

FACTS AND FICTIONS ABOUT ENERGY-EFFICIENT LIGHTING The Advantages and Disadvantages of Compact Fluorescent Lamps

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Abstract

At the beginning of the 1980s compact fluorescent lamps were first introduced to the market and immediately became synonymous with energy-efficient lighting. Their advantage: compact fluorescent lamps combine the energy-efficiency and long life of standard fluorescent lamps with the compact size and simple handling of incandescent lamps.

"Facts and Fictions" briefly introduces compact fluorescent lamps and offers a comparison to standard fluorescent and incandescent lamps. Here the advantages and disadvantages of each lamp are considered with respect to their economy, convenience of operation, and dimensions--and rated vis-à-vis "the perfect lamp."

The paper concludes with short notes on additional facts to be considered when installing compact fluorescent lamps: the advantages of electronic control gear, low temperature influences on luminous flux and lamp ignition, and lamp life.

AN OVERVIEW OF COMPACT FLUORESCENT LAMPS

Compact fluorescent lamps (CFL) were introduced at the beginning of the 1980s and represented a major breakthrough in lighting technology. Based on the same principal as standard fluorescent tubes, CFL emit light by means of an energy-efficient low-pressure electric discharge. Advances in the durability of fluorescent phosphors enabled the development of fluorescent lamps with much smaller tube diameters while still maintaining long lamp life. The small tube diameter combined with a U-shaped lamp tube led to the CFL's extremely compact dimensions.

The first CFL was a flat single tube pin base lamp that required an external ballast for operation. Soon thereafter much shorter double tube lamps were introduced and development began on lamps with integrated ballasts, both conventional and electronic. Lamps with integrated ballasts allowed for the direct exchange of CFL against standard incandescent lamps--thus presenting a viable energy-saving alternative for existing fittings.

A wide variety of CFL has been developed since the initial introduction 10 years ago. Lamp wattages range from 5W to 55W with lumen outputs from 250 lm to 4500 lm. Given this range the CFL can be viewed as an alternative to both incandescent and standard fluorescent lamps. The current product range of CFL can be divided into two groups: lamps requiring external ballasts (easily identified by their pin bases) and lamps with integrated ballasts (identified by their standard screw or bayonette bases). Both groups can then further be subdivided into lamps for conventional vs. electronic operation. The remaining variants include decorative CFL--for example globe and reflector versions or lamps producing colored light (for an overview of CFL please see diagrams 1 and 2).

THE ADVANTAGES AND DISADVANTAGES OF CFL

If one were to describe the perfect lamp it would have to fulfill three main criteria: (1) the lamp would have to be energy-efficient or "economical," (2) it should be as small as possible in order to save space and fit into most installations, and (3) it should be convenient to operate, not requiring any complicated control gear and allowing for easy lamp replacement. By mapping these points on a diagram, we can compare how current general lighting technologies measure up to the perfect lamp (diagram 3). Starting with incandescent lamps--they receive high

marks for compactness and convenience of operation, but are very inefficient energy users. Standard fluorescent tubes are, on the other hand, very economical lighting sources, but they require some standard control gear and are relatively large (long). High pressure discharge lamps are also very energy-efficient and relatively compact, but require rather complicated control gear to operate. The CFL comes a step closer to the perfect lamp because it is very compact and energy-efficient, although it too requires some standard control gear.

In this comparison the CFL can be viewed as a lamp that combines the energy-efficiency and long life of fluorescent lamps with the compact size and simple handling of incandescent lamps. Naturally the CFL cannot perfectly combine the two lamp technologies. The following discussion offers a comparison between CFL, incandescent and standard fluorescent lamps--here again the focus is on economy, convenience of operation, and dimensions. At the beginning of each section the lamps are rated relative to the perfect lamp as shown in diagram 3.

Economy

| | | | |
|---------------|------|---------------|-----|
| Perfect Lamp: | 100% | Incandescent: | 40% |
| CFL: | 80% | Fluorescent: | 90% |

The economy of a lamp can best be evaluated by comparing its relative luminous efficacy (lm/w = amount of light produced measured in lumens divided by energy consumed measured in watts). The higher a lamp's luminous efficacy, the more light it produces with each watt of energy consumed--i.e. the more energy-efficient it is. Naturally, the more energy-efficient a lamp is, the more money it will save you in energy costs. The following chart gives the approximate ranges of luminous efficacies for various lighting technologies:

| lamp type | luminous efficacy |
|---------------------|-------------------|
| incandescent | ca. 10 lm/w |
| tungsten halogen | 15-20 lm/w |
| compact fluorescent | 50-85 lm/w |
| fluorescent | 60-100 lm/w |
| metal halide | 70-100 lm/w |

From the above chart it is clear that incandescent lamps are very inefficient light sources generating only about 10 lumens of light for each watt of energy consumed, whereas CFL and fluorescent lamps produce 5-10x as much light from the same amount of energy. The reason for this difference in energy-efficiency lies in the two technologies used to produce light:

An incandescent lamp functions by heating a tungsten filament by means of an electric current to the point of glowing--through this process both heat and light are produced. Actually, an incandescent lamp could more accurately be described as a heat radiator since 90-95% of the energy consumed to produce light is radiated as heat, leaving only 5-10% which is transformed into light.

Light is generated in a CFL or fluorescent lamp by means of a low-pressure gas discharge. An electric current is passed between two filament cathodes in a tube filled with mercury vapor¹ The resulting electric discharge stimulates the mercury atoms to radiate ultraviolet radiation (and heat). The ultraviolet radiation is primarily non-visible radiation, which only by means of a phosphor coating on the inner wall of the lamp tube is transformed into visible light. This is a completely different technology for producing light and much more energy-efficient than heating a tungsten filament. Through the discharge/fluorescent process approximately 25% of energy consumed is transformed into light and 75% radiated as heat.

The following is a simple calculation indicating how much energy can be saved by substituting a CFL with integrated electronic ballast for incandescent lamps in a typical installation:

| | | |
|-------------------------------------|------------------|--------------------|
| lamp type | 20 W CFL | 100 W Incandescent |
| no. of lamps | 20 | 20 |
| burning time | 8000 hours | 8000 hours |
| average lamp life | 8000 hours | 1000 hours |
| energy consumed during burning time | 3.200 kWh | 16.000 kWh |
| energy saved with CFL | 12.800 kWh = 80% | |

Often there are questions raised about how much energy it takes to produce a CFL. Will this energy be so high that the advantage of the energy saved during the burning time will be reduced? The fact is that only 0.29% of the energy saved during burning time, of 8000 hours, is equal to the energy for production. A CFL with integrated electronic ballast takes 1.4 kWh to produce but it will save 480 kWh compared to an incandescent lamp. To produce incandescent lamps for 8000 hours (pcs.) burning time will take 1.2 kWh. Almost the same amount as for one CFL.

This is of course a simple calculation and there are other cost factors to be considered when evaluating the overall economy of an installation: for example lamp price and lifetime, cost and type of control gear, power loss from the control gear, number and type of luminaires required. In general, however, the remarkable energy savings achieved by substituting CFL for incandescent lamps--up to 80%--more than outweigh the extra costs associated with purchasing CFL and the required control gear. This is particularly true when the lamp life of CFL and incandescent lamps is taken into consideration. On average CFL last 8000 hours, or 8x as long as incandescents. This means the initial purchase price of CFL and related control gear must be viewed relative to the price of 8 incandescent lamps plus the labor/maintenance costs to replace 7 burned-out incandescent lamps.

Given that CFL and standard fluorescent lamps produce light by the same technique, there is no dramatic difference in their energy-efficiency. Due to their larger tube diameter and different gas filling standard fluorescent tubes are in fact slightly more economical lighting sources.

Convenience of Operation

| | | | |
|---------------|------|---------------|-----|
| Perfect Lamp: | 100% | Incandescent: | 90% |
| CFL: | 80% | Fluorescent: | 70% |

Despite their poor performance in energy-efficiency, incandescent lamps offer some decisive advantages when it comes to convenience of operation: the standard screw and bayonette bases allow for both easy lamp replacement as well as interchangeability among lamp wattages, lamps can be directly connected to the mains voltage (i.e. do not require any additional control gear), and when switched-on the lamps immediately produce light. A decisive disadvantage of incandescents is, however, that they burn very hot--i.e. temperature problems develop quickly when higher wattages are used. Many fittings even limit the maximum allowable wattage (often 60W), which causes problems when a higher lighting level is desired.

On the other hand, fluorescent lamps produce much less heat because they consume much less energy to produce light (compare, for example, 18W to produce 1450 lm vs. 100W to produce 1380 lm for an incandescent lamp). Also, by changing the mixture of phosphors coating the lamp tube it is possible with fluorescent lamps to achieve a wide range of light colors--from warm white to daylight. This is not possible with incandescent lamps. However, to operate fluorescent lamps either conventional or electronic control gear is required, and this must correlate to the lamp wattage (i.e. is not fully interchangeable). If conventional control gear is employed the lamp does not switch-on immediately, but may require several starts--this is what causes the uncomfortable flackering associated with fluorescent lamps.

In terms of their convenience of operation CFL cover the range between incandescent and fluorescent lamps. CFL with integrated electronic ballasts and screw or bayonette bases are easily interchangeable, can be directly connected to the mains voltage, and offer an immediate flacker-free start. Other CFL are similar to fluorescent tubes in that they require an external ballast for operation (these are the lamps with pin bases). Variants of these pin base lamps can be operated either with conventional or electronic control gear. Luminaires for fluorescent tubes or CFL with pin bases are therefore somewhat more complicated to construct (relative to incandescent luminaires) due to the additional wiring, specific lamp holders, and control gear that must be incorporated. However, once a luminaire has been constructed, the lamps are easily replaced at the end of their lifetime. In terms of convenience of operation CFL have an advantage over standard fluorescent lamps in that they require only one lampholder since they have single-ended bases. Similar to standard fluorescent lamps CFL also have relatively cool burning temperatures and are also available in a range of light colors.

Dimensions

| | | | |
|---------------|------|---------------|------|
| Perfect Lamp: | 100% | Incandescent: | 100% |
| CFL: | 80% | Fluorescent: | 40% |

It is in this category that CFL offer the greatest advantages relative to standard fluorescent tubes. However, only the lowest wattage (i.e. smallest) CFL can measure up against the extremely compact size of incandescent lamps. The following table compares the dimensions of a 20W CFL with integrated electronic ballast, an 18W CFL for operation on external ballast, an 18W standard fluorescent tube, and a 100W incandescent lamp:

| lamp | lumens | length | diameter |
|-----------------------|---------|--------|----------|
| 20 W CFL w/ ballast | 1200 lm | 168 mm | 58 mm |
| 18 W CFL w/o ballast | 1200 lm | 173 mm | 48 mm |
| 18 W fluorescent tube | 1450 lm | 590 mm | 26 mm |
| 100 W incandescent | 1380 lm | 105 mm | 60 mm |

Not only is the amount of energy required to reach a comparable light output very different between incandescent and fluorescent lamps, but also the amount of space required to do so. The CFL is two-thirds shorter than the fluorescent tube, but still 6-7 cm longer than the incandescent lamp. Similar to the comparison of energy-efficiency, this size difference can be attributed to the two distinctive techniques used to produce light and the form of the CFL.

The incandescent lamp produces light by heating a filament to incandescence (radiation) by an electric current. The extremely thin filament wire is approximately 1 meter long, but through coiling and recoiling can be wound into a filament only about a centimeter long. Thus light is produced in a very small area, which in turn means the lamp itself can be very small. With the proper gas filling the size of the lamp can be reduced to almost a point, an example of this is low voltage tungsten halogen lamps.

On the other hand fluorescent and compact fluorescent lamps require a given length to produce light. In these lamps ultraviolet radiation from a low pressure electric discharge is transformed into visible light by a fluorescing coating on the interior wall of the lamp tube. Light is therefore not produced by a small filament, but over the entire length of the (compact) fluorescent tube. To produce more light, the length of the electric discharge, and therefore the entire lamp, must increase. For this reason a standard 18W fluorescent lamp is 590 mm long, whereas a 58W lamp already reaches 1500 mm in length.

By "bending" the lamp tube or connecting two or three such bent tubes the overall discharge distance remains the same, but the length of the CFL is two-thirds to one-half shorter than the comparable fluorescent tube. This size factor accounts for the CFL's innovative image compared to fluorescent tubes. Particularly in office and commercial lighting applications the relatively small size of the CFL allows much smaller luminaires to be installed--thus contributing to an overall more elegant interior design.

ADDITIONAL FACTS TO CONSIDER WHEN INSTALLING CFL

The Advantages of Electronic Control Gear

The development of electronic (high frequency > 35 kHz) control gear solved many of the problems traditionally associated with fluorescent lamps. These are for example the lamp flackering when it is turned-on, the flimmering (or visible "waviness") of fluorescent light, and the problem of frequent switchings reducing lamp life. The advantages that electronic control gear (ECG) offer over conventional control gear can be divided into four categories (diagram 4):

simpler luminaire construction -

a single ECG replaces the ballast, starter, PFC and radio interference suppression capacitors and associated holders and wiring required for conventional operation. In addition the ECG is small and light weight.

improved lighting quality -

the high frequency operation on ECG guarantees calm, flimmer-free light with no risk of stroboscope effects, immediate lamp start without flackering, quiet lighting since the buzzing of the conventional ballast is eliminated, and no blinking at the end of the lamp's life due to an automatic shut-off mechanism.

reduced operating costs -

high frequency operation means 30-50% longer lamp life due to the especially gentle lamp start and a smaller decrease in luminous flux over the lamp life. In addition, the low power loss of ECG results in up to a 27% reduction in energy consumed.

increased operating security -

automatic shut-off of defective lamps. Reliable operation of lamps over a larger range of supply voltage deviations than with conventional control gear.

Low Temperature Influences

When operating CFL at low temperatures attention must be paid to the relative luminous flux and reliable ignition of the lamp. The luminous flux is dependent on the temperature at the coolest point of the CFL's discharge tube. This in turn is influenced mainly by the ambient temperature and burning position of the lamp (base-up, base-down, horizontal). The maximum luminous flux is reached at ambient temperatures of approximately 25 °C. Although each CFL has a specific luminous flux-ambient temperature correlation curve, in general it can be said that the luminous flux of CFL in the horizontal or base-up position decreases significantly at ambient temperatures below 15 °C, whereas for lamps in the base-down position this occurs first at temperatures below 0 °C (the specific correlation curves can be obtained from the individual lamp manufacturers and are published in their technical manuals). An important consideration for operating CFL at low temperatures is therefore the burning position--base-down is advantageous--and how well insulated the luminaire is. Since CFL also generate heat while producing light, the lamp and luminaire will warm-up during operation, thus improving the luminous flux of the lamp.

At temperatures below - 10 °C the trouble-free ignition of some CFL comes into question--as with luminous flux the exact minimum varies from one lamp type to the next. Through the use of electronic control gear trouble-free ignition can often be guaranteed to - 30 °C.

Lamp Life

The long lamp life of CFL--8000+ hours--is one of its primary advantages compared to incandescent lamps and puts the CFL almost on par with standard fluorescent lamps. The main factors effecting CFL lifetime are the type of control gear used, the switching frequency, and the supply voltage to the lamp.

As mentioned above, the use of electronic control gear extends CFL life by reducing the decrease in luminous flux over the lamp's lifetime and assuring a gentle lamp start, which extends the life of the lamp electrodes and the number of switchings possible. In conventional operation there is a direct correlation between the number of switching cycles possible and the life of the lamp.

Although the life of CFL does not as dramatically depend on the supply voltage as incandescents, this does play a role. In general one can say that variances in the supply voltage between +/- 10 % from the rated voltage have little effect on the CFL life. This is in marked contrast to incandescent lamps, where 10% over voltage reduces the lamp life by up to 70%.

REFERENCES

- [1] Through a new dosage technique using a mercury "pill", OSRAM has reduced the amount of mercury in its CFL to ca. 4 mg per lamp. This represents the current physical minimum required for CFL to function.

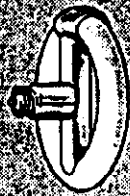
Compact lamps existing sockets integrated ballast

Diagram 1



Identical base:
no adapter necessary

Circular CFL with
electronic ballast
18W, 24W, 32W



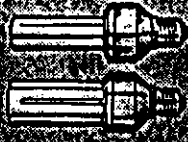
Cylindrical CFL with
conventional ballast

9W, 13W, 18W, 25W



2 and 3 U-shaped tubes
electronic ballast

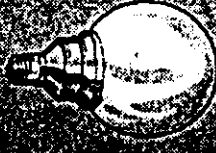
7W, 11W, 15W, 20W, 23W



Globelamps

Conventional and
electronic ballasts

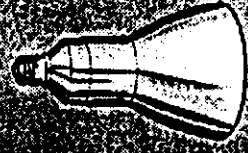
7W, 11W, 15, 20W



Reflectorlamp

electronic ballast

11W, 15W, 20W



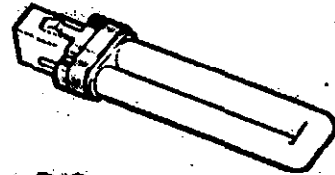
Compact lamps

External ballast necessary

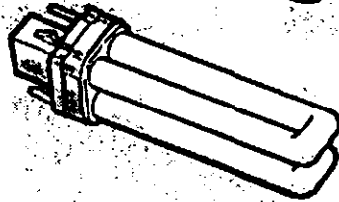
Diagram 2

Conventional

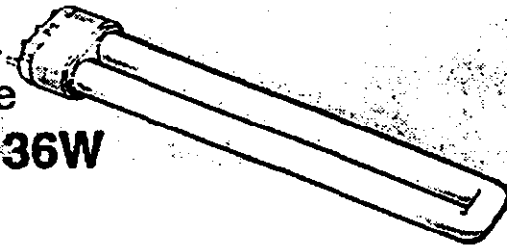
1 U-shaped tube
5W 7W 9W 11W



2 U-shaped tubes
10W 13W 18W 26W



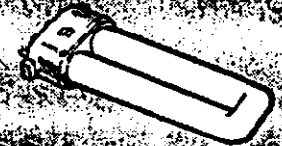
1 U-shaped tube
18W 24W 36W



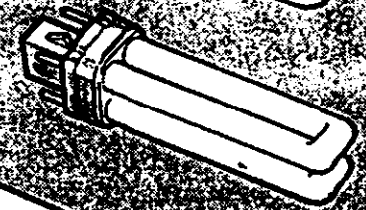
Electronic



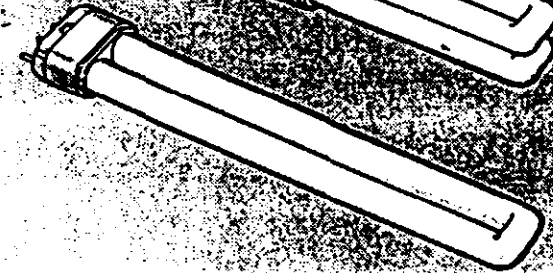
1 U-shaped tube
5W 7W 9W 11W



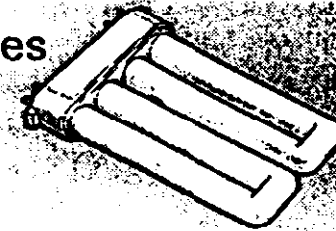
2 U-shaped tubes
10W 13W 18W 26W

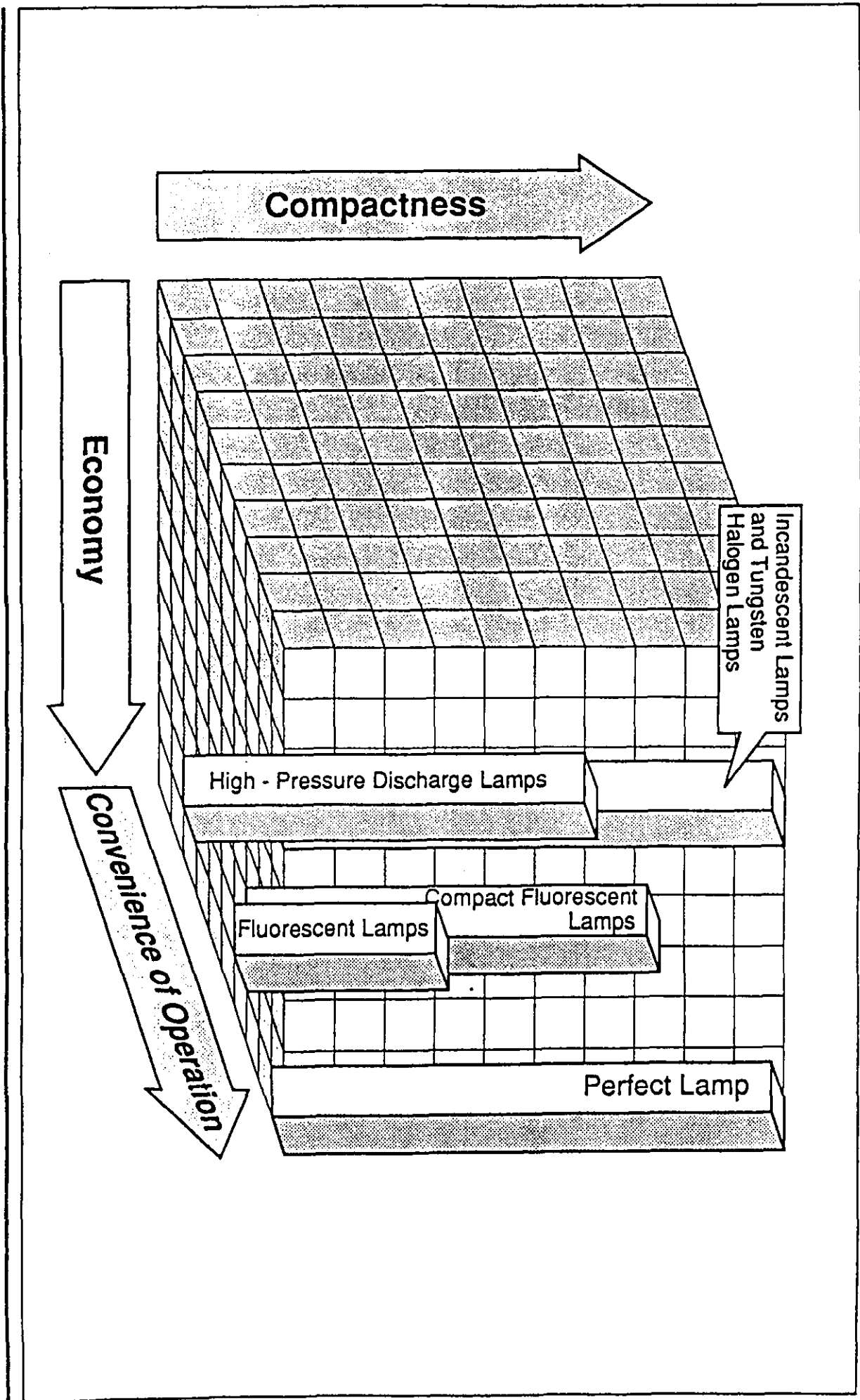


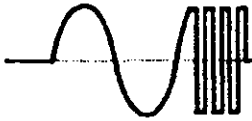
1 U-shaped tube
40W 55W



2 U-shaped tubes
in flat-form
36W







Important Reasons for Use of ECG

| | Conventional | Electronic HF | |
|---------|--------------|---------------|---|
| COMFORT | | | Flicker-free Light No Stroboscopic Effect |
| ECONOMY | | | Low Energy Costs Long Lamp Life |
| SAFETY | | | Switch off defective Lamps Use in Emergency Illumination |
| DESIGN | | | Small Size Low Weight |