

Photometry is the procedure for measuring the candlepower produced by a lighting fixture to develop the various tools for proper application of the equipment.

The proper and rigorous methods for performing photometry have been well covered by the Illuminating Engineering Society in several publications, e.g., The Practical and General Guide to Photometry. Specific publications cover the recommended methods for photometry of equipment for specific applications such as roadway and site lighting, floodlighting and indoor lighting. Briefly, candlepower is measured at various angles from directly below the fixture to directly above at various positions around the fixture.

Figure 1, illustrates the point. The fixture is located within a sphere. Each of the points of intersection represents a point at which a measurement can be taken. The radius of the sphere is large enough to allow the fixture to appear as a point source to the photocell that is mechanically placed at each one of the intersections. This radius must be at least 5 times the maximum dimension of the fixture that can be tested, which in the case of a 2x4 is at least 22.4 feet. A photocell is mechanically placed at each of the points and a reading is taken looking directly at the fixture.

In the case of indoor photometry, measurements are made in 5 degree vertical increments (Figure 2) and 22.5 degree horizontal increments. (Figure 3)

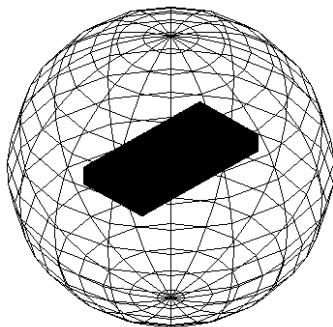


FIGURE 1

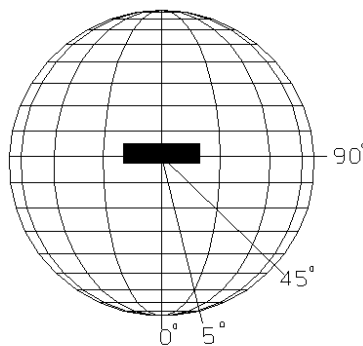


FIGURE 2

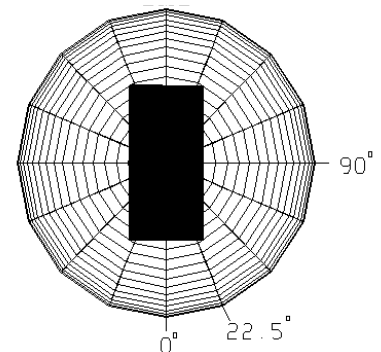


FIGURE 3

The bulk of the photometry reported assumes that the lamps used deliver the full, published rated lumens for that particular lamp. This is called 'Relative Photometry' and places all equipment on the same basis. If the actual lumen output of the lamps was used, the procedure is termed 'Absolute Photometry'. The efficiency and coefficients of utilization would not change since they are ratios, but the candlepower levels would be different from a test done on a relative basis. Experience has shown that the difference will result in lower candlepower values than those obtained by relative photometry.

The candlepower values are the basis of every other piece of information supplied in a test report.

All other information is calculated.

Figure 4 is the first page of the photometric data sheet.

Figure 4 "A" is the heading that contains all pertinent information about the test including the lamp type, number of lamps and lamp lumens used in the test. As described before, these are usually the rated lumens for that particular lamp. The heading appears on every page of the test report. The candlepower values are reported as shown in Figure 4. "B" There are five columns of numbers.

Each of the five columns corresponds to a horizontal angle as shown in Figure 3. The numbers in each column are the candlepower (candela) values for each of the vertical angles listed in the column headed "VERT ANG" as shown in Figure 2.

If there is a "Ballast Factor" listed in the heading, the candela are adjusted by that figure. If no "Ballast Factor" is listed, the multiplier is considered as 1 and the values are those that would result if rated lumens were delivered by the lamps.

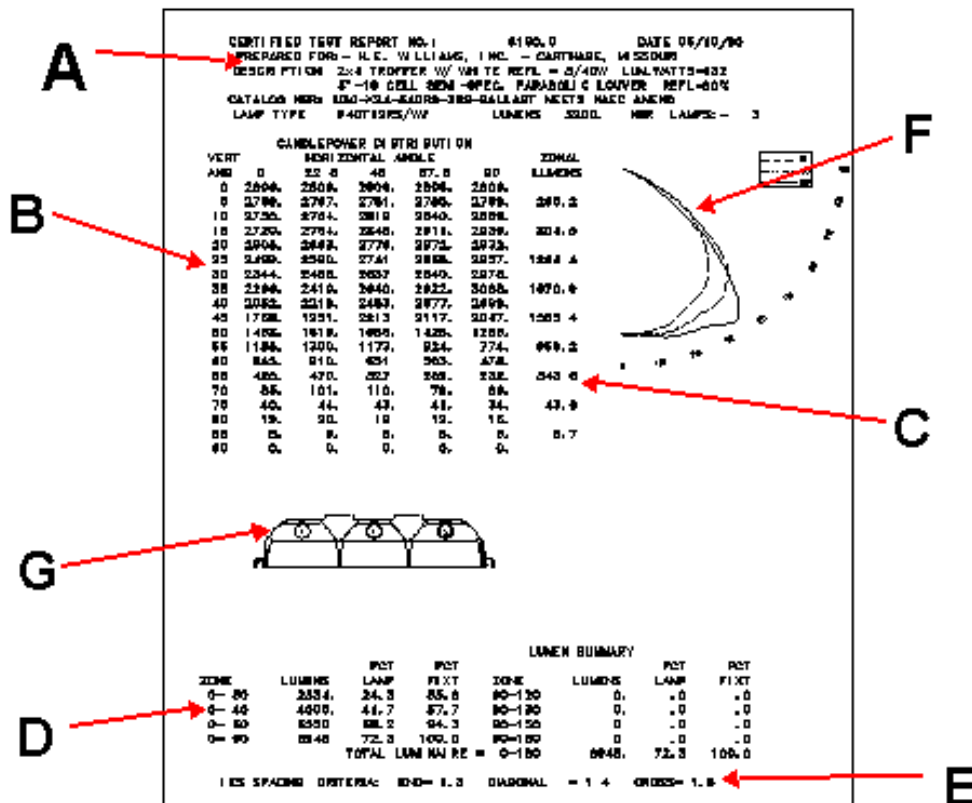


Figure 4

The candlepower distribution curve, Figure 4 "F" and the fixture sketch Figure 4 "G" are presented as visual aids only.

The numbers in the column labeled (Figure 4 "C") "ZONAL LUMENS" are the values of luminous flux emitted within the solid angle described by the limits of the 10 degree zone in which they are listed.

There are two basic assumptions made about the candlepower distribution:

1. The candlepower values are approximately uniform within each 10 degree vertical zone and a weighted average of the candlepower in the horizontal planes will represent that uniformity.
2. The average candlepower at the mid zone angle is representative of the candlepower in the zone.

In calculating the average candlepower, the 0 and 90 degree zone is weighted once and the interior angles are weighted twice. If there are 8 planes of candlepower being averaged, the total is divided by 8.

The zonal lumens are then calculated by multiplying the average candlepower at the mid zone angle by the lumen constant for that zone that converts the average candlepower directly to lumens.

$$\text{Average Candlepower} = (2769 + 2 \cdot 2767 + 2 \cdot 2781 + 2 \cdot 2785 + 2789) / 8 = 2778$$

LUMEN CONSTANTS FOR 10 DEGREE ZONES				
ZONE	MID-ZONE ANGLE	ZONE	MID-ZONE ANGLE	LUMEN CONSTANT
0-10	5	170-180	175	0.095
10-20	15	160-170	165	0.283
20-30	25	150-160	155	0.463
30-40	35	140-150	145	0.628
40-50	45	130-140	135	0.774
50-60	55	120-130	125	0.897
60-70	65	110-120	115	0.993
70-80	75	100-110	105	1.058
80-90	85	90-100	95	1.091

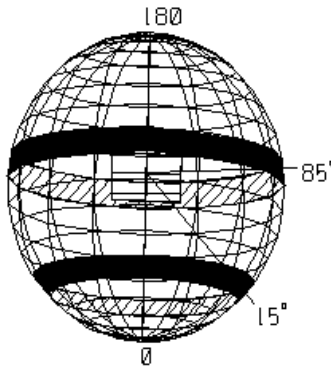


Figure 5

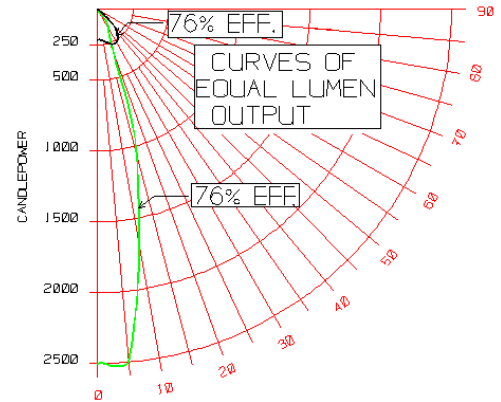


Figure 5-A

Figure 5 lists those constants for zones of 10 degrees. Since equal angular zones on the surface of a sphere are much greater in area nearer the equator than they are at the poles, a given candlepower yields more lumens at an angle nearer the equator than it does near the poles. The lumen constants are based on the relative area of those zones.

Using the numbers in Figure 4 for the 5 degree zone;
 Zonal Lumens₀₋₁₀ = Average Candlepower₅ x Lumen Constant

$$\text{Zonal Lumens} = 2778 \cdot .095 = 265.2$$

It is possible for luminaires with two radically different distributions to deliver the same total lumens, and have the same efficiency. Figure 5-A illustrates this phenomenon.

LUMEN SUMMARY							
ZONE	LUMENS	PCT LAMP	PCT FIXT	ZONE	LUMENS	PCT LAMP	PCT FIXT
0- 30	2334.	24.3	33.6	90-120	0.	.0	.0
0- 40	4005.	41.7	57.7	90-130	0.	.0	.0
0- 60	6550.	68.2	94.3	90-150	0.	.0	.0
0- 90	6945.	72.3	100.0	90-180	0.	.0	.0
TOTAL LUMINAIRE = 0-180					6945.	72.3	100.0
IES SPACING CRITERIA: END= 1.3 DIAGONAL = 1.4 CROSS= 1.6							

Figure 4 "D" and "E"

After each of the zonal lumens is calculated, the lumens can be summed for each of the combination of zones desired as shown in Figure 4 "D".

The total fixture efficiency is the sum of the lumens from the 0 to 180 degree zone as a percentage of the lamp lumens.

If the fixture had an uplight component, candlepower above the 90 degree zone, the candlepower table and the lumen summary would contain figures other than 0. The efficiency would reflect the additional lumens.

The 'IES Spacing Criteria', listed at the bottom of the photometric data sheet (Figure 4 "E"), is a one number application guide used to insure uniform illumination. The 'END', 'DIAGONAL' and 'ACROSS' designations refer to the orientation of the fixture and correspond to the '0', '45' and '90' degree horizontal planes shown in the candlepower tabulation. The numbers, '1.3', '1.4' and '1.6' are ratios of the allowable spacing between fixtures in the particular orientation to the vertical distance between the work plane and the fixture mounting height.

Uniform illumination is defined as the condition when the maximum illumination level does not exceed the average by more than 16% and the minimum is not more than 16% less than the average.

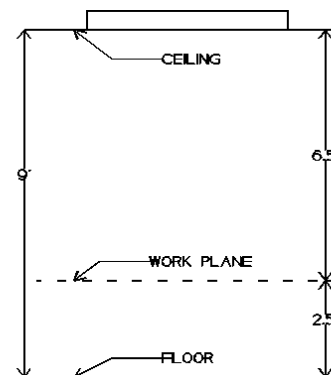
Example:

Room Height = 9 feet, work plane height = 2.5 feet.

Maximum allowable spacing (end) = $(9-2.5)*1.3 = 8.45$ feet

Maximum allowable spacing (diagonal) = $(9-2.5)*1.4 = 9.1$ feet

Maximum allowable spacing (across) = $(9-2.5)*1.3 = 10.4$ feet



That a layout complies with any or all of these spacings does not guarantee that the illumination levels will meet a design level requirement. The number of fixtures required must first be calculated and then the spacing compared to the allowable spacings calculated as described above.

The Spacing Criteria used to be referred to as the Spacing to Mounting Height Ratio (SMH). Then, the only criterion was the ACROSS orientation.

Some industrial applications using high bay symmetric distribution fixtures mounted within the specified SMH were found to have dark spots occurring on the diagonal between a square array of fixtures because the diagonal spacing was 40% greater than the across. After this condition was recognized, the calculation of the SMH was revised to include the END and DIAGONAL orientations and renamed the Spacing Criteria.

Care must be taken when applying the Spacing Criteria in applications using fixtures whose distributions have a ratio of 0 degree candlepower to the maximum candlepower in any of the 3 directions greater than 2 to 1. The Spacing Criteria may have a very high number e.g., 2.5 or greater, which will not be within the required +/- 16% variation from the average. The candlepower distribution curve will flag this condition.

Figure 5 is the second page of the photometric data sheet. Figure 5 "H" is a tabulation of the 'brightnesses' or 'luminances' of the fixture in the direct glare zones. Direct glare is the glare or brightness that your eye sees directly from a fixture. The eyebrows shield the eyes at about 45 degrees when the point of view is directly ahead. Therefore brightnesses below a vertical angle of 45 degrees will not be included in direct glare.

The assumption here is that no one ever looks up at a fixture.

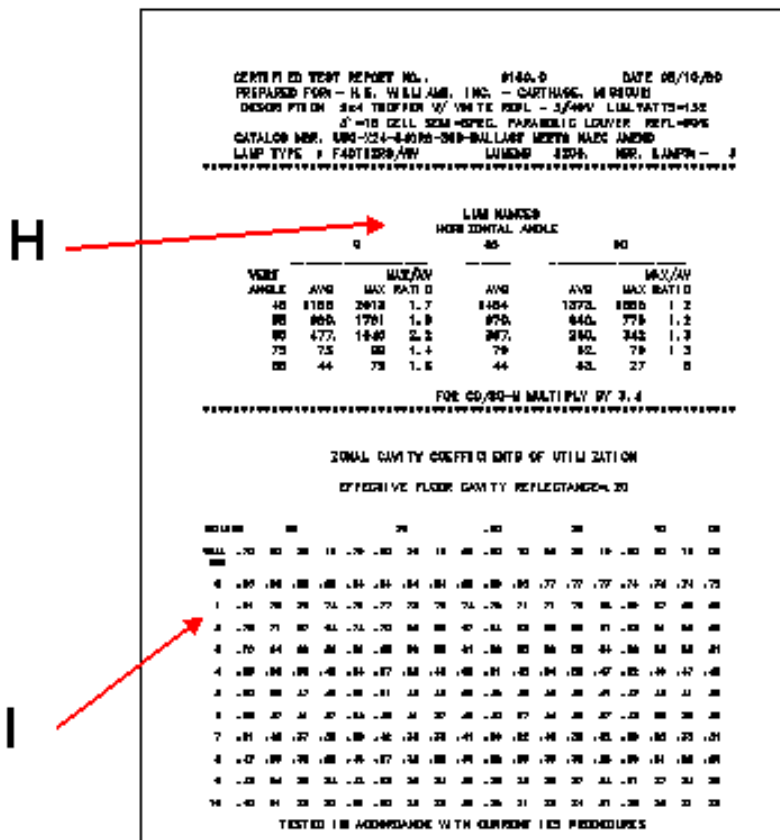


Figure 5

The direct glare photometric zones are in the 45 to 90 degree portion of the distribution and the brightnesses (luminances) are tabulated within that range.

There are two types of brightnesses (luminances) tabulated. These are the average and maximum values. Average brightness (luminance) is calculated from the candlepower data if the luminaire presents itself as a point source. The units of brightness (luminance) are FootLamberts or Candela/unit area. The unit area can be in either feet or meters.

Calculation is straight forward. The projected area is calculated from the luminous area of the luminaire multiplied by the cosine of the angle of view. The candlepower (candela) is divided by the projected area and the result is the average brightness in candela/unit area. If the units are desired in FootLamberts, the result is then multiplied by π .

Average Luminance_{av} = candela / Luminous area x cos θ

The average brightness assumes that the brightness of the face of the luminaire is uniform with no extreme bright spots that can be detected by the eye. This can generally be said to be true of a luminaire with a lens that has the lamps mounted a proper distance to avoid extreme lamp images or a small cell louver with a 45 degree or better shielding. There is sometimes a "flashing" in large cell parabolic fixtures due to the imperfections of the formations of the aluminum louver blades. Therefore, the average brightness values must be viewed with all of these conditions in mind. This flashing is not considered in the average luminance calculation.

In most applications, especially offices with VDT terminals and schools, the requirements for the average brightness control are fairly restrictive, especially at the angles above 75 degrees. There must be faith in the photometry at those angles since the candlepower values are lower to start with and may be within the non-linearity of the cell used to measure them. Also the alignment of the fixture on the photometer can cause some error.

That is the good news.

The Testing Procedures Committee of the IES has been discussing the proper method to measure maximum brightness since at least 1958. In the thirty-five years that this discussion has been going on, there has been no resolution. The maximum brightness values that are issued by most photometric laboratories are measured with an aperture of 1 circular square inch with no compensation for the projected area at the higher angles. As the angle increases, more of the luminaire surface is seen by the circular aperture which will tend to integrate or average any bright spot that might be in the field of view.

That is the bad news. Maximum brightness values must be viewed with a great deal of skepticism.

To compound the problem, some State agencies that have legislated the minimum acceptable performance of a lighting fixture for use in schools in their State, have included maximum and average brightness values as well as the ratios of the two. Therefore all of that information, rigorous or not, is published in whole or in part.

Figure 5 "H" tabulates average brightnesses for all three main horizontal angles as well as the maximum brightness and the maximum to average ratios for the 0 and 90 degree zones. The units are in FootLamberts and a multiplier is provided to obtain Candela/square meter. If Candela/square-foot are desired, the multiplier is 0.318 (1/π).

VERT ANGLE	LUMINANCES									
	0			45			90			
	AVG	MAX	MAX/AV	AVG	AVG	MAX	MAX/AV	AVG	MAX	MAX/AV
45	1185.	2019	1.7	1484.	1375.	1585	1.2			
55	980.	1791	1.8	970.	840.	775	1.2			
65	477.	1040	2.2	367.	260.	342	1.3			
75	73.	89	1.4	79.	62.	78	1.3			
85	44.	79	1.8	44.	55.	27	.9			

FOR CD/SQ-M MULTIPLY BY 3.4

The next portion of the second page of the photometric data sheet is the Coefficient of Utilization Table; Figure 5 "I".

Figure 5 "H"

Coefficients of Utilization (CU) are efficiency values of a fixture within a room. A single fixture will provide only so much light at a point. This is called direct illumination. However, when a fixture is placed in any kind of room that has some reflective surfaces, light from the fixture will bounce off those surfaces and back to the point. In other words, the light is more efficiently *UTILIZED*, hence the name, Coefficient of Utilization.

The CU's are a function of the luminous efficiency and distribution of the fixture, reflectance of the room surfaces and the room geometry.

ZONAL CAVITY COEFFICIENTS OF UTILIZATION																		
EFFECTIVE FLOOR CAVITY REFLECTANCE = .20																		
CEILING	.80			.70			.50			.30			.10			.00		
WALL HGT	.70	.50	.30	.10	.70	.50	.30	.10	.50	.30	.10	.50	.30	.10	.50	.30	.10	.00
0	.68	.86	.88	.68	.84	.84	.84	.84	.80	.80	.80	.77	.77	.77	.74	.74	.74	.72
1	.81	.78	.76	.74	.79	.77	.78	.78	.74	.72	.71	.71	.70	.68	.69	.67	.66	.66
2	.76	.71	.67	.64	.74	.70	.66	.63	.67	.64	.62	.65	.63	.61	.63	.61	.60	.60
3	.70	.64	.60	.56	.66	.63	.60	.55	.61	.58	.55	.59	.56	.54	.56	.53	.53	.51
4	.63	.58	.55	.48	.64	.57	.52	.48	.55	.51	.48	.54	.50	.47	.52	.48	.47	.45
5	.40	.52	.47	.42	.58	.51	.48	.42	.50	.45	.42	.48	.45	.41	.47	.44	.41	.40
6	.55	.47	.41	.37	.54	.48	.41	.37	.45	.40	.37	.44	.40	.37	.43	.39	.38	.35
7	.51	.42	.37	.33	.50	.42	.38	.33	.41	.36	.32	.40	.35	.32	.39	.35	.32	.31
8	.47	.38	.32	.28	.46	.37	.32	.28	.38	.32	.28	.38	.31	.28	.35	.31	.28	.28
9	.43	.34	.28	.24	.42	.38	.32	.24	.38	.32	.28	.34	.27	.24	.31	.27	.24	.23
10	.40	.31	.24	.22	.38	.30	.28	.21	.30	.28	.21	.29	.24	.21	.28	.24	.21	.20

Figure 5 "I"

The first column in Figure 5 "I" is headed RCR and is the Room Cavity Ratio or a metric describing the room geometry. The higher the number, the smaller the room. All the other columns are the CU for the particular fixture. Each column is a set of CU's for the combination of ceiling and wall reflectances.

The RCR is calculated using the following relationship (see figure 6):

$$RCR = (5 * (CH - WPH - SL) * (L + W)) / (L * W)$$

Where CH = Ceiling height

WPH = Work plane height

SL = Suspension Length

L, W = Room Length and Width respectively

The second column in the figure to the right contains the CU for an 80% ceiling and a 70% wall. All CU tables use a floor cavity reflectance of 20% as a standard.

Since the surfaces of a room contribute to the illumination, it is possible to see a CU value for a large room (RCR=0 or RCR=1) greater than 1.0.

The procedure for calculation of the CU is based on a six surface interchange of radiant energy and is described in detail in the IES Handbook.

In that calculation, the fixture distribution is divided into nine 10 degree zones for the direct portion while the uplight or indirect portion of the distribution is treated as a single package of lumens.

THE COEFFICIENTS OF UTILIZATION FOR A DIRECT DISTRIBUTION CANNOT BE USED FOR INDIRECT APPLICATIONS.

The term 'Effective Reflectance' deserves some comment.

The Zonal Cavity System considers surface reflectances as well as the modified reflectance when the CAVITY is formed by ceiling and walls or floor and walls.

If fixtures are suspended from a ceiling, the portion of the walls equal to the suspension length become a part of the gross reflecting surface above the fixtures. The walls are usually lower in reflectance and the hole caused by the suspension will absorb light by itself. Therefore, the effective reflectance of the resulting ceiling cavity will be lower than the ceiling surface. This is also true for the floor. Care must be taken to recognize the presence of cavities when selecting CU's since reflectance combination used may not be correct.

Figure 6

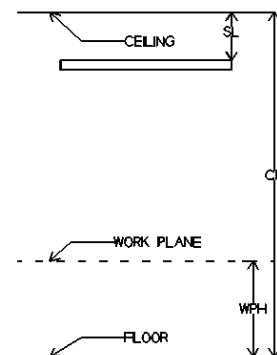


Figure 7 is the last page of the Photometric Data Sheet.

This page is optional and contains the Visual Comfort Probability (VCP) table.

The standard VCP table is calculated for an illumination level of 100 FootCandles and reflectances of 80% ceiling 50% wall and 20% floor. There are 24 different room sizes with 4 different ceiling heights and two different fixture orientations.

The VCP's are an attempt to predict the probability that a person seated 4 feet from the back wall of each of those rooms with his eye level 4 feet above floor and looking directly to the front wall will be comfortable when exposed to a lighting system. This system consists of fixtures in 5x5 modules throughout the room in question.

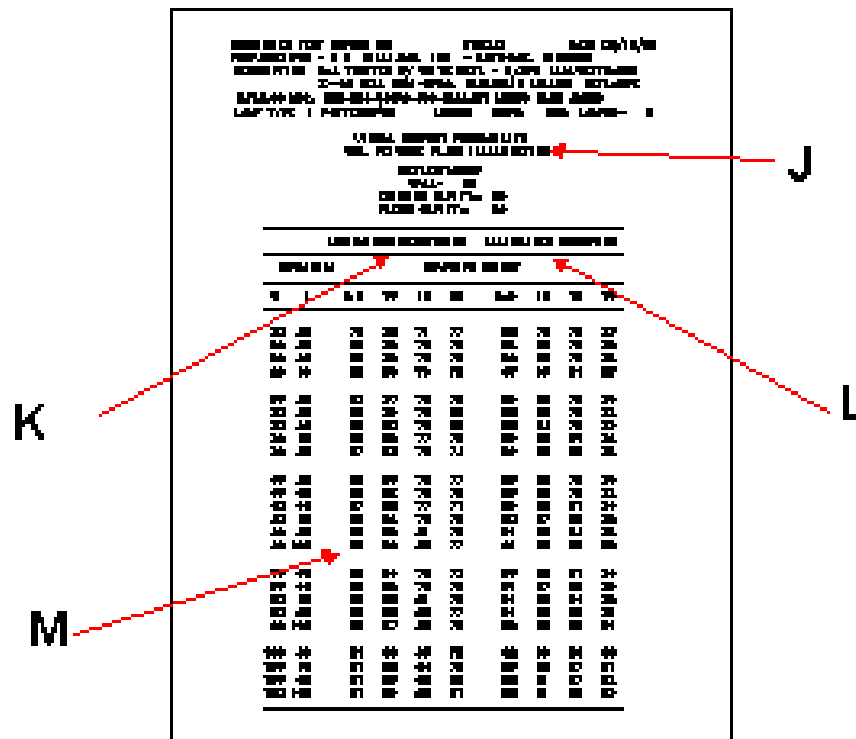


Figure 7

A VCP of 70 or above indicates a comfortable condition. The degree of significance is 5 VCP.

In other words a VCP of 68 is the same as a VCP of 73.

There is no possible way to measure Visual Comfort Probability and it is undefined for luminaires with candlepower above 90 degrees.

Changing the illumination level to some value other than 100 foot-candles, usually reduce the VCP numbers. This reduction is usually not in the range of significance if the illumination level is not less than 50 or more than 200 foot-candles.