Photometry for T5 High-Output Lamps And Luminaires

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Introduction

Fluorescent lamp technology continues its advancement with the recent development of the linear fluorescent T5 lamps. The T5 lamps become increasingly popular as ballast and luminaire manufacturers develop smaller and more energy efficient products[1]. With 5/8" diameter, T5 lamps offer better luminous efficacy when compared to T8 lamps. Also available are the high-output versions of T5 lamps (T5HO lamp) providing approximately 5000 lumens for a 4-ft lamp. The major advantage of the luminaire using the T5HO lamps is that it provides a high-lumen package in a small-profile while at the same time offering the opportunity to create better photometric performance[2].

The linear T5 and T5HO lamps are designed with an optimal operating temperature of 35°C instead of the commonly adopted temperature of 25°C for the T8 and T12 lamps. It is not the purpose of this paper to question the wisdom of designing the T5 and T5HO lamps with an optimal operating temperature of 35°C. However, concerns regarding the photometry of luminaires employing these lamps arise because of this operating temperature.

This paper will focus on the photometry of T5HO lamps and luminaires. First, we will identify the photometric issues due to different light output of T5HO lamps at different operating temperatures. Then we will report our laboratory results on the measurements of the luminous flux of T5HO lamps at 25°C and 35°C. Finally, we will propose a testing method and an abbreviated alternative method that produce the true luminaire efficiency and provides reliable photometric results for the T5HO-lamp luminaires.

Photometric Concerns with T5HO Lamps and Luminaires

The authors have been familiar with the T5HO lamp since this product was first introduced in the United States about four years ago. Since that time, we have conducted a tremendous amount of photometric testing on the T5HO lamps and T5HO-lamp luminaires. We are also very much aware of the luminous flux data reported by the lamp manufacturers – namely, that the T5HO lamp produces optimal light output at 35°C ambient temperature and decreases more than 10% from the optimal light output at 25°C ambient temperature. Our experience with the T5HO lamps, however, indicates a smaller difference in the light output these two temperatures. As a matter of fact, in some of the earlier tests showed that individual lamps actually produced higher luminous flux at 25°C than at 35°C ambient temperature.

Based on IESNA LM-41-98 standard[3], photometric measurements of the luminaire are to be performed at an ambient temperature of 25°C. Hence, the bare lamp luminous flux is measured at 25°C ambient temperature. However, the temperature of a T5HO lamp operated within the luminaire housing may exceed 25°C. This difference in operating temperature between the bare lamp at 25°C and the lamp operating inside the luminaire housing can produce incorrect photometric results and introduce unexpected consequences in photometric measurements of T5HO-lamp luminaires. First, it may generate over-rated or under-rated luminaire light output depending on what lumen rating is used for photometric calibration. Second, by using current testing procedure luminaire efficiency could exceed 100%. It is a common understanding in all scientific disciplines that efficiency is never greater than 100%[4]. An over 100% luminaire efficiency in lighting science clearly violates such understanding. Finally, our test results indicate that the difference in light output between 25°C and 35°C among different T5 lamps is not consistent. For example, one lamp may have a light output difference of 8% between 25°C and 35°C while another lamp may have a difference of 3%. Therefore, the photometric result of a luminaire will be inconsistent, and it is dependent on the characteristics of the specific testing lamp. Hence, difference laboratories with different test lamps will report different photometric results for the same luminaire.

Luminous Flux of T5HO Lamps at Ambient Temperatures of 25°C and 35°C

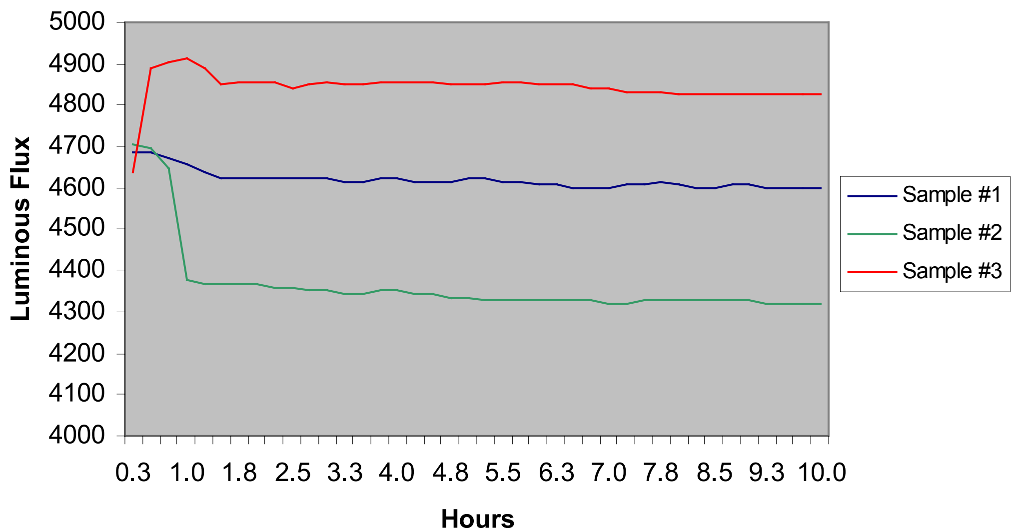
T5HO lamps have now been on the market for some time, and are in production from all major lamp manufacturers. During the past few years, we have seen that the T5HO lamps have developed sufficiently and are of consistent quality. It is fair to assume that the performance of the latest T5HO lamps is typical and representative. Thus, we have decided to further investigate the luminous flux of the latest T5HO lamps at ambient temperatures of 25°C and 35°C. We selected these two temperatures because all standard photometry performed in laboratories are at 25°C ambient temperature, while the operating temperature of the T5HO lamp is optimized at 35°C. Our purpose was to find the magnitude of the difference in the luminous flux of the T5HO lamps between these two temperatures.

Thirty T5HO lamps were randomly selected from the most recent shipments (September – December 2000), with ten lamps chosen from each of the three lamp manufacturers. These lamps were 54 watts and 1.1632 meters (45.8”) in length. They were all aged for over 100 hours in horizontal burning position and were operated with commercially available ballasts.

The measurements were taken in the photometric laboratory. Normally, our laboratory ambient temperature is held to 25°C. The 35°C ambient temperature was achieved and held steady by the means of positioning several radiator heaters around the perimeter of the photometric laboratory. The radiators were purposely located far away from the photometer so as to eliminate any air movement caused by air convection. This also created a much smoother temperature gradient around the photometer. Measurements confirmed that the laboratory temperature was held at 25°C and 35°C to within ±1°C. In addition, the temperature within a 36 inches space in any direction surrounding the area where the lamp would be tested was maintained at a stabled testing ambient temperature with a variation of ±0.1°C.

Before the measurement was performed, the lamps were stabilized in horizontal burning position at the testing ambient temperature with commercially available ballasts. To ensure that the test lamp reached their state of thermal equilibrium and that lumen-output variation was minimal, a test was conducted to determine the relationship between the relative light output and the lamp stabilization time. One lamp from each of the three groups was selected at random for the test. The lamps were mounted in a horizontal test position. Measurement data were taken at fifteen-minute intervals for the first two hours and every half-hour thereafter for a total period of 10 hours. Figure 1 shows the results of the measurements of three lamps. It is clear that the lamps were stabilized and the light-output variation of the lamps was within ±0.5% after about two hours of operation.

Figure 1
Luminous Flux of Three T5HO lamps



After this test was performed, we stabilized all the T5HO lamps for four hours before taking measurements so as to give us added confidence that the lamps were stabilized. The luminous flux of the T5HO lamp was determined by measuring the perpendicular intensity of the lamp with a photo-detector located thirty feet from the lamp. After the lamp(s) was stabilized for four hours, it was carefully and quickly mounted to the center of the photometer. The total time taken for the transfer of the lamp was under 10 seconds. The test lamp was mounted and operational on the photometer for another half-hour before a first reading was recorded. Subsequently, a second reading was taken fifteen minutes later. A final reading was recorded at the end of one hour. The final reading was used to determine the luminous flux of the test lamp. The first two readings were used for comparison purposes only. Measurements were taken for all thirty T5HO lamps at both 25°C and 35°C ambient temperatures with total of sixty photometric readings. In no case did we find the difference between the three measurements to be greater than 0.5%. It should be noted that all the lamps were operated with the same ballast while they were mounted on the photometer. The ballast factor was assumed to be 1.0 per manufacturer's specification.

In order to determine the actual luminous flux of T5HO lamps operated at the two ambient temperatures (25°C and 35°C), absolute photometry technique was used. The total luminous flux of a T5HO lamp (F_{Lamp}) was calculated by multiplying the bare-lamp reading (I_R) with the lumen-candlepower ratio (R_{lc}) and the absolute-photometry-calibration factors (K_c), or

$$F_{Lamp} = I_R \times R_{lc} \times K_c \qquad (1)$$

where the bare-lamp reading (I_R) is the reading of the photo-detector 9.14m (30 feet) away from the lamp at a direction perpendicular to the axis of T5HO lamp. The lumen-candlepower ratio (R_{lc} = 9.19) was derived by the average value of many T5HO-lamp measurements from the photometer[5]. It is the ratio of the intensity reading of the lamp to its total luminous flux. The absolute-photometry-calibration factor (K_c) is the ratio of the rated intensity value of a laboratory certified incandescent filament standard lamp to the reading of that same standard lamp measured by our photometer. In this case K_c is equal to 0.872 at 25°C ambient temperature. Since the temperature variations would affect the performance of the photo-detector and testing equipment components, a temperature correction factor for 35°C was needed to determine an absolute-photometry-calibration factor (K_c) for photometer readings at 35°C. This was done by taking the ratio of standard lamp readings at 25°C and at 35°C. We found that the temperature correction factor for K_c at 35°C is 1.0186. Therefore, the absolute-photometry-calibration factor (K_c) is 0.8882 (0.872 x1.0186) for 35°C ambient temperature. Applying the factors to equation (1), results in

$$F_{Lamp25} = I_{R25} \times 9.19 \times 0.872$$

and

$$F_{Lamp35} = I_{R35} \times 9.19 \times 0.8882$$

where F_{Lamp25} and F_{Lamp35} are the luminous flux of the T5HO lamp at ambient temperature of 25°C and 35°C. I_{R25} and I_{R35} are the bare-lamp readings of the T5HO-lamp at ambient temperature of 25°C and 35°C respectively. In the above analysis, it is taken as a matter of fact that the luminous intensity of a standard incandescent lamp does not vary from 25°C to 35°C. We further assumed that the ballast performance also does not vary with the change of the ambient temperature from 25°C to 35°C.

The luminous flux of thirty T5HO lamps and the percentage difference of the luminous flux of these lamps between the two ambient temperatures 25°C and 35°C are shown in Table 1. Three average values of lamp luminous flux are also listed for individual lamp manufacturer.

Table 1
Luminous Flux of T5HO(54W) lamps at 25°C and 35°C ambient temperature

Group#1	25°C	35°C	Difference	Group#2	25°C	35°C	Difference	Group#3	25°C	35°C	Difference
100A	4616	4916	-6.10%	200A	4287	4622	-7.23%	300A	4792	4932	-2.83%
100B	4632	4883	-5.14%	200B	4327	4654	-7.02%	300B	4824	4981	-3.14%
100C	4696	4858	-3.34%	200C	4367	4662	-6.33%	300C	4808	4981	-3.47%
100D	4728	4948	-4.45%	200D	4383	4622	-5.15%	300D	4784	4948	-3.32%
100E	4600	4883	-5.80%	200E	4408	4720	-6.61%	300E	4800	4997	-3.94%
100F	4616	4818	-4.19%	200F	4351	4589	-5.18%	300F	4800	4965	-3.31%
100G	4584	4891	-6.28%	200G	4375	4654	-5.99%	300G	4760	4981	-4.43%
100H	4664	4883	-4.48%	200H	4343	4638	-6.35%	300H	4752	4973	-4.44%
100I	4712	4883	-3.50%	200I	4512	4638	-2.72%	300I	4744	4981	-4.75%
100J	4600	4867	-5.48%	200J	4432	4703	-5.78%	300J	4768	4997	-4.58%
Average	**4645**	**4883**	**-4.88%**	**Average**	**4379**	**4650**	**-5.84%**	**Average**	**4783**	**4974**	**-3.82%**

Normalized Average Data: 5000 lm at 35°C, 4759 lm at 25°C, Difference -4.82%

It is evident that the difference of lamp luminous flux between 25°C and 35°C is relatively small. The average difference is about 5% of all thirty lamps. Assuming that the T5HO lamp produces 100% of the luminous flux at 35°C, then at 25°C it will produce approximately 95% of the luminous flux. This difference is significantly less than the published data (more than 10%) from the lamp manufacturers. One explanation of this difference may be that our measurements were performed using a different lamp stabilization orientation than that employed by the lamp manufacturers. The data published by the lamp manufactures were measured with the lamps stabilized in a vertical position (brand-side-down) while our testing method stabilized the lamps in a horizontal position. We believe that our method is more reasonable and realistic for luminaires installed horizontally. Our stabilization orientation conforms to the way the lamp(s) is mounted in the luminaire. This difference in lamp stabilization orientation may explain the different results in luminous flux for T5HO lamps. It is our opinion that T5HO lamps are not only temperature sensitive, but they are position sensitive as well. This is similar to the compact fluorescent and HID lamps, where the luminous flux depends on the burning position (horizontal, base-up, and base-down). Therefore it may be necessary for the lamp manufacturers to provide different sets of data for different orientations of the T5HO lamps.

It is worth noting that for each lamp manufacturer, the luminous flux given for individual lamps is consistent for both 25°C and 35°C temperatures. Additionally, the difference in the luminous flux between 25°C and 35°C among individual lamps for each manufacturer is small. For example, the average difference in the luminous flux between 25°C and 35°C for group#3 is –3.82% with absolute differences ranging from 2.83% to

4.75%. However, the percentage difference among different manufacturers is much higher, from 2.83% to 7.23%. In addition, we found that the lumen-output measurements of the T5HO lamps are consistent with repeated stabilization in horizontal burning position. Table 2 shows three separate measurements for each of ten T5HO lamps. The maximum difference is within 0.5%. Finally, we did not detect any lamp that had a reversal in luminous flux between the two temperatures (a higher luminous flux at 25°C than at 35°C). These results point to the conclusions that the T5HO lamp has developed sufficiently, is proven to be of consistent quality, and the differences among individual lamps for the same manufacturer are small. It is, however, somewhat surprising that there is a noticeable difference in the luminous flux among different manufacturers.

Table 2
Repeat Measurements for the T5HO lamps

Lamps	Test #1	Test #2	Test #3	Difference
400A	4956	4940	4940	0.3%
400B	4965	4956	4948	0.3%
400C	4973	4956	4948	0.5%
400D	4989	4981	4981	0.2%
400E	4932	4924	4916	0.3%
400F	4973	4989	4981	0.3%
400G	4997	5005	5005	0.2%
400H	4948	4940	4940	0.2%
400I	4997	4981	4973	0.5%
400J	4956	4940	4932	0.5%
Average	4969	4961	4956	0.3%

Photometry of T5HO-lamp Luminaires

According to IESNA Standards[3,5,6], photometric testing should be performed at an ambient temperature of 25°C. This testing ambient temperature has been well accepted in lighting industry for many years, especially in the testing of fluorescent luminaires. Until the introduction of the T5HO lamps, almost all fluorescent lamps had an optimal operating temperature of 25°C. In the process of determining the efficiency of a luminaire, the bare-lamp light output is tested at 25°C ambient temperature. The light output of the luminaire is, however, determined by the luminous flux of the lamp(s) at Lamp Operating Temperature Inside the Luminaire housing (LOTIL). For any luminaire, LOTIL can be equal or higher than 25°C. For example, in an indirect or highly ventilated luminaire, LOTIL is at or near the ambient temperature of 25°C. On the other hand, LOTIL in a totally enclosed luminaire could be much higher than the 25°C ambient temperature. In either case, the efficiency of the luminaire is determined by the ratio of the luminous flux of the luminaire to that of the bare lamp. The efficiency value arrived in this fashion incorporates both the optical and the thermal effect due to the design of the luminaire. Traditionally, this has served us well. It makes logical sense that a luminaire that runs hotter than 25°C inside the luminaire should have a reduction in efficiency[7]. It is also comforting to know that because the optimal operating temperature of the bare lamp(s) is at 25°C, the efficiency of the luminaire will never be higher than 100% - an upper limit that a physicist appreciates.

The introduction of the T5HO lamp(s) with a higher optimal temperature, however, has created a dilemma where the reported efficiency of the luminaires can be inconsistent and go beyond 100%. There is a simple explanation: the luminous flux of the bare lamp is measured at 25°C while the luminous flux of the T5HO lamp(s) operating inside the luminaire is measured at a higher temperature. This higher LOTIL can increase the luminous flux of the T5HO lamp(s). Therefore it is possible, in some cases, that the gain in luminous flux due to higher operating temperature outweighs the loss due to optics. In cases such as this, an "efficiency" of over 100% can result.

In general, there are two factors that contribute to the "efficiency" of a luminaire. First, is the optical efficiency. This has to do with the performance of the optical design of the luminaire such as a lens or reflector. The optical efficiency by laws of physics will never exceed 100%. Second, is the thermal effect. The thermal effect is the luminous flux variation of the lamp due to the temperature change within the housing that the lamp operates. Optical efficiency of a luminaire is independent of temperature under which the luminaire is tested. Hence, a solution to the dilemma facing the photometry of T5HO-lamp luminaires is to separate the optical efficiency from its thermal effect. We propose to report the photometric performance of a T5HO-lamp luminaire at a temperature that the lamp(s) is operating within the luminaire housing, namely at LOTIL. In order to accomplish this, we need to measure and report the luminous flux of the T5HO lamp at the same temperature as it operates inside the luminaire housing. In essence what we propose is to report the optical efficiency as the efficiency of the luminaire. The actual photometric performances such as intensity distributions and zonal lumen summary are rated with the luminous flux of the T5HO lamp(s) at LOTIL. Indeed this method gives us the true photometric performance of the luminaire because it reports exactly how the lamp(s) and luminaire behave both optically and thermally. The major difference between what we propose and the existing practice is that we measure the luminous flux of the T5HO lamp(s) at the temperature that the lamp(s) actually operates within the luminaire housing rather than at the temperature of 25°C.

Practical Implementation of Proposed Method for Photometry of T5HO-lamp Luminaire

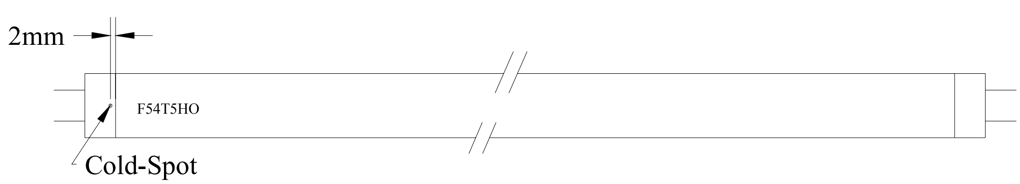
Traditionally, photometric testing of a luminaire is conducted by taking a bare-lamp reading and the measurements of the luminaire at 25°C. We do not want to burden the reader with the details on the procedure of standard photometric testing. It is assumed that all the laboratory conditions, including laboratory ambient temperature of 25°C and other proper practices, are followed. We focused only on the areas that are different between the proposed method and the existing procedure.

In the proposed method, because the bare-lamp reading is to be taken at LOTIL, the T5HO lamp(s) need to be stabilized inside the luminaire at the orientation in which the luminaire is to be installed. After a sufficient period of stabilization, the lamp(s) is quickly transferred and mounted on the photometer for a bare-lamp reading. Our tests showed that if the transfer is done within 15 seconds, we could obtain accurate bare-lamp reading at the same temperature as the lamp(s) operating inside the luminaire housing. This bare-lamp reading at LOTIL remains stable for at least two minutes before its output starts drifting to the 25°C laboratory ambient temperature.

After taking the bare-lamp reading, the lamp(s) is re-installed inside the luminaire. The photometry of the luminaire is performed in the same manner as in general practice. As a matter of fact, in order to save time one can take a photometric of the luminaire first and then take the lamp out from the luminaire and quickly record the bare-lamp reading.

An added step for the proposed method is to measure the temperature inside the luminaire housing and determine the rated luminous flux of the T5HO lamp(s) at LOTIL. We found that this is not an easy task because it is difficult to obtain consistent temperature readings inside the luminaire. More consistent data can be obtained by measuring the cold-spot temperature of the lamp (CSTL). The CSTL is located on the metallic end cap (brand side) within 2 mm from the glass as shown in Figure 2. It should be noted that technically it is the temperature of the cold spot that determines the luminous flux of a T5HO lamp(s). However, according to lamp manufacturers' literature, there is a 10°C difference between the CSTL and the ambient temperature of the lamp's operating temperature. For example, a CSTL of 45°C (113°F) translates to a LOTIL of 35°C. Due to this direct temperature correlation, the luminous flux of the T5HO lamp(s) can be determined either by LOTIL or by CSTL. Once the temperature is measured, the exact luminous flux of the T5HO lamp(s) at that specific temperature can be determined with the information of the luminous flux furnished by the lamp manufacturers. This value is the lumen rating of the T5HO lamp(s) that will be used in the calibration process of the proposed method.

Figure 2
The Typical Location of the Cold-Spot of T5HO-lamp



The final step of our proposed method is to calibrate the measured data. Using calibration procedure, luminous intensity (I) of the T5HO-lamp luminaire is computed by the product of the photometric reading of the luminaire (I_L) and the photometric calibration constant (K),

$$I = I_L \times K \qquad (2)$$

where K is the ratio of the lumen rating of the T5HO lamp(s) (F_{Lamp}) at LOTIL to the product of the lumen-candlepower ratio ($R_{LC} = 9.19$) and bare-lamp reading (I_R) at LOTIL. Then the luminous intensity value (I) of the luminaire will be:

$$I = I_L \times F_{Lamp} / (9.19 \times I_R) \qquad (3)$$

The total luminous flux (F_{lum}) from of the luminaire is determined from this intensity distribution data and zonal constants. The luminaire efficiency is the ratio of the total luminous flux of the luminaire (F_{lum}) to the lumen rating of T5HO lamp(s) (F_{Lamp}) at LOTIL, F_{lum} / F_{Lamp}.

It should be pointed out that for the proposed method, the photometry of a luminaire is independent from the luminous flux characteristic of a particular test lamp. We may use a lamp that has a very small or large luminous flux difference between 25°C and 35 °C. For example, in Table 1, lamp 200A has a luminous flux difference of 7.2% between 25°C and 35°C while lamp 300A has a difference of only 2.8%. Whichever of these two lamps that we happen to use as a test lamp does not affect the accuracy of the photometric results. This is because the efficiency that is reported by using proposed method is the luminaire optical efficiency. The optical efficiency of the luminaire is not affected by the luminous flux differences between 25°C and 35°C for that specific test lamp. Furthermore, we use the cold-spot temperature of the test lamp inside the luminaire housing simply to obtain a lumen rating of a typical T5HO lamp at that temperature with the information furnished by the lamp manufacturer. The final luminous flux of the luminaire is independent with the actual luminous flux of the test lamp, which is the beauty of the relative photometry and the proposed method.

Photometric Reports Using Proposed Method and Existing Method

To demonstrate the results of the photometric reports by using our proposed method, a T5HO-lamp luminaire was designed to provide optimal luminous flux at LOTIL. The photometry of the luminaire was performed in the standard 25°C laboratory condition. Two bare-lamp readings were recorded for the same lamp – one reading (537) at ambient temperature of 25°C, and another reading (564) at LOTIL. Assume that the lumen ratings of T5HO lamp are 4450 lumens at 25°C and 5000 lumens at LOTIL. Applying equation (3), two photometric reports are generated for the same luminaire – one with the proposed method and the other with the existing method. The results are shown in Figure 3 and Figure 4.

Report #A shows a photometric report using the proposed method. Since T5HO lamp operates at its optimal temperature inside the luminaire and the bare-lamp reading is taken at LOTIL, it generates accurate photometric results with a luminaire efficiency of 96.3%. This bare-lamp reading taken at LOTIL together with the lumen rating of a typical T5HO lamp determine the relative values of intensity distributions, zonal lumen summary and luminance data of the luminaire. The efficiency of the luminaire obtained by this proposed method can be regarded as a pure optical efficiency, and never exceeds 100%.

Figure 3

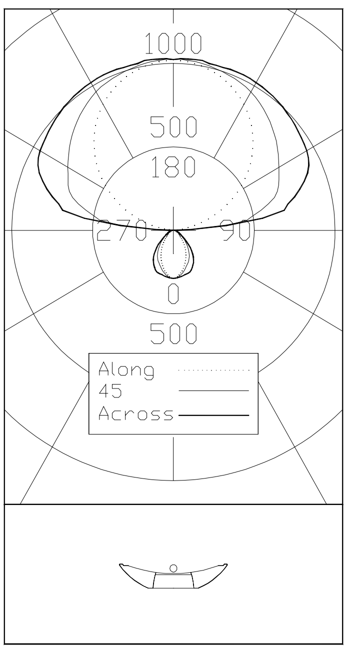
The Photometric Reports by Using Proposed Method

FAR-FIELD PHOTOMETRY

DATE: 1-24-2001

REPORT NUMBER: A

CATALOG NUMBER: ABC-1T5HO
LUMINAIRE: 9"W X 3"H STEEL INDIRECT/DIRECT LIGHT WITH WHITE PAINTED REFLECTOR AND OPAL-PERF BAFFLE
LAMP(S): 1-F54/835 RATED @ 5000 LUMENS EACH
BALLAST: QT-1X54/120PHO
MOUNTING:
LUMEN TO CANDELA RATIO USED = 9.19
TOTAL INPUT WATTS = 59.8 AT 12.0 VOLTS
THE 0 DEGREE PLANE IS PARALLEL WITH THE LAMPS.



CANDELA DISTRIBUTION

	0.0	22.5	45.0	67.5	90.0	FLUX
0	288	288	288	288	288	
5	278	281	283	286	285	27
15	236	241	253	267	275	72
25	182	190	214	246	262	100
35	123	135	168	197	217	105
45	70	88	115	136	147	86
55	43	50	63	68	72	54
65	25	31	33	37	40	34
75	15	19	21	23	24	22
85	6	9	10	12	11	12
90	5	9	15	19	18	
95	26	208	326	333	330	271
105	179	391	609	730	776	582
115	367	510	720	875	925	681
125	541	638	792	918	965	695
135	693	758	866	959	994	663
145	819	859	930	991	1015	581
155	914	937	976	1013	1027	450
165	978	989	1004	1015	1024	284
175	1014	1019	1022	1028	1030	97
180	1023	1023	1023	1023	1023	

ZONAL LUMEN SUMMARY

ZONE	LUMENS	%LAMP	%FIXT
0- 30	198	4.0	4.1
0- 40	303	6.1	6.3
0- 60	443	8.9	9.2
0- 90	512	10.2	10.6
90-120	1533	30.7	31.8
90-130	2229	44.6	46.3
90-150	3472	69.4	72.1
90-180	4304	86.1	89.4
0-180	4816	96.3	100.0

LUMINANCE DATA IN FOOTLAMBERTS

ANGLE IN DEG	AVERAGE 0-DEG	AVERAGE 45-DEG	AVERAGE 90-DEG
45	156.	256.	326.
55	117.	162.	174.
65	94.	104.	110.
75	94.	88.	77.
85	60.	71.	47.

TOTAL LUMINAIRE EFFICIENCY = 96.3 %
CIE TYPE - SEMI-INDIRECT

APPROVED BY:

TESTED IN ACCORDANCE WITH IES PROCEDURES, TEST DISTANCE EXCEEDS 25.0 FEET

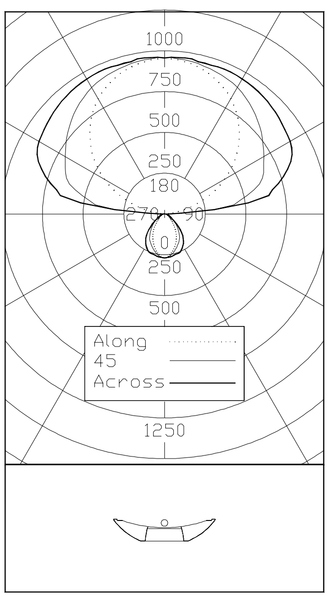
Report #B of Figure 4 shows a photometric report of the same luminaire using the existing method. In this case, the lumen rating of T5HO lamp and the bare-lamp reading are taken at 25°C ambient temperature. Since the lamp operates at a higher temperature inside the luminaire, the T5HO lamp produces more luminous flux than it produced at 25°C. When the loss of the light due to the optical property of the luminaire is less than the gain of the lamp luminous flux due to higher luminaire operating temperature, the resulting luminous flux of the luminaire is 4501 lumens and luminaire efficiency is 101.2%. These results are, of course, erroneous.

Figure 4

The Photometric Reports by Using Existing Method

FAR-FIELD PHOTOMETRY
DATE: 1-14-2001
REPORT NUMBER: B

CATALOG NUMBER: ABC-1T5HO
LUMINAIRE: 9"W X 3"H STEEL INDIRECT/DIRECT LIGHT WITH WHITE PAINTED REFLECTOR AND OPAL-PERF BAFFLE
LAMP(S): 1-F54/835 RATED @ 4450 LUMENS EACH
BALLAST: QT-1X54/120PHO
MOUNTING:
LUMEN TO CANDELA RATIO USED = 9.19
TOTAL INPUT WATTS = 59.8 AT 12.0 VOLTS
THE 0 DEGREE PLANE IS PARALLEL WITH THE LAMPS.



CANDELA DISTRIBUTION

	0.0	22.5	45.0	67.5	90.0	FLUX
0	269	269	269	269	269	
5	260	262	265	267	267	25
15	221	225	236	249	257	67
25	170	178	200	230	245	94
35	115	126	157	184	202	98
45	65	82	108	127	137	80
55	40	47	59	64	67	51
65	24	29	31	35	38	32
75	14	17	20	22	22	20
85	6	8	10	11	11	11
90	5	9	14	18	17	
95	24	195	305	311	308	253
105	168	366	569	683	725	544
115	343	477	673	818	864	636
125	506	596	740	858	902	650
135	647	709	809	896	929	620
145	766	803	870	926	949	543
155	854	876	913	947	960	420
165	914	925	938	949	957	266
175	948	953	955	961	963	91
180	956	956	956	956	956	

ZONAL LUMEN SUMMARY

ZONE	LUMENS	%LAMP	%FIXT
0- 30	185	4.2	4.1
0- 40	283	6.4	6.3
0- 60	414	9.3	9.2
0- 90	478	10.7	10.6
90-120	1433	32.2	31.8
90-130	2083	46.8	46.3
90-150	3246	72.9	72.1
90-180	4023	90.4	89.4
0-180	4501	101.2	100.0

TOTAL LUMINAIRE EFFICIENCY = 101.2 %
CIE TYPE - SEMI-INDIRECT

LUMINANCE DATA IN FOOTLAMBERTS

ANGLE IN DEG	AVERAGE 0-DEG	AVERAGE 45-DEG	AVERAGE 90-DEG
45	145.	239.	304.
55	109.	152.	162.
65	88.	97.	102.
75	87.	82.	72.
85	56.	66.	44.

APPROVED BY:

TESTED IN ACCORDANCE WITH IES PROCEDURES, TEST DISTANCE EXCEEDS 25.0 FEET

As we pointed out earlier, the difference in light output between 25°C and 35°C among various T5 lamps is not consistent. As a consequence, the photometric result of a luminaire by using existing method is dependent on the characteristics of the specific testing lamp. To illustrate this important point, let us assume that we have a T5HO luminaire with a lamp operating temperature inside the luminaire of 35°C. Let's further assume that the published data for the T5HO lamp is 4450 lumens at 25°C and 5000 lumens at 35°C. Report #1 of Table 3 shows the photometric results of the luminaire from our proposed method. This includes bare-lamp reading perpendicular to the lamp (I_R), the total luminous flux of the luminaire (F) and luminaire "efficiency" (F/F_{lamp}). Report #2 through #6 represent results obtained with existing method. The difference among those reports is that the various lamps with different characteristics are used to generate the photometries. Report#2 was generated with a test lamp having a luminous flux difference of 2.5% between 25°C and 35°C while Report#6 was generated with an 11% difference.

Table 3

A Comparison of Proposed Method and Existing Method Using Different Test Lamps

Report No.	F_{lamp}	I_R	F	F/F_{lamp}	Descriptions & Assumptions
Report # 1	**5000**	**564**	**4816**	**96.3%**	Proposed Method
Report # 2	4450*	550	4395	98.8%	Existing Method with 2.5% of LOD25/35*
Report # 3	4450*	537	4501	101.1%	Existing Method with 5.0% of LOD25/35*
Report # 4	4450*	522	4631	104.1%	Existing Method with 7.5% of LOD25/35*
Report # 5	4450*	508	4758	106.9%	Existing Method with 10.0% of LOD25/35*
Report # 6	4450*	502	4816	108.2%	Existing Method with 11.0% of LOD25/35*

* 4450 is the lumen rating of T5HO lamp at 25°C based on the published data from lamp manufacturer
*LOD25/35 is Lamp Light-Output Difference between the temperatures of 25°C and 35°C

It is clear from Table 3 that using the existing method, individual test lamps with various light output difference between 25°C and 35°C will yield different total luminous flux (F) and luminaire "efficiency" (F/F_{lamp}). Hence, it is conceivable that for the same luminaire, one laboratory may report a total luminous flux of 4395 lumens and 98.8% efficiency while another laboratory may report 4816 lumens and 108.2% efficiency simply by using different test lamps. It is misleading in both cases. Only with the proposed method we can obtain the accurate photometry both in terms of total luminous flux and luminaire efficiency regardless of the individual characteristics of test lamp.

It is also important to point out that the above illustration dispels any notion that the existing method will result in the same total luminous flux even though the efficiency may not.

An Abbreviated Alternative Method

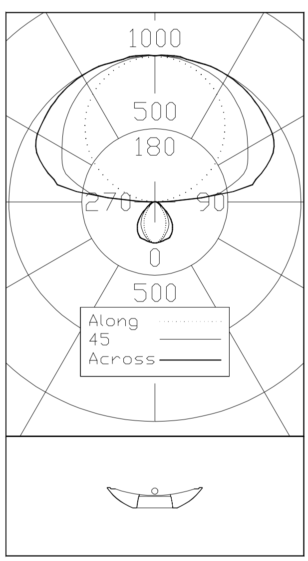
In the proposed method, it is necessary to measure the cold-spot temperature of the T5HO lamp(s) (CSTL) to obtain the lumen rating. As we can see from Table 1, the average difference of the luminous flux for the T5HO lamps between 25 °C and 35 °C is around 5% or ±2.5%. This is a relatively small difference. Hence, an alternative to the proposed method is to take a mid-point in the luminous flux of the T5HO lamp as the average lumen rating of the lamp for photometric calibration. For example, if the optimal lumen rating of the T5HO lamp is 5000 lumens at 35°C, and 4750 lumens at 25°C, then we can assign 4875 lumens as the average value of T5HO-lamp lumen rating. In this case, we would not take the cold-spot temperature measurement of T5HO lamp(s). We would simply take the bare-lamp reading when it is thermally stabilized in the luminaire. As we mentioned before, this should be done within 10 seconds from the time it is removed from the luminaire to the time the bare-lamp reading is recorded.

Figure 5

A Photometric Report of Abbreviated Alternative Method

FAR-FIELD PHOTOMETRY
DATE: 2-16-2001
REPORT NUMBER: C

CATALOG NUMBER: ABC-1T5HO
LUMINAIRE: 9"W X 3"H STEEL INDIRECT/DIRECT LIGHT WITH WHITE PAINTED REFLECTOR AND OPAL-PERF BAFFLE
LAMP(S): 1-F54/835 RATED @ 4875 LUMENS EACH
BALLAST: QT-1X54/120PHO
MOUNTING:
LUMEN TO CANDELA RATIO USED = 9.19
TOTAL INPUT WATTS = 59.8 AT 12.0 VOLTS
THE 0 DEGREE PLANE IS PARALLEL WITH THE LAMPS.



CANDELA DISTRIBUTION

	0.0	22.5	45.0	67.5	90.0	FLUX
0	281	281	281	281	281	
5	271	274	276	279	278	26
15	230	235	246	260	268	70
25	177	185	209	240	255	98
35	120	131	164	192	211	102
45	68	86	112	132	143	84
55	42	49	62	67	70	53
65	25	30	32	36	39	34
75	15	18	20	23	23	21
85	6	8	10	12	11	12
90	5	9	15	18	18	
95	25	203	318	324	322	264
105	175	382	594	712	756	568
115	357	497	702	853	901	664
125	527	622	772	895	941	678
135	675	739	844	935	969	646
145	799	837	907	966	990	566
155	891	914	952	988	1001	439
165	954	965	979	990	998	277
175	989	994	996	1002	1004	95
180	998	998	998	998	998	

ZONAL LUMEN SUMMARY

ZONE	LUMENS	%LAMP	%FIXT
0- 30	193	4.0	4.1
0- 40	296	6.1	6.3
0- 60	432	8.9	9.2
0- 90	499	10.2	10.6
90-120	1495	30.7	31.8
90-130	2173	44.6	46.3
90-150	3385	69.4	72.1
90-180	4196	86.1	89.4
0-180	4695	96.3	100.0

LUMINANCE DATA IN FOOTLAMBERTS

ANGLE IN DEG	AVERAGE 0-DEG	AVERAGE 45-DEG	AVERAGE 90-DEG
45	152.	250.	318.
55	114.	158.	169.
65	92.	101.	107.
75	91.	86.	75.
85	58.	69.	46.

TOTAL LUMINAIRE EFFICIENCY = 96.3 %
CIE TYPE - SEMI-INDIRECT

APPROVED BY:

TESTED IN ACCORDANCE WITH IES PROCEDURES, TEST DISTANCE EXCEEDS 25.0 FEET

A photometric report of the abbreviated alternative method is shown in Figure 5. It should be noted that the efficiency reported using this abbreviated alternative method is correct and it is the same as that for the proposed method. The maximum error in the luminous flux of the luminaire introduced in the photometry will be ±2.5%. This is valid for the temperature inside the luminaire ranging from 25°C up to 45°C, which is based on the assumption that similar lumen-output reduction will occur once LOTIL passes the 35°C optimal temperature. This 20°C temperature differential, we believe, is a very generous range and covers most of the T5HO-lamp applications. As an example, we found that one can put two T5HO(54W) lamps in a 7" X 2.5" fully enclosed steel luminaire housing with typical reflector optics, resulting in an LOTIL which is still less than 45°C. Almost all T5HO lamps operate at temperatures higher than 25 °C inside the luminaries if the luminaire operates at 25°C ambient temperature. This is the case even for an open indirect luminaire. Hence the actual expected error will be less than the maximum ±2.5% when the average lumen rating of the T5HO lamp(s) is used. We believe that this abbreviated alternative method is sufficiently robust for most lighting applications with T5HO-lamp luminaries. Should a higher precision be needed, or if the LOTIL is higher than 45°C, one can always perform the proposed method in its entirety.

Conclusions and Recommendations

In this paper, we have addressed the issue of the luminous flux of the T5HO lamps at two important operating temperatures, 25 °C and 35°C. Our finding is that if the T5HO lamp(s) is stabilized horizontally, the resulting difference in the luminous flux between the two temperatures is an average of 5%. Here we have also proposed a photometric testing method for T5HO-lamp luminaires. This proposal calls for bare-lamp measurements to be performed at the lamp operating temperature inside the luminaire housing (LOTIL). Finally, we devised an abbreviated alternative for the proposed method that is simple and practical for most of the T5HO-lamp applications.

Based on the above study our recommendations are:

1) Since T5HO lamp(s) is temperature and position sensitive, lamp manufacturers should furnish technical data on the luminous flux vs. the ambient temperature for the T5HO lamps at the vertical and horizontal operating positions.

2) According to our test results, there are some differences in the luminous flux of T5HO lamps among different manufacturers at a temperature ranging from 25°C to 35°C. We would prefer to see a smaller variance in luminous flux among manufacturers.

3) We would like to have the IESNA Testing Procedure Committee consider the Proposed Method and Abbreviated Alternative Method as outlined in this paper.

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