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Evaluating Performance Characteristics of Energy Efficient Lighting Systems

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Introduction

From the dawn of civilization until quite recently, human beings created light solely from fire. At the turn of the century, torches and petroleum lamps gave way to another type of heat source: electric incandescent lamps. As we advanced technologically, our heat sources became more sophisticated. Yet, very little consideration was given to the performance characteristics of lighting systems. Most consumers thought of lamps in terms of the power consumed rather than the amount of light delivered. All-in-all, lamps were rather simple and similar devices: "toasters that happen to give off a bit of light" one might say. Today, incandescent lamps give about 10% light and 90% heat, according to the IES Lighting Handbook.

Only in the past few decades have lighting products become much more sophisticated and varied. For example, considerable chemistry and physics are required to create an electric arc within a fluorescent lamp, and then to convert the energy from that arc into useful light.

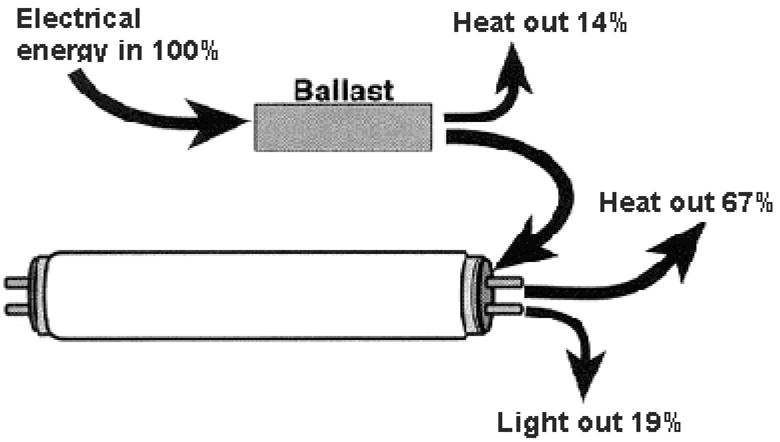

Figure 1. Fluorescent systems

All fluorescent lamps and other discharge lamps require ballasts, which themselves have very different performance characteristics. The types and combinations of different products are almost endless, which complicates the task of selecting lighting systems for particular applications. We tolerate the complexity because these more complicated systems usually are more efficient. Classic 4 foot fluorescent systems convert approximately 19% of their energy into light. The remainder of the energy is lost, mainly as heat, through the lamp and through the ballast.

As is usually the case, the more complicated the product, the higher the initial cost. We invest more funds up front in the hope that lower operating costs will bring us a return on investment within the near future.

If the lighting systems do not perform as expected, the operating costs may increase and we don't necessarily get the savings we expect. We might even lose more than we invest. The new National Energy Code for Buildings will challenge us to invest in more efficient lighting products. The key to effectively meeting this challenge is to make sure that our lighting systems will perform as expected in actual situations. In order to do that, we must know what to look for, and what questions to ask.

This paper defines some key performance characteristics used in comparing lamps and ballasts, to help ensure that the most effective components are specified for a given application.

Performance Characteristics

Light

Flux, illuminance and luminance

Total flux, in lumens, is the parameter that lighting manufacturers use when describing the total amount of light given off in all directions. Lumens do not, however, tell us how much light will be received where it is needed.

Illuminance, in lux, tells us how much light will reach a given surface. Lux is a short form for lumens per square metre of surface area. It is the metric equivalent of footcandles. There are 10.76 lux in one footcandle, but the lighting industry usually tolerates rounding this factor down to 10 for simplicity. (Imperial units are frequently used for consistency with the other trades in the Canadian building industry.)

Luminance, in candela per square metre (cd/m^2 is a measure of how bright an object appears ($1\ cd/m^2 = 0.29$ foot-lamberts, the imperial unit for luminance). Luminance is a representation of the amount of light seen by the eye. Luminance is sometimes specified for critical lighting designs (e.g., IES Recommended Practice RP-24 for Offices with Video Display Terminals). Luminance is not used much in general lighting design because of practical considerations. Illuminance is usually the parameter of preference. It is indirectly related to what the eye sees. Knowing the reflectance properties of the illuminated surfaces, it is possible to calculate luminance from illuminance using procedures in the IES Lighting Handbook. IES Lighting Recommendations are usually given in terms of illuminance because it is practical to measure and because it is indirectly related to visibility.

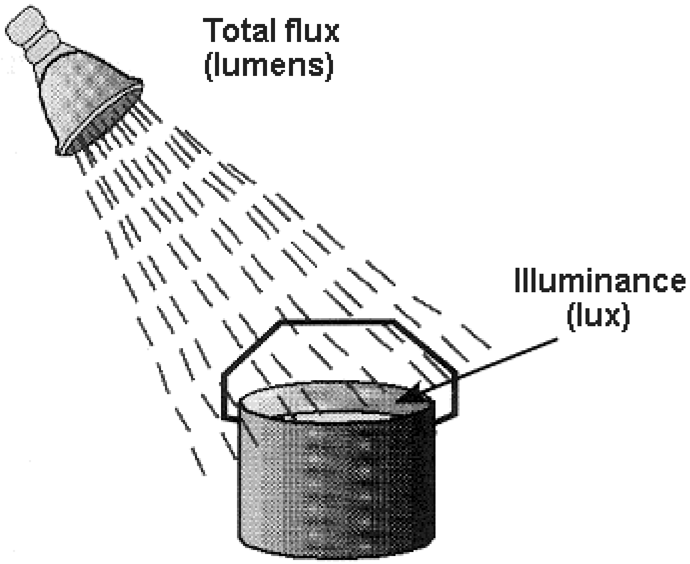

Figure 2. Flux and illuminance

The following is a useful analogy when explaining these fundamental concepts of lighting to others. If we compare a lighting fixture to a shower head, then the lumen output is the rate of flow of water and illuminance is the amount of water collected in a bucket at a given time. The key point is that the same total flux can give different amounts of water in the bucket, simply by moving the bucket, or by changing the spray pattern or by changing any physical obstructions between the source and the bucket. Total flux doesn't specify how much illuminance will be provided where it's needed. This is true, in part, because the luminaire, reflectors, lenses and other optical media can greatly affect the flow of light from the source to the surface of interest. Failure to remember this is a frequent cause of poor lighting design, especially in retrofit applications.

For lighting designs, we should not assume that two lamps with the same lumen rating will each give the same amount of light where needed.

Distribution

Figure 3 shows an incandescent lamp on the left being replaced by a compact fluorescent lamp on the right. Here, a wide adapter ballast is used. The ballast blocks out most of the direct light from the lamp to the work surface. The distributions of light are completely different in the two cases. The result is significantly less illumination on the work surface than what one might expect from comparisons of total lumen output.

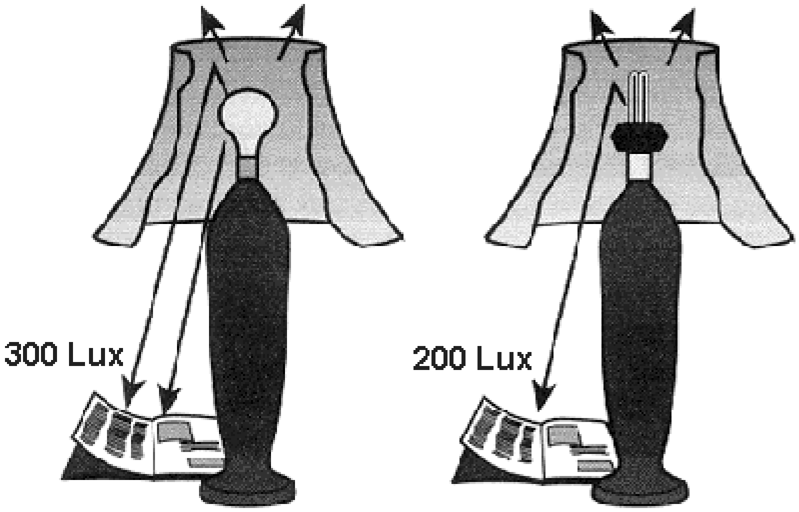

Figure 3. Effect of installing retrofit lamp in unsuitable fixture

Thus, lighting distribution is an important parameter for the performance of lighting systems. This applies not only to table fixtures but to all fixtures including recessed fixtures. Manufacturers' photometric reports give polar graphs showing the distributions of candelas in all directions. The distribution data is also available in tabular form and on diskette for input into various computer programs which calculate illuminance throughout the space. These are very useful tools for evaluating the illumination delivered by various design options.

If computers and software are not available, then rough estimations of illuminance can be made by dividing the candelas by the square of the distance between the light source and the surface illuminated. For example, if a fixture gives 2000 candelas in the downwards direction, and if we mount that fixture in a 10 foot high ceiling, then the illuminance from that fixture will be approximately $2000/10^2 = 20$ footcandles at the floor directly below the fixture. In metric units, one would calculate $2000/(3.048\text{m})^2 = 215$ lux. Calculations of this type work as long as the distance to the surface is at least four times greater than the maximum dimensions (i.e., length or width) of the light source. For shorter distances, the calculations may still be used but they are subject to a greater uncertainty.

In a lighting retrofit situation, we would want to make sure that the new lighting system gives a distribution at least as good as the lighting system being replaced. This requires comparing illuminance values not only directly below the fixture, but throughout the entire space illuminated. For example, it is sometimes said that with the help of a reflector insert, two lamps can be removed from a four lamp fixture without compromising illuminance. This might be true directly below the fixture, but it is important to study the entire illuminance distribution to ensure that illuminance isn't compromised elsewhere in the space. A retrofit of this kind might require changing luminaire spacing ratios in order to maintain the same uniformity of illumination throughout the space.

Colour

Colour is also an important aspect of performance. Poor colour is often noticed right away. If, for example, the meat in a showcase doesn't look red enough, it simply will not sell. If our flesh looks a bit grey or greenish, as it might under mercury lighting, we notice that too.

Colour temperature describes the colour appearance of lamps, not the object being viewed. Colour temperature ranges from 3000 Kelvin for warm sources like incandescent, to approximately 6500 Kelvin for cool sources like daylight fluorescent. Colour temperature data is readily available from lamp manufacturers. The selection of colour temperature is a matter of personal preference.

Colour rendering index, or CRI, specifies how coloured objects would appear compared to their appearance under a reference lamp of the same colour temperature. A CRI of 100 means no difference, while a negative CRI means a big difference. Incandescent lamps give a CRI of approximately 100, but that doesn't mean that they always give suitable results. Suppose, for example, we wish to illuminate white cabinets in a kitchen or a hospital examination room. A design objective might be to enhance the impression of whiteness, cleanliness and sterility. In this case, the colour temperature of incandescents would be too low to achieve the desired effect. As a general rule, one should therefore select colour temperature first, then pick the lamp giving the optimum CRI for the application.

Many new lamps on the market give surprisingly good colour rendering. For example, one may now obtain high pressure sodium lamps which give higher CRI than many fluorescent lamps.

Iridescence

Iridescence, or spectral banding, is a problem of increasing concern since the introduction of triphospor lamps and anodized luminaire surfaces. It shows up as unwanted colours in luminaire surfaces, much like rainbow patterns on thin oil or soap films on water. The appearance of these colours lowers the perceived quality of a lighting installation.

Our laboratory has demonstrated that the effect of iridescence is due to interactions of light within the thin (2 to 7, µm) transparent optical coating used to keep the metal luminaire surfaces shiny. Optics specialists call the effect thin film interference. The effect is not new nor unique to the lighting industry. It was, in fact, studied in the 17th century by Sir Isaac Newton and his contemporaries.

By varying the thickness, texture, and index of refraction of the transparent optical coatings, manufacturers now offer luminaire surfaces giving little or no iridescence. Where lighting quality is a concern, these low-iridesence materials should be used, especially when triphosphor or other narrow band lamps are specified.

Power

Nameplate vs. actual power

Nameplate power is not necessarily the power used in calculating one's energy bill. It is simply the manufacturer's rating based upon laboratory measurements under carefully controlled conditions, not under the conditions to be used in practice.

The power consumed by fluorescent systems depends upon field conditions. For example, well ventilated 2-lamp fluorescent fixtures often use less power than the combined nameplate power of their lamps and ballast. This is due to the effect of temperature on the performance of fluorescent systems, as explained in the section on Field Effects. In this case, the effect leads to greater savings than anticipated. Opposite effects have also been documented, especially where field conditions are much poorer than ideal.

The power consumption of both lamps and ballasts should be considered when determining the power consumption of lighting systems. Failure to do so could lead to serious under estimations of pay back times. For example, our lab measured a 24 watt compact fluorescent lamp which, together with its ballast, consumed 34 watts at room temperature. In this case, reliance solely on the lamp nameplate watts would have given a 29% underestimation of the actual power consumed. Not all compact fluorescent ballasts draw such a proportionately large amount of power. In fact, we observed some self-ballasted systems that consumed significantly less than the nameplate power. Table 1 summarizes some of these results for representative compact fluorescent and 4 foot fluorescent lamps and ballasts installed in enclosed luminaires operated at normal room temperatures. The results demonstrate the magnitude of uncertainty in using nameplate lamp power.

Table 1. Rated and measured power consumed by sample fluorescent systems

Lamps	**Ballast**	**Actual System Wattage**	**Combined Nominal Lamp Wattage**	**Percent Difference**
2 x 40 watt WW, T12	Magnetic, Dimming (dimmer at max. setting)	87W	80W	-8
2 x 40 watt WW, T12	Magnetic, Nondimming	80W	80W	0
2 x 40 watt WW, T12	Electronic, Nondimming	70W	80W	+14
2 x 34 watt WW, T12	Magnetic, Nondimming	70W	68W	-3
2 x 34 watt WW, T12	Electronic, Nondimming	63W	68W	+8

1 x 24 watt TT, T5	Magnetic, High PF	34W	24W	-29
1 x 26 watt Quad, T4	Magnetic, High PF	30W	26W	-13
1 x 13 watt TT, T4	Magnetic, Normal PF	17W	13W	-24
1 x 28 watt Quad, T5	Magnetic, Normal PF	34W	28W	-18
1 x 20 watt Quad, T4	Electronic, integral, Normal PF	19W	20W (lamp + ballast)	+5

For pragmatic reasons, the National Energy Code for Buildings will probably allow the use of nameplate power for calculating unit power densities. They should not be relied upon, however, for economic analyses. For these, it is best to use the closest available approximation to actual power under the field conditions that the lighting systems will undergo. This might involve consulting the detailed technical data provided by reputable manufacturers. It might involve consulting published scientific papers such as those listed in the IRC Lighting Laboratory Publications Listing[1]. It might also involve measurement in a mockup that resembles, as closely as possible, the conditions of use. Or it might involve using a comfortable overestimate of power to minimize the risk of not obtaining an expedient return on the lighting investment.

Power factor

Power factor is a measure of how much useful work is done by the electricity consumed by the lighting system. It is defined in Equation 1.

$$\text{Power factor} = \frac{\text{Watts}}{\text{Volts x amps}} \qquad (1)$$

The lower the power factor, the more it costs the utility to meet the power demand. Depending upon the local utility pricing structure, a portion of this excess cost is passed on to the electricity customer.

Power factor depends mostly upon the choice of lighting ballast. It can range from approximately 40% to 100%. Anything above 90% is generally considered very good. Such ballasts are often called high power factor ballasts. Undimmed incandescent systems have power factors of 100%. Anything below 90% is usually considered a normal power factor. Paradoxically, when it comes to lighting ballasts, "normal" does not necessarily mean good. In the current market, it is generally safe to assume that ballasts are normal power factor unless otherwise indicated by the manufacturer.

One important but often overlooked consideration is that the lower the power factor, the more current a lighting system draws for the same amount of watts. This is shown in Equation 2 and illustrated in the case studies below.

$$\text{Amps} = \frac{\text{Watts}}{\text{Volts x Power factor}} \qquad (2)$$

The impact is that the more current is drawn, the greater the circuit capacity required to handle the same amount of power. This can seriously affect costs when installing new circuits, as in the construction of new buildings (Case Study 1). Furthermore, it should not be overlooked in retrofit applications (Case Study 2).

Case study 1: compact fluorescents in new installation

Problem: A lighting design called for twelve 13 watt compact fluorescent lamps in the reception area of a new hotel operating on 347 volt supply. A small step down transformer was used to provide the necessary 120 volts to the ballasts. Assuming each ballast consumed 3 watts, it was estimated that the compact fluorescent units would consume 16 watts each. or 12 x 16 watts = 192 watts in total. Based upon these calculations, a 300 VA step down transformer was installed to power the compact fluorescent ballasts. The lamps operated for only 15 minutes before the transformer overheated and destructed. This came as a surprise because it was presumed that the transformer had a reserve capacity of at least 300 - 192 = 108 watts. Concluding that the transformer was defective, the owner demanded compensation from the supplier. The supplier refused.

Explanation: Normal power factor ballasts were used, giving a power factor of 0.45, or 45%. From Equation 2, the supplier calculated the current as 192 watts / (120 volts x 0.45) = 3.6 amps. This greatly exceeded the transformer rating of 300 VA / 120 volts = 2.5 amps. The supplier correctly concluded that the customer had voided the warranty by overloading the transformer. The customer had underestimated the compact fluorescent load by failing to account for the low power factor. Incidentally, if the ballasts had been of a high power factor (e.g., 90%), the total current would have been only 192 watts/(120 V x 0.90) = 1.8 amps. This lower current would not have overloaded the transformer.

Case study 2: high pressure sodium (hps) in retrofit application

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P> Problem: The security lighting of a building was originally provided by ten 150 watt incandescent PAR lamps on a 15 amp circuit. The total power was 10 x 150 watts = 1500 watts. The total current load was 1500 watts / 120 volts =12.5 amps. In the interest of energy efficiency, the 10 PAR lamps were replaced by five 150 watt HPS lamps installed in wide beam fixtures. Measurement showed that the power of the retrofitted circuit was 850 watts, representing a 43% reduction from the original 1500 watts. Yet, the circuit's breaker frequently tripped.

Explanation: Simple magnetic ballasts were used, giving a power factor of

0.45 or 45%. Total current was 850 watts/(120 volts x 0.5) = 16 amps. This exceeded the circuit's 15 amp rating and greatly exceeded the requirements of most electrical codes, which call for a 20% reserve capacity on all circuits. The problem was solved at the expense of a separate new circuit for two of the HPS fixtures. With high power factor ballasts of 98%, total current for the 5 fixtures would have been only 850 watts/ (120 volts x 0.98) = 7 amps, and the extra circuit would not have been necessary.

Harmonic distortions

Harmonic distortions are a power quality problem closely related to power factor. Harmonic distortions can be thought of as electric pollution superimposed onto normal electric wave forms. They are blamed for producing many of the problems associated with current overload, radio and telephone interference and glitches in electronic devices like computers. They are also blamed for such fire safety problems as overheating of motors, transformers, and neutral wires of 3-phase circuits. The problems are becoming more prevalent as more electronic and other sensitive equipment is plugged into the electrical system.

Loads which cause harmonic distortions are called nonlinear loads. They include variable speed drives, uninterruptable power supplies, arc welders, electronic equipment and, yes, lighting ballasts.

Fortunately, lighting ballasts have rarely been known to cause widespread electrical havoc. Nevertheless, electric utilities are concerned about the cumulative effect of distortions from an ever-increasing proportion of low current electronic loads on their networks. From this point of view, lighting ballasts are part of an ever-growing problem. From the perspective of the building practitioner, harmonic distortion should be carefully considered when installing lighting in a building where power quality is an existing or potential problem.

It is rather difficult to use corrective devices to eliminate harmonic distortions once they have been created. The best way to avoid problems is to install ballasts which produce as little total harmonic distortion (THD) as possible. Europe has introduced a power quality standard (IEC 555) of THD less than 34%, and the Canadian Standards Association (CSA) is presently considering similar limits. Canadian electric utility companies typically recommend a more stringent limit of 20%. Ballasts are presently available which give still lower THD values.

Total Harmonic Distortion

Two different definitions of THD are commonly used. One is expressed in terms of RMS current or voltage. The other is based upon percent fundamental current or voltage. The two definitions are equally valid, but they can give different THD values, especially when distortions are high. THD based upon RMS values can range from 0 to 100%, while those based upon fundamental values can range from 0 to infinity. A given lighting system could have THD ratings of 80% or 150%, depending upon which definition is used. Therefore, when comparing different lighting systems, it is important to ensure that the same definitions of THD are used, especially when THD values greatly exceed 30%. There is good agreement between the two definitions when THD values are less than 30%.

Longevity

Obviously, energy-efficient lighting products must survive beyond the break-even point to realize savings over cheaper but less efficient alternatives. Lamps are fragile products. The risks of premature breakage and theft are occasionally overlooked in economic analyses. Sufficient contingency should be included in all economic analyses wherever such risks are high.

Most manufacturers publish rated lifetimes for their lamps and ballasts. It is generally understood that such ratings are statistical values which do not necessarily represent the actual lifetime of any given lamp or ballast. A rated lifetime is simply the duration over which 50% of a large number of identical units are expected to expire when operated under a given strictly controlled condition. Some units will survive much longer than the rated lamp life, while others will expire much sooner. The strictly controlled conditions typically involve an ambient temperature of 25℃ and a duty cycle of 3 hours "on" followed by 20 minutes "off." The rated lifetimes do not apply when the products are operated under any other field condition.

Field effects

Field effects can affect the performance of our lighting products, yet they are outside of manufacturers' control. Field effects are the principal reasons why our actual lighting costs might differ from predicted costs based upon rated values. For fluorescent systems, the effects of ambient temperature and the frequency of "on/off" switching are the two most important field effects to consider.

Switching

Electricity bills are for energy (kilowatt hours) rather than power (watts). That means we can reduce our electricity bills by decreasing the time that we draw power from our light sources. Thus, it makes sense to switch off lamps when they aren't needed. This runs counter to the urban myth that lamps should be left on to avoid power surges and losses in lamp life incurred during the stresses of later restarting. To test the support for that myth today, our lab conducted a survey in a Toronto office. Only 40% of people believed that energy could be saved by turning the lights off for 15 minutes. Thus, many people still believe that energy is wasted by switching.

For incandescent lamps, the myth isn't true. Power surges during starting are so brief that the extra energy used during starting can be offset by turning them off for as little as 0.04 seconds. Also, the lifetime of incandescent lamps is not affected by switching. Otherwise, flashing theatre marquees, for example, would require very frequent maintenance.

For fluorescent lamps, the myth is partially true. Every time a fluorescent lamp is switched on, a very small amount of emmissive coating is lost from the lamp's electrodes, until eventually it will no longer start. Thus, lamp life is reduced by a very small degree every time a fluorescent lamp is started. In fact, 4 foot T12 cool white fluorescent lamps can be expected to last 170% of their rated lifetimes when operated continuously instead of on a 3 hour duty cycle. On the other hand, they are expected to expire prematurely when operated much less than 3 hours at a time.

This doesn't mean, however, that we should always leave fluorescent lamps on. What it means is that we should weigh the savings in unused electricity against the cost of reduced lamp life. We should also consider that if we operate a lamp needlessly, we are effectively reducing the number of hours that the lamp and ballast will later be able to give us useful light. Of course, the cost of electricity and relamping schedules also come into play.

Weighing all these factors together, our laboratory calculated that we can usually save money by turning off fluorescent lamps when they aren't needed for a period of 15 minutes or more. This applies even when electricity rates are as low as $0.03/kWh. In many cases, the calculated break even period can be less than 60 seconds (e.g., for 40W T12 lamps on magnetic ballasts with electricity at $0.10/kWh). The analysis applies to the more conventional types of 4 foot lamps. The break even period would probably increase for premium lamps, due to the higher cost of lamp replacement.

What this means is that costs of fluorescent lighting can increase when duty cycles are very short. Occupancy sensors, when used with fluorescent lamps, should be installed and adjusted carefully to avoid unnecessary switching.

Temperature

Ambient temperature is an important field parameter for fluorescent lamps. In the cold, some lamps require several switches to start. This can lead to wear and tear on the electrodes, and hence reduced lamp life. This is especially important with lamps operated on preheat ballasts as commonly used with compact fluorescents. In sub zero temperatures, our lab tested magnetically ballasted preheat systems which started only after minutes of wear and tear to their starting circuits. We also noted that other fluorescent systems (e.g., one-piece electronically ballasted compact fluorescent systems) started very well at very low temperatures. Table 2 summarizes our results. To avoid starting problems, check the detailed product specification ratings for the lamps to make sure they will start suitably throughout the temperatures in which they will be operated.

Table 2. Starting times (seconds) for 12 different compact fluorescent systems at different ambient temperatures

			Ambient Temperature, ° C					
Lamp	Ballast	Min. Rated Temp. ° C	-18	-9	0	10	25	45
Twin, T4, Exposed	Magnetic, Separate	-5	25	3	3	3.5	3	2.5
Misc., T4, Enclosed	Magnetic, Integral	-5	11	6	5	3	2.5	2
Quad.,T4, Exposed	Electronic, Integral	-18	3	2	2	1.5	1	1.5
Misc.,T4, Enclosed	Electronic, Integral	-18	5	5	5	3	2	1.5

Quad., T4, Exposed	Magnetic, Adapter	-4	205	Failed	6.5	4.5	5	5
Quad., T4, Enclosed	Magnetic, Adapter	-4	451	25	5	5	6	5
Quad., T4, Exposed	Magnetic, Separate, HP# O,	-9	411	5	4	4	2.5	3
Twin, T5, Exposed	Magnetic, Separate, HP#	+10	Failed	Failed	1.5	0.5	2.5	0.5
Quad., T5, Exposed	Magnetic, Separate	-29	4	4	3.5	4.5	2.5	1.5
Quad., T4, Exposed	Magnetic, Separate	-4	20	20	3.5	4.5	4	4
Twin, T4, Exposed	Magnetic, Adapter	-4	40	40	5	3.5	5.5	4
Twin,T4, Exposed	Magnetic, Separate	-5	Failed	Failed	5	5		5

HP = High Power Factor

At elevated temperatures, electronic and electrical components don't necessarily last as long as they do under normal room temperatures. This can apply to ballasts in enclosed or unventilated fixtures. The Canadian Standards Association reports measuring ambient temperatures of 45°C within recessed compact fluorescent fixtures installed in insulated ceilings. Before installing ballasts in such fixtures, one should check detailed product specifications to ensure that the ballasts will survive those temperatures for the time required.

Temperature can affect the electrical and photometric performance of fluorescent lamps, as shown in Figure 4. The data are for 4 foot rapid start fluorescent lamps in an open fixture.

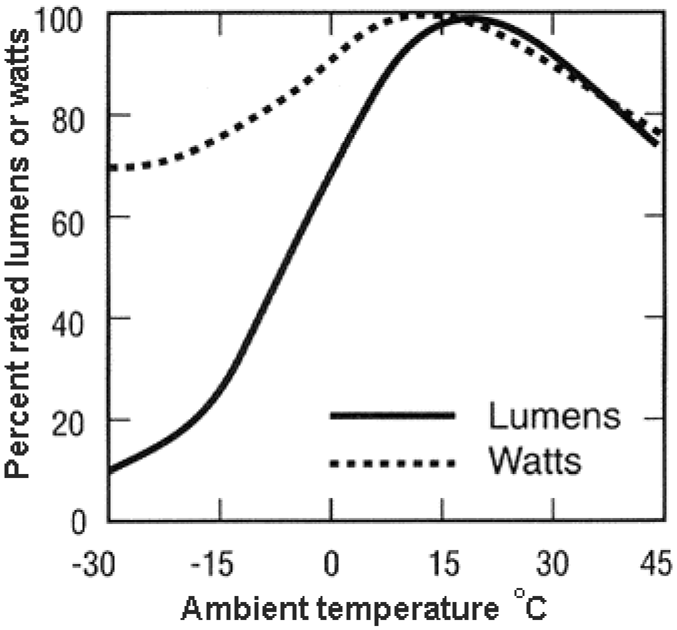

Figure 4. The effect of ambient temperature on light output (lumens) and power consumption (watts).

The graph shows that the optimum temperature for standard 4 foot T12 systems is slightly below room temperature and that performance can be improved by cooling the lamps. It indicates that good thermal management is an area of potential savings for fluorescent lighting. The thermal management techniques include the following.

- The use of active or passive ventilation through the fixture.
- Using open 2 lamp fixtures instead of enclosed 4 lamp fixtures, which could build up more heat.
- The use of more efficient ballasts, which give off less wasted heat.
- The use of cooling devices or heat sinks, which are presently emerging on the lighting market.

Not all fluorescent lamps are alike in terms of their response to temperature. Figure 5 is a graph of light output from different compact fluorescent samples started at various ambient temperatures ranging from -18℃ to +45℃. Clearly, not all compact fluorescent products are suitable for all temperatures. The first sample, for example, is best for use at room temperature and above, even though it is rated for use at -5℃. The second sample, on the other hand, contains amalgams in the arc tubes which gave superior light output through all the temperatures tested. The third sample stabilized relatively quickly, but it gave poor light output at the lower temperatures. The fourth sample is another amalgam-containing lamp, but this one has very long warm up times at some temperatures. Ironically, the manufacturer's abbreviated product fact sheet specifies that the time to full light output is 60 seconds. The same manufacturer's detailed product specification sheet, however, gives data consistent with that shown in Figure 5. This highlights the need to consult detailed rather than abbreviated product specification data. The fifth sample stabilized quickly and gave reasonably high light output, except in subzero temperatures. The sixth sample is the same as sample 5, except that it is enclosed within a diffuser, which elevated the temperature of the lamp surfaces. The result was improved performance in low ambient temperatures, but decreased performance in higher ambient temperatures. All six samples are efficient products, each with strengths and weaknesses depending upon the ambient temperature in which they will be operated.

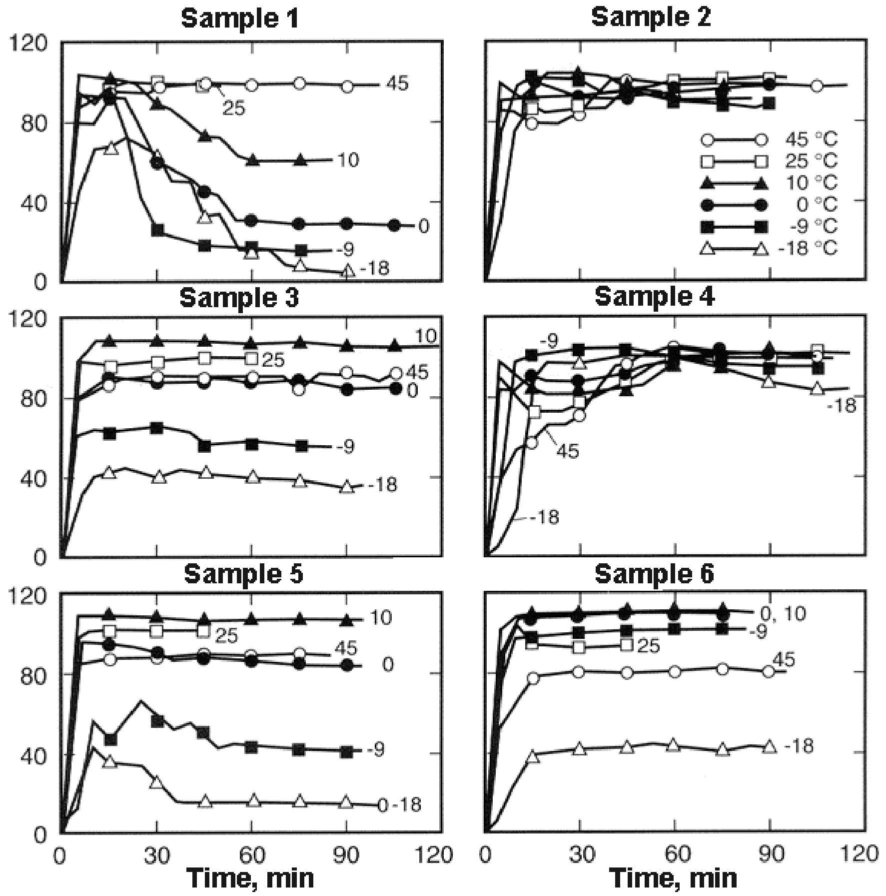

Figure 5. Relative light output from 6 compact fluorescent systems at different ambient temperatures between -18℃ and +45℃.

Conclusion

Efficient lighting products can help one meet the proposed National Energy Code for Buildings and provide good lighting that consumes less energy. These products are diverse and quite sophisticated compared to the products of only a few decades ago. They usually involve a greater initial investment, which can be recovered if they perform as specified in field conditions. On the other hand, if they do not perform as expected, the risks for loss are high. The key to ensuring a good return on investment is to select only those products which will perform as expected throughout the range of field conditions in which they will be used. Understanding the basic performance characteristics of various lighting components is a good first step towards that end.

Acknowledgement

The Canadian Electrical Association and Natural Resources Canada/CANMET are thanked for their financial support of NRC/IRC research on the performance of compact fluorescent systems. Some results

of the project are presented in this paper. The complete report from this project is titled CEA Report No. 9038-U-828, "The Evaluation of Compact Fluorescent Lamps for Energy Conservation" and is available from the Canadian Electrical Association.

Michael Ouellette has been employed with the National Research Council of Canada, Institute for Research in Construction since 1980. He has participated as a team member and project manager in lighting research in visual performance, emergency lighting, energy efficiency, photometry and spectroradiometry and ergonomics. He has authored or co-authored over 50 papers in these areas. He is a member of the IES (Illuminating Engineering Society of North America), the IEEE (Institute of Electrical and Electronics Engineers), and the CIE (Commission Internationale de l'Éclairage). He participates in various technical committees of these organizations.

[1] Available by telephoning 613-993-2466

This article was published as part of the technical documentation produced for Building Science Insight '92, "Effective and Efficient Lighting," a series of seminars presented in major cities across Canada in 1992.