

# LIGHTING FACTORY SPACE IN CHINA: COST OF COMPLIANCE WITH LATEST REGULATIONS

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## Abstract

**In 2011 and 2012 85% of China's provinces experienced power outages. China's Electricity Council forecasts domestic electricity demand by 2020 will be nearly double 2010. One of the ways China's National Energy Commission (NEC) has responded to the energy shortfall is by requiring:**

- **New buildings must be at least 50% more energy efficient than 2005**
- **Energy use as a fraction of GDP by 2015 will be 16% lower than 2011**

**Toward these ends, China's National Development and Reform Commission declare halogen bulbs by Oct 2014 will be illegal.**

**This research answers for a factory in China lit to the national illumination standard, "Is it economical to switch from halogen lamps?" And, if so, "Does the change meet NEC energy efficiency targets?"**

**The factory in this study reduces lighting power nearly 6x switching from halogens to fluorescents. The 6 month payback is economical and the 30% drop in total workshop power is nearly double NEC energy efficiency targets. Neither high intensity discharge (HID) nor light emitting diode (LED) lamps are found to be suitable alternatives.**

## Introduction

Since 2009, China has surpassed the US to become the world's largest energy consumer [1]. Likewise, China has surpassed the US to become the world's largest producer of manufactured goods. Manufacturing now accounts for approximately 40% of China's GDP and 60% of its energy consumption [2].

In 2011 and 2012 85% of China's provinces experienced power outages. For manufacturers summer month power restrictions are all too common. Shortages in power are not due to insufficient capacity; an article entitled *China's Power Shortage* notes 60% of China's power generation equip-

ment is idle [3]. In an effort to keep inflation below 4% [4], China's National Development and Reform Commission (NDRC) has allowed electricity prices to rise only 15% since 2007. However, coal (used to produce 70% of China's power) has risen in price 80% over the same period. In the first half of 2011 Chinese power companies lost \$2.3 billion [5]. Rather than losing more money generating more power companies elect to idle capacity.

In light of mounting power company losses, The China Daily reports factories in China should continue to face 5% year-on-year electricity price increases through 2015 [6]. With China's Electricity Council projecting domestic electricity consumption to double from 2010 to 2020, energy policy is clearly at the heart of China's economic development [7].

China's National Energy Commission (NEC) has responded to the energy shortfall by requiring:

- New buildings (which account for 28% of China's energy consumption) must be at least 50% more energy efficient than 2005 levels [8].
- Energy use per unit of GDP in 2015 should reduce 16% compared to 2011 [9]

This paper seeks to answer for a factory in China lit to the national illumination standard (GB 50034-92), "Is it economical to switch from halogens to fluorescents, high energy discharge (HID) or light emitting diodes (LED)?" And, if so, "Does the change meet NEC efficiency targets?"

## Background

In order to understand potential energy savings associated with different lamp types, basic operating principles of each are presented.

In an incandescent light electric current passes through a drawn tungsten wire filament. Friction from the flow of electrons causes filament temperature to rise. More current, more heating, more visible light emitted. Unfortunately, only 5% of incandescent bulb power is converted to visible light and bulbs last on the order of 1000 hrs. [10]. China's NDRC (which in addition to writing national macroeconom-

ic policy also sets electricity prices) decreases from Oct 1st 2012 the use and sale of incandescent lights over 100 watts is illegal. By Oct 1st 2014 the threshold limit drops to 60 watts. And, by Oct 1st 2016 the limit falls to 15 watts.

Halogens lamps, while in the incandescent family of lights, use nearly 2x less power and last approximately 4x longer than standard bulbs. Such efficiency gains are possible due to the tungsten halogen regenerative process. For example, under high temperature and pressure, atomic halogen and tungsten combine inside the bulb to form tungsten halide. As this compound volatilizes halogen gas is released; tungsten is re-deposited on the filament; and the process begins again [11]. Even with such energy savings, China's NDRC decides from Oct 1st 2014 the use and sale of tungsten halogen lamps is illegal. For new building projects, failure to comply with lighting restrictions results in fines from \$30k – \$80k.

Unlike incandescent lights, fluorescent and HID lights are ballast powered. Ballasts initiate current flow between tungsten electrodes located on either end of quartz tubes. A starter forces an inductor in the circuit to release this stored current. In the case of fluorescents as electrons hit the tube's phosphorous coating visible white light is created. For metal halide lights as tubes heat up metal salts inside evaporate; under high pressure the result is high intensity, neutral white light. Compared to halogens, ballast powered lamps are nearly 5x more efficient at converting electricity to light and last almost 5 times longer. Driving the energy efficiency is the fact once the flow of electrons is underway little additional power is needed.

LED lamps, rather than using ballast power, convert AC into DC voltage across a semiconductor crystal. Negative charged electrons in the diode's electron transport layer combine with positively charged holes; excess energy is converted to light. White light is achieved either by mixing red, blue and green LED lamps or using an indium gallium nitride (InGaN) semiconductor material. Since LED's do not depend on electrodes, useful life is double ballast powered lamps.

Methodology

The workshop in this study is lit to GB 50034-92 24hrs/day every day over 4 years. A four year timeframe accounts for (1) differences in lamp type useful hours and (2) China's rising electricity prices. Electricity prices for industrial users are assumed to rise at 5% per year from \$0.13 per kilowatt hour (kwh) in year 1 [12].

Lamp fixtures in this study are: reflector fit, enclosed, and emitting white light with a color rendering index exceeding 80%. Per Figure 1, the workplane is 1.5m above the floor;

luminaires are 5.5 meters above the workplane; and lamps hang 1.5m below the ceiling.

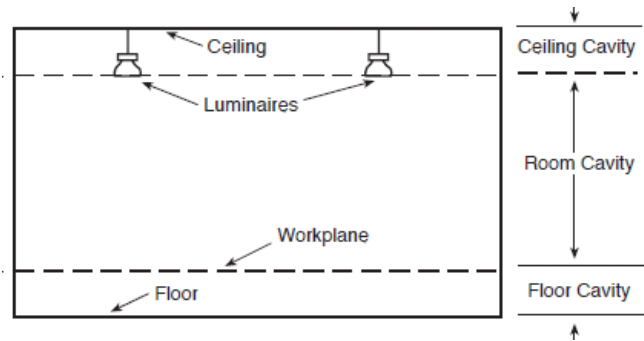


Figure 1. Workshop Lighting Dimensions

Following generally accepted lamp spacing rules, the researcher sets variable S in Figure 2 equal to 1.5\*Room Cavity Height. Per Equation (1), 28 luminaires are needed in each row of the factory [13].

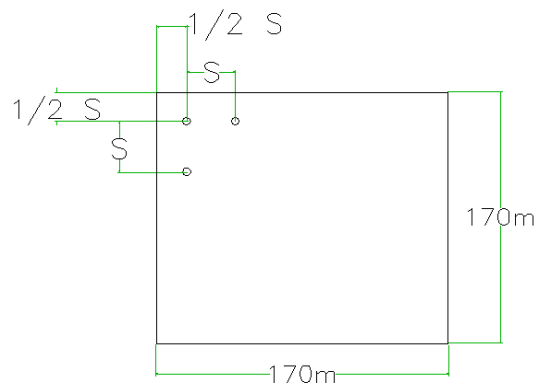


Figure 2. Luminary Spacing in the Workshop

$$\frac{1}{2} S = \frac{1}{2} * (1.5 * 4m) = 3m$$

$$\frac{[170m - (\frac{1}{2} S + \frac{1}{2} S)]}{S} = \frac{[170m - 6m]}{6m} = 27.3m \tag{1}$$

Since the workshop is square, 28 rows are needed for a total of 784 luminaires in the workshop.

According to China's Industrial Enterprise Illumination Design Standard (GB 50034-92), 300 lumens/m<sup>2</sup> intensity at the workplane is needed when general machining is done to tolerances greater than 0.1mm. When selecting lamp types to achieve this intensity, the researcher considers 4 factors:

1. Pupil effect
2. Luminary efficacy rating (LER)
3. Coefficient of utilization (CU)
4. Lumen loss factor (LLF) over useful hours

The human pupil is more receptive to light at the blue end of the spectrum. The researcher, therefore, applies a lumen per watt pupil correction factor (PCF) for each lighting type [14].

LER is a measure of lumens emitted per watt of power consumed. Transmission losses considered when computing LER values include: operating at non ideal temperature, ballast losses, voltage fluctuations, light trapped in the fixture and bulb blemishes.

Room surfaces are potential absorbers (and reflectors) of light. Reflectance percents for the workshop in this study are: ceiling 80%, walls 30% and floor 10%. Using reflectance and cavity sizes for the workshop, the researcher considers percentage of light reaching the workplane (i.e. CU) by light type.

All lighting systems experience lumen loss over time. For example, incandescent and HID bulb filaments decay; phosphor coatings on fluorescent lamps break down; and LED diodes degrade. Since China's GB system of national standards are legally enforceable, lamp intensity values are increased by LLF to ensure compliance at the workplane over useful lamp life.

## Results

By multiplying the 300 lumens/m<sup>2</sup> intensity by the 28,900m<sup>2</sup> workshop area the researcher initially calculates 8,670,000 lumens are needed at the workplane. In accordance with the inverse square law, the researcher measures for the 5.5 meter luminary height in this study intensity drops on average 36% from source to workplane [15]. The 8,670,000 lumens are multiplied by 1.36 to calculate intensity at the luminaries. By light type this value is adjusted. Adjustment includes: dividing by PCF, multiplying by (1+LLF) and multiplying by 1+(1-CU).

Table I and Table 2 values for PCF, LLF, CU%, and LER are based on manufacturers' documentation and secondary research (i.e. [16], [17], [18], [19], [20], [21] and [22]).

Per Table 1 installed lumens are lowest for LED and fluorescent lights.

**Table 1. Fluorescents Need the Least Installed Intensity to Light the Workshop to GB 50034-92**

	Pupil Correction Factor	Lumens Loss Factor (LLF)	CU %	Intensity @ workplane (lumens)	Intensity @ lamp(lumens)
LED white (warm)	1.62	30%	85%	8,001,019	10,881,385
Fluorescent	1.58	4%	65%	7,704,228	10,477,750
HID	1.49	34%	65%	10,526,195	14,315,625
Tungsten halogen	1.32	5%	71%	8,896,602	12,099,379

Over a 4 year period Table 2 shows fluorescent lights are 23% less costly to power compared to the 2<sup>nd</sup> alternative LED's.

**Table 2. Fluorescents Cost the Least to Power**

	Lumens/ Light fixture	LER (lumens/kw)	Kw/Light Fixture	Electricity cost over 4 years (\$)
LED white (warm)	13,880	78000	0.18	688,174
Fluorescent	13,360	97000	0.14	532,645
HID	18,260	97000	0.19	728,002
Tungsten halogen	15,430	20000	0.77	2,983,591

Per Table 3 LED lights last 25% longer than fluorescents. However, when compared to LED's, initial investment costs in China for fluorescents are 8x lower than LED's; fluorescent replacement bulb cost over a 4 year period is 11x cheaper than LED's.

**Table 3. Fluorescents Cost the Least to Install and Maintain**

	Useful Life (Hrs) Adjusted for LLF	Cost per initial fixture (\$)	Replacement Lamp Cost (\$)	Initial Fixture Investment to Cover Workshop	Lamp Replacement Cost over 4 years
LED white (warm)	35,000	411	395	1,999,200	1,922,995
Fluorescent	25,000	53	26	258,720	175,817
HID	14,000	73	33	352,800	402,259
Tungsten halogen	4,000	77	34	376,320	1,442,246

Table 4 shows for the 28,900m<sup>2</sup> Chinese workshop lit in compliance to GB 50034-92 fluorescents over 4 years are the least costly.

**Table 4. Fluorescents are the Least Expensive Lighting Solution for the Workshop in China**

	Total Lighting Spend over 4 Years (\$)
LED white (warm)	4,610,369
Fluorescent	967,182
HID	1,483,061
Tungsten halogen	4,425,837

## Discussion

Based on research findings workshop management decides to install fluorescent lighting (Figure 3).



**Figure 3. Switch to Fluorescent Lighting**

At first glance, LED lights would have seemed an upgrade compared to fluorescents. For LED's, coefficient of utilization (CU) is 15% higher, pupil correction factor (PCF) is 2.5% higher, and useful life is 2x longer. However, over useful lamp life, a fluorescent bulb experiences only 4% lumen loss. This is over 7x less than LED lumen loss. Since a general machining workshop in China, by law, must be lit to 300 lumens/m<sup>2</sup> at the workplane, installed LED intensity is 4% higher than fluorescent lamps. When combining lower installed intensity with a 20% higher LER rating, Chinese fluorescents in this study are almost 30% cheaper to power than LED's.

Lower monthly electricity fees, however, represent only 5% of the savings using fluorescents instead of LED's in China. For the 13,000 to 14,000 lumens/fixture used in this study, Chinese fluorescent luminaries are almost 8x cheaper than Chinese LED's. Even after accounting for the lower useful life of fluorescents compared to LED's, costs to replace Chinese fluorescent bulbs over 4 years are 11x cheaper than maintaining Chinese LED's.

When comparing fluorescents to HID's, while the CU and LER values are similar, fluorescents have 7x less lumen loss. When taking lower lumen loss and lower PCF into account, the researcher finds Chinese fluorescents are almost 30% cheaper to power than HID's.

For the 13,000 to 14,000 lumens/fixture used in this study, Chinese fluorescent luminaries are 35% cheaper than Chinese HID's. Moreover, for fluorescents useful life is nearly 2x longer than HID's. When considering replacement bulb costs for fluorescents in China are almost 30% lower than HID's, 80% of the savings using fluorescents over HID's is attributed to maintenance costs.

## Conclusions

The first part of the research question asks, "Is it economical to switch from halogens to fluorescents, HID's or LED's?" This is a timely question as the sale and use of tungsten halogen bulbs in China is illegal from Oct 2014. The study finds at \$8.95/m<sup>2</sup> initial investment when switching from halogens to fluorescents, the 6 month payback is highly economical.

A switch from halogens to fluorescents saves the workshop in this study approximately \$3.56 million over 4 years. Compared to installing LED's, fluorescents consume 30% less power and save \$3.6 million. Compared to HID's fluorescents consume 40% less power and save \$515,000.

The second part of the research question asks, "How much does a lighting change contribute toward meeting NEC energy efficiency targets?" The workshop in this study uses 4.3 million kwh less power per year switching from halogen to fluorescent lights. Installed meters show average annual power consumption for all equipment in the workshop is 15.6 million kwh. A lighting change from halogens to fluorescents represents a 30% drop in total power consumption; this is nearly double the NEC's target of 16% less power used per unit manufactured.

Energy efficiency in Chinese building construction has been slow to take hold. For example, annually new buildings in China total 2 billion square meters [23]. Yet, in 2009 only 10 buildings applied for recognition under China's green-building rating system launched in 2007 [24]. It is the researcher's hope this study shows factory managers in China fluorescents are an economical way to comply with lighting regulations.

## References

- [1] Hays, J. "Energy in China" Available from: <http://factsanddetails.com/china.php?itemid=324&subcatid=85> retrieved 10 March 2013.
- [2] Badkar, M. "The Ultimate Guide to China's Voracious Energy Use" Available from: <http://www.businessinsider.com/china-energy-use-2012-8?op=1> retrieved 20 Feb 2013.
- [3] "China's Power Shortage: Challenges Today Opportunities Tomorrow" Available from: <http://www.china-briefing.com/news/2011/05/19/chinas-power-shortage-challenges-today-opportunities-tomorrow.html> retrieved 25 May 2013.

- [4] Riley, C. "Inflation Slows Dramatically in China" Available from: <http://money.cnn.com/2013/04/08/news/china-inflation-cpi/index.html> retrieved 30 May 2013.
- [5] Lubin, G. "Chinese Power Companies Need a Bailout or Permission to Raise Electricity Prices" Available at: <http://www.businessinsider.com/china-power-companies-losses-2011-8> retrieved 20 April 2013.
- [6] "CEC Projects Higher Electricity Prices" *China Daily*. Available from: [http://www.chinadaily.com.cn/bizchina/2012-03/13/content\\_14826146.htm](http://www.chinadaily.com.cn/bizchina/2012-03/13/content_14826146.htm) retrieved 16 June 2013.
- [7] "Electricity Consumption to almost Double by 2020" *China Daily*. Available from: [http://www.chinadaily.com.cn/china/2010-12/21/content\\_11736078.htm](http://www.chinadaily.com.cn/china/2010-12/21/content_11736078.htm) retrieved 9 June 2013.
- [8] Thompson, E. "Improving Energy Consumption Efficiency: Urgent" Available from: <http://www.esi.nus.edu.sg/publications/2012/02/27/improving-energy-consumption-efficiency-urgent> retrieved 10 April 2013.
- [9] "China's energy use per unit of GDP down 2% in 2011" *China Daily*. Available from: [http://www.china.org.cn/environment/2012-08/17/content\\_26259275.htm](http://www.china.org.cn/environment/2012-08/17/content_26259275.htm) retrieved 20 March 2013.
- [10] Lamptech: "Operating Principle" Available from: <http://www.lamptech.co.uk/Documents/IN%20Operation.html> retrieved 23 May 2013.
- [11] Cobotex. Available from: <http://www.cobotex.com/lamps-26-led/halogen.pdf> retrieved 12 April 2013.
- [12] "The Price of Power: China's Confusing Electricity Rates" Available from: <http://www.wantchinatimes.com/news-subclass-cnt.aspx?cid=1202&MainCatID=12&id=20130515000080> retrieved 1 July 2013.
- [13] Mitroy, J. "Methods for Calculating Illumination" Available from: <http://www.cs.cdu.edu.au/homepages/jmitroy/sph244/Lecture06.pdf> retrieved 20 May 2013.
- [14] "Measuring Lumens- What Are Pupil Lumens" Available from: [http://lvdbulbs.com/pupil\\_lumens.htm](http://lvdbulbs.com/pupil_lumens.htm) retrieved 12 May 2013.
- [15] "Artificial Lighting Intensity" Available from: [http://www.firstrays.com/lighting\\_intensity.htm](http://www.firstrays.com/lighting_intensity.htm) retrieved 13 June 2013.
- [16] "LED lumens per Watt Chart" Available from: <http://pnastaffing.com/wp-content/plugins/get-the-image/led-lumens-per-watt-chart> retrieved 13 June 2013.
- [17] "HID vs Florescent for High Bay Lighting" Available from: [http://www.mge.com/business/saving/madison/PA\\_46.html](http://www.mge.com/business/saving/madison/PA_46.html) retrieved 27 June 2013.
- [18] "Light Output Comparisons" Available from: [http://www.sunillumination.com/light\\_output.html](http://www.sunillumination.com/light_output.html) retrieved 1 June 2013.
- [19] "Comparing Performance: LED vs. Fluorescent" Available from: <http://ledlightinggroupllc.com/wp-content/uploads/2010/02/Performance-email.pdf> retrieved 22 June 2013.
- [20] "Coefficient of Utilization Lookup" Available from: [http://www.geconsumerandindustrial.com/environmentalinfo/tools\\_calculators/pop\\_cu\\_ratings.html](http://www.geconsumerandindustrial.com/environmentalinfo/tools_calculators/pop_cu_ratings.html) retrieved 19 June 2013.
- [21] "Maintenance Factor" Available from: <http://www.erco.com/guide/simulation-and-calculation-95/maintenance-factor-2713/en/intro-1.php> retrieved 8 June 2013.
- [22] "HID vs LED Lighting" Available from: [http://www.innovativelight.com/led\\_facts/hid-vs-led-lighting/](http://www.innovativelight.com/led_facts/hid-vs-led-lighting/) retrieved 27 June 2013.
- [23] Larson, C. "The Cracks in China's Shiny Buildings" Available from: <http://www.businessweek.com/articles/2012-09-27/the-cracks-in-chinas-shiny-buildings> retrieved 1 July 2013.
- [24] Hays, J. "Energy in China" Available from: <http://factsanddetails.com/china.php?itemid=324&subcatid=85> retrieved 10 March 2013.

## Biography

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