1	-2.1	-2.2	0.1	-0.6	-0.5
624	-0.4	-1.5	-1.9	0.4	-0.3	0.1
622	-0.4	-1.3	-1.7	0.3	-0.1	0.1
D7	-0.6	-0.9	-1.6	0.2	-0.1	0.1
597	-0.4	-0.8	-1.3	0.3	-0.2	0.1
620	-0.2	-1.5	-1.7	0.2	0.0	0.2
B9	-0.4	-1.4	-1.8	0.5	-0.1	0.4
F3	-0.7	-0.9	-1.6	0.1	-0.1	0.1
621	0.0	-1.8	-1.8	0.6	0.0	0.5
F40	0.0	-1.9	-1.9	0.6	-0.3	0.3
A19	0.3	-0.2	0.0	0.1	-0.2	0.0
E7	-0.4	-1.1	-1.5	0.5	0.1	0.6
X19	-0.2	-2.0	-2.2	0.3	0.1	0.4
Z19	1.2	-2.4	-1.2	0.7	-0.4	0.3
C2X	-0.7	-1.7	-2.4	0.1	-0.1	0.1
Mean abs. diff.	0.4	1.5	2.0	0.3	0.2	0.3

VIII. Whiteness and brightness differences



3. Brightness differences between an E2000, E3000, and CT instrument after adjustment to the C illuminant using sample C2X with an assigned brightness value [Open symbols and broken lines indicate differences if the adjustment to the C illuminant is made using an assigned CIE (C/2°) whiteness value.]

The adjustments in relation to CIE whiteness value was made using ASTM E308-95 functions. Data for the Technidyne ColorTouch came from an instrument using a GG395 filter for the UV adjustment.

Brightness

Table V gives the brightness values obtained in the various instruments after adjustment of the UV content of the illumination to match the CIE illuminant C. The figures in italics are the brightness values obtained after adjustment of the three abridged spectrophotometers to agree with the assigned CIE whiteness value of sample C2X. The final three columns are the brightness values obtained after adjusting the three spectrophotometers to agree with the assigned brightness values of sample C2X. Agreement among these three instruments is obviously much better in the latter case. The agreement with the Micro-TB-1C with no adjustment is poorer. The fluorescence contribution to the brightness (B_F) is also shown here calculated as the difference between the brightness value with the illumination adjusted to the C illuminant and the brightness value of the substrate obtained by eliminating the fluorescence effect with a 420-nm cut-off filter.

CIE whiteness

Table VI gives whiteness data after adjustment of the three spectrophotometers. As in the previous table, the data in italics are the results obtained after adjustment using the CIE whiteness value. The figures in the last three columns are those obtained after an adjustment using the brightness value. The main interest is in the last three columns and the potential for achieving agreement between the Elrepho 2000, Elrepho 3000, and ColorTouch using this technique, but the agreement obtained with the Micro-TB-1C is also a matter of interest.

To provide a complete picture of the characteristics of the samples in this test, the values of the fluorescence component (W_F) associated with the C/2° whiteness are also given. These were obtained by subtraction from the whiteness value of the value obtained for the substrate after elimination of the fluorescence effect with a 420-nm cut-off filter.

CIE tint values

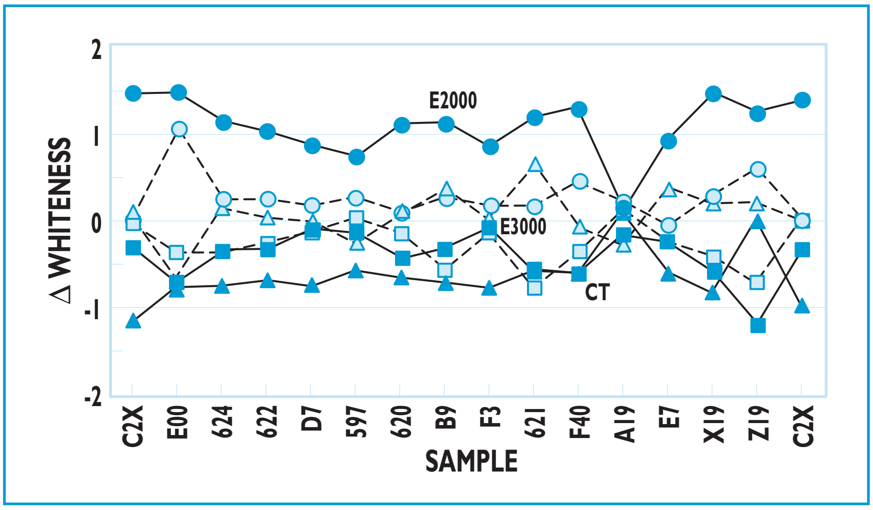
Table VII gives corresponding tint values after adjustment of the UV content of the illumination. The values obviously depend upon the parameter chosen for the filter adjustment. The fluorescence contribution to the tint ($T_{W(F)}$) is the change in tint from that associated with the base substrate to that obtained when an FWA is added and excited by a source corresponding to the C illuminant.

Differences between instruments

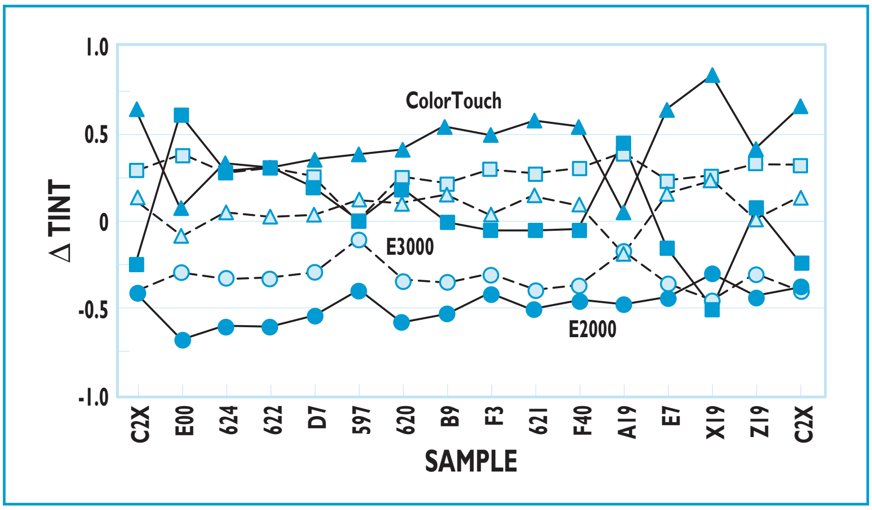
Many factors require consideration in an exhaustive analysis of the data. This analysis only considers the differences in whiteness and brightness in **Table VIII** between the ColorTouch, E3000, and E2000 instruments after adjustment using the brightness values. The table also shows the mean absolute differences. The variations among the instruments regarding brightness values are uniform. In the case of the whiteness values, the two modern instruments are in general in closer agreement with each other than with the older E2000 instrument.

Although the mean differences are small, there are considerable differences in some cases, particularly with samples E00 and Z19. Sample E00 is glossy, and there is a risk that differences in gloss exclusion in the three instruments may influence the results. Sample Z19 is the only sample with a positive tint value. Adding FWA to the substrate obviously alters the tint of this paper by the same amount as in the other samples. Sample E00 is the only sample except the non-fluorescent sample A19 that shows no change in tint when FWA is added to the substrate.

Although some differences seem to be due to anomalous properties of certain samples, differences in the actual characteristics of the illumination in the different instruments will also affect the results.



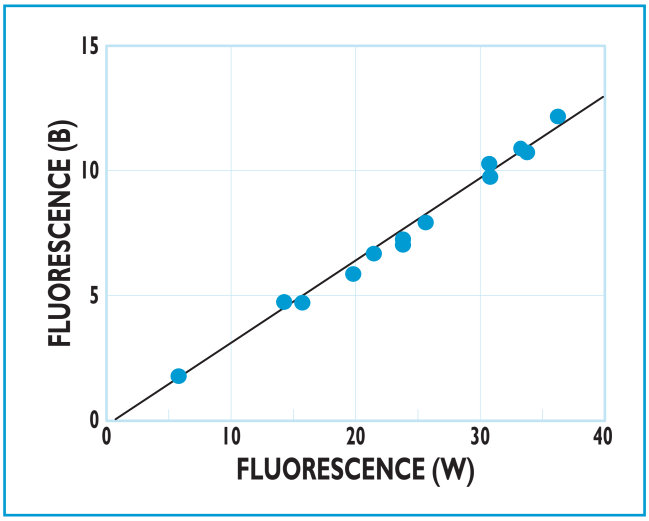
4. Whiteness differences between an E2000, E3000, and CT instrument after adjustment to the C illuminant using sample C2X with an assigned brightness value [Open symbols and broken lines indicate differences if the adjustment to the C illuminant is made using an assigned CIE (C/2°) whiteness value.]



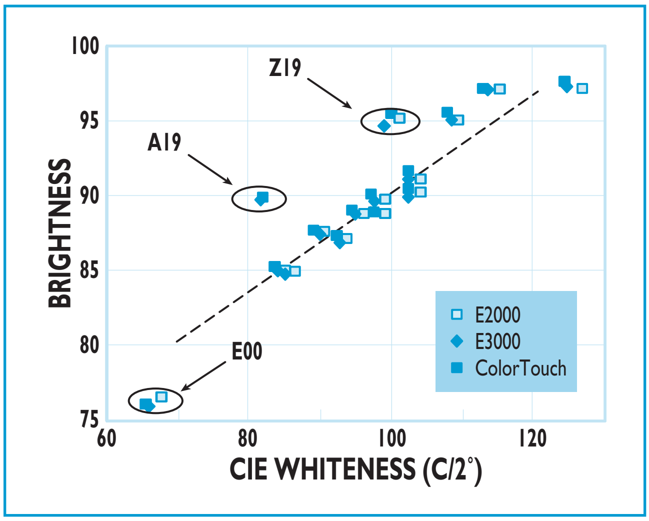
5. Tint differences between an E2000, E3000, and CT instrument after adjustment to the C illuminant using sample C2X with an assigned brightness value [Open symbols and broken lines indicate differences if the adjustment to the C illuminant is made using an assigned CIE (C/2°) whiteness value.]

Figure 3 shows the brightness differences. In this representation, the values in Table VIII have been recalculated to show for each sample the differences between the values obtained in the different instruments and the mean value for the three instruments. This figure also shows the size of the differences that would occur if the adjustment were made on the basis of the CIE whiteness value. The variations between the different instruments are unacceptably large when the adjustment uses a whiteness value, but the divergence is usually small when the adjustment is made on the basis of the brightness value.

Figure 4 shows whiteness differences plotted in the same way. In this case, agreement between the different instruments is greater if the adjustment is made using the CIE whiteness value, but most differences are within ±1.0 whiteness units from the mean even when the



6. Fluorescence component of the brightness value plotted against the corresponding fluorescence component of the CIE (C/2°) whiteness value (Calculations show that the theoretical curve is slightly curved.)



7. Relationship between the brightness and CIE whiteness (C/2°) values obtained for the 15 samples in three different instruments

adjustment is made using an assigned brightness value.

Figure 5 shows tint differences plotted in the same way. Tint differences are more a question of a systematic difference between different instruments, but there are some anomalies in this figure. The differences are smaller when the adjustment to the C illuminant is made on the basis of an assigned whiteness value rather than an assigned brightness value.

Tables V and VI show the components of the brightness and whiteness values due to FWA. **Figure 6** shows these values plotted against each other. A simple relationship obviously exists between these two parameters. No such simple relationship exists however between the total brightness and total whiteness values, as **Fig. 7** shows. This figure emphasizes that brightness and whiteness are different properties. The broken line in the figure is derived from Fig. 6 and shows the approximate relationship that would result if there were perfect agreement between brightness and whiteness.

Sample Z19 is extremely anomalous. This sample may contain a different fluorophor, and the UV adjustment may not be fully adapted to this sample. In this figure, E00 is also anomalous. Sample A19 is the only non-fluorescent sample in this series.

In the case of tint differences, there are clear displacements between the different instruments. The magnitudes of these differences depend on the size of the fluorescence component of the whiteness, W_F.

A comparison between the spectral radiance curve corresponding to the C illuminant supplied by NRC and corrected at STFI for photometric differences and the curves obtained in the Datacolor E3000 and Technidyne ColorTouch instruments after adjustment shows that all curves agree closely. The curves obtained after adjustment to an assigned brightness level are of course different from those obtained after adjustment to an assigned whiteness level. These differences and the limitation of only one degree of freedom available in the adjustment of the UV content cause the variation in tint values.

The curve for the E2000 instrument also corresponds fairly well. The fact that the whiteness values in the E2000 are computed from 20 nm data is another factor that disturbs the comparison.

CONCLUSIONS

The pulp and paper industry needs a simple standardized routine to adjust instruments for measuring an indoor whiteness function. The industry also requires a more precise definition of ISO brightness recognizing that the measurement of this property in the Zeiss Elrepho and the Micro-TB-1C instruments involves a certain degree of fluorescence excitation if the sample contains FWA.

Accepting earlier work *(2)* concerning the perception of indoor whiteness, this proposal recognizes a relationship between these two needs.

The choice of CIE illuminant C for indoor whiteness resolves the problem. UV adjustment can be achieved by a traceable calibration to a laboratory having the necessary two-monochromator equipment to provide absolute spectrofluorimetric data.

Agreement between different types of instruments is still imperfect. The precision with which brightness can be measured decreases with increasing degree of fluorescence in the sample. The proposal nevertheless provides an unambiguous procedure for adjusting instruments to measure a defined brightness.

Early agreement on this would provide a basis for instrument makers to identify those features that are essential for even greater inter-instrument agreement. Work within ISO/TC6 is proceeding in this direction by linking ISO brightness and indoor whiteness to the CIE illuminant C. Because of the industry's need for greater precision in a brightness measurement, adjustment of the UV content in the instrument illumination should be based on an assigned ISO brightness value rather than on an assigned CIE whiteness value. The ISO brightness level is established in reference instruments at the ISO/TC6 authorized laboratories on the basis of a transfer of absolute data associated with the CIE illuminant C.

The fact that the level achieved is higher than that in the Micro-TB-1C instrument could be problematic. It is not possible to correct this by merely calibrating the instrument with a fluorescent reference standard, since this disturbs the photometric level for a nonfluorescent material. Technidyne Inc. report that they have already addressed this anticipated problem by incorporating an adjustable auxiliary UV source in the Micro-TB-1C instrument. **TJ**

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LITERATURE CITED

1. Parkes, D., *Tappi J.* 72(9):95(1989).
2. Jordan, B. and O'Neill, M. A., *Tappi J.* 74(5):93(1991).
3. Bristow, J. A., *Tappi J.* 77(5):174(1994).
4. Gundlach, D., *Die Farbe* 32/33:81(1985/86).
5. Zwinkels, J. C., Gignac, D. S., Nevins, M., *et al.*, *Applied Optics* 36(4):892(1997).
6. Bristow, J. A., *Color Res. & Appl.* 19(6):475(1994).