Technical Bulletin 7

Fluorescent Lamps

Canadian Conservation Institute
National Museums of Canada

1. Introduction

The concern for the proper illumination of museums and art galleries is ever present in the mind of the conservator, who is only too aware of the potentially damaging effects of light and ultraviolet radiation on artifacts and works of art, and of the curator, who knows that the type of lighting will have a direct bearing on the acceptability of an exhibition. The possibility of achieving a balance between sound conservation practice and aesthetical appearance exists. Unfortunately, those who are responsible for installing lighting systems in museums and art galleries are often not sufficiently knowledgeable in the proper design of such systems.

In the past, natural light was the predominant source of lighting for museums and art galleries, while artificial light was used only sparingly to complement the existing natural light. Nowadays, this trend has been almost totally reversed, certainly for Canadian institutions. (See Reference 7.) Although there is a slight preference for incandescent lamps, the use of fluorescent tubes is widespread. The basic construction, operation and visual characteristics of fluorescent lamps differ significantly from that of the incandescent bulb. The only similarity existing between the two is that they both produce visible light. Whereas the quality and general appearance of the light emitted by incandescent lamps varies little from one type of bulb to the other, drastic differences exist within fluorescent lamps. The ignorance of these differences and why they occur can lead to lighting conditions that can be damaging to artifacts and works of art, while at the same time creating an aesthetically unpleasant ambiance and mood in an exhibition.

2. Operation of Fluorescent Lamps

Most fluorescent lamps are made with tubular glass bulbs varying in diameter from ⅝ inches (T-5) to 2⅛ inches (T-17), and in over-all length from 6 to 96 inches. They are available in various wattages from 4 to 215 watts. The standard designation for fluorescent lamps is explained in Figure 1.

The popular 4-foot, 40-watts tubes are normally designated simply as F40CW, F40WW, F40D, etc., without the shape and diameter of the bulb.

A schematic diagram of a typical fluorescent lamp is presented in Figure 2. Two electrodes are hermetically sealed into the bulb, one at each end. A small amount of mercury is contained in the tube together with a rare gas to facilitate ignition of the discharge. The light-emitting process proceeds in the following way: When a current is applied to the electrodes, a flow of electrons is generated from one electrode (the cathode) to the other (the anode). During their path, these electrons will collide with the atoms of mercury present in the tube and impart some of their energy to them, thus forming electronically excited atoms of mercury. After collision, the electron will continue along the tube to excite one or more additional mercury atoms and finally end up on the wall of the tube or collected at the anode.

The excited mercury atoms thus formed release the absorbed energy by emitting electromagnetic radiation (mostly UV) at very specific wavelengths. The main emission occurs at 253.7 nanometers in the ultraviolet region. Weaker emissions occur at about 313, 334, 365, 405, 436, 546 and 578 nanometers and are the mercury lines typical of a fluorescent lamp's spectral distribution curve. The UV radiation produced (at 253.7 nm) will strike the interior wall of the tube which has been previously coated during manufacturing with substances known as phosphors. These phosphors will absorb this energy and release it as visible light. Each particular phosphor has a characteristic fluorescent band, some emitting blue-green light, others pink, etc. (See Reference 5). The selective combination of phosphors will determine the colour appearance of a lamp. Thus, a manufacturer has much flexibility in determining the spectral distribution of a given lamp type simply by selecting the proper blend of phosphors.

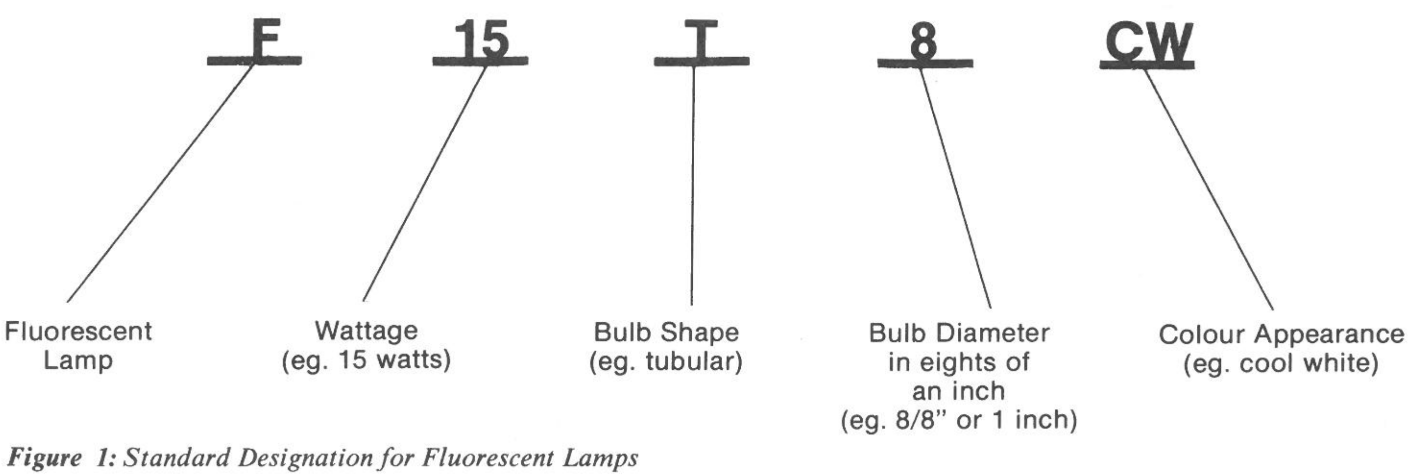

Figure 1: *Standard Designation for Fluorescent Lamps*

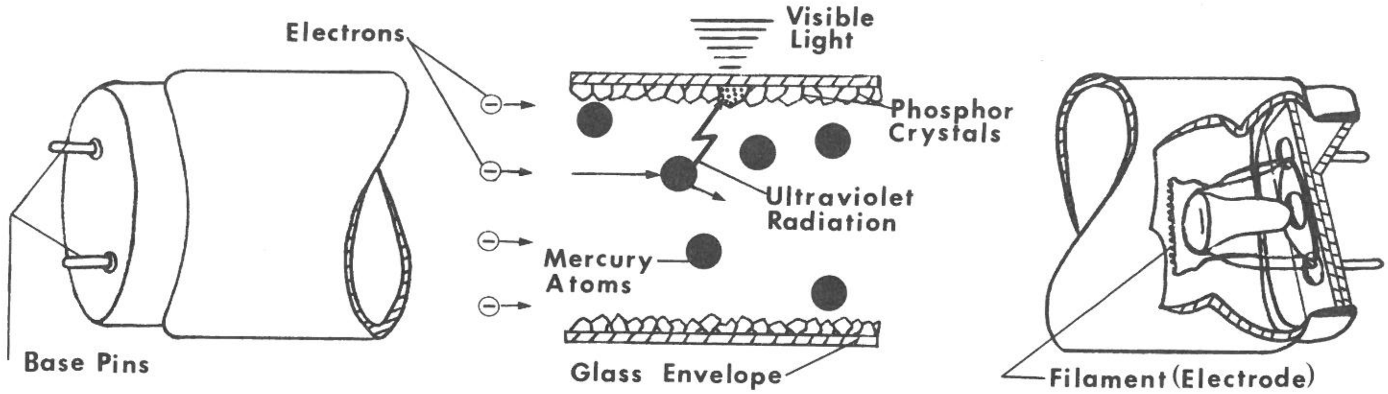

Figure 2: Schematic representation of a typical fluorescent lamp.

The spectral power distribution curve of a typical cool white fluorescent lamp is given in Figure 3. The mercury emission lines, often illustrated as bars instead of lines, are due to the energy released by the activated mercury atoms. The strongest line at 253.7 will activate the phosphors which then produce the continuum of visible light and some UV. The glass envelope will absorb any UV below about 320 nm which manages to go through the phosphor unabsorbed. The visible light continuum in this example would seem to be produced by two different phosphors.

Four different visual properties will be directly affected by the phosphor blend: the correlated colour temperature (C.C.T.), the colour rendering index (C.R.I.), the ultraviolet radiation emission and the lumen output.

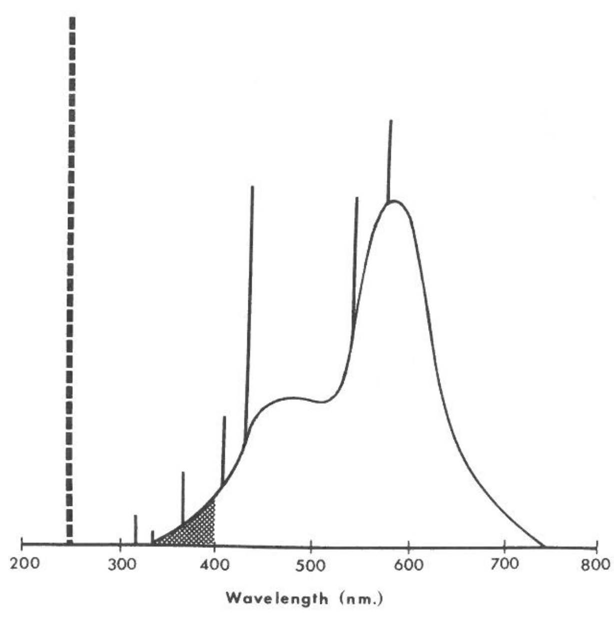

Figure 3: Spectral Energy Distribution of a Typical Fluorescent Lamp.

Although these have been discussed before in other publications (See References 1, 2, 3, 9), new technology and improvements in lamp manufacturing warrants an up-to-date survey of fluorescent lamps on the market. Each characteristic will be dealt with separately.

A basic understanding of light and its properties is necessary to comprehend fully the intent of this exposé. We would hope that the reader has previously read CCI's Technical Bulletin No. 2 on Museum Lighting by K.J. Macleod. (See Reference 8).

3. Correlated Colour Temperature

The correlated colour temperature (C.C.T.) of a light source is a value used to characterize the spectral distribution curve of that source and hence its colour appearance. For example, a light source with a C.C.T. of 3000K is the same colour as a theoretical black body radiator whose temperature is 3000K. Perfect white light—i.e., light containing approximately equal amounts of all colours—has a C.C.T. of about 5500K. Below this value, there is a proportional increase in the yellow orange and red region of the spectrum and the light appears progressively yellower. Above 5500K, the blue/violet region is increased and the light appears blue; the higher the C.C.T., the bluer the light gets.

Unlike incandescent lamps, fluorescent tubes are available in a variety of "whites" or colour temperatures. The reader is certainly familiar with the main three categories of fluorescent lamps. The warm white tubes have typical C.C.T.'s of 2700 to 3100K and give off a yellowish white light similar to incandescent bulbs. The daylight lamps whose C.C.T. is 6000K or more have a bluish cast and are used to complement natural daylight. Somewhere in between at about 4200K is the popular cool white, used extensively in office lighting. Other than the main three groups, there exist other fluorescent lamps of various colour temperatures; e.g., natural white, supermarket white, colour-matching, etc. These are normally produced for specific applications where the appearance of certain materials is improved by a particular colour temperature. Such lamps can be well suited for other situations and one should not be misled by the name.

The colour of an object will appear different under a warm illumination (low C.C.T.) than it would under a cool illumination (high C.C.T.). Fortunately, the human eye has an adaptive mechanism which will psychologically correct these differences. The incandescent light bulbs which illuminate your house give off essentially white light. When you are outside, the illumination provided by the combination of sunlight and daylight again appears white. Yet, when you compare the two directly, one is definitely yellowish, the other quite blue (daylight). One is not mentally aware of this difference until the direct comparison is made.

Certain considerations must be taken into account when deciding what colour temperature one should use for a particular exhibition. If a room is also lit by incandescent bulbs and the fluorescent lamps are used to complement the existing lighting, then a warm white (C.C.T. < 3200K) could be used to avoid the unpleasant contrast between the two types of lamps. If, on the other hand, there are many windows or skylights in the room, a daylight fluorescent lamp (C.C.T. > 5000K) would be more appropriate.

For exhibits depicting outside scenes or for artifacts normally seen outdoors, the use of daylight fluorescent lamps can create a more natural and pleasant mood. There exists, however, a psychological preference for a warmer illumination when light levels are low. For light sensitive objects kept at 50 lux, a warm illumination will be much more pleasant than a cool one.

Needless to say, personal preference plays a big part in the final choice of colour temperature. The best approach would be to try out various types to see which one creates the most pleasing effects.

4. Colour Rendering Index

The spectral energy distribution of most light sources does not match perfectly that of a black-body radiator, even though the light they emit may appear to have the same colour. The extent of this difference is described quantitatively by the colour rendering index (C.R.I.). A maximum value of 100 is assigned to a light source whose spectral energy distribution matches that of a black-body radiator of the same colour temperature. If their spectra do not match, then the C.R.I. of that source is less than 100; the larger the mismatch, the lower the C.R.I. becomes. The actual calculation of the colour rendering index of a source involves the evaluation of the colour appearance of eight standard colours under the light in question, as compared to a theoretical black-body radiator of the same colour temperature.

It is important to realize that two lamps can have the same correlated colour temperatures but drastically different colour rendering indices. In such cases, the two lamps would have the same colour, yet objects would appear different from one to the other. Figure 4 compares two cool white fluorescent lamps with a black-body radiator of the same colour temperature. One of the lamps has a low C.R.I.; the other, quite high.

Unfortunately, the human eye has no adaptive mechanism to compensate for these colour differences as it does for colour temperature variations. Colours are said to be rendered normally under light sources having a C.R.I. of 100. Anything less can create colour distortion; this becomes

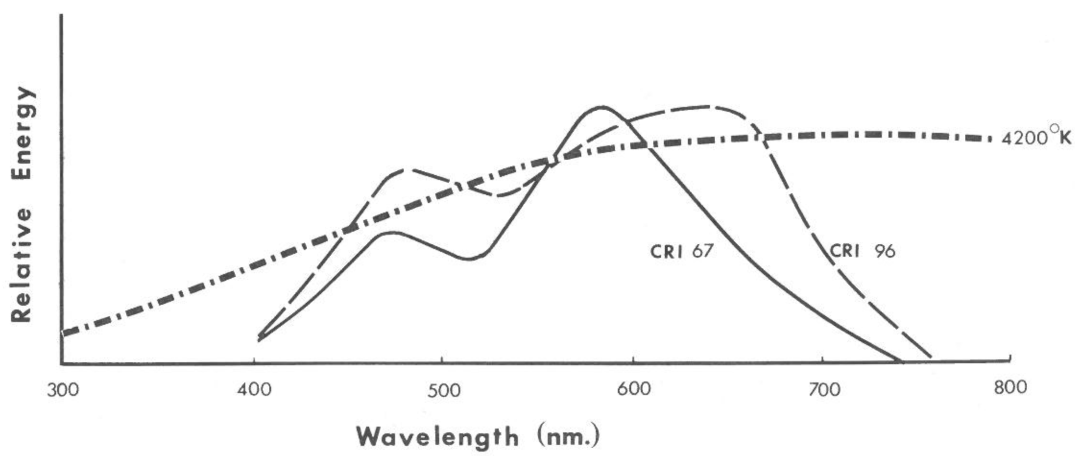

Figure 4: *Comparison between good and poor colour rendering cool white fluorescent lamps.*

more pronounced for very low C.R.I.'s. No doubt you have experienced this type of colour distortion at some point in your life. The most common example is in covered parking lots where mercury or sodium lamps provide the illumination. In these situations, the colour of your car or clothing takes on a peculiar shade due to the poor colour rendering properties of the lamps. In general, light sources whose C.R.I. is above 85 will render colours well: any colour distortion would be so small that it would be undetectable to the human eye.

Since colour appreciation is of utmost importance in museums and art galleries, serious consideration must be placed on the colour rendering indices of lamps. Incandescent lamps have very high C.R.I.'s and cause no problems. Fluorescent lamps, on the other hand, can have varying colour rendering properties; thus it becomes important to consider this aspect of illumination. A minimum acceptable C.R.I. is difficult to establish precisely; as a rule of thumb, a lower limit of about 85 can be arbitrarily chosen.

Normal versions of fluorescent lamps now produced have poor colour rendering properties (e.g., ordinary cool white has a C.R.I. of about 65). One would immediately wonder why such lamps are produced. Unfortunately, good colour rendering is often achieved at the expense of lumen output. Fluorescent lamps of high C.R.I. emit less light per watt of electricity than those of low C.R.I. (sometimes as much as 45% less light). High energy costs make the normal cool whites, warm whites and daylight tubes more popular than their deluxe and special deluxe counterparts. For museum and art galleries, the reduced light output may actually be a blessing in disguise since lighting levels are on the average much higher than the recommended values.

5. Ultraviolet Radiation Emission

In the museum world, the fluorescent lamp has always been associated with excessive ultraviolet radiation emission. The UV is produced by the excited mercury atoms—the mercury lines—and by the phosphors whose emission bands can tail off into the UV region. Little can be done to reduce the strength of the mercury lines, but the judicious choice of phosphors can significantly reduce the quantity of UV given off as part of the light continuum.

To a lamp manufacturer, any UV radiation emitted by the phosphors is essentially wasted energy since it contributes nothing to seeing. There are fluorescent lamps now on the market that emit considerably less UV than before. Most lamp manufacturers offer specially designed low UV emitting lamps for situations where photochemical deterioration is of some concern, such as in clothing and departments stores and, of course, in museums and art galleries. In one case, this is achieved by applying a UV absorbing coating to the lamp at the time of manufacturing.

Most manufacturers' information sheets or catalogues give very little information on the actual quantity of UV given off by fluorescent lamps. They will sometimes provide spectral distribution curves for various lamps or some indication that UV is low or high, as in the case of sunlight simulating lamps. Unfortunately, this information means little to the curator of a museum who is faced with the task of purchasing fluorescent lamps for his institution.

A simple yet effective means of assessing the suitability of a lamp in terms of its ultraviolet radiation emission is to determine the proportion of UV emitted per unit of visible light. The unit of measurement is most commonly microwatt/lumen (μw/lm). A small device known as the Crawford UV Monitor Type 760 is now available for carrying out these measurements. (See Reference 6). Incandescent bulbs normally emit less than 75 μw/lm of UV, whereas sunlight is composed of about 400 μw/lm of UV.

For museum and art gallery applications, light sources should emit less than 75 μw/lm; otherwise, UV absorbing filters should be used. Unfortunately, most museums cannot afford to purchase a UV monitor such as the one mentioned above. For this reason, the authors have carried out the UV measurement of most fluorescent lamps available on the market today. These values are reported in Table 1, along with manufacturers' information on colour temperature, the colour rendering index and lumen output.

For this study, 72 types of 40-watt (F40T12) and 42 types of 15-watt (F15T8) tubular fluorescent lamps were purchased from manufacturers and tested as received without prior aging. This would represent the maximum achievable UV output of a given lamp since UV emission (and also lumen output) diminishes with time. (See Reference 4).

Standard fluorescent fixtures were mounted on a dark room wall and used without diffusers. To eliminate errors due to surface reflectance, all walls and the ceiling of the dark room had previously been painted black.

Three Crawford Type 760 UV monitors, previously calibrated against a standard light source, were used to measure the UV output of each lamp in μw/lm. Measurements were taken from a distance of three feet by directing the monitor at the central portion of the lamp. One reading from each monitor was taken for two or three replicates of each different type of lamp.

Before testing, each lamp underwent a ten-minute warm-up time to permit a stable operating temperature to be attained. Warm-up periods in excess of ten minutes were not found to produce further changes in UV output. The average and standard deviation were calculated for each different lamp type.

Fluorescent lamps emitting less than 75 μw/lm of UV do not require UV absorbing filters. Often the extra cost of filters prohibits their use, especially in smaller institutions where operating budgets are limited. The judicious choice of low UV emitting lamps would eliminate the need for filters resulting in substantial savings. Since purchase price can vary from one lamp to the other, it would be necessary to establish both the actual cost of a lamp and whether higher costs would offset these savings.

6. Lumen Output

Lumen output is the total amount of visible light given off by a source. We have reported this value in the table to serve as a guide in judging the quantity of lamps necessary for a given lighting installation. Lumen output varies considerably from one lamp to another. We feel that for museum and art gallery applications, lumen output should not be the deciding factor in choosing a lamp. Colour temperature, UV emission and the colour rendering index take precedence over lumen output.

Lamp wattage is often used as an indication of the quantity of light given off by a lamp. This leads to a very disturbing misconception of the light output of fluorescent lamps. The wattage of a lamp is the amount of electrical energy it consumes. This electrical energy is converted into light energy by various means, such as incandescence of a tungsten filament, fluorescence of phosphors, etc. The efficiency of each mechanism varies considerably. The term "luminous efficacy" is used to describe the total quantity of visible light given off for each watt of electricity consumed. Fluorescent lamps have typical luminous efficacies of from 40 to 75 lumen/watt. On the other hand, incandescent bulbs vary from 6 to about 15 lumen/watt.

Consider the common 4-foot fluorescent tube (F40), rated at 40 watts. It can emit anywhere from 1700 to 3400 lumens of light. Consider now a household incandescent bulb of the same wattage. It gives off only 360 lumens. For comparison, an R40, 150-watt spot or floodlight emits 1825 lumens. We believe that museum staff are often misled by lamp wattages. The result is excessively strong lighting, especially in display cases lit by fluorescent lamps.

Because of the high energy costs of recent years, lamp manufacturers have strived to increase the lumen output of their lamps without increasing the wattage or significantly decreasing the colour rendering index. The recently introduced "prime colour" fluorescent lamp is a good example of this quest. The human eye responds most strongly to three specific narrow bands of colour in the visible light spectrum: blue-violet, pure green and orange red. Visual response to wavelengths other than these three bands is weaker. A fluorescent lamp which would emit light in only three discrete bands matching those of the visual system would have excellent lumen output, yet maintain reasonably good colour rendering properties; hence the "prime colour" illuminants.

The authors are aware of at least two companies producing these so-called prime colour fluorescent lamps (Philips' TL80 series and Westinghouse's Ultralume series). Colour rendering indices of 85 are reported and UV emissions are low (see Table 1). Manufacturers also claim that prime colour lamps increase "seeability" and visual clarity. Because these lamps have become available only recently, there exists as yet no information on their suitability for museum and art gallery applications.

7. Choosing the Proper Fluorescent Lamp

Table 1 incorporates necessary information on correlated colour temperature, ultra-violet radiation emission, the colour rendering index and lumen output for each lamp tested.

All the data was supplied to us by the manufacturers, except for UV emission, which was measured in our laboratories. The proper choice of fluorescent lamp will be done by referring specifically to this table. The following suggested sequence can be followed:

1. Specify a range of colour temperature that would best suit the type of exhibition and pick out all lamps that fall within this range.
2. From this list, eliminate those lamps that have a colour rendering index less than 85.
3. If possible, obtain the price of the remaining lamps. Some companies will give discounts for bulk orders.
4. Lamps which emit less than 75 μw/lm will not require filters, but some are more expensive. Determine whether it would be cheaper to use a low UV-emitting lamp, as opposed to a combination of high UV-emitting lamp and a UV filter. Remember, UV filters can be reused for many years (at least ten).

References

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5. Illuminating Engineering Society, *I.E.S. Lighting Handbook,* 5th ed., 1972, pp. 2-8, 8-18.

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9. Thomson, Garry, "A New Look at Colour Rendering, Level of Illumination and Protection from Ultraviolet Radiation in Museum Lighting", *Studies in Conservation,* vol. 6, 1961, p. 71.

Note:

These books may be obtained from your local libraries or through interlibrary loans.

TABLE 1

Fluorescent Lamp	Correlated Colour Temperature (K)	Ultraviolet Emission* (μw/lm)	Colour Rendering Index	Lumen Output
Philips				
F40				
Warm white 29	2950	70	53	3100
Warm white deluxe 32	2950	99	86	2100
• Warm white special deluxe 27	2700	33	94	1700
cool white 33	4250	87	67	3200
cool white deluxe 34	3850	103	85	2100
cool white special deluxe 37	4200	33	96	1700
daylight 54	6700	103	82	2500
daylight deluxe 55	6400	107	95	2000
daylight special deluxe 57	7400	257	93	1700
• colour-matching 47	5000	33	98	1830
TL 84	4000	73	85	3400
CM 5000	5000	122	> 90	N.A.
CM 7500	7500	143	> 90	N.A.
Westinghouse				
F40				
warm white	3000	87	53	3200
warm white deluxe	3000	160	71	2150
cool white	4100	101	67	3150
cool white deluxe	4200	144	89	2200
white	3500	90	58	3200
Living white	4300	103	90	2380
daylight	6500	106	73	2600
natural	3400	166	85	2080
merchandising white	3450	128	85	2410
supermarket white	4100	150	80	2330
colour match	purple	644	N/A	N/A
ultralume 3000	3000	59	85	2900
ultralume 4100	4100	47	85	2900
ultralume 5000	500	51	85	2900
F15				
warm white	3000	102	53	870
warm white deluxe	3000	160	71	610
cool white	4100	100	67	870
cool white deluxe	4200	135	89	610
daylight	6500	127	73	750
soft white natural	3400	155	85	590
white	3500	95	58	870
supermarket white	4100	155	80	650
VERILUX				
F40				
Full spectrum VLX/M	6200	47	high	1984
Full spectrum VLX	6200	152	high	2168

F15

Full spectrum VLX	6200	182	high	600

VERD-A-RAY

F40

cool white	4500	95	68	3150
daylight	6500	110	N.A.	2680
north white	5100	107	91	2740
north white fadex	5100	46	91	2740
CEZ	6750	90	N.A.	2730
CEZ/DP fadex	6750	28	N.A.	2730
verd-a-lite	3900	46	N.A.	2440
verd-a-lite fadex	3900	40	N.A.	2440
criticolour	5700	110	91	2120
criticolour fadex	5700	52	91	2120
emberglow	3100	78	N.A.	3250
indorsun	5700	152	91	2180
DSW 30	3000	56	N.A.	1860

F15

cool white	4500	105	N.A.	880
daylite	6500	118	N.A.	740
north white	5100	125	91	N.A.
north white fadex	5100	68	91	N.A.
CEZ	6750	95	N.A.	800
CEZ fadex	6750	56	N.A.	800
verd-a-lite	3900	57	N.A.	690
verd-a-lite fadex	3900	50	N.A.	690
criticolour	5700	125	91	600
criticolour fadex	5700	43	91	600
emberglo	3100	95	N.A.	890
indorsun	5700	150	91	710
DSW 30	3000	65	N.A.	475

DURO-TEST

F40

cool white	4500	100	68	3100
cool white double cathode	4500	95	68	3350
white	3500	83	64	3200
daylite	6500	112	75	2650
super white	5300	98	72	2860
super soft white	N.A.	190	58	2320
candelite	3000	83	56	3200
vita-lite	5500	223	91	2180
super deluxe 45	4300	150	73	2450
colour classer 75	7500	117	93	2100
optima 32	3200	123	82	2400
optima 50	5000	107	91	2200

F15

cool white	4500	96	68	870
daylite	6500	110	75	770
super soft white	N.A.	177	58	660
vita-lite	5500	157	91	640
optima 32	3200	105	82	675
optima 50	5000	100	91	640

Sylvania				
F40				
warm white	3050	85	55	3200
warm white deluxe	2950	103	73	2150
cool white	4300	90	67	3150
cool white deluxe	4100	123	86	2150
white	3500	88	62	3200
daylight	6500	110	79	2600
natural	3700	133	81	2050
design white	5000	112	82	2300
incandescent-fluorescent	2700	50	90	1600
F15				
warm white	3050	99	55	890
cool white	4300	110	67	865
cool white deluxe	4100	150	86	585
white	3500	95	62	890
daylite	6500	123	79	740
natural white	3700	113	81	530
incandescent-fluorescent	2700	50	90	455
General Electric				
F40				
warm white	N.A.	75	N.A.	3150
warm deluxe white	N.A.	85	N.A.	2150
cool white	4200	88	65	3150
cool white deluxe	4200	107	89	2200
daylight	7000	110	79	2600
white	N.A.	88	N.A.	3200
natural	N.A.	107	N.A.	2100
sign white	N.A.	103	N.A.	2440
chroma 50	5000	102	92	2200
chroma 75	7500	143	94	2000
F15				
warm white	N.A.	82	N.A.	870
warm white deluxe	N.A.	67	N.A.	600
cool white	4200	87	65	870
cool white deluxe	4200	95	89	610
daylight	7000	108	79	750
natural	N.A.	98	N.A.	590
Macbeth				
5000 F40	5000	237	high	N.A.

N/A Not Applicable
N.A. Not Available

Note: Lamps of wattages other than 40 and 15 will have similar C.C.T., U.V. emission and C.R.I. to the lamps listed here. Lumen output will be proportionally higher or lower.

*The average standard deviation in the ultraviolet radiation emission measurements was 9 μw/lm ($\pm$5) and was mainly due to instrument differences rather than variations between lamps.

• These lamps are available in orders of 6 000 or more from Europe (Holland).