Artificial lighting for green or sustainable buildings and their fire safety concerns

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Abstract: In this paper, environmental aspects of artificial lighting including incandescent lamps and compact fluorescent lamps are reviewed. The impact on green or sustainable buildings is discussed from the energy use viewpoint. As there are complaints on the falling down of plastic components, and the long ignition time required for compact fluorescents, the fire environment is simulated with Computational Fluid Dynamics. Results indicated that combustibles placed adjacent to a lamp with the possibility of igniting should be watched carefully.

Keywords: artificial lighting; sustainable building; fire safety

1. Introduction

Green buildings [1,2] are designed to give less damage to our Earth by using less energy, discharging less pollutants including greenhouse gases to reduce the Global Warming Potential (GWP) and halogenated agents to have zero ozone depletion potential (ODP), but maintaining the same or even better thermal comfort and building operating conditions. This can be achieved through developing new architectural features, environmental control system and management scheme to use more renewable energy, natural ventilation and daylighting; maximize or minimize solar heat gain to give more warming or reduce more heating effects. Basically, this is a problem on solving energy and mass transfer. Environmental assessment methods were designed to assess energy use, indoor air quality, daylighting and natural ventilation provisions, water conservation and waste management, etc. The concept for assessing the building is moved from a 'relative' scale to an 'absolute' scale, giving sustainable buildings.

Energy used for lighting is one of the key elements. As surveyed before, up to 50% of building energy might be used for lighting in commercial buildings. The value is not likely to be less than 20% of the total building energy use in domestic buildings. There are many luminaries available in the market with different efficacy, i.e. lumen output per energy used.

In this paper, two common luminaries for electrical lighting system will be reviewed. Those are incandescent lamps and compact fluorescent lamps. Typical applications of tungsten filament include homes, hotels, public houses and historic buildings. For compact fluorescents, lower wattage types are used for amenity, effect and display lighting (self-ballasted versions are plug-in replacements for filament light bulbs). Higher wattages are used for general lighting of offices, retail stores and others. Whether they are suitable for green or sustainable buildings will be discussed. Further, fire safety [3] of compact fluorescent lamps will be discussed with Computational Fluid Dynamics [4,5].

The concept on efficiency of lamps can be quite confusing. For other energy systems such as heating systems, there is a limit on the energy that the fuel can give. The amount of energy achieved from that system is denoted by its efficiency, say 30% or 40%. But for lighting system, output is the lumen. The term efficacy is often used instead of efficiency. Efficacy is the lumen output divided by the watts of power input (lumens per watt). Standard incandescent lamps would produce (10 to 20) $\mathrm{lm \cdot W^{-1}}$, while fluorescent lamps produce (50 to 90) $\mathrm{lm \cdot W^{-1}}$. High-pressure sodium lamps would give up to 140) $\mathrm{lm \cdot W^{-1}}$.

2. Tungsten filament lamp

Incandescent lamps are commonly used over the world as the light bulbs are readily available [6]. Light will be produced when electricity passes through to heat up a thin tungsten filament up to 1000 K. When more power is dissipated, light intensity will increase and the peak wavelength of the emitted electromagnetic spectrum will shift to the blue and violet region. Typical vacuum lamps would be heated up to filament temperatures ranging from 1800 K to

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2700 K. The light emitted from the lower temperature lamps appears reddish yellow, while the high temperature lamps appear to be 'whiter'. However, tungsten filament itself would be evaporated more rapidly as its temperature goes up. The evaporated tungsten would be deposited on the glass envelope with light absorbed. Depending on the application, the light output obstruction could be high enough to end the useful life of the lamp. Eventually, evaporating too much filament material will cause the filament to break, completely ending the life of the lamp. This is more obvious when there is mechanical vibration. These effects are strongly dependent on the filament temperature. That is why long life vacuum lamps tend to be operated at the lower temperature range and so the light appears yellow.

The electrical resistance of the tungsten filament at room temperature is initially quite low. When electrical power is supplied to the lamp, a large 'transient' (or 'in-rush') current would give rapid heating of the filament. The resistance of the filament might rise up five to ten times the cold resistance. The current drawn by the lamp would then be stabilized, giving a more steady light output. Depending on the size of the filament, the 'in-rush' period varies from (10 to 100) ms. This in-rush current requirement should be considered in selecting the power source for a specific lamp application in green or sustainable buildings.

3. Compact fluorescent lamp (cfl)

Another type of light bulb commonly used is the fluorescent lamp [6]. Light will be produced when electricity passes through the filament in a tube containing a small amount of mercury vapour to emit ultraviolet radiation. The inner surface of the glass envelope is coated with white fluorescent powder, UV radiation would be absorbed and re-emitted as visible light. Note that part of UV light would pass through the glass envelope, giving health effects to the users.

The compact fluorescent lamp is a new type of fluorescents. They are smaller, more long-lasting, and have a more pleasant colour than traditional fluorescents. New models can even be used in sockets for incandescent lamps, giving flexibility and choices for the users. These lamps must still be filtered. However, the compact fluorescent lamp is actually a fairly conventional, although somewhat miniaturized fluorescent tube packaged with an integral ballast (either iron ("magnetic") or electronic) in a standard screw base that can be installed into most of the table lamps or lighting fixtures.

Some compact fluorescents are of the "modular" type, with bulbs and ballasts separated. Those components can be replaced separately. Others are of the "integral" type, in which the ballast is permanently built into the bulb. It has to be disposed with the bulb when the bulb is burnt out.

Compact fluorescent lamps are also specified by the 'wattage' in the same way as normal bulbs. As less energy is used, a lower wattage bulb would give out the same amount of light. For example, a 100 W bulb is equivalent to a 20 W to 25 W CFL, and a 150 W bulb gives similar light output of a 32 W CFL. Further, they have an average working life from 9000 h to 10 000 h, up to 13 times longer than that of standard incandescent bulbs.

4. Comparison and cost analysis

The capital cost of a CFL is about 10 to 20 times that of an incandescent bulb of the same lumen output. The cost of electricity in Hong Kong is about HK$1 for 1 kWh. Using the lamp for an hour will cost about HK$0.1. If the life of the bulb is 1000 h, the running cost of an ordinary 100 W light bulb is HK$100. The cost for a light bulb is about HK$2, only a small part of the total cost of HK$102. A 21 W compact fluorescent lamp would use 20 % of the energy for a light bulb. The operating cost for 1000 h is HK$20. Therefore, the saving can be very significant. CFLs can replace incandescents in saving up to 75% of the energy for lighting.

For example, using a single 100 watt incandescent bulb for 8 hours per day will cost about HK$0.8 per day or HK$300 per year. An equivalent 18 w compact fluorescent bulb serving the same number of hours will cost less than HK$0.2 per day or only HK$60 per year. This gives a saving of over HK$200 per year.

Although it is not easy to change the attitude of paying HK$20 to HK$100 to buy a CFL bulb, this simple example shows how much can be saved by operating the two types of luminaries to give the same lumen. Note that a CFL might even have a lifetime of 10 000 h, 10 times that of an incandescent.

Further, it takes cost to replace the lamp. There would be significant savings if the lamps are not replaced so frequently. Note that high headroom

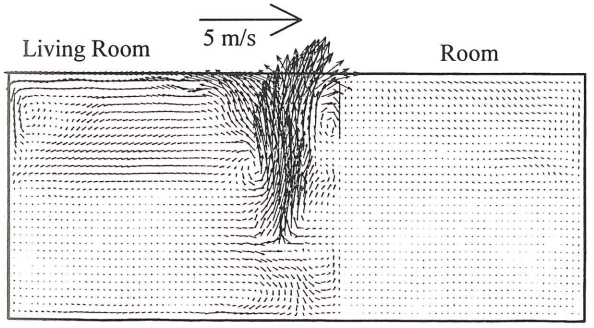
atrium might require scaffolding for the maintenance works.

Colour rendering and the colour appearance of light sources should be considered. Colour rendering is on describing how close the lit surface will be to the colours in daylight. Artificial light source would give different colour of the surfaces receiving light. The colour rendering property of a lamp is classified by the colour rendering index (CRI).

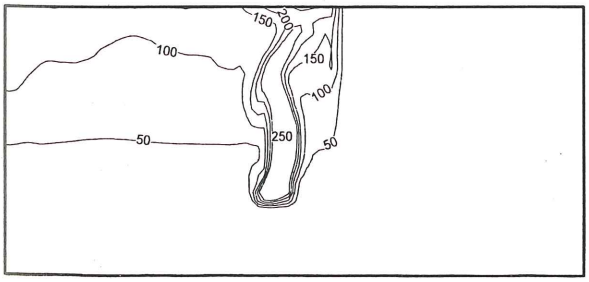
Compact fluorescent lamps have an average CRI of 82. Rare earth tri-phospor would give true colour in having excellent colour rendering. Other types would offer a choice of colour options from warm to cool. Users can get their own tone and atmosphere desired. But incandescent lamps have a near-perfect CRI rating of 97, much bettter than CFLs.

5. IGNITION TIME AND FIRE SAFETY CONCERN

Modern electronically-ballasted CFLs are faster to ignite than the earlier magnetically-ballasted models. However, most of them would take up to 1 min to reach 90% of brightness. When first energized, at least 10 s will be required to reach 50% of full brightness. This has resulted in snap back or reversion to incandescent lamps in some residential applications. For tungsten filament lamp, the in-rush period is much faster, of 10 to 100 ms.



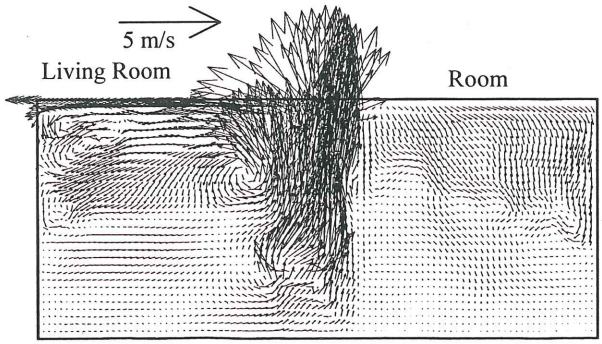
(a) Velocity vectors



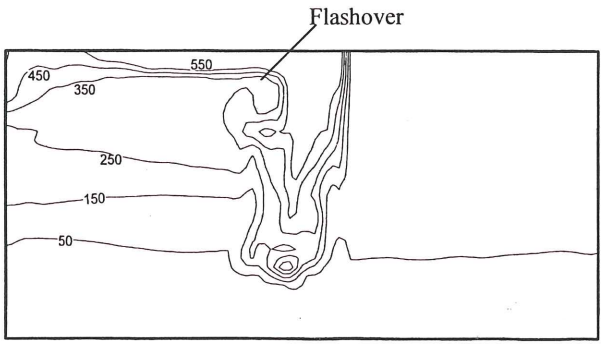
(b) Temperature contours

Fig. 1: Fire environment across the fire plane for a CFL ignited

Long ignition times drawing large current is very dangerous. Dissipation with heat conducted to the adjacent plastic parts and components would give a possible ignition source. Vigorous tests on assessing their fire behaviour should be designed. Several big accidental fires were in fact started from small table lamps. The plastic components should be treated with adequate fire retardants. However, there were numerous complaints on plastic base falling down easily [7]. This part must be watched as it is critical to fire safety.



(a) Velocity vectors



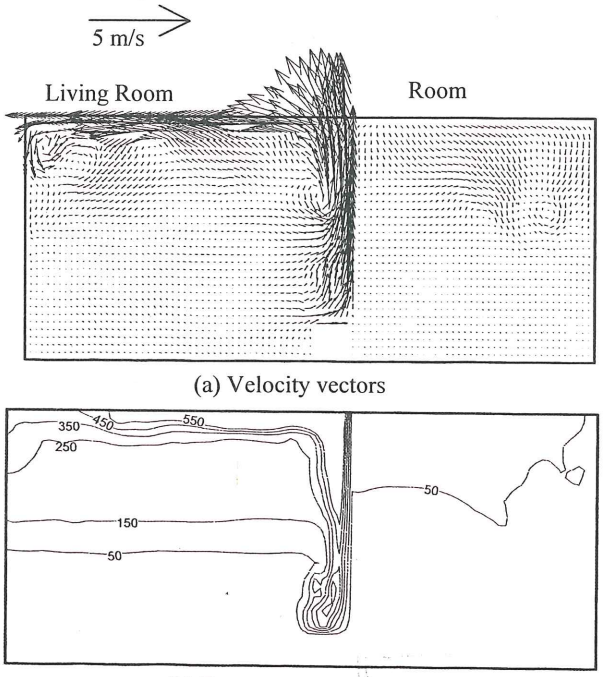
(b) Temperature contours

Fig. 2: Fire environment for igniting an adjacent furniture

As those electrical appliances might catch fire and had already led to several big fires, care must be taken on testing whether the plastic components satisfied appropriate fire tests. There were some complaints that plastic components might even fall down. Suppose a small fire was started due to failure in a typical 56 m^2 apartment with two bedrooms. The new Computational Fluid Dynamics (CFD) software Fire Dynamics Simulator FDS version 3.01 [4,5] was used. This fire on the plastic component might spread over a table with combustibles up to an area of 0.25m^2 to give 500 kW heat. The fire environment predicted by FDS across the plane of the fire is shown in Fig. 1. Flashover did not occur and the gas temperature might go up to only 150 °C at the ceiling. Such a fire is not too serious and occupants should have sufficient time to take appropriate action or to evacuate.

However, if there is an adjacent object like polyurethane foam (PUF) sofa ignited, a 3 MW fire

might be resulted to give a fire environment as shown in Fig. 2. Flashover would occur as temperature adjacent to the ceiling is higher than 550 °C. The consequences can be very serious and suspected to give a big fire in a high-rise building before. Results for a 5 MW fire are shown in Fig. 3.



(a) Velocity vectors

(b) Temperature contours

Fig. 3 Fire environment for a 5 MW fire

6. Conclusions

To achieve green or sustainable buildings, environmental control systems have to be designed and operated by using less energy but keeping the same or even better indoor environment. Using CFL is an obvious choice, which uses much less energy than incandescent lamps. The cost for maintenance on replacing the lamps is also reduced.

As reviewed, a CFL is suitable for replacing an incandescent lamp from the energy use point of view. For replacing a 100 W incandescent lamp by a 18 W CFL, only 180 kWh of electricity will be spent over 10000 hours lifetime. At HK$1 per kWh, the total operating cost is about HK$180. Adding to that the cost of say HK$20 for the bulb, the total lighting cost for that lamp is about HK$200. Operating a 100 watt incandescent bulb over the same 10 000 h, 1000 kWh of electricity would be used to give the same light output, costing HK$1000. Since incandescents only last for at most 1000 hours, it has to be replaced for 10 times. A cost of about HK$2 would give a total cost of HK$1020. A compact fluorescent light bulb can save up to HK$820 over the expected lifetime, excluding maintenance cost!

In conclusion, CFLs are better than tungsten filament lamps in the total cost, energy consumption, lifetime, and efficacy. However, tungsten filament lamps are better than CFLs in having shorter ignition time and higher colour rendering index.

However, safety aspects due to the longer ignition time and emission of ultra-violet should be watched more carefully. There are always conflicts between environmental friendly designs and fire safety [3]. The long ignition time of drawing high currents should be watched. There might be a possibility of igniting neighbouring objects such as plastic products not treated with fire retardants.

Of course, there is no excuse for not using more energy-saving appliances. Technology nowadays can solve almost any technical problems encountered. Working out good fire safety management programmes to replace the electrical appliances likely to catch fires regularly is another means to keep the green or sustainable building safe.

References

1 ASTM E 2114 Standard Terminology for Sustainability Relative to the Performance of Buildings, American Society of Testing and Materials, PA, U.S.A. (2001).

2 C.M. Leung, C.M. Chung, M.F. Hui and M.S.H. Lau "The Green building initiatives" Sustainable Building 2002: Proceedings of the 3rd International Conference on Sustainable Building, Oslo, Norway, September 23-25 (2002).

3 W.K. Chow and C.L. Chow "Awareness of fire safety for green and sustainable buildings" Paper 2, Session 3 on "Fire engineering and the community", International Conference – Fire Asia 2003, 26-28 February 2003, Hong Kong (2003).

4 K.B. McGrattan, G.P. Forney, J.E. Floyd, S. Hostikka and K. Prasad, Fire dynamics simulator (version 3) user's guide. NISTIR 6784, National Institute of Standards and Technology, Gaithersburg, MD, U.S.A. (2002).

5 K.B. McGrattan, H.R. Baum, R.G. Rehm, A. Hamins, G.P. Forney, K. Prasad, J.E. Floyd and S. Hostikka, Fire dynamics simulator (version 3) - technical reference guide. NISTIR 6783, National Institute of Standards and Technology, Gaithersburg, MD, U.S.A. (2002).

6 J.R. Coaton and A.M. Marsden, Lamps and lighting, 4th edition, Arnold, London; Wiley, New York, 1997.

7 Oriental Daily, 16 April (2002).