# Transformative Lighting Strategies in Vancouver's Urban Context

## Using Less, Living Better

by

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## Abstract

We are now facing the challenge of sustainable development. This thesis focuses on the building illumination of one downtown hospitality building, the Renaissance Vancouver Hotel (RVH), to demonstrate three options for sustainable development of architectural lighting.

The thesis employs architectural exterior lighting based on the technology of light emitting diodes (LEDs) as a vehicle to demonstrate how to reduce the energy consumption and maintenance costs of decorative lighting on building façades via three transformative lighting strategies. These three transformative lighting strategies demonstrate three possibilities of applying LEDs to develop architectural creativity and energy sustainability for an outdoor decorative lighting system.

The first transformation utilizes LEDs for the retrofit of existing compact fluorescent lights (CFLs) on the RVH's façades and rooftop, in order to improve and diversify the building's illumination in a sustainable manner.

The second transformation optimizes the yearly programming of the new outdoor decorative LED lighting in accordance with differing seasonal and temporal themes in order to save energy, demonstrate architectural creativity via versatile lighting patterns, and systematically manage the unstable generation of renewable energy.

The third transformation explores the potential of on-site electricity generation in an urban context instead of its purchase from BC Hydro. Photovoltaic (PV) panels will generate the electrical requirements of the RVH's decorative exterior LED lighting. This transformation will transfer daytime solar energy to electricity for night outdoor building illumination; consequently, it can encourage outdoor activities in the nighttime for Vancouverites, and is a means of compensating for the limited daytime hours in Vancouver's winter months.

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**Lists of Acronyms and Abbreviations**

| | |
|---|---|
| 3Ds Max | Autodesk 3Ds Max |
| AC | Alternating Current |
| CFL | Compact Fluorescent Light |
| CRI | Colour Rendering Index |
| CVR | Constant Voltage Regulator |
| DC | Direct Current |
| H | Hour |
| HID | High-Intensity Discharge |
| HIR | Halogen Infrared |
| HPS | High-Pressure Sodium |
| IDA | International Dark-Sky Association |
| IEA | International Energy Agency |
| KW | Kilowatt |
| KWH | Kilowatt Hour |
| Laser | Light Amplification by Stimulated Emission of Radiation |
| LCD | Liquid Crystal Display |
| LED | Light Emitting Diode |
| LPS | Low-Pressure Sodium |
| LUTW | Light Up The World Foundation |
| MH | Metal Halide |
| MV | Mercury Vapor |
| MW | Megawatts |
| N | Negative |
| OLED | Organic Light Emitting Diode |
| P | Positive |
| PC | Personal Computer |
| Philips | Koninklijke Philips Electronics N.V. or Royal Philips Electronics Inc. |
| PV | Photovoltaic |
| RGB | Red, Green, and Blue |
| RVH | Renaissance Vancouver Hotel |
| SAD | Seasonal Affective Disorder |
| SSL | Solid-State Light |
| TABIA | Toronto Association of Business Improvement Areas |
| UNWCED | UN World Commission on Environment and Development |
| US DoE | US Department of Energy |
| W | Watt |
| V | Volt |

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# Chapter 1:
# Introduction

## 1.1 Defining the Problem

"Meeting predicted worldwide energy consumption needs over the next hundred years will require fundamental changes in how we generate and use energy."[1] In the field of architectural illumination, the problems we encounter are how to retain high levels of effective night lighting in the context of energy depletion and scarce resources; how to reduce electricity consumption and maintenance costs in the meantime to develop architectural lighting creativity and energy sustainability via an outdoor decorative lighting system; and how to provide electricity in an urban context for the mentioned building illumination in a renewable, reliable and environmentally sound manner.

Global lighting energy use in 1997, which included the corresponding lighting-related electricity production and global fuel-based household lighting, was significant, totaling about US$ 230 billion. It also corresponded to a carbon dioxide emission of 2019 million metric tonnes.[2] In 2007, the total lighting industry represented $70 billion globally.[3] Compared with new buildings, existing buildings consume a great deal of electricity because of their reliance on inefficient light bulbs. In addition, existing lighting systems are more likely to be out of date in contrast to updated electrical light technology or be at the end of their economic life due to their short life span and need to be replaced.[4] Approximately half of the world's total lighting electricity is demanded

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[1] Basic Energy Sciences, Basic Research Needs for Solid-State Lighting, Report of the Basic Energy Sciences Workshop on Solid-State Lighting, May 22-24, 2006, (Office of Basic Energy Sciences) 3. 11 July 2008 <http://www.sc.doe.gov/bes/reports/files/SSL_rpt.pdf>.

[2] Evan Mills, "The $230-billion Global Lighting Energy Bill," Expanded from version published in the Proceedings of the Fifth International Conference on Energy-Efficient Lighting (Stockholm, 2002) Abstract, 31 March 2008 <http://eetd.lbl.gov/emills/PUBS/PDF/Global_Lighting_Energy.pdf>.

[3] Kevin Dowling, LED Essentials (Department of Energy: Webinar, Oct. 2007) 4, 31 March 2008 <http://www.netl.doe.gov/ssl/PDFs/DOE-Webinar-2007-10-11.pdf>.

[4] Ulrike Brandi and Christoph Geissmar-Brandi, Light for Cities: Lighting Design for Urban Spaces. A Handbook (Basel: Birkhäuser, 2007) 25.

by the 23 International Energy Agency (IEA) countries.[5] These 23 countries are major industrialized and urbanized ones with complex infrastructure where the reduction of the electricity demand of existing urban structures/forms has become necessary.

Currently, building illumination faces two critical challenges: one is the reduction of electricity consumption, and the other is the reduction of light pollution. There are many stated causes of light pollution, and some accounts may be accurate, but often there are variations in how light pollution is defined, and findings can be refuted. The human eye has different reactions to lighting and its colours at night; we do not understand the interrelationships completely. Some of the arguments about light pollution can be challenged. For instance, Wilson and Yang's *City Lighting and Light Pollution*[6] claims that:

> The trend to increase the amount of exterior lighting for both utilitarian and decorative applications in cities must generate more light pollution and its associated adverse effects which include wasted energy, artificial sky glow and varying degrees of population discomfort. However in many cases the current and proposed quantities of such lighting are both unacceptable and unnecessary.[7]

Two assertions here are misleading. The first is the idea that an increase in the amount of exterior lighting automatically and directly leads to more light pollution. The

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[5] Mills 1. The 23 International Energy Agency (IEA) countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, the USA.

[6] Reg. R.Wilson and Shiguang Yang, "City Lighting and Light Pollution," Right Light 6, Shanghai 9-11 May (2005), 31 March 2008 <http://www.rightlight6.org/english/proceedings/Session_18/City_Lighting_and_Light_Pollution/f098wilson.doc>.

[7] Wilson & Yang 1.

definition of light pollution by the International Dark-Sky Association (IDA)[8] is "any adverse effect of artificial light including sky glow, glare, light trespass, light clutter, decreased visibility at night, and energy waste."[9] According to this definition, we can increase the quantity of exterior lighting which functions for night activity, if the installation and application of these lights can be well managed without the production of these effects. In addition, exterior lighting has been ignored far more than interior lighting. If we just limit the amount of exterior lighting without considering its function, nighttime city safety and security will be compromised. Therefore, it is possible to design night lighting while avoiding the detriments associated with light pollution as identified in Wilson and Yang.

The second misleading assertion is the statement that exterior lighting applications are associated with wasted energy. Energy waste means we cannot reuse the energy that provides the lighting, so the authors' hypothesis only involves the utilization of non-renewable energy for electric exterior lights. Nowadays, people are not only thinking about using more renewable energy and how to generate it, but also state-of-the-art technologies and successful experience have demonstrated that no matter whether we are considering exterior or interior lighting, we must fundamentally shift the principles of energy consumption from traditional ones to those that are more effective, renewable, and sustainable.

The demand for and uses of night lighting in cities have pushed the lighting industry into continual development. Solid-state lighting is emerging as a pivotal technology for the lighting industry. Light Emitting Diodes (LEDs) have demonstrated an advance in general illumination as a viable source. LEDs are an energy-saving lighting resource, a new technology used for outdoor night lighting, so lighting companies are developing

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[8] The International Dark-Sky Association (IDA) is a U.S.-based non-profit organization to preserve and protect the nighttime environment and our heritage of dark skies through quality outdoor lighting. Its official website is: <http://www.darksky.org/>.

[9] IDA's light pollution definition was accessed online, 31 March 2008 <http://www.darksky.org/>.

LEDs rapidly. Cree, Inc.[10] is one of the leading companies heavily involved in doing so in Toronto, Canada, one of the first large cities to shift to LEDs. On July 11, 2007, the Toronto Association of Business Improvement Areas announced that the city would initiate an installation of LEDs throughout its infrastructure. Toronto was the second city to join the LED City™ program after Raleigh, North Carolina. Toronto's citizens should notice LEDs throughout parks, parking garages, and in architectural lighting over the course of 2008.[11] On June 28th, 2007, The CN Tower lighting was transformed from traditional light bulbs to vibrant, dynamic, and more energy-efficient LEDs, designed to use 60 percent less energy than the conventional lighting of the 1990s. Other current and planned LED projects in the city include solar-powered LEDs in a park and LEDs in a public parking garage.[12]

Vancouver is not only well-known as one of the most livable cities in the world, but also as a famous tourist destination because of its natural beauties and unique urbanization – Vancouverism, which means, ideally, building equity, amenity, and livability in a hyper-dense city. This thesis considers "Night Vancouverism." However, through my observations, I have found that Vancouver's waterfront public spaces have been far too little used at nighttime as compared to the daytime. In the dark, the waterfront walkway becomes unattractive and people refrain from using it. In this thesis, the illumination of the Renaissance Vancouver Hotel (RVH), one hospitality building in Vancouver's downtown, is the focal point in demonstrating three options in

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[10] Cree, Inc., a North Carolina corporation established in 1987, produces LEDs, SiC and GaN material products, and high-powered products using SiC and GaN materials. It is an LED pioneer. Its official website is: http://www.cree.com/.

[11] "Toronto Shifts to LED Lighting as Answer for Energy Efficiency," LED City Press Room, LED City, 11 July 2007, 31 March 2008 <http://www.ledcity.org/press-room/toronto-shifts-to-led-lighting.html>.

[12] "CN Tower Illuminated – Toronto, Meet Your New Skyline!" posted by Adam Schwabe on BlogTO website, 29 June 2007, 31 March 2008 <http://www.blogto.com/city/2007/06/cn_tower_illuminated_toronto_meet_your_new_skyline/>; "Lighting Canada's National Tower: Spectacular Light Show Launches CN Tower Illumination – June 28, 2007," Toronto: CN Tower Website Release June 2007, 31 March 2008 <http://www.cntower.ca/portal/GetPage.aspx?at=1579>.

outdoor lighting strategies for the sustainable development of architectural lighting. LEDs not only offer solutions to the legibility of urban structure/form, which will be tested, developed, and evaluated in this thesis, but also allow outlets for illumination flexibility and diversity, features that will also be presented. This thesis has coincidentally been written in parallel with Vancouver's emerging nighttime image and enhancements associated with the special "Look of the City" for the 2010 Olympic celebrations. The City of Vancouver is not only defining urban lighting opportunities city wide, but also considering issues of civic identity and energy efficiency at a variety of scales. The focus of this thesis on building illumination of a hotel located on the waterfront in downtown Vancouver shares its questions, analyses, approaches, and simulations with further potential pragmatic projects in various scales, so it is a timely and feasible consideration of Vancouver's urban lighting development.[13]

### 1.2 Defining solutions

#### 1.2.1 Literature Review

George Monbiot's *Heat: How to Stop the Planet from Burning* has demonstrated that we can achieve a 90% reduction in carbon emissions by 2030 without bringing civilization to an end. He shows that we can transform our houses, our power, and our transport systems to alleviate climate change. Monbiot cites some scientifically important statistics: Canadians emit an average of 19.05 tonnes of carbon dioxide a year, compared with the Germans who emit 10.2 tonnes, and the French 6.8. By Monbiot's calculation, the sustainable limit for carbon dioxide emissions per capita is 1.2 tonnes.[14] Manbiot suggests that "Canada should cut her carbon emissions by 94% between now and 2030."[15] Thanks to new technologies and a few cunning applications as mentioned in this book, Monbiot shows that this target will be

[13] Refer to Chapter 2 Environmental sustainability – Vancouver's Emerging Actions.

[14] George Monbiot, Heat: How to Stop the Planet from Burning (Toronto: Doubleday, 2006), 16. The total capacity of the biosphere to absorb carbon will be reduced to 2.7 billion tonnes a year by 2030 when the world's peoples will likely number around 8.2 billion. Carbon emissions per person will be no greater than 0.33 tonnes, so carbon dioxide emissions will be 3.667 times 0.33, equalling 1.2 tonnes.

[15] Monbiot X.

achievable only by "the world's most powerful political movement."[16] Monbiot is so compelling and provocative that his thoughts and proposals have had wide appeal, even though they will still require massive political support and international involvement.

Perhaps it might seem impossible to think that all politicians will ever team up to deal with the serious issues of global warming now, but that revolution may happen. The key information I have gained from Monbiot is that new technology and its applications may save us from aggravated climate change, even if as an architecture student, I prefer to think about something more practical and pragmatic for my research. My position is to study new technology for energy saving purposes in a selected building. According to BC Hydro's statistics, lighting consumes 20 per cent of total household electricity. LED lights use only 5-10 per cent of the electricity of traditional light bulbs, but offer the same luminance. Even if we added double the capacity of general lighting in every building in Vancouver with LEDs, we still would consume less than 5 per cent of the total electrical demand of current consumption.[17] Theoretically, if this 5 per cent of electricity could be supplied by renewable energy, the lighting system would consume zero electricity from the grid of BC Hydro.

From Monbiot's book, I understand how urgent global warming now facing human beings is, so we should undertake coordinated planet-wide initiatives. Monbiot addresses the special quality of electricity: "Not only must it be made when we want it; it must also be made in precisely the quantities we demand."[18] He analyses present resources supplying electricity world wide and concludes that the alternative to existing power systems is renewable energy. Therefore, my thesis proposes to do something by way of a project that is useful and feasible with respect to a renewable energy system from the architectural stand point.

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[16] Monbiot XXV.

[17] According to BC Hydro's statistics and by my estimate and generally, LED lights use less than 10 % of the electricity of traditional light bulbs, even a doubled capacity of lighting by LEDs will consume less than 5% electricity: 2x10%x20%x100%=4%<5%

[18] Monbiot 79.

Monbiot identified a serious concern about the reliability of renewable energy. He concluded that even if we adopt renewable energy as much as is possible, we still will not be able to turn off power stations which burn fossil fuel.[19] Hence, we need to design an electricity consumption system to accomplish reliability in renewable energy. Therefore, one objective of my research is to demonstrate that: "Buildings, instead of being passive consumers of energy, would become power stations, constituent parts of local energy networks... ."[20] In my thesis, a building's lighting illumination and its power supply have been designed to be independent from the grid. My hypothesis is that numerous mini-power stations associated with energy-saving technology will support the "energy Internet"[21] idea eventually.

Also pertinent is research released by the UN World Commission on Environment and Development (UNWCED). In 1987, this research group published "Our Common Future",[22] which focused the world's attention on sustainability, climate change, and energy issues. The report underlined that global warming and climate change, energy crisis, resource and food shortages, and economic and social instability, are the predictable results of not changing development and consumption patterns so that they can be sustained into the foreseeable future.

In "Our Common Future", "sustainable development" is given a wide context:

> Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.[23]

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[19] Monbiot 107.

[20] Monbiot 124.

[21] Monbiot 124

[22] Our Common Future (1987) is a report from the UN World Commission on Environment and Development (WCED) and was published in 1987 by former Norwegian Prime Minister Gro Harlem Brundtland with a highly qualified and influential political and scientific team.

[23] Gro Harlem Brundtland et al., Our Common Future, Report of the World Commission on Environment and Development (Oxford: Oxford University Press, 1987) 24, 31 March 2008 <http://www.worldinbalance.net/pdf/1987-brundtland.pdf>.

The report states “Energy efficiency can only buy time for the world to develop 'low-energy paths' based on renewable sources, which should form the foundation of the global energy structure during the 21st Century.”[24] In addition, the report also states that: “A mainspring of economic growth is new technology, and while this technology offers the potential for slowing dangerously rapid consumption of finite resources, it also entails high risks, including new forms of pollution and the introduction to the planet of new variations of life forms that could change evolutionary pathways.”[25] The authors note that we are at the stage of utilizing new technologies for the prosperity of civilization and the reduction of energy consumption, despite some potential side-effects. In the future, it is certain that we will need to apply new technologies, reduce our energy consumption, and so offer energy without pollution, but rational and detailed studies will be required to diminish the undesirable side effects, including pollution. My research is focused on current LED technology for building illumination. Technological advances and patterns of use and design will be addressed in a sustainable manner and simulated.

### 1.2.2 Solutions

LEDs are a relatively recent technology. LED lights show their benefits in nocturnal, decorative, and advertisement lighting in the architectural and construction fields, offering a high degree of efficiency, long life, brilliant colours, optional optics, low maintenance costs, low profile height, simple installation, and ease of integration into architecture.[26] They are ideal for illuminating heat-sensitive materials and operates smoothly even at low temperatures, and are suitable for outdoor use if appropriately protected. LEDs are one-stop systems for customized solutions, safe operation, high resistance to breakage, easy mounting, and operation with solar power and

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[24] Our Common Future (1987) 10.

[25] Our Common Future (1987) 21.

[26] J. Brent Protzman and Kevin W. Houser, “LEDs for General Illumination: The State of the Science,” LEUKOS Vol. 3 No. 2 October (2006) 122; Energy Efficiency and Renewable Energy, US Department of Energy, 31 March 2008 <http://www.netl.doe.gov/ssl/>.

batteries.[27]

According to the US Department of Energy(US DoE)'s estimation, by 2025 LED lighting could reduce lighting energy consumption by 50 per cent, and the savings from 2000 to 2020 by using LEDs could eliminate the need for 100 1000MW power plants with monetary savings of over $100 billion in the USA.[28]

Taken a step further, strategies and methodologies related to architectural lighting design and applications for the "transformation/changeover" from conventional lighting systems to energy-saving LED systems are only now receiving limited consideration. Separation of electricity suppliers, LED manufacturers, and end-user requirements may be defeating the extensive adoption of LED lighting systems. Generally speaking, interior illumination consumes more electricity than exterior illumination, but the latter needs more maintenance and replacement by highly professional crews. While LEDs' initial costs are still higher than those of conventional lights, higher maintenance costs of conventional lights will offset this as well. Immediate LED installations will offset the ongoing costs of the degradation of conventional lights on building façades.

From North America, and from Europe to Asia, we have seen LED technology incorporated into building design without sustainable strategies or without transferability of applications to other cities. For instance, Scot Hein, city senior planner, has stated that the City of Vancouver expects different light application from those of Las Vegas, Dubai, and Shanghai. This result has been an *ad hoc* proliferation of LED use for decorative architectural functions that has consumed an unwarranted amount of both energy and time devoted to maintaining these systems. Colour-changing and energy-saving LEDs should be designed and used for high-quality architectural illuminations instead of simply switching from conventional to LED lamps.

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[27] "Using LEDs to Their Best Advantage," Building Technologies Program: Solid-State Lighting (US Department of Energy), 31 March 2008 <http://www.netl.doe.gov/ssl/usingLeds/app-series-advantage.htm>.

[28] Dowling 4.

## 1.3 Objective

The goal of my research is to outline "transformative lighting strategies" and create a sustainable development methodology for the incorporation of LED technology into individual building illumination with the aim of reducing energy and maintenance costs of outdoor decorative lighting. Furthermore, the thesis will explore the potential for micro-renewable energy production.

This thesis employs three transformative lighting strategies based on LED technology and renewable solar energy as applied to the façades of an urban building. My three transformative lighting strategies form three different possibilities of applying LEDs individually and collectively to a high-rise building with applicability to different commercial buildings.

### 1.3.1 Three transformative lighting strategies

The first transformation utilizes LEDs for the retrofit of existing compact fluorescent lights (CFLs) on the façades and rooftop of the Renaissance Vancouver Hotel (RVH), in order to improve and diversify the building's illumination in a sustainable manner.

The second transformation optimizes the yearly programming of the new outdoor decorative LED lighting in accordance with differing seasonal and temporal themes in order to save energy, to demonstrate architectural creativity via versatile lighting patterns, and systematically to manage the unstable generation[29] of renewable energy.

The third transformation explores the potential of on-site electricity generation in an urban context instead of purchase from BC Hydro. Photovoltaic panels (PVs) will generate the electrical requirements of the RVH's decorative exterior LED lighting. This transformation will transfer daytime solar energy to electricity for night outdoor building illumination; therefore, it will encourage outdoor activities in the nighttime for Vancouverites, and is a means of compensating for the limited daytime hours in

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[29] Monbiot 107. Most renewable energy resources, such as solar, wind and wave, cannot produce energy in a continuous and stable-capacity state.

Vancouver's winter months.

1.3.2 Research Questions:

1. Why does Vancouver's urban context need to adopt transformative lighting strategies?
2. How much electricity and total cost will be saved for the Renaissance Vancouver Hotel, based on my first transformative lighting strategy?
3. How much better in quality and saving in quantity will the second transformative lighting strategy of outdoor decorative lighting (LED), in accordance with differing seasonal themes, be?
4. Can adequate electricity be supplied to the RVH's transformative lighting by on-site electricity generation via photovoltaic(PV) panels?

## 1.4 Methodology

### 1.4.1 Study Site

An initial study of the site included an interview with the Director of the Engineering Department of Renaissance Vancouver Hotel, Mr. Carl Corrigan, in December 2007. From this interview, I gained basic knowledge about the RVH and its outdoor lighting, which contributed to chapter 3. The RVH management is paying close attention to its night appearance and believes that its nightscape has an impact on its number of guests. Architect Bing Thom used outdoor decorative lighting on both rear and front façades to represent the hotel's welcoming attitude and attractive qualities. Its outdoor decorative lights have been changed from 60W incandescent lights to 18W CFLs, which give out static, warm yellowish light. Photocells and timers have been used to control this outdoor decorative lighting. In summer, the operation time is from 9:30pm to 1:00am; in the winter, from 4:30 pm to 1:00 am.[30] The building currently consists of a static CFL lighting array of 194 18-watt bulbs on its rear and front façades and 120 18-watt bulbs on its circular top structure. This lighting design consumes

[30] Carl Corrigan, Personal Interview, Vancouver, 3 December 2007.

approximately 12364 KW hours of energy per year at a cost of $556 per annum.[31] The commercial rate of BC Hydro's electricity bill is 4.5 cents per KWh, one of the cheapest electricity rates in North America. Information provided by the RVH included data on the existing exterior lighting, the lighting control system, environmental concerns, and future plans. This information was incorporated in AutoCAD drawings for illustrative and project design purposes.

### 1.4.2 Site Survey

A site survey of the RVH's building façades and the round rooftop structure was conducted to incorporate measurements not readily available from the RHV structural blueprints into the AutoCAD illustrations for further 3-dimensional modeling and the array of solar panels.

Nightscape surveys were undertaken from at least 50 different viewpoints, distances, and times-of-day to foster understanding of the physical, social, and emotional perception of different nightscape impressions. In order to illustrate the shifting nightscape of Vancouver's skyline from day to nighttime, photographs of the city's waterfront skyline were taken, a series of photographs from Stanley Park between 10:00 am. and 10:40 pm. on May 12, 2007. A second series of photographs were taken from the same location on January 28, 2008 between 5:00 pm. and 5:30 pm. to illustrate Vancouver's waterfront nightscape during the early dusk of the spring and winter seasons. A panoramic picture was created by three photographs from the same location with shifting angles of view, producing a comprehensive waterfront urban image. Additionally, the existing conditions of the selected site at daytime and nighttime are documented by a number of digital pictures, utilized as a first-hand inventory for understanding the existing lighting of the chosen site and to develop experimental design concepts.

[31] Calculation by author based on the data of the number of lamps and the current electricity rate released by the RVH's Engineering Department.

### 1.4.3 Representational and Analytical Tools

#### 1.4.3.1 Maxwell Render

Maxwell Render™,[32] a computer simulation, was used to test and demonstrate the different lighting distributions that could be achieved with each lighting scenario. This system combines photo-realistic rendering with detailed photometric computation to provide a series of digital models illustrating the visual effects of different lighting scenarios for comparison. Maxwell Render claims to be a physically correct, unbiased rendering engine capable of simulating light within a "real world" context. All lighting calculations are performed using spectral information and high dynamic range data.

Through my learning about and practice with Maxwell Render, the Maxwell plugin for Autodesk 3Ds Max (3Ds Max) allowed me to choose a nighttime for my rendering in the section of "Environment Settings," and apply it to Vancouver. Even though Maxwell Render claims that its unique displacement technology is capable of simulating any detail without extra memory consumption, my computer, with an Intel Core4 CPU, still needed almost 8 hours to render a high resolution image in 1200X1200 pixels through the Maxwell plugin. My first concern about the application of Maxwell Render was its special requirement for a powerful computer, since it calculated all data settings for the rendering to be adjusted later on without any new calculations.

Maxwell Render's illumination system, "Emitter", provides parameters of colour, luminance, temperature, MXI/HDR texture, Watts, and Lumens. LEDs as general lighting are a new application and in ongoing technological development, so, I could not get LED materials from Maxwell's material library. I had to create my own LED emitter materials with various parameters because of my different light patterns. Additionally, those newly created LED materials were applied to geometric cylinders according to my proposed LED light fixtures to be mounted on the building façades. Creating lights by applying emitter materials is different from the previous method of using 3D Max to imitate lights illuminated on the surface. Because the complexity of my lighting design involved colour and intensity changes, I needed to set up those lights individually. Once the rendering has been produced by Maxwell Render, the

[32] Maxwell Render software, 31 March 2008 <http://www.maxwellrender.com/>.

colour and intensity can be adjusted and those images will be clearer and more photorealistic. But I found the application "Multilight" to be very time-consuming due to the complexity of my light design and the number of lights. However, the final renderings by Maxwell Render were of much higher resolution and more impressive than those by 3Ds Max. Because the parameters of physical location, date, and time in Maxwell Render are pre-set, the real physical conditions within the code of this software are also pre-set within certain limitations to reflect the complexity of real circumstances.

#### 1.4.3.2 Autodesk 3Ds Max

Autodesk 3Ds Max™[33] was used for upfront modeling. The computational model was derived from direct digital photos, Google maps, and relevant attribute measurements in real space for accurate architectural prototypes consisting of geometric, material property, and photometric data.

### 1.4.4 Comparative Analysis

Comparative approaches of qualitative and quantitative data, including case studies, interviews, historical design theories, comparative calculations, computational visualizations, and observational studies have been used throughout the design and evaluation processes. The transformative lighting design has been compared with existing night lighting in terms of design rationale, visual differences, and programming flexibility. The transformative design approach is synthesized from a retrofit of the existing light setting and LEDs' noted design approaches, such as intelligent colour-changing, pattern creation, dimming, and rainbow colour series.

### 1.4.5 LED Efficiency Assessments

LEDs differ from other conventional lights by using direct current (DC), versus alternating current (AC). Energy efficiency enhancement of the LED transformative lighting aspect of this study will be obtained through the use of versatile lighting scenarios and an on-site, direct current (DC), and renewable energy generation

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[33] Autodesk 3Ds Max software, 31 March, 2008
<http://usa.autodesk.com/adsk/servlet/index?id=5659302&siteID=123112>.

system. Supplying the LED lighting system with direct current reduces energy consumption that otherwise would be required to convert the standard 120 volt alternating current (AC) electrical service to the 12 or 24V DC utilized most effectively by LED systems. I will explore the potential of an on-site electricity generation system with photovoltaic panels to charge a battery system and subsequently provide the electrical energy requirements for the RVH's outdoor LED lighting system. However, the cost of power supply units and controllers will not be included in the calculation of the total cost of LED lights in my first transformative strategy. Furthermore, to achieve a dynamic and vibrant nightscape for the RVH's façades, colour-changing LEDs to retrofit existing CFLs, could be controlled by an intelligent system for better performance. However, the cost of an intelligent colour-changing control system is beyond the scope of my light comparative analysis based on my first transformative strategy, because the existing CFL array only shows a static yellowish effect.

Energy consumption will be calculated by comparison of 1) the hourly and 50,000 hour electricity consumption of the proposed LED light fixtures with that of the existing CFLs via manufacturers' specifications and 2) annual changes in electricity consumption of the optimized lighting system with that of existing CFL lighting for a summer, spring-fall, and winter program.

Cost comparison is based on a lifecycle assessment of 50,000 hours, consisting of product, maintenance, and energy costs. Basic data obtained from lighting product specifications, the RVH's engineering department, and B.C. Hydro have been used to illustrate the electricity consumption of the existing CFL lighting scenario. Electrical consumption of the proposed LED lighting will be calculated according to the LED manufacturers' specifications and the expert knowledge of local suppliers. Based on international market availability, popularity, quality, and standardization of electric lighting, CFLs manufactured by "Marathon" under the umbrella of "Philips"[34] and LEDs' manufactured both by "Philips Color Kinetics" and by "LightWild" will be used for comparison purposes. The proposed LED coloured lighting fixtures have been

[34] Koninklijke Philips Electronics N.V. or Royal Philips Electronics Inc. usually known as Philips is one of the largest electronics companies in the world, founded and headquartered in the Netherlands

employed on building façades for many years with guaranteed qualities.[35]

LED coloured decorative lighting is a recent addition to the marketplace with research still ongoing; leading companies include CREE, Philips Color Kinetics and Lightwild in North America, OSRAM in Europe, and Marginlight in China. Marketing is so new that the prices of LEDs vary between both manufacturers and countries given marketplace availability, and the early stages of product research and development. A price comparison using some of the above manufacturers will be performed to determine the present market potential, and possible energy and monetary savings of using LEDs instead of conventional and CFL lighting designs so as to reveal the potential of sustainable development of LEDs in Vancouver.

### 1.4.6 Power supply

According to the experimental design employing the first and second transformative design strategies, a very limited amount of electricity will be needed. In an urban context, due to the constraints of the architecture itself and its surrounding environments, most renewable energy generation is not suitable or doable, The RVH exists in such an urban context and as an existing building expectant to retrofit. The proposed on-site system explores a viable solution for self-sufficient energy generation by using photovoltaic panels and a battery storage system integrated with the RVH building.

## 1.5 Value of Thesis

The thesis concludes with an argument for a perspective on LED outdoor decorative lighting based on its technological and economical advantages, the optimization of architectural design, and its enhancement with the contribution of micro-renewable energy to urban sustainability and quality of life. The research reveals that, although LED technology application to architectural outdoor lighting has not yet achieved its maximum potential, it does have positive uses for architectural lighting that should contribute to images of nocturnal cities. This factor indicates that there is room for

[35] The manufacturers' specifications of existing CFLs and proposed LEDs are referred to in Appendices I, II and III.

using LEDs for improvement in architectural lighting.

This thesis addresses some specific issues: LED technology, architectural outdoor lighting, the existing urban context, and building-integrated renewable energy. The strengths and weaknesses of those issues are explored to establish three transformative lighting strategies as three possibilities for accomplishing energy efficient and sustainable night lighting, reflecting the current Canadian government's concept of "using less, living better." A series of design approaches and evaluation tools have been implemented in the re-design of the illumination used for the RVH to examine and demonstrate the feasibility and sustainability of the three strategies.

Vancouver's urban context as defined in the thesis includes a variety of architectures and landscapes. Due to the limitation of time, participants, and data collection, the thesis has been narrowed down to the RVH, which is a typical hospitality building of modern design. Extrapolating research to other types of architecture, offices, residences, institutions, and commerce in general will extend different design approaches and evaluation perspectives, enriching the nocturnal illumination of Vancouver's urban context.

In chapter three, I present a background analysis of the relationship between nocturnal illumination and the selected Vancouver urban context. The fundamental issues associated with why the waterfront of downtown Vancouver needs night lighting can be extended to more precise and detailed studies in varying scales and contexts. In my thesis, my focus is on energy sustainability proven by cost evaluation, and achieved via building-integrated renewable energy production in a practical and measurable manner. Unlike most studies of LED, which reside in engineering disciplines and their related publications, my thesis is positioned within the disciplines of sustainable development and architectural design applications, and hence is related to literature in these fields. It uses systematic strategies, their implementation, and their subsequent evaluation as relevant to design. In this thesis it is impossible to discuss and solve all the environmental, economic, and social issues in terms of Vancouver's nocturnal illumination. However, I have investigated LED lighting design approaches and evaluation methods in an appropriate and valid way via one small project that might contribute to such solutions by introducing three transformative lighting strategies.

Chapter four of the thesis addresses the financial and electrical savings to be garnered via the retrofit of existing CFLs to LEDs on the RVH's façades. In chapter five, my experimental project design will include various intelligently controlled lighting programs for different nights, such as those for normal weekday and weekend nights, and also for holiday, special event, and festival nights, all with the ability to monitor energy consumption and regulate light colours, patterns, and brightness on the building façades according to energy availability, as derived from the PV system. Chapter six looks at the incorporation of a mini-renewable energy technology, a photovoltaic system, to provide the electrical energy requirements for a coloured LED outdoor decorative lighting system. The flexibility of the system will strengthen public awareness of the night lighting performance. The new system will be more suitable to the unstable availability of electricity from renewable resources. Chapter seven offers the conclusion of my thesis and discusses possible further and related studies.

# Chapter 2:

# Lighting Technologies

## 2.1 Technical Knowledge

The design (and application) of artificial lighting is associated with the development of lighting technology. This chapter will introduce some qualities of current lighting technology including conventional light bulbs and LEDs. First of all, knowledge of light, colour, and light sources must be seen as essential to light design.

### 2.1.1 Light and Colour

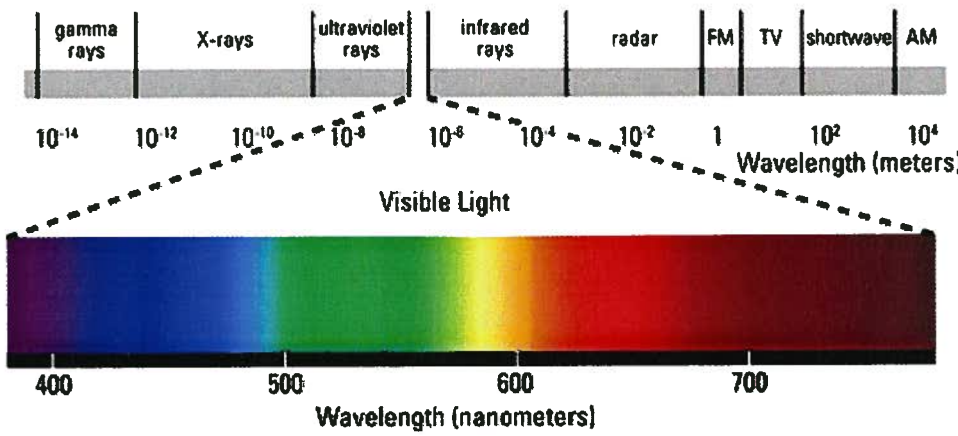


Fig 2.1 The Visible Spectrum[36]

Light is part of the electromagnetic spectrum. Visible light is about 380 nm to 770 nm in wavelength, with a colour range from deep violet to rich red.[37] Normally, the visible spectrum is a rainbow – a continuous coloured light. The three primary colours of light are red, green, and blue, producing white light when mixed. Colour is influenced by the light source, the properties of the object, the sensitivity of the eye, and brain reactions. When light is incident on an object, a part of it is absorbed, a part is reflected, and a part may be transmitted. The object may also emit light. All these characteristics contribute to the observed colour. A specularly reflecting material reflects light incident

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[36] "Light and Color Basics," Building Technologies Program: Solid-State Lighting (US Department of Energy), 31 March 2008 <http://www.netl.doe.gov/ssl/usingLeds/general_illumination_color_basics.htm >.

[37] Gary Steffy, Architectural Lighting Design 2nd ed. (New York: Wiley, 2002) 11.

on it in the same angle that it came from. A diffusely reflecting material scatters light incident on it in all directions. A glossy and semi-glossy material contains a combination of both specular and diffuse reflectance. Observers usually discount specular reflection when visually evaluating the colour of a material. Diffuse reflectance is an important characteristic when determining colour and appearance.[38] As above, this basic knowledge is necessary to a fundamental understanding of light, its perception and the composition of different spectra. The important background is that using the three primary colours of light, red, green, and blue, produces white light and the rainbow spectrum to achieve LED colour changes.

2.1.2 Light Sources

Natural light sources include sunlight, moonlight, starlight, natural flames and bioluminescence. Man-made light sources can be controlled by humans. Electric lights have been utilized in built environments since their invention. Electric lamps consume electricity to make visible light. Electricity can be generated from natural sources.[39] Electric lights for building illumination have been consuming a great deal of electricity. Nowadays, because of energy depletion and scarce resources, sustainable and environmentally sound approaches to building illumination use energy-saving lights (LEDs), but barely consume electricity from renewable resources. However, Dr. Dave Irvine-Halliday, a Professor of Electrical Engineering at the University of Calgary, founded Light Up The World Foundation (LUTW) in 1997, which was the first humanitarian organization to utilize renewable energy and solid-state lighting technologies in developing countries.[40]

2.1.3 Brief history and types of electric lights

Historically, electrical lighting technology dates back to the invention of the light bulb, the incandescent lamp, invented in 1879 by Thomas Alva Edison. He was neither the

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[38] Silja Holopainen, Colorimetry, (Finland: Metrology Research Institute, Helsinki University of Technology, 2006), 31 March 2008 <http://metrology.tkk.fi/courses/S-108.4010/2006/Colorimetry.ppt>.

[39] Mark Karlen and James Benya, Lighting Design Basics (Hoboken: Wiley, 2004) 3.

[40] "About Us," (Light Up The World Foundation), 31 March 2008 <http://www.lutw.org/>.

first nor the only person who tried to invent an incandescent light bulb. Since then, the light bulb has profoundly changed human existence by illuminating the night and making it hospitable to a wide range of human activities.[41]

2.1.3.1 Incandescent

Fig 2.2 Incandescent Lamp Spectrum 350-700, adopted.[42]

Over one hundred years ago, the invention of incandescent lamps totally changed people's lives. Nowadays, the conventional incandescent lamp is the least expensive lighting product to purchase, but is also the most energy-consuming and inefficient light source, both for indoors and outdoors. In incandescent lamps, when electric current heats a filament, visible light is generated by less than 10% of the input energy, 90% of the energy being dissipated as heat. Incandescent lamps are commonly used in applications where such low outputs (below 2000 lumens) are needed, and where the lighting is often switched on and off. Some applications, such as incubation, take advantage of the relatively high heat production of such lamps. However, due to the energy crisis, inexpensive incandescent lamps are becoming less favorable for many consumers. Their disadvantages include short lifetimes (fewer than a few thousand hours), low efficiency (about 5-20 lumens/watt), with resultant high per-lumen energy use and life cycle cost, attraction of insects, and high heat production.[43]

2.1.3.2 Halogen

Halogen lamps are a type of incandescent lamp with longer life, ranging from 2000 hours to 10,000 hours, but marginally more efficient. Halogen lamps are best suited for

[41] Dietrich Neumann, with essays by Kermit Swiler Champa et al, Architecture of the Night: the Illuminated Building (New York: Prestel, 2002)10.

[42] International Dark-Sky Association, Outdoor Lighting Code Handbook Version 1.14. (Tucson: International Dark-Sky Association, December 2000 / September 2002) 20, 31 March 2008 <http://www.darksky.org/handbook/lc-hb-v1-14.html>.

[43] International Dark-Sky Association 20; Karlen and Benya 6.

spotlights and are often dimmed for use with motion sensors; for example, outdoor security/convenience lights frequently cycle on and off. Halogen light has low efficiency, about 15-25 lumens/watt.[44] A recent development in halogen technology is the halogen infrared (HIR) lamp with better efficiency. HIR technology results in more light output and significantly less waste heat for the same energy use.[45]

Low-voltage incandescent and tungsten-halogen lamps with 12 volts are smaller and easier for accenting and display functions. Employing 12 volts of electrical current, different from the 120 volts common for primary power in North America, is part of the process in the operation of low-voltage lamps.[46]

2.1.3.3 Fluorescent

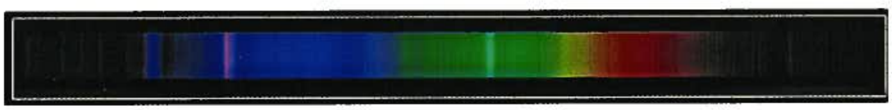

Fig 2.3 Fluorescent Lamp Spectrum 350-700, adopted.[47]

Fluorescent lights are the most common source of lighting in residential, commercial and institutional facilities. In the fluorescent lamp, electric energy excites mercury gas, generating ultraviolet light, which excites a thin film of phosphors to give off visible light. Fluorescent lamps are occasionally seen in outdoor area lighting. High-efficiency fluorescent lighting can reduce energy costs by up to 75% and last the equivalent of eight life times of incandescent lights. Today's fluorescent lamps come in a variety of shapes and sizes to fit many different applications. The most common diameters are 5/8" (T5), 1" (T8), and 1 1/2" (T12) for linear fluorescent lamps. Fluorescent lamps have high efficiency, about 40-70 lumens/watt, good color rendition, and long lifetimes (10,000 - 20,000 hrs). Disadvantages of fluorescent lamps include fragility, poor output maintenance, attraction of insects, and potentially hazardous mercury waste. A ballast

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44 Karlen and Benya 7.

45 BC Hydro, "Energy-Efficient Lighting," BC Hydro for Generations, (Vancouver: BC Hydro), 31 March 2008 <http://www.bchydro.com/powersmart/elibrary/elibrary679.html>.

46 Karlen and Benya 6.

47 International Dark-Sky Association 21.

is required to operate compact fluorescent lights (CFLs) for easy switching. However, CFLs can be screwed into light sockets to replace incandescent lamps with relatively low initial cost.[48]

### 2.1.3.4 Mercury Vapor (MV)

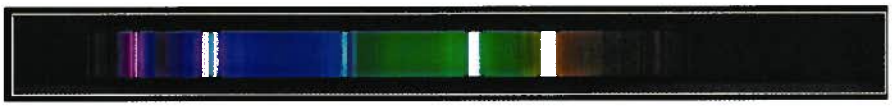

Fig 2.4 Mercury Vapor Lamp Spectrum 350-700, adopted.[49]

Mercury vapor lamps were the first widely used high-intensity discharge (HID) lamps, introduced after the Second World War. Because of their low luminous efficiency, poor color rendition, and high ultra-violet output, they are almost never used in new construction.[50]

### 2.1.3.5 Metal Halide (MH)

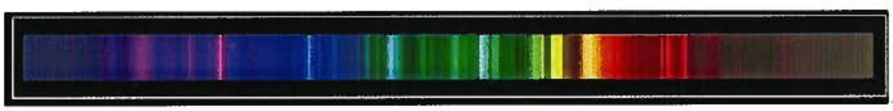

Fig 2.5 Metal Halide Lamp Spectrum 350-700, adopted.[51]

Metal halide lamps are HID lamps with mercury vapor and small amounts of various metallic halides. A ballast is required for application, and full output is not reached for 2-10 minutes after power is applied. They give off white, blue-white or slightly different colour characteristics. Their colour rendering index (CRI)[52] is 65 to 70, which means that the colour under this illumination is poor, even though metal halide lamps are very commonly used in commercial outdoor lighting. The latest ones are called ceramic metal halide lamps, with CRI 80 to 85. Advantages include a wide variety of moderate to high luminous output lamps (3500-170,000 lumens mean output), high efficiency

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48 International Dark-Sky Association 21; Karlen and Benya 7.

49 International Dark-Sky Association 21.

50 International Dark-Sky Association 22; Karlen and Benya 10.

51 International Dark-Sky Association 22.

52 The Colour Rendering Index (CRI) is a quantitative measure of the ability of a light source to reproduce the colours of various objects faithfully in comparison with an ideal or natural light source.

(45-90 lumens/watt mean), and good colour rendition. Disadvantages include output maintenance, shorter lamp lifetime, poor colour changes, ultra-violet output if not adequately filtered, and potentially hazardous mercury waste.[53]

2.1.3.6 High-Pressure Sodium (HPS)

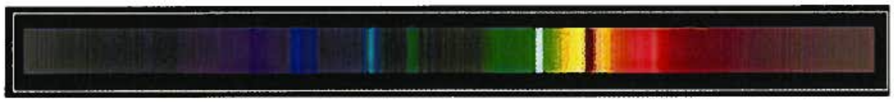

Fig 2.6 High-Pressure Sodium Lamp Spectrum 350-700, adopted.[54]

High-pressure sodium lamps are currently the most widely used HID lamps for roadway and parking lot lighting. Light is produced by passing an electric arc through a small tube filled with sodium vapor at about 1/4 atmospheric pressure, and a ballast and warm-up of about 10 minutes are required. Advantages include a long lifetime, a wide variety of moderate to high luminous output lamps (2000 - 120,000 lumens mean output), high efficiency, and wide variability of cost of lamps and luminaires. Disadvantages include poorer colour rendition, poorer output maintenance and efficiency than with low-pressure sodium, and potentially hazardous mercury waste.[55]

2.1.3.7 Low-Pressure Sodium (LPS)

Fig 2.7 Low-Pressure Sodium Lamp Spectrum 350-700, adopted.[56]

Low-pressure sodium lighting is favored where energy consumption and costs are major concerns and where color discrimination is either not needed or is supplied by other lighting. A ballast is required and 7-15 minutes are needed to reach full output. Advantages include higher luminous efficiency and lowest energy use in conventional lights, low glare associated with the large lamps, good visibility especially for the aging eye and under poor atmospheric conditions such as fog or where light tends not to

[53] International Dark-Sky Association 22; Karlen and Benya 9.

[54] International Dark-Sky Association 22.

[55] International Dark-Sky Association 23; Karlen and Benya 10.

[56] International Dark-Sky Association 23.

scatter, minimal effects on insects and other wildlife, as well as a lack of hazardous mercury wastes. Disadvantages include the lack of color rendition, shorter lamp lifetime, higher lamp replacement costs compared to HPS, and large lamp size in the higher output lamps.[57]

2.1.3.8 "Neon"

"Neon" or "luminous tube" lighting is a term applied to a variety of small-diameter glass-tube sources for decorative purposes and signage. When electrical current passes through the gas fill, light is produced with a colour or spectrum characteristic. Since "Neon" lighting is used particularly for various colour applications requiring shape flexibility, mostly not suitable for those of the lighting sources above, it is unnecessary to compare "Neon" light traits with those of other lighting sources. However, when used for architectural outlining, "Neon" lights can consume a lot of energy.[58] "Neon" lighting lasts 20,000 to 40,000 hours, can be dimmed, and can even be flashed on and off without affecting lamp life.[59]

2.1.3.9 Laser and Search Lights

Laser is an acronym: Light Amplification by Stimulated Emission of Radiation. As a light source, a laser can have various properties, depending on the purpose for which it is designed. Lasers can cause eye damage if aimed directly into the eye so laser illumination should be properly designed. The utility of sweeping laser or searchlight beams in attracting attention to commercial activities or community events is questionable, but the wide-reaching effects are not in question. These practices of turning the entire night sky into an advertising medium can affect the appearance of the nighttime environment for thousands or even millions of people. The IDA[60] discourages this use of the common nightscape, and the USA Pattern Code reflects this limitation.[61] Laser light is useful in entertainment because the coherent nature of

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[57] International Dark-Sky Association 24; Karlen and Benya 10.

[58] International Dark-Sky Association 25.

[59] Karlen and Benya 12.

[60] The International Dark-Sky Association (IDA)'s official website: www.darksky.org

[61] Wikipedia, "Laser," 31 March 2008 <http://en.wikipedia.org/wiki/Laser>.

laser light causes a narrow beam to be produced, which allows the use of optical scanning to draw patterns or images on walls, ceilings or other surfaces or stage effects, including theatrical smoke and fog.[62]

### 2.1.3.10 Summary

The table 2.1 approximately summarizes those different qualities of the most salient lamp types for the most common sizes encountered in outdoor lighting, exclusive of sports lighting. More relative comparisons will depend on the details of the application.

Tab 2.1 Lamp Type Comparison – Summary[63]

| | Lamp Type | | | | |
|---|---|---|---|---|---|
| Factor | Incandescent | Fluorescent | Metal Halide | High-Pressure Sodium | Low-Pressure Sodium |
| Wattage | 25-150 | 18-95 | 50-400 | 50-400 | 18-180 |
| Output (lumens) | 210-2700 | 1000-7500 | 1900-30000 | 3600-46000 | 1800-33000 |
| Efficiency (lumens/watt) | 8-18 | 55-79 | 38-75 | 72-115 | 100-183 |
| Lumen Maintenance (%) | 90 (85) | 85 (80) | 75 (65) | 90 (70) | 100 (100) |
| Lamp Life (hours) | 750-2000 | 10000-20000 | 10000-20000 | 18000-24000 | 16000 |
| Energy Use | high | medium | medium | low | lowest |
| Wattage | 25-150 | 18-95 | 50-400 | 50-400 | 18-180 |

Note:

- Output: approximate mean luminous outputs of lamps most commonly used in outdoor lighting
- Efficiency: mean luminous efficiency for lamp output range above, taken at 50% of mean lifetime (does not include ballast losses)
- Lumen Maintenance: percent of initial lamp output at 50% of mean lamp lifetime and at end of mean lifetime (in parentheses)
- Color Rendition: relative ability of average observer accurately to perceive colors under lighting from indicated lamps only (* under pure LPS light, some discrimination of reds and oranges is possible, though they will appear as shades of brown).

## 2.1.4 Lighting Control System

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[62] Wikipedia, "Laser Lighting Display," 31 March 2008 <http://en.wikipedia.org/wiki/Laser_lighting_display>.

[63] International Dark-Sky Association 26.

The utilization of lighting controls becomes critical in reducing electricity consumption and its costs. Unneeded light and unnecessarily lit areas will cause a waste of energy.[64] We are at the stage where we need to be seriously concerned about energy efficacy and reduction of greenhouse gas emissions. Today's progress in light design has been bringing lighting controls to a more important stage in terms of dynamic transitions, intelligent operations, and interactive responses. Listed below are some devices available to create better control systems.

#### 2.1.4.1 Dimmers

Dimmers are devices used to vary the intensity of the light output by changing the voltage to the lamp. Dimmers are used for both domestic and public lighting, and high powered units are used in large theatres or architectural lighting installations. The ability to dim lamps can enhance the versatility or aesthetics of space and backgrounds for special ambience and effects. Mostly, dimming lighting does not lead directly to energy savings because conventionally only certain inefficient lamps, such as incandescent and halogen, can be dimmed.[65]

#### 2.1.4.2 Timer

A timer is a specialized type of clock used to control the sequence of an event or process. Timers can save energy and control interior or exterior lighting, or even appliances, by turning them on and off at a determined time. Most modern timers are digital, easy to operate, affordable, and can be programmed from 24 hours to 7 days on a seasonal daylight schedule. Many timers are plug-in products, so installation does not require an electrician.[66]

#### 2.1.4.3 Motion Sensor/Detector

A motion sensor transforms the detection of motion into an electric signal by

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[64] BC Hydro, "Automatic Lighting Controls," BC Hydro for Generations (Vancouver: BC Hydro). 31 March 2008 < http://www.bchydro.com/powersmart/elibrary/elibrary682.html>.

[65] BC Hydro, "Dimmers"; Wikipedia, "Laser Lighting Display," 31 March 2008 <http://en.wikipedia.org/wiki/Dimmer>.

[66] BC Hydro, "Timers"; Wikipedia, "Timer," 31 March 2008 <http://en.wikipedia.org/wiki/Timer>.

measuring optical or acoustical changes to trigger a timing device. These devices function to prevent illumination of unoccupied spaces. Outdoor security lights can account for a large portion of overall lighting energy costs, and are often left on when not needed. Motion sensors are a good choice for controlling outdoor security lights as long as there is movement. After motion has stopped, the detector switches the lights off.[67]

#### 2.1.4.4 Photocells

A device altered by the effect of light is used for measuring or detecting light or other electromagnetic radiation. Photocells are especially good for outdoor or security lighting control. They sense natural light and turn electric lights on when natural light levels are low, off when light levels are higher. They allow the outdoor lighting system to adjust to the changing seasons. If exterior lighting is needed for only a portion of the night, a photocell can be used to turn lighting on and a time clock can turn it off. Some photocells have delay mechanisms to prevent temporary cloud cover from turning the lights on.[68]

All of those mentioned lighting control devices are adopted for my experimental building illumination. Moreover, a personal computer (PC) is used to allow control software to direct a system combining all above control devices to achieve responsive, colour-changing and energy-saving lighting effects. Chapter 5, Philips Color Kinetics system, and Figure 5.11 demonstrate a comprehensive lighting control system suitable for LED building illumination.

## 2.2 Outdoor Lighting Design

### 2.2.1 Design History

Very early in history, the Chinese and Japanese used lanterns for functional and

[67] BC Hydro, "Motion Sensors"; Wikipedia, "Motion Detector," 31 March 2008 <http://en.wikipedia.org/wiki/Motion_detector>.

[68] BC Hydro, "Photocells"; The Free Dictionary by Farlex, "Photocell," 31 March 2008 <http://encyclopedia.farlex.com/Photocells>.

decorative lighting. The canals in the Versailles gardens were illuminated in 1674 and the buildings of Ghent were lit in the honor of Emperor Charles VI in 1717.[69] Before the nineteenth century, gas lamps, oil lamps, and bright electric arc lights had been used for outdoor illumination.[70] Around 1814, gas lighting had begun to appear in London with gas explosions and serious accidents continuing throughout the century. Through the 1860s and 1870s, the arc lamp was widely used for decorative purposes.

In the 1880s, international exhibitions showcased the newest electric lighting developments in arc lamps and incandescent lights. At the Paris World's Fair in 1889, strings of incandescent bulbs adorned major buildings, and coloured arc lights with moveable filters allowed colour changes. The Eiffel Tower demonstrated all available lighting types and technologies, gas lamps, incandescent bulbs, searchlights, and a rotating lighthouse lamp with colour changes.[71] At the Chicago World's Fair in 1893, Luther Stieringer employed around 130,000 incandescent bulbs for outline lighting to demonstrate the urbanistic concept of a "White City."[72] Outdoor lighting design theory has been developed with the evolution of electric lights, even if before the end of the nineteenth century few architects had thought about how their buildings looked at night.

Nocturnal architectural concepts appeared with the rise of modern architecture. In the 1920s, architects who sought avant-garde technical and aesthetic solutions for cities took building façades at night as central concerns in their design practices and debates.[73] In 1927, the term "light architecture" was used for the first time by Joachim Teichmuller in Germany.[74] The newest types of lighting, coloured floodlights, first became popular at the 1929 World's Fair in Barcelona. After 1945, the differences in

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[69] Neumann 10.

[70] Neumann 11.

[71] Neumann 10.

[72] Neumann 11.

[73] Marion Ackermann, "Introduction," Luminous Buildings : Architecture of the Night. eds. Marion Ackermann and Dietrich Neumann, texts by Marion Ackermann [et al.] (Ostfildern: Hatje Cantz, 2006) 12.

[74] Neumann 28.

nighttime lighting between the cities of the United States and those of Europe were slight. Continued evolution is exemplified in Nicolas Schoffer's cybernetic illumination of the 1970s.[75] The energy crisis of 1973 temporarily ended the design development of all nocturnal illuminations after the new enthusiasm of the fifties and sixties.[76] Nowadays, media façades, interactive zones, and changing surfaces have been demonstrated on luminous buildings with all kinds of lighting technologies, blurring the boundaries of art, architecture, and science.[77]

### 2.2.2 Design Approaches

Seven approaches to lighting design highlight its development: outline lighting, floodlighting, glass blocks, reflection, luminous advertising, "interactive building skins," and responsive environments.

At the beginning of the twentieth century, the French inventor Georges Claude produced the first neon tube, for colourful illuminated advertisements and festive lights. At the same time, incandescent bulbs were used in an arrangement of dotted lines as outline lighting. In 1928, Osswald designed a type of contour lighting for the Tagblatt Tower.[78]

Floodlighting forced designers to reckon with new concepts of aesthetic perception and judgment; it was both a pragmatic and a philosophic challenge to architecture. Harvey W. Corbett, in 1930, was the first designer to discover how to create a "floating" effect in buildings by only illuminating the topmost portions of them.[79]

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[75] Marion Ackermann 13.

[76] Lucy Bullivant, Responsive Environments: Architecture, Art and Design (London: V & A, 2006) 26.

[77] Bullivant 9

[78] Simone Schimpf, "Outline Lighting," Luminous Buildings: Architecture of the Night, eds. Marion Ackermann and Dietrich Neumann, texts by Marion Ackermann [et al.] (Ostfildern: Hatje Cantz, 2006) 70.

[79] Sanday Isenstadt, "Floodlight," Luminous Buildings : Architecture of the Night, eds. Marion Ackermann and Dietrich Neumann, texts by Marion Ackermann [et al.] (Ostfildern: Hatje Cantz, 2006) 72.

Bruno Taut's glass blocks, used in the expression of architectural utopias, date from 1920, and changed traditional buildings into spots of colourful light. The Tittot Glass Museum (2004) with various colours of glass blocks attained a special effect, recalling a buoyant watercolour at night.[80]

The history of reflection began after modern architectural materials, such as glass and steel started to dominate high-rise structures. In 1955, the Manufacturers Trust Building employed trans-illumination strategies, lighting the building from the inside out.[81]

In 1870, *The New York Times* announced the first ever gas-lit advertisements in the city; lit from behind multi-coloured glass screens, the style introduced luminous advertising. In 1892, the first electric advertising in New York was seen at the same intersection. By 1929, flashing, vanishing, moving, and reappearing electric signs were so popular that they covered the whole building.[82]

The term "Interactive building skins" is used to describe how architecture has been designed to respond to surroundings through building surfaces/façades. Buckminster Fuller's Pavilion Dome for the U.S. at the 1967 Expo in Montreal was thought to be an early programmable surface design, which followed the sun's changes every 20 minutes. Fuller's lighting as a major expressive medium was controlled by an electronic operating system, wireless sensing, and computer programming to create building façades that acted as mediating devices for a new social statement. Architects' design interests now overlapped strongly with those of designers,

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[80] Cara Schweitzer, "Glass Blocks," Luminous Buildings : Architecture of the Night, eds. Marion Ackermann and Dietrich Neumann, texts by Marion Ackermann [et al.] (Ostfildern: Hatje Cantz, 2006) 74.

[81] Margaret Maile Petty, "Reflection," Luminous Buildings : Architecture of the Night, eds. Marion Ackermann and Dietrich Neumann, texts by Marion Ackermann [et al.] (Ostfildern: Hatje Cantz, 2006) 76.

[82] Dietrich Neumann, "Luminous Advertising," Luminous Buildings : Architecture of the Night, eds. Marion Ackermann and Dietrich Neumann, texts by Marion Ackermann [et al.] (Ostfildern: Hatje Cantz, 2006) 80.

scientists, engineers, and artists. This shift in priorities transcended objects to reinvent design as more of an event-based installation concept. In 1992, Christian Moeller's "Kinetic Light Sculpture" developed a light installation on the Zeil-galerie's façade, to transform it like a chameleon with blur-yellow clusters of light.[83]

Bullivant states "responsive environments – by definition spaces that interact with the people who use them, pass through them or by them – have in a very short time become ubiquitous."[84] Responsive and intelligent designers/artists are reacting to "the electro-physical flux of the environments."[85] They are mixing new technologies into design concepts to create environments in which human beings become realized design elements instead of just users of final products. Bullivant explains: "Digital technologies are fostering an experimental dissolution of disciplinary forms; working with space is no longer the exclusive preserve of designers, and designers no longer confine themselves to traditional visual devices and sources of inspiration."[86] I understand this exposition to mean that designers are creating open-ended projects because they are using some dynamic and uncertain elements to showcase the flexibility and spontaneity of their design.

My research in this realm suggests that outdoor lighting design theory is not thriving to the same degree as architectural design generally. Therefore, well-known architectural illumination examples are fewer than for well-known buildings. We have heard of green architecture, sustainable architecture, and zero-energy architecture as today's focus when we encounter the problems of global warming, green house gas emissions, and energy shortages. But we have not heard about green illumination, sustainable illumination, and zero-energy illumination yet.

## 2.3 LEDs

### 2.3.1 LED Development

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[83] Bullivant 19.

[84] Bullivant 8.

[85] Bullivant 66.

[86] Bullivant 9.

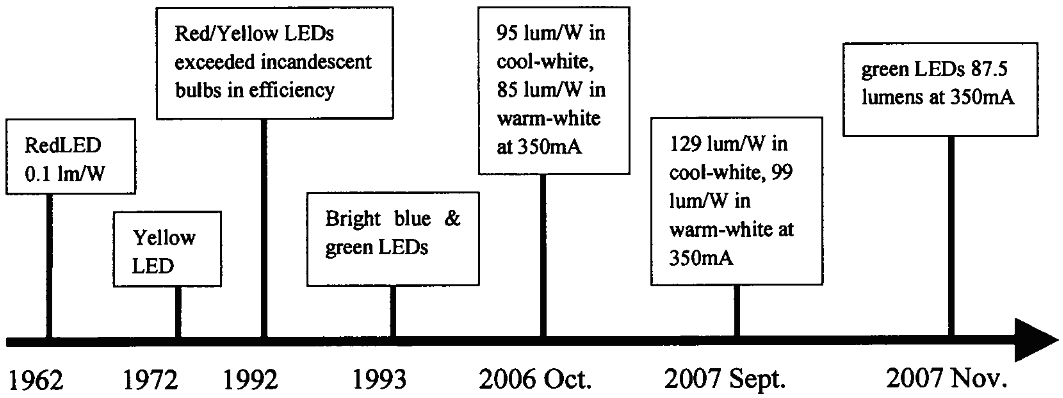


Fig 2.8 LED Development.[87]

The US Department of Energy (DOE) states that solid-state lighting is a pivotal emerging technology with much potential to save energy and enhance the quality of our building environments. Solid-State Lights (SSLs) include Light Emitting Diode Lights (LEDs) and Organic Light Emitting Diode Lights (OLEDs).[88] In 1962, Nick Holonyak demonstrated the first use of LEDs with luminous efficacies of only about 0.1 lm/W (1/20 the efficacy of Edison's first electric light bulb), while he was working at General Electric. However, the efficiencies of red and yellow LEDs had exceeded those of red-colour-filtered incandescent lamps by 1992. Bright blue and green LEDs were produced by Shuji Nakamura working at the Nichia Corporation in late 1993. During the past ten years, the efficiencies of all LEDs have been increasing constantly and dramatically.[89]

### 2.3.2 LEDs' Characteristics

LEDs are used in a wide range of applications with qualities such as low forward

[87] David G. Pelka and Kavita Patel, "An Overview of LED Applications for General Illumination," Design of Efficient Illumination Systems, ed. R. John Koshel, sponsored by Society of Photo-optical Instrumentation Engineers (SPIE) (Bellingham, Wash., USA: SPIE, 2003) 15.

[88] "DOE Solid-State Lighting Portfolio," Building Technologies Program: Solid-State Lighting, US Department of Energy, 31 March 2008 <http://www.netl.doe.gov/ssl/ >.

[89] Pelka and Patel 15; Protzman and Houser 121-42.

voltage, exceptionally small size, thinness and flexibility, low heat generation, high tolerance/resistance, inherently directional light emission, good performance under low temperatures, low glare on lit surfaces and on the human eye, and longer useful life (50,000 to 100,000 hours) with little maintenance. LEDs are comparatively efficient for colored light applications. Unlike incandescent, fluorescent and HID sources using coloured filters or lenses associated with 90% energy waste, LEDs are near-monochromatic light sources for coloured lights. One of the most dramatic and conspicuous uses of LED light has been in dimming and colour-changing applications. LEDs do not cause pollution with mercury or other heavy metals, helping to preserve the environment not only during their operational life, but also during their landfill time.[90]

### 2.3.3 Canada's CN Tower illuminated by Coloured LEDs

The CN Tower, Canada's national tower, at 553.33 metres (1,815 ft 5 in), the World's tallest freestanding tower, is a symbol of Canadian building achievement recognized around the world. On June 28th, 2007, the CN Tower was lighting demonstrated its transformation from traditional lighting to vibrant, dynamic, and more energy-efficient LEDs, designed to use 60 percent less energy than in the 1990s. Each LED fixture can produce 16.7 million colours controlled by an intelligent digital system; the "Philips Color Kinetics lighting system,"[91] programmable from a single computer console. Intelligently and individually programmed, every LED fixture has its unique "address," meaning an electric location that can receive data from a control system to achieve an

[90] Feng Zhao and John Van Derlofske, "Side-Emitting Illuminators Using LED Sources," Design of Efficient Illumination Systems ed. R. John Koshel, sponsored by the Society of Photo-optical Instrumentation Engineers (SPIE) (Bellingham, Wash.: SPIE, 2003) 33; "Solid-State Lighting Portfolio Strategy," Building Technologies Program: Solid-State Lighting, (US Department of Energy), 31 March 2008 < http://www.netl.doe.gov/ssl/strategy.html >.

[91] "Highlighting the CN Tower: Testing of Innovative Illumination Technology Begins Early June 2007," Toronto: CN Tower Website Release June 2007, 31 March 2008 <http://www.cntower.ca/portal/GetPage.aspx?at=1577>.

infinite variety of lighting effects with "precisely directed illumination."[92]

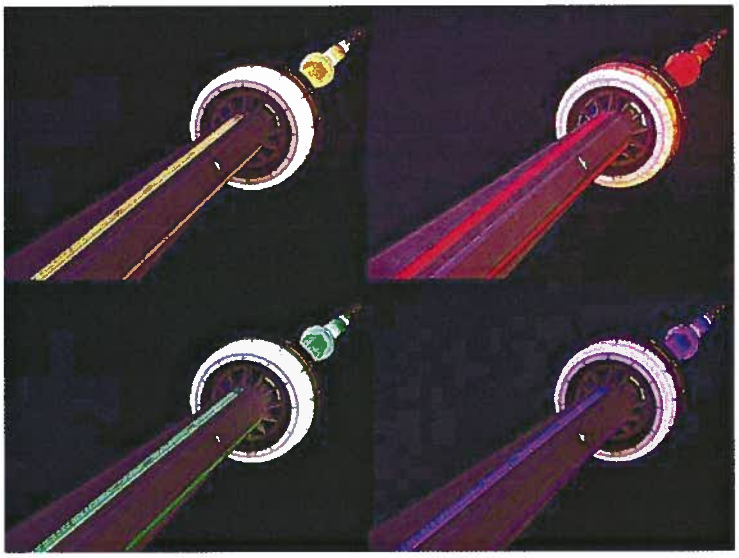

Fig 2.10 Canada's CN Tower Illuminated by Coloured LEDs, adopted.[93]

### 2.3.4 Toronto: LED City

On July 11, 2007, The Toronto Association of Business Improvement Areas (TABIA) announced that Toronto would initiate a citywide installation of light-emitting diode (LED) lighting throughout its infrastructure. Toronto was the second city joining the LED City™ program, the first being launched in February by City of Raleigh officials and LED manufacturer Cree, Inc. Toronto's commitment to the LED City initiative showed a willingness to increase its use of the technology in order to support the Canadian legislative agenda focused on energy efficiency. Toronto has been a center for LED consumer education and an early adopter of LED Lighting. TABIA will evaluate, deploy and promote the use of LEDs across multiple lighting applications. Other current and planned LED projects include solar-powered LED lights in a park and LED lighting in a public parking garage. Toronto Mayor David Miller said: "We

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92 "Core Technologies," Philips Solid-State Lighting Solutions, Philips Color Kinetics, 31 March 2008 <http://www.colorkinetics.com/technologies/core/>.

93 Photo "rainbowtower" by Sean Galbraith, blog to Flickr Pool contributor, 31 March 2008 <http://blogto.com/city/2007/06/cn_tower_now_in_strawberry_lemon_lime_and_grape/>.

expect that by deploying LEDs throughout Toronto, including on our most famous landmark, the CN Tower, we will be accomplishing the goal of reducing energy use, costs and green house gas emission."[94]

[94] LED City Toronto, n.pag.

# Chapter 3:
# Vancouver

### 3.1 Defining Vancouver's Urban Context

Transformative lighting strategies depend upon Vancouver's urban context. Lance Berelowitz's *Dream City*[95] delineates Vancouver's historic transformation and its unique urbanization called "Vancouverism."[96] Vancouver's downtown development model is that people live in the downtown consuming infinite, astounding natural environments, and drive out of downtown, or walk into it, or to their job locations. For the typical North American, a single-family house is the dream, but my understanding is that for Vancouverites, the vision encourages downtown living as a sort of transformative dream of "the single-family", where the well-preserved Stanley Park is seen as the backyard for the whole downtown. Vancouver's symbolic Coal Harbour waterfront, symbolic because it is the site of the first European occupation, perfectly conveys this concept of the "Dream City"[95], so this site has become my research context in my thesis on transformative lighting strategies.

The investigated area ranges from Richards Street to Chilco Street, mainly in a northeast to southwest direction, and from Waterfront Road to Robson Street, mainly in a southeast to northwest direction. The shape of the area conforms to the significant buildings and the landscape visible from Burrard Inlet. Historically, within this area significant buildings and landscape features not only form Vancouver's urban skyline, but also enrich Vancouver's urbanization – "Vancouverism." [97] I understand "Vancouverism" is sort of high-density residential living different from the rules of expected North American urbanism. The chosen site symbolizes Vancouver due to its historical significance with its successful transformation from the original terminus of Canada's first trans-continental railroad to being a particular downtown high-density

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[95] Lance Berelowitz, Dream City: Vancouver and the Global Imagination (Vancouver: Douglas & McIntyre) 2005.

[96] Julie Bogdanowicz, "Vancouverism," Canadian Architect August 2006, 31 March 2008 <http://www.canadianarchitect.com/Issues/ISarticle.asp?id=177934&story_id=164583120907&issue=08012006>.

[97] Trevor Boddy, "New Urbanism: The Vancouver Model," Places 16.2, (Richard Shepard 2004). eScholarship Repository: University of California, 31 March 2008 <http://repositories.cdlib.org/cgi/viewcontent.cgi?article=2152&context=ced/places>.

residential area. This site and its panorama inspired me, but also presented me with challenges when I observed that its architecture and surroundings easily distinguished during the day became submerged during the night: only a few buildings with their decorative night lighting could still be recognized. Vancouver's urban nightscape has much potential for revitalization and transformation, to fulfill its role as a significant segment of the downtown core, both functionally and perceptually.

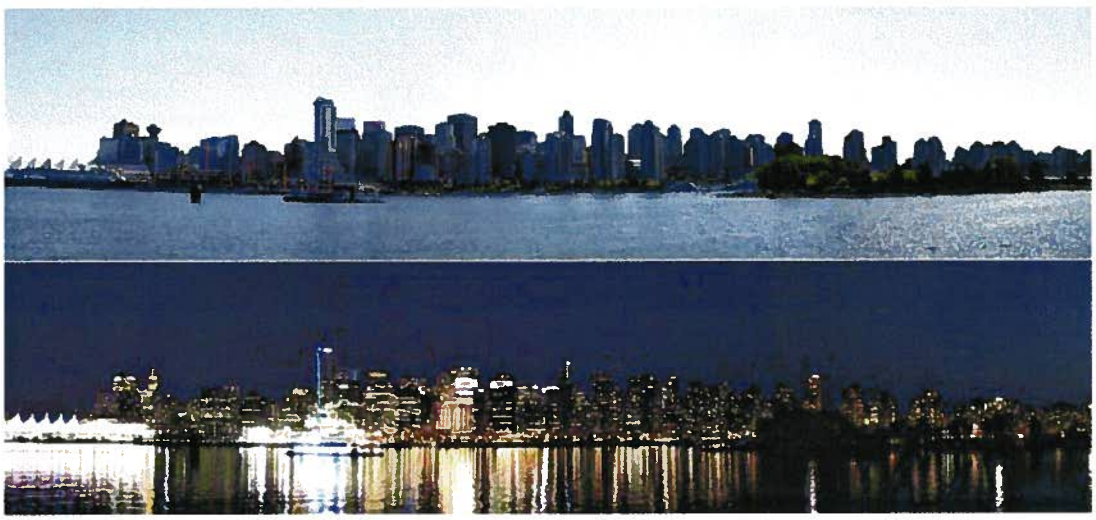

Fig 3.1 Daytime and Nighttime Panorama of Vancouver's Skyline

### 3.2 Urban Context Transformation History

In terms of the lighting strategy of Vancouver's urban context, the first thing that I needed to do was to choose a particular site. In *Dream City*, I was informed that as a result of Expo 86, the Coal Harbour waterfront was transformed from a working port to a high-density residential development, a significant contribution to "Vancouver's emerging new lifestyle myth."[98] From Canada Place facing west along the Burrard Inlet to Stanley Park, a major development plan for the 32-ha (80-acre) site—17ha (41 acres) of land and 15ha (39 acres) of water—has become one of the most significant factors in building Vancouver's skyline. According to Berelowitz's words: "The shape and form of the new shoreline were cued off the existing one and scalloped to create a

[98] Berelowitz 106.

series of focal points along the length of the site. The usual Vancouver waterfront walkway/bikeway is well integrated here, entrenching an ever-present impulse to look out at the setting rather than in towards the city."[99]

Another important component of the chosen site is the Bayshore Gardens, developed by the Aoki Corporation of Japan in response to Marathon's early construction in Coal Harbour. According to Berelowitz, the current Bayshore Gardens is different from the original plan, which was a kind of bland expansion of the "archaic" Western Hotel chain, 6.5 ha (16 acres). But the Bayshore Gardens development has been transformed into "several distressingly similar, unremarkable residential towers arrayed around a series of formal gardens" and a small public green space that forms the roof of a central public parkade.[100] So we can see that Vancouver, as a young city, has significant transformation history in its waterfront.

### 3.3 Introduction to Urban Lighting

Recently, sophisticated lighting concepts for cities have been showcased in Germany, Switzerland, the U.S.A., and Asia. Decisions in terms of which parts of the city will be accentuated and which areas should remain dark are being made according to physical conditions, functional considerations, image, and historic significance.[101] As I know, Shanghai has decided to light up its historical and tourist buildings along the Huangpu River that became the center of Shanghai's foreign business establishment and the symbol of Shanghai's identity as a modern city. Although there are many needs for outdoor lighting, "obtrusive lighting"[102] without proper consideration of negative consequences, such as light trespass, glare, sky glow, and energy waste affecting our environment should be rejected. Generally speaking, those lighting

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[99] Berelowitz 102.

[100] Berelowitz 105.

[101] Ackermann 13.

[102] CELMA, CELMA Guide on Obtrusive Light 1st ed. June (2007) 4, 31 March 2008 <http://www.celma.org/archives/temp/First_edition_Celma_Guide_on_obtrusive_light.pdf>. Obtrusive light is that part from an installation that does not serve the purpose for which it was designed.

consequences are defined as light pollution.[103] But they can also be effectively controlled or eliminated by carefully considered attention to design, installation, and operation. The RVH has been clearly positioned in the downtown core in the waterfront area next to the Burrard Inlet, which symbolizes Vancouver's architectural and historical significance. Through a series of investigations, the following background analysis determines the fundamental reasons that this segment of Vancouver's urban context will benefit from the implementation of transformative urban lighting strategies in support of important technical, energy, economic, environmental, and social aspects of sustainability as well as sports sustainability in terms of the hosting of the 2010 Winter Olympic Games.(See figure 3.2) The performance of transformative lighting strategies will create comprehensive and diverse opportunities for employment and investment in the Vancouver downtown and contribute to its long term prosperity.

Since 1997, the Kyoto Protocol has been set to achieve the stabilization of greenhouse gas concentrations in the atmosphere to prevent aggravation of global warming. Greenhouse gases, especially carbon dioxide, have been proven to be produced from our energy systems based on fossil fuels. Therefore, reducing energy consumption will decrease greenhouse gas emissions. Global lighting energy use is significant, totaling about $230 billion per year.[104] According to the statistics of the U.S. Department of Energy, lighting consumes about 20 per cent of total electricity use.[105]

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[103] CELMA 4.

[104] Mills 1.

[105] Dowling 4.

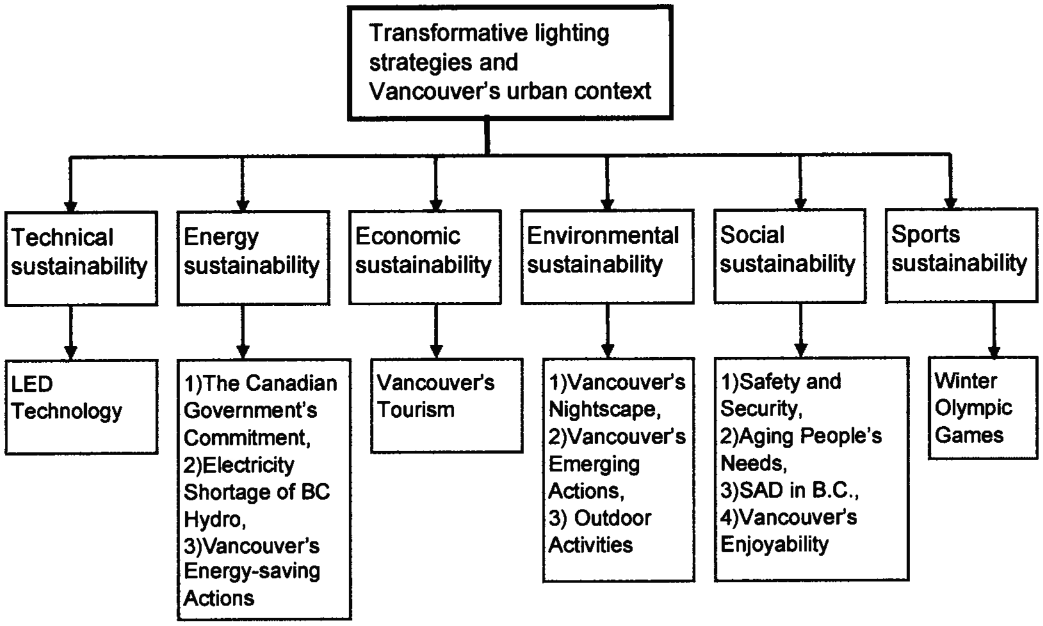


Fig 3.2 Transformative Lighting Strategies and Vancouver's Urban Context

For establishing an integrated impression, the following sections will address the whole relationship of Vancouver's urban context and the transformative urban lighting strategies in terms of sustainability in technical, energy, economic, environmental, social, and sports aspects.

### 3.3.1 Technical sustainability

I have related technical sustainability to LED technological applications to architectural lighting. Currently, LED technology is timely and critical in electrical energy savings and noise diminishment. First of all, LEDs are being widely adopted in coloured lighting applications, such as in signals, liquid crystal display (LCD) screens, decorative strings, and tiny electronic facilities. LED market penetration will accelerate as higher efficiency LEDs with better colour rendering become available. Now and in the next few years, with their qualities, LEDs should dominate the lighting market. Efficiency and cost breakthroughs must be achieved to enable LEDs substantially to replace conventional lighting. A need for reliable unbiased product performance information for high-performance SSL products is the prerequisite to foster the developing market.[106] These breakthroughs may require the utilization of nanotechnology, resulting in the "ultimate winner in energy-efficient lighting."[107] DOC LED technology continues to change and evolve very quickly. New generations of LED devices become available approximately every 4 to 6 months. In the further LED lights section, more detailed and precise discussions about LEDs applications to building illumination will be brought up.

### 3.3.2 Energy sustainability

The Canadian Government has committed itself to the battle against global warming and green house gases. On April 25, 2007, the Honourable Gary Lunn, Minister of Natural Resources, joined by the Honourable John Baird, Minister of the Environment, announced "Lighting the Way to a Greener Future: Canada's New Government to Ban Inefficient Light Bulbs": by 2012, all energy-inefficient lighting and bulbs will be banned in Canada. The legislation aimed at implementing the ban over the following three years was introduced in May, 2007. Mr. Lunn said: "The environmental benefits are clear. By banning inefficient lighting, we can reduce our greenhouse gas emissions by more than 6 million tonnes per year. More than that, these new standards will help reduce the average household electricity bill by approximately $50 a year."[108] Many other jurisdictions around the world have recently moved toward banning standard incandescent bulbs, which lose most of their energy as heat. Australia blazed the way, announcing in February 2007 that it was going to prohibit the use of incandescent bulbs by 2010 in an effort to reduce greenhouse gas emissions. It is estimated Australia's ban will result in an 800,000-tonne reduction in emissions within five

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[106] "DOE CALiPER Program," Building Technologies Program: Solid-State Lighting, (US Department of Energy), 31 March 2008 < http://www.netl.doe.gov/ssl/comm_testing.htm >.

[107] "DOE Study Finds Commercial LED Lamps Fall Short of Claims-December 20 2006," EERE News, (US Department of Energy), 31 March 2008 <http://www.eere.energy.gov/news/news_detail.cfm/news_id=10471>.

[108] "Lighting the Way to a Greener Future: Canada's New Government to Ban Inefficient Light Bulbs," Eco Action: Using Less, Living Better, (Government of Canada, April 25, 2007), 31 March 2008 <http://www.ecoaction.gc.ca/news-nouvelles/20070425-eng.cfm>.

years.[109] On December 19, 2007 President George Bush signed the Energy Independence and Security Act of 2007, legislating more efficient lighting solutions such as CFLs and LEDs.[110]

B.C. Hydro has announced a hydroelectricity shortage because of low water levels as caused by global warming, and raised electricity demands. B.C. Hydro owns and operates 80 percent of BC's 14,000 MW of dependable generating capacity. More than 85% of the Vancouver region's electricity is generated at hydro dams in the interior of the province. During periods of below-average water inflows into BC hydroelectric reservoirs, BC imports electricity from Alberta and the United States to meet provincial needs. The official estimate of importing requirements is between 25% and 45% within 20 years. Figure 3.3 shows BC Hydro in a net import position since 2001. Residents and industries are increasingly vulnerable to price volatility and supply risk. BC Hydro expects to meet about a third of its future electricity needs through conservation. BC Hydro offers significant financial support for electrical reduction initiatives and for years BC Hydro's official website has been publishing information on incentives to use efficient lighting.[111] On November 19, 2007, Premier Gordon Campbell and BC Hydro president and CEO Bob Elton announced that the provincial government and BC Hydro have entered into a new "Public Sector Energy Conservation Agreement" to achieve significant reductions in electricity consumption across more than 6,500 public sector buildings.[112]

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[109] "Lights to Go out on Inefficient Bulbs by 2012," CBCnews, April (2007), 31 March 2008 <http://www.cbc.ca/canada/story/2007/04/25/lunn-bulbs.html>.

[110] "US energy legislation mandates $20 million prize fund," LEDs Magazine, Jan. (2008), 31 March 2008 <http://www.ledsmagazine.com/features/5/1/3>.

[111] "BC Hydro Submits 2006 Integrated Electricity Plan and Long Term Acquisition Plan to the BC Utilities Commission." BC Hydro for Generations (BC Hydro 29 March 2006), 31 March 2008 <http://www.bchydro.com/news/2006/mar/release43489.html>; Scott Simpson, "Electricity Gap Threat to B.C. Energy Future: Hydro Options Include Coal-fired Power Generation Plant," The Vancouver Sun 30 March (2006).

[112] "Province & BC Hydro Target Conservation in Public Sector," BC Hydro for Generations (BC Hydro 19 Nov. 2007), 31 March 2008 <http://www.bchydro.com/news/2007/nov/release54144.html>.

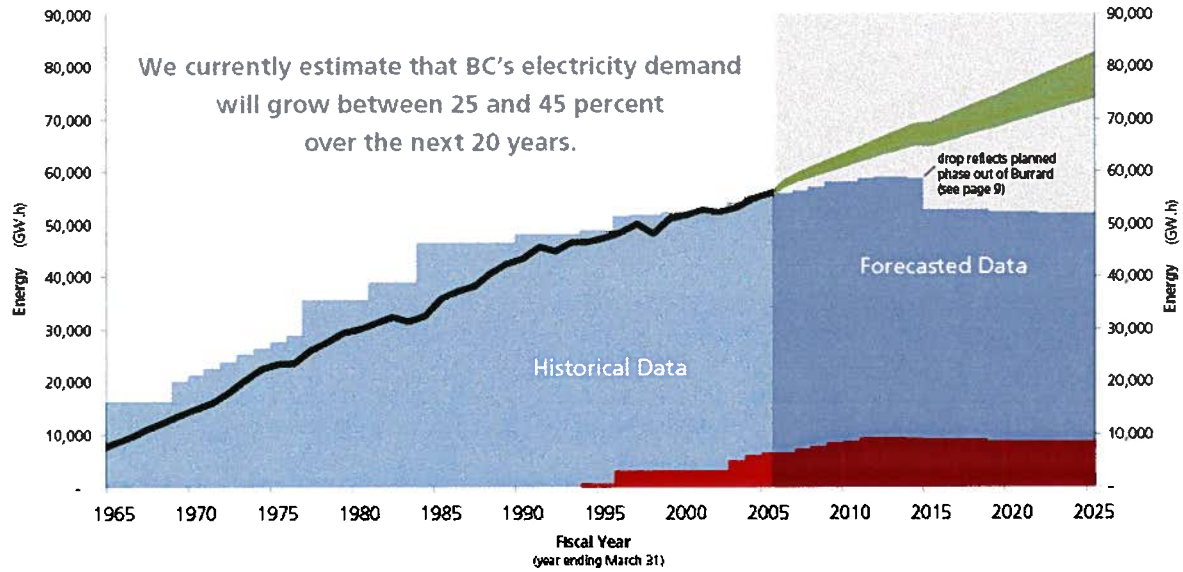


Fig 3.3 BC's Electricity Gap from 1965 to 2025
Note: Burrard Thermal Generating Station is an aging plant and inefficient by today's standards. BC Hydro is planning to replace the energy and capacity at Burrard Thermal. [113]

In Vancouver, lots of energy-saving actions have been taken to reduce the electrical demand of public lighting systems. These actions have proved that design methods and criteria of increased visibility maximize safety and security without causing higher levels of light or wasted power consumption. For instance, public lighting has changed from incandescent and mercury lamps to high intensity discharge and fluorescent lamps over the years, contributing to energy consumption reduction. The electricity used for street lighting decreased by 24% from 1990 to 1999 due to the evolution in lighting system technologies. Using this historical rate of improvement in efficiency, the City is forecasting a further 29% decrease between 1999 and 2010.[114] Further decrease in energy consumption is currently being researched through the use of

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[113] BC Hydro, Challenges and Choices: Planning for a Secure Electricity Future (BC Hydro March, 2006), 31 March 2008 <http://www.bchydro.com/rx_files/info/info43492.pdf>.

[114] The Climate-friendly City—A Corporate Climate Change Action Plan for the City of Vancouver (City of Vancouver, Apr. 2004) 23-4, 31 March 2008 <http://vancouver.ca/sustainability/documents/corp_climatechangeAP-1.pdf>.

induction lamps, pulse-start metal halide lamps, light emitting diodes (LED), energy-efficient luminaries, and electronic ballasts for high intensity discharge lamps. Additionally, the City continues to monitor the lighting industry to take advantage of improvements in lighting technologies. Improvements in new design areas can result in reduction of the amount of power required to light any given area. The Engineering Services' Electrical Design branch is currently researching the potential of enhanced new achievements in technology to continue to reduce the electrical demands of our street, lane, and park lighting systems.[115]

### 3.3.3 Economic sustainability

One of the most important aspects of economic sustainability is enhancing the tourist industry of Vancouver. In 2005, Vancouver was ranked among the top ten best cities to visit in the world in surveys done by *Condé Nast Traveller* magazines.[116] BC Stats uses room revenue as the statistic that provides detailed geographical breakdowns related to the tourism sector. In 2007, room revenue for Greater Vancouver (Metro Vancouver) was $784 million – 39.83% of the total room revenue throughout B.C.; room revenue for downtown Vancouver was $475 million making it the most popular specific destination within the Province.[117] Tourists come to the city for its heritage resources, the image of the city, arts, culture, architecture, conferences, and special events.[118] Urban night lighting could help the city to present a welcoming appearance as an additional attraction. A vibrant nightscape could increase the number of tourists. For instance, Shanghai, well known as "the Oriental Paris," has developed a vivid nightscape along the HuangPu River, considered as a magnet for increasing the numbers of tourists since 1992. Nowadays, tourist destinations often promote "cluster

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[115] Corporate Climate Change Action Plan: 2004 Annual Report (City of Vancouver, 15 March 2005), 31 March 2008 <http://www.city.vancouver.bc.ca/ctyclerk/cclerk/20050329/rr1a-annual.pdf>.

[116] A Guide to the BC Economy and Labour Market (BC Ministry of Advanced Education and BC Stats 2006) 131, 31 March 2008 <http://www.guidetobceconomy.org/Library/GBCE.pdf>.

[117] British Columbia Tourism Room Revenue by Region—Annual 2007 (BC Stats June 2008) 2-5, 31 March 2008 <http://www.bcstats.gov.bc.ca/data/bus_stat/busind/tourism/trra2007.pdf>.

[118] Martin Selby, Understanding urban tourism: image, culture and experience, (London; New York: I.B. Tauris; New York: In the U.S. and Canada, distributed by Palgrave Macmillan, 2004) 12-24.

segments," which means a mix of attributes of tourist preferences.[119] Urban tourism as part of cultural tourism has been promoted as an approach to reducing traffic needs and to re-use old buildings.[120] Vancouver needs to promote its urban tourism industry, not only for overseas tourists, but also for those from Canada and the US who may find it an alternative to distant destinations. By these means, Vancouver will prosper in its tourist industry, and will keep this industry sustainable by promoting "Urban Tourism." Urban tourism has been defined as part of sustainable tourism.

3.3.4 Environmental sustainability

Vancouver's Nightscape

Porteous states that vividly identified, powerfully structured, highly useful mental images of the environment can be facilitated by shape, color, or arrangement. These images of the environment help orientation, movement, and awareness of the location.[121] The socio-cultural ambiance of a city also arises from its highly imaginable physical form, so nowadays with increasing tourists and new residents, we are facing more needs for cityscapes, landscapes, streetscapes, and nightscapes to assist them with way finding.

Hanyu states that the appearance of a place significantly evokes emotions or inferences about the significance or friendliness of the place. Consequently, spatial and emotional interaction affects physical behaviour. A place evoking a positive feeling may attract individuals just by looking, to approach, stay or live there, while a place evoking a negative feeling may lead to escape and avoidance. Thus, in environmental psychology, aesthetic aspects of the city have been a central concern.[122] The

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[119] Kevin Meethan, Tourism in Global Society: Place, Culture, Consumption (Basingstoke, Hampshire [UK]; New York: Palgrave, 2001) 72.

[120] Christopher M. Law, Urban Tourism: the Visitor Economy and the Growth of Large Cities (London ; New York : Continuum, 2002) 69.

[121] Cyril B Paumier, Creating a Vibrant City Center: Urban Design and Regeneration Principles (Washington, D.C.: Urban Land Institute, 2004) 49-65.

[122] Kazunori Hanyu, "Visual Properties and Affective Appraisals in Residential Areas after Dark," Journal of Environmental Psychology 17 (1997) 301-315.

nightscape becomes an important asset to build a city's aesthetic forms. Vancouver's spectacular setting, its intimate and apparently happy cohabitation of nature and built fabric, the tightly packed gleaming new condo towers downtown, the public waterfront, and the enlivened city skyline during daytime benefit the city in every aspect.[123] But compared with its day-time image, Vancouver somehow lacks a vibrant nightscape, including city nightlife and nocturnal illumination.

After detailed site surveys of existing night lighting, I have found that the typical application in Vancouver means turning the interior lights on for exterior luminance, installing interior-function lights in exterior environments, and installing exterior lighting often in a disorderly way. Vancouver's nightscape of almost monochromatic and yellowish lighting fails to create beauty in our urban landscape, and is not energy efficient. Most downtown towers' interior fluorescent lights give out light toward the exterior environment. The luminance from windows is limited and not efficient for people on the street. The more interior artificial lights are turned on, the more electricity is wasted.

Vancouver's standard street lamp is High Pressure Sodium (HPS). Most High Pressure Sodium lamps produce a noticeably yellow light. Since this type of lighting is extensively used on Vancouver's streets, the phenomenon causes some negative effects on city nightscapes, such as dull streetscapes, yellowish night images, and a lack of legibility.

Vancouver's Emerging Actions

The city of Vancouver has the intention to re-establish its nocturnal civic identity in a smart, sustainable, logical, and accentuated order. Hosting the 2010 Winter Olympic Sport Games is a turning point for Vancouver similar to Expo 86. After decades of urbanization, Vancouver's urban structure/form begins to take shape in its unique responses to light, climate and context, and so city decision makers are considering the vibrancy and attraction of Vancouver's nightscape. In terms of formulating the nocturnal atmosphere of the urban stage, these questions are always intriguing: who

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[123] Berelowitz 1.

is Vancouver and what do we mean when we discuss Vancouver's civic identity? What should be displayed city wide to discover historically original meanings or to breathe new life into the city as the initial strategy to organize its nocturnal vision? Figure 3.4 demonstrates Vancouver's lighting initiatives. The four working initiatives include buildings, heritage buildings; street, Granville Street; premises, Chinatown; and place, Olympic Village, in varying stages and conditions. The Olympic Village will be a newly built area on the waterfront of False Creek so its large-scale lighting design has been proposed with the master plan of the athlete village in the original site context as a response to the former "ship yard." Granville Street's lighting concept reflects the effect of the "Great White Way," with supplemental pedestrian lighting. Light fixtures and the array were published in January, 2008, by the City of Vancouver. The illumination proposals for Chinatown, especially for the re-introduction of historic, large-scale neon signage and for special heritage buildings in Vancouver are also in the policy implementation stage.[124]

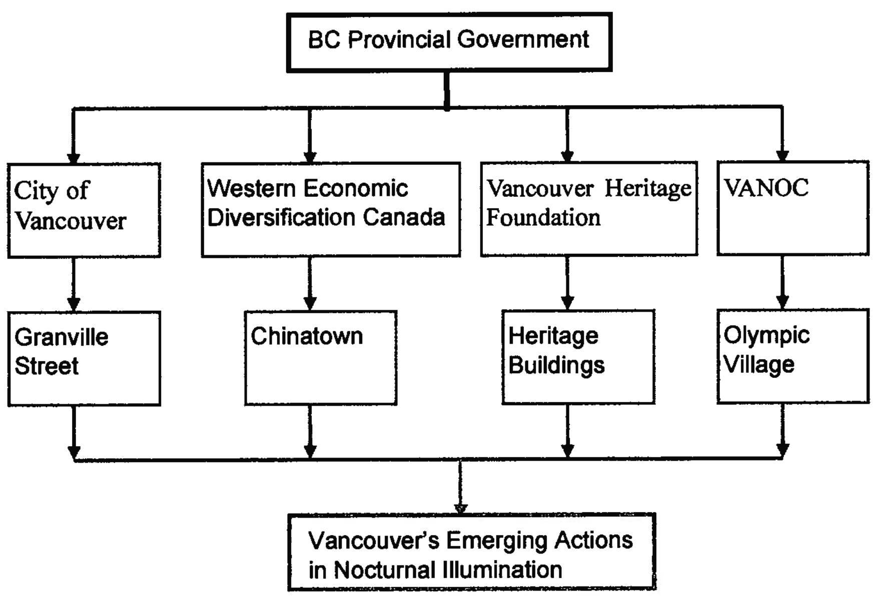


Fig 3.4 Vancouver's Emerging Actions in Nocturnal Illumination

## Outdoor Activities

After a century of the urban design system dominated by automobiles, lessons have been learned regarding its consequences for public health and the resource crisis. Recent urban planning theories have been adopted to create pedestrian-friendly and

[124] Information adopted from Scot Hein, senior city planner at the City of Vancouver.

bikeable neighbourhoods. In Vancouver, the urban environment needs pedestrian-oriented streets and architectural illumination to provide comfort and pleasure for safe, healthful, and enjoyable walking, bicycling, and human associations. Children after school, seniors, and those with disabilities, or those with companions or family members, as well as office workers after working hours, could enjoy their outdoor activities via street and building illumination.

### 3.3.5 Social sustainability

#### Safety and Security

According to a digital photograph showing the light captured by satellite in 2001, Vancouver's urban light emission is one seventh that of Calgary. Vancouver performs well in the control of its city light emissions, but Vancouver's city streets have similar fixtures and qualities as those in other cities in Canada. Such comparisons reveal that

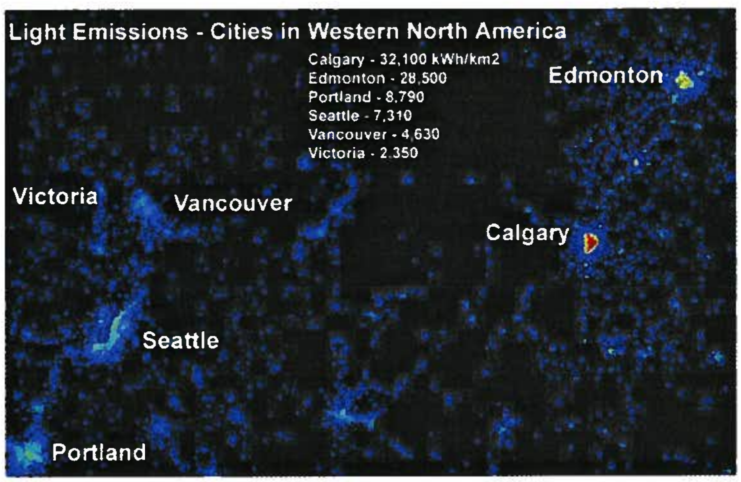


Fig 3.5 Satellite Photograph of Light Emission – Cities in Western North America, adopted.[125]

Vancouver's urban light emissions are conservative and well-controlled. We do not hear complaints about outdoor lighting or discussion of our urban nocturnal appearance, but we notice that in the near future we will not have enough outdoor night lighting for the safety and security of our citizens, given that Vancouver will have

[125] A satellite photograph shows the light over western Canada and the United States in 2001. Light emission intensity measured in kilowatt-hours per square kilometre (kwh/km2), 31 March, 2008 <http://content.calgary.ca/CCA/City+Hall/Business+Units/Roads/Street+Lights/Envirosmart+Street+Light+Retrofit+Program.htm>.

to discontinue inefficient light bulbs by 2012. For the third biggest city in Canada, better planning and design to employ efficient lights and fixtures before 2012 are urgent issues.

I have taken digital pictures of Vancouver's waterfront as shown in Figure 3.6. Compared with Figure 3.7, a manipulated picture that eliminates lighting produced by inefficient light fixtures and approaches, Figure 3.7 only shows a few light patches created by efficient LED lights. In reality, the inefficient light fixtures captured in 3.6 will be replaced by efficient outdoor lights, so that the manipulated picture 3.7 will never appear. Nevertheless, switching light bulbs on old fixtures is not efficient either, and may cause more energy waste. Mark S. Rea and John D. Bullough suggest a new measure of efficacy for lighting applications based upon both the lamp and the luminaire rather than, as is usually the case, lamp efficacy.[126] A simulation project at the RVH will retrofit its outdoor decorative lighting from 18-watt CFLs to energy-saving LEDs.

Fig 3.6 Digital Photography of Vancouver's Nightscape

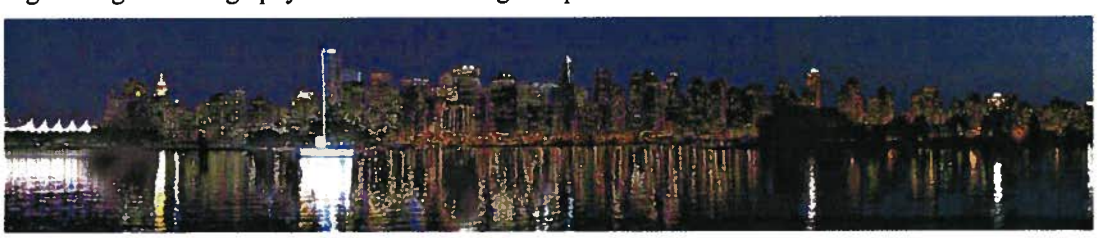

Fig 3.7 A Treated Picture without Inefficient Lighting

Aging people's needs

The average 55-year old needs twice as much light to see as well as a 25-year old. As we age, the thickening and yellowing of the eye's lenses decrease the amount of light

[126] Mark S. Rea and John D. Bullough, "Application Efficacy," Journal of the Illuminating Engineering Society Vol. 30 No. 2 Summer (2001): 73-96.

going into the eye. Further, the thickening lens scatters light within the eye, causing more glare for older eyes and a reduction in the contrast of the retinal image. As the population ages, demand for more light, good lighting, and coloured light will continue to increase.[127] Robert G. Davis and Antonio Garza find that elders prefer high luminance levels and coloured lights. They are more comfortable with a black background instead of a white one and also generally find non-uniform conditions to be favourable.[128] In 2005, another similar study showed that the most important variable for color discrimination and preference is illuminance.[129]

In Canada, the oldest of the baby boomers, the generation born from 1946 to 1965, have started to turn 60 years of age. More than 400,000 Canadian boomers, almost 1,100 a day, have had their 60th birthday since 2006.[130] One out of seven Vancouverites is 65 years or older. Almost 40 per cent of Vancouverites are 45 years or older. Because Vancouver has very short winter daylight periods, the city not only needs to provide enough city street lighting for aging people to see infrastructure, buildings, signs, and public areas in the city at nighttime, but also to provide a healthy, emotionally warm, and well-lit environment for its aging residents. Therefore, more lighting is required, and needs to be well-designed to prevent glare. As the population ages, demand for lighting will continue to increase.

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[127] Lighting for Tomorrow 2007 Year Book 4; Darcie A O'Connor, and Robert G Davis, "Lighting for the Elderly: The Effects of Light Source Spectrum and Illuminance on Color Discrimination and Preference," LEUKOS Vol. 2 No. 2 October (2005): 123-132.

[128] Robert G. Davis and Antonio Garza, "Task Lighting for the Elderly," Journal of the Illuminating Engineering Society Vol. 31 No. 2 Winter (2002): 25.

[129] O'Connor and Davis 123-132.

[130] Statistics Canada, "Canada's population by age and sex - as of July 1, 2006," The Daily Thursday, Oct. 26 (2006), 31March, 2008 <http://www.statcan.ca/Daily/English/061026/d061026b.htm>.

Tab 3.1 Age Characteristics of the Population in Vancouver and British Columbia by 2001 and 2006 Census[131]

| Age Characteristics of the Population | Vancouver, City | | | British Columbia | | |
|---|---|---|---|---|---|---|
| | 2001 | 2006 | 2001 to 2006 population change (%) | 2001 | 2006 | 2001 to 2006 population change (%) |
| Total - All persons | 545,670 | 578,040 | 5.9 | 3,907,740 | 4,113,485 | 5.3 |
| Age 45-64 | 128,040 | 148,920 | 16.3 | 979,455 | 1,169,270 | 19.4 |
| Age 65-84 | 60,965 | 65,420 | 7.3 | 473,055 | 523,755 | 10.7 |
| Age 85 and over | 9,370 | 10,570 | 12.8 | 60,030 | 76,045 | 26.7 |
| Age 45 and over | 198,375 | 224,910 | 13.4 | 1,512,540 | 1,769,070 | 17 |
| % of the population ages 45 and over | 36.4 | 38.9 | | 38.7 | 43 | |

SAD in British Columbia

Inappropriate lighting at the wrong moments can have a negative effect on our health, as does darkness. Lighting, including day lighting and night lighting has visual, biological, and emotional effects on human beings. Recent research in photobiology has revealed links between light and human health that are likely to have a significant effect on lighting practice. Scientific studies have found that maximum visual sensitivity lies in the yellow-green wavelength region, and the maximum biological sensitivity lies in the blue region of the spectrum.[132] It is widely considered that light therapy is an effective treatment for the clinical condition known as seasonal affective disorder (SAD). Vancouver has very limited daylight hours from October to March. About 3% of British Columbians, 120,000 people, suffer from clinical depression that usually traps patients into a "dark, miserable vortex" in the fall and clears on its own each spring. Dr. Raymond Lam, director of the Mood Disorders Clinic at UBC, emphasizes that the human biological clock is strongly affected by light, sleep, and activity. Light therapy has evolved over time into hand-held, cheaper, and energy-saving LED "Lite books" providing blue light, a spectrum of light found to be more therapeutically effective. For some, the strongest effect requires exposure to artificial bright light for an hour during the long winter. In addition, night time outdoor

[131] Statistics Canada

[132] Wont van Bommel, "Visual, Biological and Emotional Aspects of Lighting: Recent New Findings and their Meaning for Lighting Practice" LEUKOS Vol. 2 No. 1 July (2005): 9.

activities are encouraged.[133]

Tab 3.2 By Month, Vancouver's Sunlight Hours, Daylight Hours and Extreme Daily[134]

| Month | Total Hours | Days with measureable (hours) | % of possible daylight hours | Extreme Daily | Date (yyyy/dd) |
|---|---|---|---|---|---|
| Jan | 60.4 | 17.5 | 22.4 | 9.1 | 1996/30 |
| Feb | 84.6 | 19.2 | 29.6 | 10.5 | 1996/29 |
| Mar | 134.1 | 24.6 | 36.5 | 11.8 | 1998/28 |
| Apr | 182.4 | 26.6 | 44.4 | 14.1 | 1989/30 |
| May | 230.7 | 28.5 | 48.7 | 15 | 1993/24+ |
| Jun | 229.1 | 27.8 | 47.3 | 15.7 | 1989/23 |
| Jul | 294.5 | 29.3 | 60.2 | 15.4 | 1996/07 |
| Aug | 267.9 | 29.4 | 60 | 14.7 | 1987/02 |
| Sep | 199.1 | 27.5 | 52.5 | 13 | 1972/01 |
| Oct | 124.8 | 23.6 | 37.2 | 10.5 | 1971/16+ |
| Nov | 64.3 | 18.3 | 23.4 | 9.4 | 1995/01 |
| Dec | 56.1 | 16.1 | 21.8 | 8.1 | 1972/07 |

Vancouver's Enjoyability

From the annual reports of the Mercer Quality of Living Survey and The Economist's World's Most Livable Cities, Vancouver is announced as one of the most livable cities in the world. Promoting its livability and enhancing the social and environmental admiration of Vancouver's downtown by creating a livable, walkable, sustainable neighbourhood which contributes to the well being of residents and visitors is a priority. Beyond livability, inhabitants search for enjoyable areas in the city for fun and for outdoor/indoor activities. Vancouver is a relatively young city in the midst of urban development, so it may have unknown potential for more investment and enjoyability

[133] Society for Light Treatment and Biological Rhythms, 31 March 2008 official website: <http://www.websciences.org/sltbr/>.

[134] Environment Canada's World Wide Web Site, 31 March 2008 <http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=ALL&StationName=vancouver&SearchType=BeginsWith&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=889&>.

of leisure activity. Vancouver's nightscape needs to be organized in a more attractive, vibrant and energy-efficient way to celebrate its unique natural, social, and historical contexts. In the waterfront areas of the downtown core, enjoyability is not only what people want and appreciate, but also a characteristic of new urbanism and modernism. I call the night urban enjoyment as "Night Vancouverism."

3.3.6 Sports sustainability

Winter Olympic Games

2010 will be a very important year for Vancouver, because it will host 17 days of Olympic Games events from February 12th to 28th and 10 days of Paralympic Games Events from March 12th to 21st.[135] Vancouver is preparing to welcome the world and the world's best winter athletes in 2010 and ready to deliver spectacular Games when the world arrives.[136] Vancouver could learn from the previous host city of the 2006 Winter Olympic Games, Torino, Italy.

Torino opened its doors to athletes, journalists, and the public, showcasing its city's appearance to the whole world and welcoming 800,000 foreign tourists. Saturday, 11 February and Saturday, 26 February, 2006 were called "The White Nights".[137]

Hosting an international Game will bring Vancouver to the world stage. Not only the natural beauties of Vancouver and Whistler, but also its appearance and tourist resorts will become eye-catching locations for the world. Most of Vancouver's hospitality buildings are located in downtown area, especially, at the waterfront facing the Burrard Inlet. Because of Vancouver's short daytime hours during the Games, enriched nighttime activities and enjoyment for visitors and inhabitants, while achieving environmental sustainability, will be the challenge for Vancouverites preparing for and hosting the Games.

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[135] Vancouver's Olympic official Website, 31 March 2008 <http://www.vancouver2010.com/en>

[136] Vancouver Organizing Committee, Vancouver 2010 Progress Report, Presented to the International Olympic Committee 119th Session July 2007, Guatemala City: 2, 10 July 2008 <http://www.vancouver2010.com/resources/PDFs/IOCReport2007_EN.pdf>.

[137] Torino's official Olympic Website, 31 March 2008 <http://www.torino2006.org/>.

# Chapter 4:

# The First Transformative Lighting Strategy

4.1 Chosen Site - Renaissance Vancouver Hotel

The Renaissance Vancouver Hotel (RVH), is a 3-star hotel located in downtown Vancouver. It has 19 stories, includes 429 rooms and 8 suites, and is over 30 years old. The RVH's façades are composed of modern post-and-beam structure infilled with rectangular glazed windows and glazed balconies. In 1987, architect Bing Thom designed the exterior lighting for this building, then called the New World Hotel. The RVH has beige-coloured stucco wall finishing, while adjacent buildings are black. In order to make the hotel stand out from its black background at nighttime, the architect used outdoor decorative lighting to give the hotel a welcoming attitude and attractive qualities. According to the statement of Carl Corrigan, Director of the Engineering Department of the RVH, in summer the lighting operation runs from 9:30 pm to 1:00 am for a total of 3.5 hours in one night; in the winter, the operation runs from 4:30 pm to 1:00 am for a total of 8.5 hours in one night.

The RVH's outdoor decorative lights were changed recently from 60W incandescent lights to 18W CFLs giving out static warm yellowish light. The building currently has a static CFL lighting array of 194 18-watt bulbs on its façades and 120 18-watt bulbs on its circular top structure. There are 110 CFLs on the rear façade, and 84 CFLs on the front. This lighting array consumes approximately 12364 KW hours of energy per year at a cost of $556 per annum at B.C. Hydro's current commercial rate, 4.5¢ per KWH, which is lower than most electricity rates in Canada and the United States.[138] This 18W outdoor CFL bulb with a capsule-style shape is ideal for use in weather-protected outdoor fixtures.[139] Strictly speaking, the building façades and the rooftop of the RVH are not qualified as weather-protected because the light bulbs are exposed. These conditions will shorten CFLs useful lifetime considerably. Photocells and timers have been used to control this outdoor decorative lighting. The whole outdoor lighting has

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[138] Calculation by author based on data from the RVH's engineering department.

[139] Product specification of Philips Marathon's 18W outdoor CFL bulb, refer to appendix I.

no festival function and no colour or pattern change at different times. The electricity costs for the entire hotel operation are $20,000 per month. The RVH is willing to take more energy-saving actions in a doable and sustainable matter.[140]

The RVH director provided information on the existing exterior lighting, the lighting control system, environmental concerns, and future plans. This information was then incorporated into AutoCAD drawings for illustrative and project design purposes. Through site surveys and Google Maps of the RVH, I have found that its flat rooftop can be adapted for photovoltaic cell panels to produce electricity because the rectangular rooftop gets very little shade on a yearly basis and so the panels would cause the lowest degree of disruption. Because I will be working with three transformative lighting strategies, the RVH will provide a platform for the discussion of the feasibility of those strategies and the range of electricity reduction achievements proposed.

## 4.2 Lighting Transformation Case Study

### 4.2.1 The Shaw Tower

In my chosen waterfront site, the architecture with the most "stunning"[141] and energy-efficient LED lighting is the Shaw Tower, a 40-storey office/condominium tower developed by Westbank Projects Corp. It is one of the tallest buildings in Vancouver, located in the Coal Harbour district of downtown. The building, completed near the end of 2004, incorporates amenities such as a fitness centre, daycare, and 5 levels of underground parking with separate entrances for Shaw company employees, the

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[140] Date from Mr. Carl Corrigan, Director of the Engineering Department of the RVH.

[141] Trevor Boddy, a local architecture critic, issued his seal of approval in the spring of 2005, calling the Shaw Tower "stunning," cited from "Lighting Vancouver's Newest Landmark," The Globe & Mail – July 15 (2005), 31 March 2008 <http://www.jeffmacintyre.com/archives/2005/07/diana_thater_globe_mail.htm>.

residential units, and public areas of the building.[142] The building incorporates an automation control system for mechanical equipment as well as lighting systems, as designed by Nemetz (S/A) & Associates Ltd.[143] The outstanding night illumination of the Shaw Tower, a LED light-tube art installation extending along the entire height of the building, was designed by Los Angeles-based artist Diane Thater.[144] Her artistic works and lighting-featured architecture have been showcased around the world, but the Shaw Tower is her first public art work.[145]

The LED lighting of the Shaw Tower is a flagship design, a pathbreaker for the whole urban nightscape in Vancouver's downtown waterfront core. The lights are computer programmed to dissolve into a seamless spectrum – green to cyan to blue – up the face of the building, to the rooftop, which is crowned by a beacon of moonlight blue.[146] The innovative technology, 4896 LED lamps, called Destiny DL,[147] requiring only 8 kilowatts of power, is provided by Vancouver-based TIR Systems. There are 12 lamps per foot: 4 red, 4 green, and 4 blue. Via mixing intensities of the red, green, and blue (RGB) spectrum, 1.6 million colours can be available for any artistic creation.[148]

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[142] "Shaw Tower," Westbank official website, 31 March 2008 <http://www.westbankcorp.com/mixed.cfm?projectid=19>.

[143] "Shaw Tower," Project Files, Bridge Electric Corp. official website, 31 March 2008<http://www.bridgeelectric.com/projects_feature.php>; "Shaw Tower," Mixed Use Projects, Nemetz (S/A) & Associates Ltd. 31 March 2008 <http://www.nemetz.com/mixed_use.htm>.

[144] Diane Thater was born in 1962, in San Francisco, California, U.S.A., and now living and working in Los Angeles.

[145] Wikipedia, "Diana Thater," 31 March 2008 <http://en.wikipedia.org/wiki/Diana_Thater>.

[146] Ian Chodikoff, "A Full Deck," Canadian Architect Aug. (2006), 31 March 2008 <http://www.canadianarchitect.com/issues/ISarticle.asp?id=177935&story_id=164652120909&issue=08012006&PC=>.

[147] TIR Systems' Destiny DL, 31 March 2008 <http://www.tirsys.com/products/architectural/destiny-dl.htm>; "Destiny DL" Philps Sense and Simplicity (Philips Lighting), 10 July 2008 <http://www.lightpipe.com/products/architectural/destiny-dl.htm>.

[148] "Lighting Vancouver's Newest Landmark," The Globe & Mail – Seven – July 15 (2005), 31 March 2008 <http://www.jeffmacintyre.com/archives/2005/07/diana_thater_globe_mail.htm>.

Studying the chosen site and Shaw Tower's successful outdoor lighting applications in Vancouver's urban context and lighting design theories have helped me to formulate my transformative project in LED lighting design for Vancouver's waterfront.

Fig 4.1 The Shaw Tower's Night Lighting

4.2.2 Canada Place

Located on the waterfront of the Burrard Inlet, Canada Place is one of the most interesting and unique architectural landmarks in Vancouver. Canada Place Corporation has reduced by 40 percent the electricity consumption of its outdoor lighting (compared with the electricity for lighting designed in the 1990s) by introducing high performance colour-changing LEDs with help from Illumivision Inc., based in Edmonton, Alberta. Its featured products, called illumivision LED Light Wave LX, have been specially embedded in glass balls. These glass balls have been titted with stinging hair to discourage seagulls. The LED lights of the iconic sails use merely a little more power than two hairdryers. This symbolic lighting gesture, combined with its energy conservation, will support and encourage energy conservation. The interesting thing is that the lighting designer of Canada Place is the Canada Place Corporation,[149] because normally a professional designer will be hired for such a project.

Fig 4.2 Canada Place's Night Lighting, adapted by author (left 2) and including published images (right 3)[150]

4.3 The First Transformative Lighting Strategy

4.3.1 Introduction

The decorative arrangement of existing lighting on the top round structure, front façade, and rear façade of the RVH was designed by Vancouver's Bing Tom architecture firm in 1987. Recently, 18-watt outdoor CFLs have replaced the former 60 watt incandescent light bulbs for increased energy efficiency and reduced maintenance

[149] "Canada Place," Illumivision (Edmonton: Illumivision Inc.), 31March 2008 <http://www.illumivision.com/showcase/Canada_Place>.

[150] "Canada Place," (Illumivision Inc.) n.pag.

costs. This study provides a further means of reducing energy and maintenance costs through the replacement of the current CFL lighting system with updated LED light products providing either singular warm white light or RGB-mixed white light. The RGB-mixed LEDs can provide both white colour, with full intensities of all coloured LED chips, and different colours. In this chapter, I adopt the former condition, RGB-mixed LEDs to provide white colour, for energy calculation purposes.


Fig 4.3 The RVH's Night Lighting Fixtures and Effects

### 4.3.2 LED Lighting Product Selection

What kinds of LEDs should be chosen for the RVH's building illumination? Basically, the effects of the colour of the lighting, and the appearance of the fixtures, impacts on surroundings, and energy usage should be taken into consideration. [151] In this research, the selected lights are technically-proven, market-ready, and branded products. CFLs branded "Marathon" and LEDs branded "Philips Color Kinetics" and "LightWild" will be used for standardization purposes of this study. Marathon in Mexico and Philips Color Kinetics in the USA are both under the umbrella of Philips Lighting, an internationally-known electrical company with its lighting products sold and readily available throughout the world. LightWild is an Overland Park, Kansas manufacturer producing software-controlled solid-state LED products for the architectural lighting market. The local exclusive BC distributor and representative of Philips Color Kinetics and LightWild is CDM2lightworks, a full service lighting company

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[151] The Chartered Institution of Building Services Engineers (CIBSE), "Environmental Considerations for Exterior Lighting." Factfiles, Society of Light & Lighting. No.7 Nov.(1998, updated 2003) 1-2, 31 March 2008 <http://www.cibse.org/pdfs/fact72003.pdf>.

based in Vancouver. The following calculations are based on the lighting manufacturer's specifications of the chosen lights and the expert knowledge of a local exclusive supplier.[152]

### 4.3.3 Retrofit of Lighting on the Rooftop of the RVH

This structure sitting atop the Renaissance Vancouver Hotel (RVH) is a round, glass-sided architectural crown functioning as a restaurant and bar that offers panoramic views of Vancouver's downtown waterfront. The diameter of this crown is about 1050 feet and the perimeter is about 3,300 inches. The length of each LED string is about 200 inches, so via calculation and adjustment, replacing the existing 18-watt CFLs will require 16 strands of linear LEDs. Table 4.1 lists basic features of existing CFLs, proposed white LEDs, and proposed RGB-mixed LEDs.

Tab 4.1 Comparison of Features of the CFLs and LEDs on the Rooftop

| Lights | Name | Quantity | Unit price ($) | Electricity (KWH) | Lifespan (Hours) |
|---|---|---|---|---|---|
| Existing Yellowish CFLs | 18W CFLs | 120 | 12 | 0.018 | 10,000** |
| Proposed WarmWhite LEDs | eW Flex SLX | 16 | 750 | 0.050* | 50,000*** |
| Proposed RGB-mixed LEDs | iColor Flex SLX | 16 | 550 | 0.050* | 30,000*** |

* : Maximum Power Consumption, which means all LEDs composed of LED lamps are lit up in full intensity.

**: The lifespan of outdoor 18-watt CFLs is based on product specifications in the market.

***: Philips Color Kinetics rates product lifetimes using lumen depreciation to 50% of original light output. When the LED manufacturers' test data in terms of the lifetime it is in a range, the calculation of this research is taken at the lowest one.

152 Kris Chemenkoff from Bernard & Associates.

Fig 4.4 Proposed LED lights: eW Flex SLX and iColor Flex SLX from Philips Color Kinetics

From the table above, among all three lights, CFLs have the shortest lifespan with the cheapest cost, but more light bulbs would be needed to achieve the decorative lighting effect on top of the RVH. White LEDs are the most expensive light product with the longest lifespan. RGB-mixed LEDs are the intermediate products in price and lifespan. There are 120 CFL bulbs installed on the rooftop circular wall. According to the LED lighting retrofit proposal, the total LED cost would be $12,000 ($750X16=$12,000) on white LED strands or $8,800 ($550x16=$8,800) on RGB-mixed LED strands. At each unit length of every CFL, white LED strands cost $100, while coloured LED strands cost $73.33. We see CFLs are more competitive than LEDs only from the unit cost column in Table 4.1. However, white LEDs will last 5 times longer than CFLs, and RGB-mixed LEDs will last 3 times as long. When LEDs' prices of each length unit are divided by 5 or 3 (times of CFL lifetime), a white LED strand only costs $20 and an RGB-mixed LED strand costs $ 24.45 compared to each unit length of every CFL in their first 10,000 hours, which is a CFL lifetime. From this analysis and calculation, we can see that white LEDs at each unit length of every CFL cost only $8 more than every CFL for the same time period of a CFL lifetime. However, if we use a white LED lamp lifetime, 50,000 hours to calculate, CFLs will need replacement 4 times while a white LED lamp will not need it at all. Table 3.2 compares CFLs with LEDs in both electricity and total cost. The maintenance cost of CFLs has been calculated and demonstrated since the long lifetime of LED lights is critical to their applications to building illumination.

4.3.4 Total Cost of Lighting on the Rooftop of the RVH

The total cost of lights is the total amount of product cost, electricity cost, and maintenance cost. In 50,000 hours, if using 18-watt outdoor CFLs, without any incident damage, ideally and theoretically, and with these light bulbs lasting 10,000 hours, the cost will be 5 times that of the initial product purchase. Because lights on the rooftop of the RVH can be easily changed, the replacement for each light bulb will cost $7.[153] At present, B.C.Hydro's electricity rate for a commercial building is 4.5 ¢ per KWH although B.C. Hydro has announced that the electricity rate will be raised 25 per cent in 3 years. LEDs with a 50,000 hour lifetime do not need replacement until the end of their life span. In the same manner, RGB-mixed LEDs with a 30,000 hour lifetime will need replacement at a rate of 5/3.

Due to the complexity of electrical products and utilization, all electrical lights need preliminary and regular maintenance on a daily or weekly basis. There are so many uncertain factors impacting the maintenance costs that this research has adopted the maintenance cost on the basis of replacing all lights when they have run their ideal lifetime, as claimed by manufacturers. Eighteen-watt outdoor CFLs need 4 replacements to reach the 50,000 hour calculation time. White LEDs do not need replacement to reach 50,000 hours because of their long lifetime. In the same manner, coloured LEDs need one replacement to last another 30,000 hours; for 50,000 hours, the replacement cost is 2/3 of one full cost. The cost of replacing existing CFLs in 50,000 hours will be higher than the cost of RGB-mixed LEDs and white LEDs. The total cost of RGB-mixed LEDs over 50,000 hours is the highest one followed by that of CFLs' cost, and then that of white LEDs, while the existing CFLs arrangement consumes the largest amount of electricity, 108,000 KWH in 50,000 hours.

[153] estimate by a local supplier, Kris Chemenkoff from Bernard & Associates.

Tab 4.2 Electricity Consumption and Total Cost of the CFLs and LEDs on the Rooftop

| Name | Product Cost ($) | Electricity Consumption (KWH) | Electricity Cost* ($) | Maintenance Cost($)** | Total Cost ($) |
|---|---|---|---|---|---|
| 18W CFLs | 1440x5=7200 | 108000 | 4860 | 840x4=3360 | 15420 |
| eW Flex SLX | 12000 | 40000 | 1800 | 0 | 13800 |
| iColor Flex SLX | 8800x5/3=14667 | 40000 | 1800 | 112x2/3=75 | 16542 |

Note: Electricity consumption and electricity cost are for 80,000 hours.

*: At 4.5¢ per KWH of B.C. Hydro current commercial rate

**: Maintenance cost: Replacing a lamp at $7.00/bulb, replacing 120 CFLs costs $840 and replacing 16 LED strands costs $112

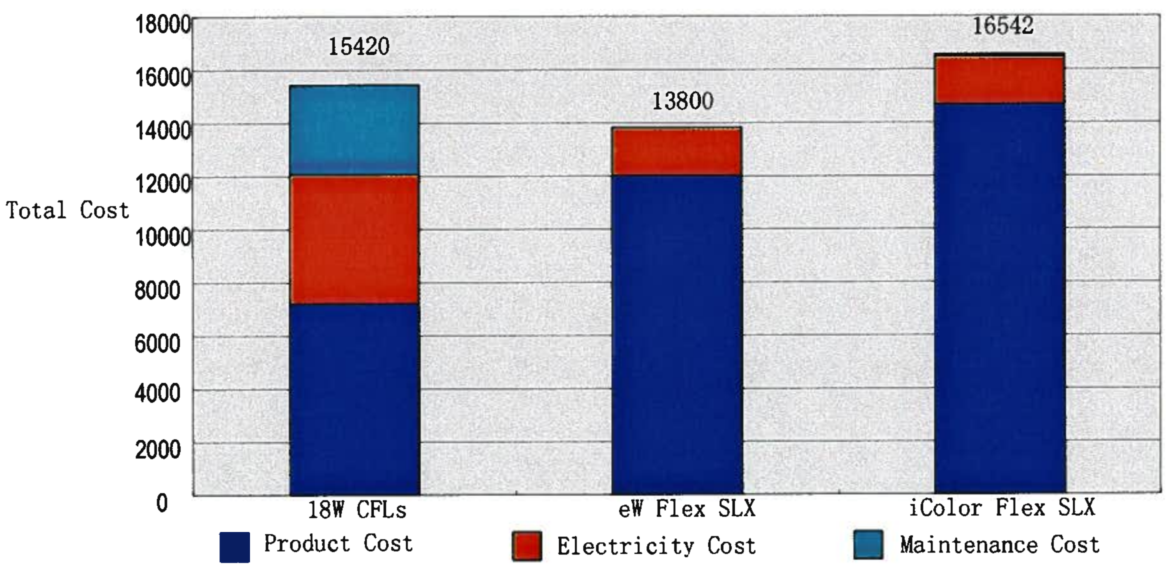



Fig 4.5 The Total Cost of the CFLs and LEDs on the Rooftop

### 4.3.5 Retrofit of Lighting on the Façades of the RVH

The experimental design of the RVH is to retrofit the existing 18-watt CFLs with the proposed white LEDs and RGB-mixed LEDs in each mounting point of the existing lighting array. Table 3.3 lists basic features of existing CFLs, and the proposed white and RGB-mixed LEDs, LW-UP-18-1C and LW-UP-19-1C from LightWild.

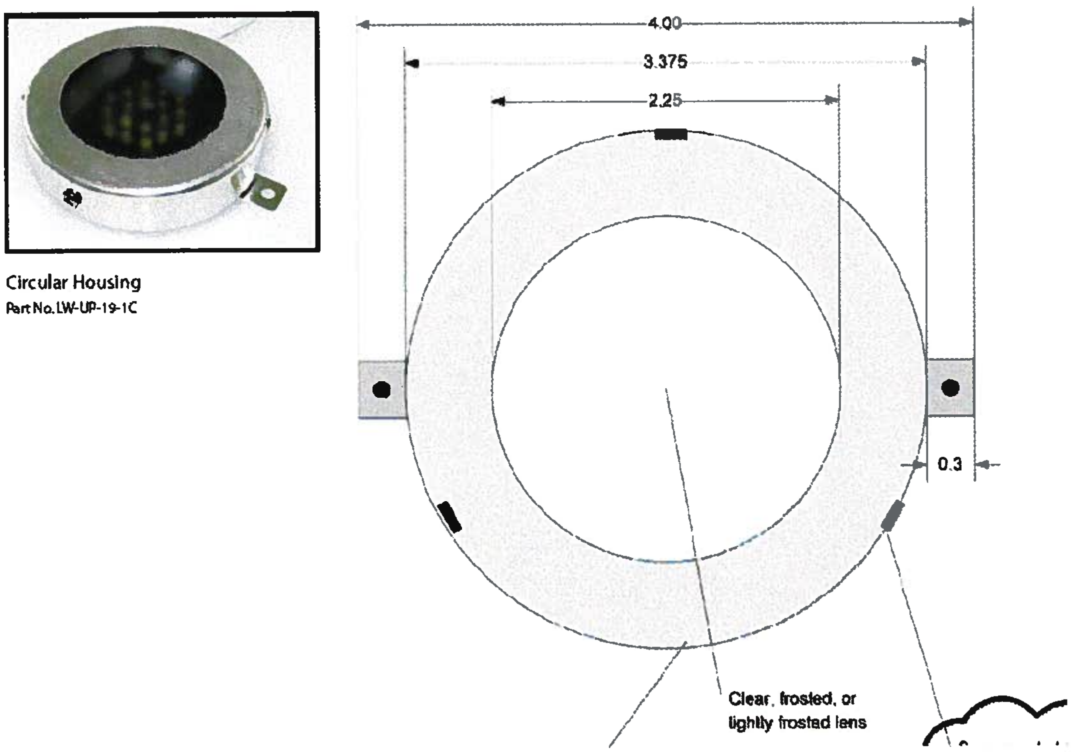



Fig 4.6 Proposed LED lights: LW-UP-18-1C and LW-UP-19-1C, adopted from LightWild

Tab 4.3 Comparison of Features of the CFLs and LEDs on the Façades of the RVH

| Lights | Name | Quantity Rear/front | Unit Price ($) | Electricity (KWH) | Lifespan (Hours) |
|---|---|---|---|---|---|
| Existing Yellowish CFLs | 18WCFLs | 110/84 | 12 | 0.018 | 10,000** |
| Proposed WarmWhite LEDs | LW-UP-18-1C | 110/84 | 105 | 0.002* | 50,000*** |
| Proposed RGB-mixed LEDs | LW-UP-19-1C | 110/84 | 105 | 0.002* | 50,000*** |

* : Maximum Power Consumption, which means all LEDs composed of the LED lamp are lit up.

**: The lifespan of outdoor 18-watt CFLs is based on product specifications in the market, see Appendix I.

***: LightWild rates product lifetimes using lumen depreciation to 50% of original light output. When the LED manufacturers' test data in terms of the lifetime it is in a range, the calculation of this research is taken at the lowest one.

From the table above, among all three lights, CFLs have the shortest lifespan and the cheapest cost. The warm white and RGB-mixed LEDs from LightWild are more expensive but also more durable. The following compares CFLs with LEDs in both electricity consumption and total cost. The calculation time of 50,000 hours conforms to the life time of chosen LEDs.

4.3.6 Total Cost of Lighting on the Façades of the RVH

The total cost of lights on the building façades of the RVH in 50,000 hours, if using 18 watt outdoor CFLs, without any incident damage, ideally and theoretically, with light bulbs that last 10,000 hours, is $52,137, including the costs of four replacements, 50,000 hour electricity consumption, and a total of 5 product purchases. Because lights on the RVH's façades cannot be easily changed, the replacement of lights will require a crew of two for 2 3 days with special equipment to replace the 110 CFL lights on the rear façade and the 84 CFL lights on the front façade. One time replacement of all 194 CFL lights will cost $8,160 over the CFLs' lifetime, equivalent to 10,000 hours, which means more than 4.5 years at current operation time of the RVH's night lighting, 2,196 hours per year. Theoritically, over their 50,000 hour lifetime, LEDs will not incur maintenance costs. An assumption of this research is that the general electrical maintenance for CFLs and LEDs is equal (even though CFLs require more maintenance), so general maintenance will not count in the cost comparison. Actually, the cost of replacement in 10,000 hours, $8,160, is very low, if we consider the replacement will only happen every 4.5 years.

Tab 4.4 Electricity Consumption and Total Cost of the CFLs and LEDs on the RVH's Façades

| Name | Product Cost ($) | Electricity Consumption (KWH) | Electricity Cost* ($) | Maintenance Cost($)** | Total Cost ($) |
|---|---|---|---|---|---|
| Electricity Consumption and Total Cost of the CFLs and LEDs on the Rear Façade | | | | | |
| 18WCFLs | 1320x5=6600 | 99000 | 4455 | 4080x4=16320 | 27375 |
| LW-UP-19-1C (WarmWhite) | 11550 | 11000 | 495 | 0 | 12045 |
| LW-UP-19-1C (RGB) | 11550 | 11000 | 495 | 0 | 12045 |
| Electricity Consumption and Total Cost of the CFLs and LEDs on the Front Façade | | | | | |
| 18WCFLs | 1008x5=5040 | 75600 | 3402 | 4080x4=16320 | 24762 |
| LW-UP-19-1C (WarmWhite) | 8820 | 8400 | 378 | 0 | 9198 |
| LW-UP-19-1C (RGB) | 8820 | 8400 | 378 | 0 | 9198 |

Note: Electricity consumption and electricity cost are for 50,000 hours.

*: At 4.5¢ per KWH of B.C. Hydro's current rate

**: Maintenance cost: the estimated time of replacing light fixtures on a façade of the RVH is 24 hours and two electricians. An electrician costs at approximately $35.00/hour. The labour cost of replacement is equal to 2x35x24=$1680. Miscellaneous equipment rental is about $800.00/day; therefore, the equipment rental of replacing light fixtures on a façade of the RVH costs $2,400.00 (Equipment rental day based on 8 hours)

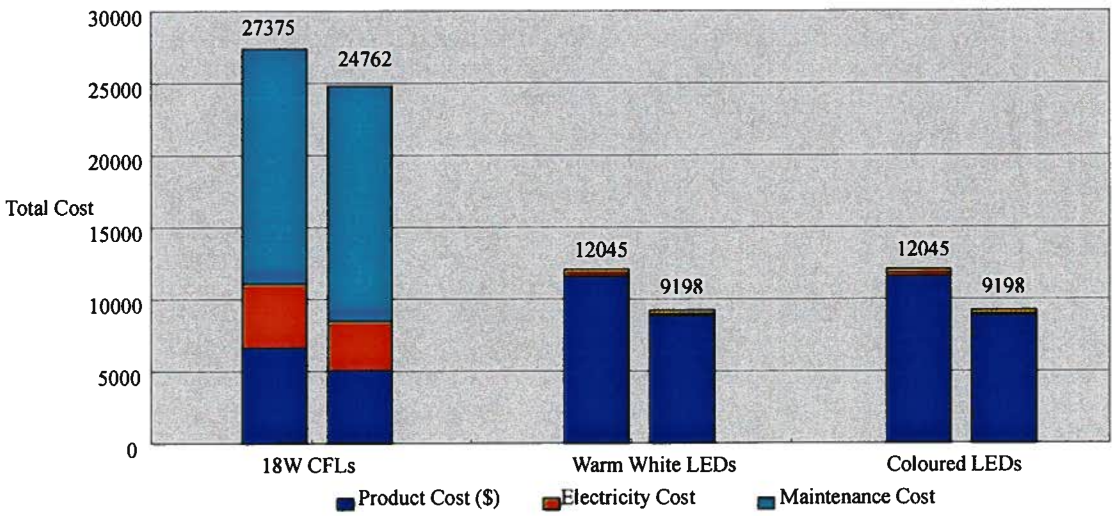



Fig 4.7 The Total Cost of the CFLs and LEDs on the Façades

The average replacement cost every year is about $1,800, which is $8,160 divided by 4.5 years. The amount is much lower than the one-month salary for hiring an electrician would be. However, in the long run, 50,000 hours, LEDs do not need replacement, but CFLs need replacement 4 times on the building façade, which make CFLs' maintenance cost $32,640, 63 per cent of CFLs' total cost.

The total cost of existing CFLs for 50,000 operating hours is the highest, 2.5 times of the total cost of proposed LEDs. The electricity consumption of existing CFLs in 50,000 operation hours is 174,600 KWH, 9 times the electricity consumption of proposed LEDs.

Tab 4.5 Electricity Consumption and Total Cost of the CFLs and LEDs on the RVH's Façades

| Name | Electricity Consumption (KWH) | Total Cost ($) |
|---|---|---|
| 18WCFLs | 174600 | 52137 |
| LW-UP-19-1C(WarmWhite) | 19400 | 21243 |
| LW-UP-19-1C(RGB) | 19400 | 21243 |

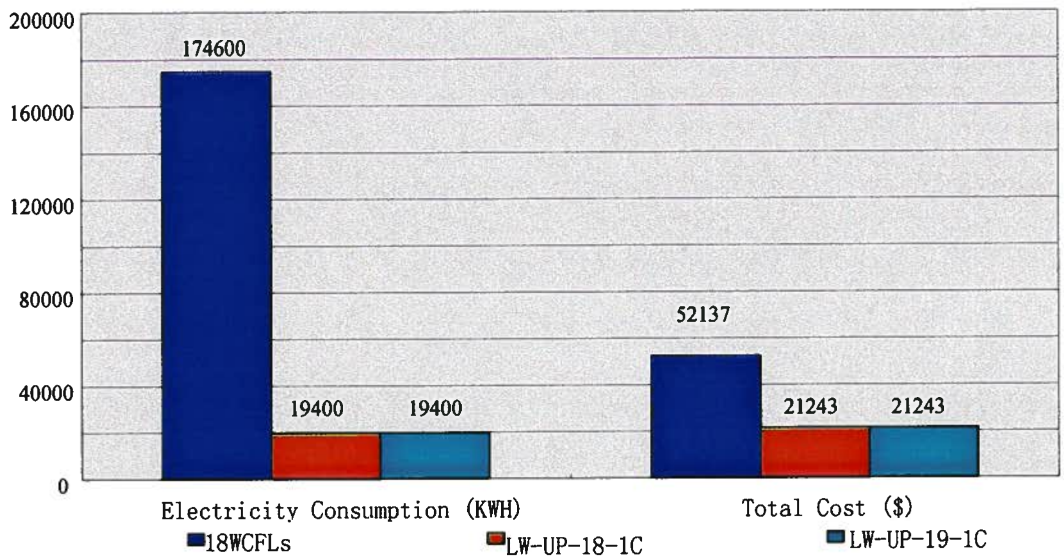



Fig 4.8 The Electricity Consumption and Total Cost of the CFLs and LEDs on the Façades

## 4.4 Conclusion

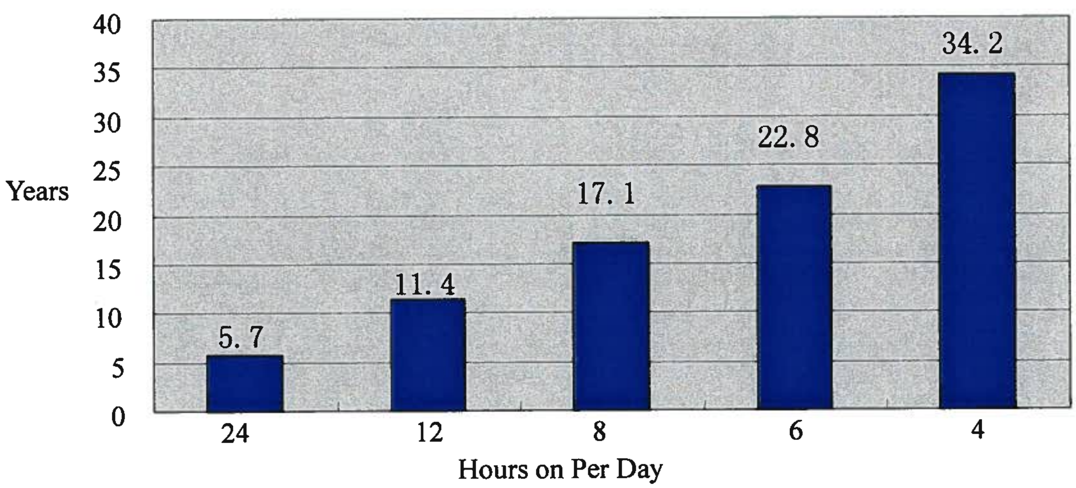



Fig 4.9 What 50,000 Hours Means in Practical Terms

Most LED lights can provide at least 50,000 hours of useful lifetime before they gradually degrade below 70% of their initial light output. This lifetime exceeds that of most conventional lamps. As shown in Figure 4.9, LEDs can last two decades, operating 6 hours per day, which is almost equal to the average operation time of the RVH's building illumination.

In 50,000 hours, retrofit from 18W CFLs to white LEDs on the top and façades of the RVH will save $32,514 on the total amount of light fixtures, electricity costs and maintenance costs, which is 48 per cent of CFLs' total cost. Furthermore, changing CFL electricity-saving bulbs to LEDs will save at least 223,200 KW over 50,000 hours, which is equivalent to more than 79 per cent of the CFLs' electricity consumption.

Tab 4.6 Electricity Consumption and Total Cost of the CFLs and LEDs on the Top and Façades

| Lighting arrangement | Electricity Consumption (KWH) | Total Cost ($) |
|---|---|---|
| Existing Yellowish CFLs | 282600 | 67557 |
| Proposed WarmWhite LEDs | 59400 | 35043 |
| Proposed RGB-mixed LEDs | 59400 | 37785 |

Note: Electricity and total cost are for 50,000 hours.

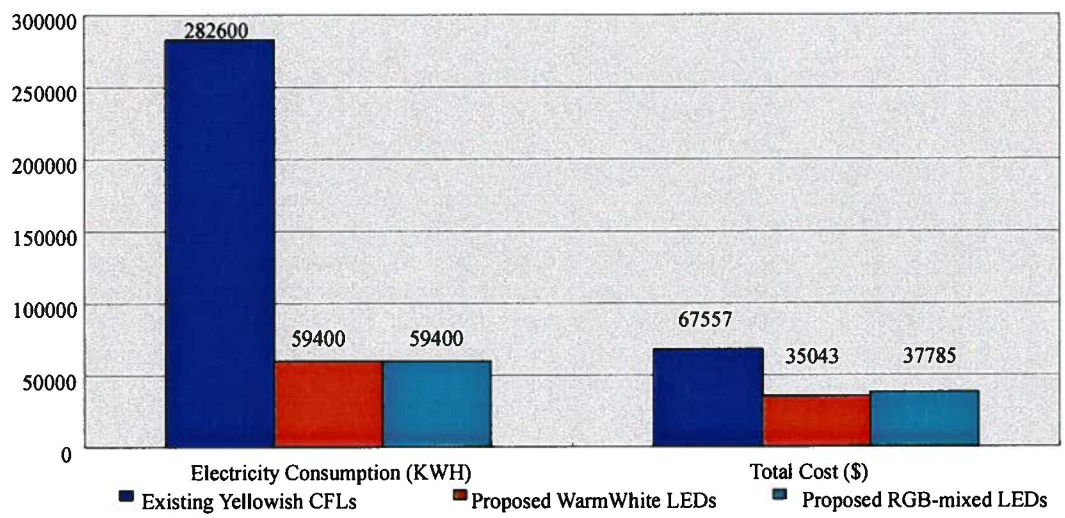



Fig 4.10 The Electricity Consumption and Total Cost of the CFLs and LEDs on the Façades and Rooftop

Superficially, based on unit prices of LED lamps and CFLs, LED products appear very expensive. Nowadays, consumers have expressed their reservations about purchasing LEDs because of their high prices. Since LED lights cannot be purchased from the general lighting market now, most of their unit prices are not clear to end users. Table 4.7 lists features of three similar RGB LED fixtures. Two prices are from companies in North America, and another price is from Zhongshan Margin Lighting Co., Ltd. in China. The price of the Lightwild Pixel LW-UP-19-1C is $105 and is 48 times higher than the price of the LED lamp of the Margin Lighting, $2.13,[154] and $33.75 more than the price at SailorSams Company. However, Lightwild Pixel's price is for the whole fixture, including the 120 VAC adapter. It seems that price difference comes from manufacturer countries, brand products, and selling methods.

Fig 4.11 Lightwild Pixel LW-UP-19-1C

It is understandable that each product's price consists of advertisement, product cost, import duties, transportation expenses, manpower, and commercial profit. In this present-day lighting industry of LED lighting, Cree[155] and Osram[156] are leading manufacturers in producing and inventing high-end and high-efficiency LED chips and modules, and their products are sold in the international market. Consequently, local and international manufacturers are designing their light fixtures and assemble/customize LED chips to make different LED lamps for marketing. CREE has

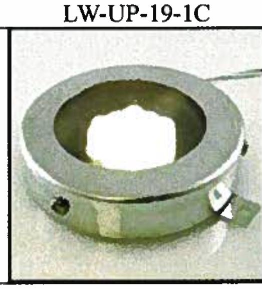
[154] Data provided by Joe from Zhongshan Margin Lighting Co., Ltd.

[155] Cree Inc. is a Durham, North Carolina based, American corporation which manufactures semiconductor materials and devices. It was formed in 1987, 31 March, 2008 <http://www.cree.com/>.

[156] Osram is one of the two largest lighting manufacturers in the world, founded in year 1906. This international company, with its headquarters in Munich, Germany, 31 March, 2008 <http://www.osram.com/>.

retrofitted its indoor and outdoor workplace to LED lamps and all LED light fixtures have been provided by other light fixture manufacturers, even when they use CREE LED chips or modules.[157] LED lighting is a new industry, so there is potential for its businesses and products to develop. Therefore, before 2012, when the government bans inefficient lighting in Canada, local manufacturers need to be ready to supply local LED lighting markets and applications, which can be considered as one aspect of sustainable development in terms of reducing transportation and developing local products.

Tab 4.7 Comparison of Prices of Warm-white LED Light Fixture

| Company Name | Lightwild | Zhongshan Margin Lighting Co., Ltd. | SailorSams |
|---|---|---|---|
| LED Name | Lightwild Pixel LW-UP-19-1C | N/A | IMT-ILE26-90LED120V |
| Pictures |  |  |  |
| Location | Outdoor/Indoor | Outdoor/Indoor | Outdoor/Indoor |
| LEDs form | 19 LEDs, 7 red, 6 blue, 6 green | 20LEDs with cover | Warm White/7 red, 6 blue, 6 green |
| Power requirement | 24VDC | 230V AC or 12VDC | 120 VAC |
| Max. Power consumption | 2 watts | 1.8 watts | 9 watts |
| Temperature Range | -25℃ to +65℃ | -35℃ to +60℃ | |
| Dimension | Lens 2.25" | Diameter: 50MM | Lens 2.75 |
| Lifetime | 50,000 to 80,000 hours | 50,000 hours | 50,000 hours |
| **Price** | **$ 105** | **$2.13** | **$ 71.25** |
| Installation | Mounting beads | E27, MR16, E14, or GU10 | E27 |
| Website | www.lightwild.com | www.marginlight.com | www.sailorsams.com |
| Contact info. | 7320 W 162nd St. Overland Park, KS 66085 | Caoer Xinxing Avenue, Guzhen Town, Zhongsha City, Guangdong, China | 7832 Kavanagh Ct Sarasota, FL 34240 |

[157] Date from Cree's Ledworkplace website, 31 March 2008 <http://www.ledworkplace.org/>.

# Chapter 5:

# The Second Transformative Lighting Strategy

## 5.1 Introduction

My first transformative lighting strategy, using LEDs to retrofit CFLs of the RVH's building illumination, achieved 79 per cent in electricity savings and 48 per cent of monetary savings, according to my calculations. My second transformative lighting strategy optimizes the yearly programming of the LED building illumination on the RVH in accordance with seasonal or annual themes, in order to save more energy, demonstrate architectural creativity via versatile LED lighting patterns, and to manage systematically the unstable generation of renewable energy.

Of the 52 weeks of the year I set weekday nights from Monday to Thursday and weekend nights from Friday to Sunday, or a total of 208 weekday nights and 156 weekend nights. Since the RVH is in the hospitality industry, its operational time is 7-days a week and 24-hours a day. Consequently, the hospitality business seeks to attract more customers to spend holidays and weekends on its premises in the interest of financial feasibility. The RVH can strengthen its identity and attraction through its outdoor, vibrant holiday night lighting. In addition, every year, Vancouver hosts some special festivals and events to facilitate its tourist industry. Those nights occurring during the period of festivals and events will be occasions for applying festive nocturnal illumination.

For instance, in 2008, and with special consideration for the RVH, there will be in my estimation 64 weekday nights, 45 weekend nights and 12 festival and event nights in the 4 months of winter; there will be 67 weekday nights, 43 weekend nights and 12 festival and event nights in the 4 months of spring-fall; and there will be 66 weekday nights, 48 weekend nights and 9 festival and event nights in the 4 months of summer. The operating time for every summer night will be 3.5 hours, and for every winter night, 8.5 hours based on the RVH's current operating hours; the operating time for every spring-fall night will be 6 hours, an average of the summer and winter operating hours.

Tab 5.1 2008: Seasonal Time Frequency Table

| | Month | Hours in operation | Weekday nights | Weekend nights | Festival and event night | RVH's event nights | Days |
|---|---|---|---|---|---|---|---|
| Winter | Jan | 8.5 hours | 18 | 11 | 1 | 1 | 31 |
| | Feb | | 15 | 12 | 1 | 1 | 29 |
| | Nov | | 15 | 13 | 1 | 1 | 30 |
| | Dec | | 16 | 9 | 4 | 2 | 31 |
| Spring-Fall | Mar | 6 hours | 16 | 11 | 3 | 1 | 31 |
| | Apr | | 17 | 10 | 1 | 2 | 30 |
| | Sep | | 17 | 11 | 1 | 1 | 30 |
| | Oct | | 17 | 11 | 2 | 1 | 31 |
| Summer | May | 3.5 hours | 16 | 13 | 1 | 1 | 31 |
| | Jun | | 17 | 11 | | 2 | 30 |
| | Jul | | 18 | 11 | 1 | 1 | 31 |
| | Aug | | 15 | 13 | 1 | 2 | 31 |
| | Total | | **197** | **136** | **17** | **16** | **366** |
| | | | 64 / 67 / 66 | 45 / 43 / 48 | 7 / 7 / 3 | 5 / 5 / 6 | |

## 5.2 The Second Transformative Lighting Strategy

### 5.2.1 LEDs' Maximum Electricity Consumption

The experimental LED lighting design of the RVH's building illumination adopts Lightwild's Pixel LW-UP-19-1C on the building façades and Philips Color Kinetics' iColor Flex SLX on the rooftop. According to the manufacture's specifications, the maximum power consumption of these two LED lights is 2 watts and 50 watts respectively.

Maximum power consumption for each summer night is:

(2W x 110+ 2W x 84 + 50W x 16) x 3.5H/1000 = 4.158 KWH

Maximum power consumption for each spring-fall night is:

(2W x 110+ 2W x 84 + 50W x 16) x 6H/1000 = 7.128 KWH

Maximum power consumption for each winter night is:

(2W x 110+ 2W x 84 + 50W x 16) x 8.5H/1000 = 10.098 KWH

5.2.2 LEDs' Electricity Consumption on Weekend Nights

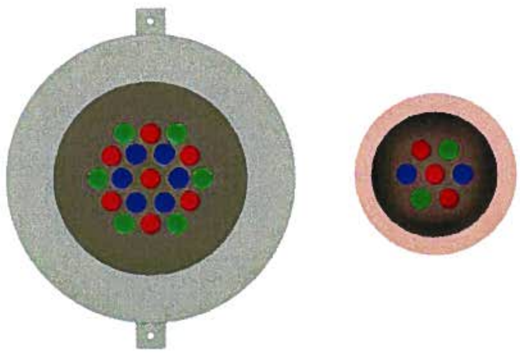


Fig 5.1 The LED Forms of Lightwild Pixel LW-UP-19-1C and Philips Color Kinetics' iColor Flex SLX

Lightwild's Pixel LW-UP-19-1C and Philips Color Kinetics' iColor Flex SLX are composed of red, green, and blue LED chips. Almost every colour consumes 1/3 of the electricity at maximum power. On weekend nights, the LED lighting program mainly adopts colour changes from the blue to green spectrum. Even when homochromatic LEDs are at full intensity, the electricity consumption is only 1/3 of maximum power consumption:

1/3 of maximum power consumption for each summer night is:
1/3 x 4.158 KWH = 1.386 KWH
1/3 of maximum power consumption for each spring-fall night is:
1/3 x 7.128KWH = 2.376 KWH
1/3 of maximum power consumption for each winter night is:
1/3 x 10.098KWH = 3.366 KWH

5.2.3 LEDs' Electricity Consumption on Weekday Nights:

In my experimental design, a dimming pattern on weekday nights has been adopted to save energy consumption without ever reducing the whole illumination effect. The electricity consumption on weekday nights is 72.4 per cent of the electricity consumption of weekend nights.

Tab 5.2 The Percentage of Dimmed Illuminance on RVH's Rear Building Façade

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.80 | 0.85 | 0.9 | 0.9 | 0.95 | 1 | 1 | 1 |
| 2 | 0.80 | 0.80 | 0.85 | 0.9 | 0.9 | 0.95 | 1 | 1 |
| 3 | 0.75 | 0.80 | 0.80 | 0.85 | 0.9 | 0.9 | 0.95 | 1 |
| 4 | 0.70 | 0.75 | 0.80 | 0.80 | 0.85 | 0.9 | 0.9 | 0.95 |
| 5 | 0.70 | 0.70 | 0.75 | 0.80 | 0.80 | 0.85 | 0.9 | 0.9 |
| 6 | 0.65 | 0.70 | 0.70 | 0.75 | 0.80 | 0.80 | 0.85 | 0.9 |
| 7 | 0.60 | 0.65 | 0.70 | 0.70 | 0.75 | 0.80 | 0.80 | 0.85 |
| 8 | 0.60 | 0.60 | 0.65 | 0.70 | 0.70 | 0.75 | 0.80 | 0.80 |
| 9 | 0.55 | 0.60 | 0.60 | 0.65 | 0.70 | 0.70 | 0.75 | 0.80 |
| 10 | 0.5 | 0.55 | 0.60 | 0.60 | 0.65 | 0.70 | 0.70 | 0.75 |
| 11 | 0.5 | 0.5 | 0.55 | 0.60 | 0.60 | 0.65 | 0.70 | 0.70 |
| 12 | 0.5 | 0.5 | 0.5 | 0.55 | 0.60 | 0.60 | 0.65 | 0.70 |
| 13 | | | 0.5 | 0.5 | 0.55 | 0.60 | 0.60 | 0.65 |
| 14 | | | 0.5 | 0.5 | 0.5 | 0.55 | 0.60 | 0.60 |
| 15 | | | 0.5 | 0.5 | | | | |
| | 7.65 | 8 | 9.9 | 10.3 | 10.25 | 10.75 | 11.2 | 11.6 |

How much percentage of normal illumination does the dimming pattern consume?

7.65+8+9.9+10.3+10.25+10.75+11.2+11.6=79.65/110=72.4%

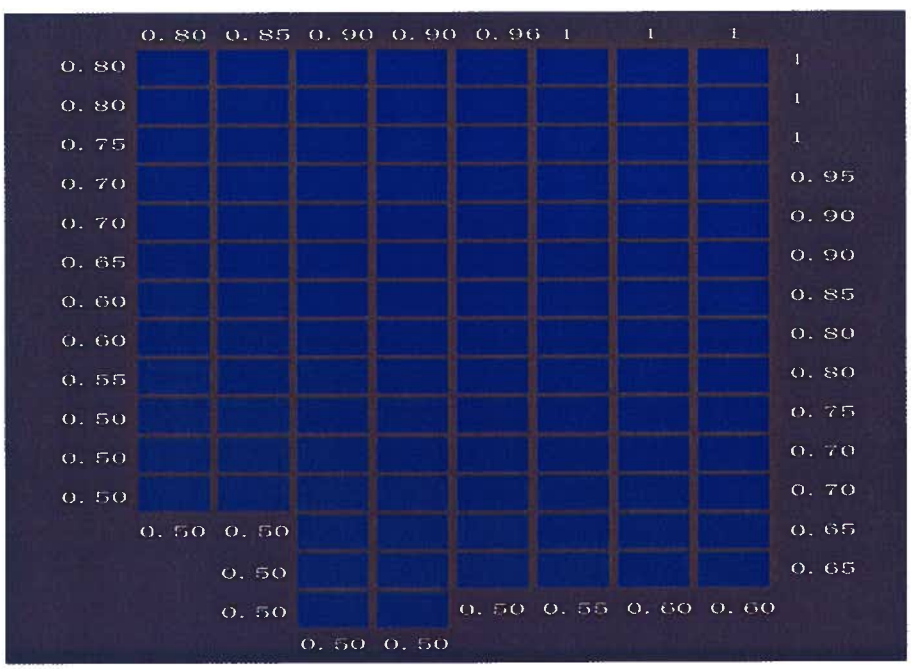



Fig 5.2 The Dimming Pattern on RVH's Rear Building Façade at Nighttime

The electricity consumption on every summer weekday night is 72.4 per cent of that on a weekend night, 72.4% x 1.386 KWH = 1.004 KWH

The electricity consumption on every spring-fall weekday's night is 72.4 per cent of that on a weekend night, 72.4% x 2.376 KWH = 1.720 KWH

The electricity consumption on every winter weekday's night is 72.4 per cent of that on a weekend night, 72.4% x 3.366 KWH = 2.437 KWH

### 5.2.4 LEDs' Electricity Consumption on Festival Nights

The light effect for festival and event nights will be a rainbow of colour changes. Every LED node or fixture is composed of red, green, and blue LED chips. Lightwild's Pixel LW-UP-19-1C is composed of 7 red, 6 green, and 6 blue chips; Philips Color Kinetics' iColor Flex SLX is composed of 3 red, 2 green, and 2 blue LED chips. The RGB chips can be justified to form 1.6 million colours. The table below adopted basic colours of the rainbow series for the calculation of average electricity consumption when in a rainbow colour circuit.

Tab 5.3 The Average Electricity Consumption of Basic Rainbow Colours

| | Red | Green | Blue | LEDs | Average Electricity Consumption |
|---|---|---|---|---|---|
| LW-UP-19-1C s | 7 | 6 | 6 | 19 | |
| Red | 7 | 0 | 0 | 7/19 | |
| Violet | 7 | 0 | 6 | 13/19 | |
| Blue | 0 | 0 | 6 | 6/19 | 9.2/19≈50% |
| Aqua | 0 | 6 | 6 | 12/19 | |
| Green | 0 | 6 | 0 | 6/19 | |
| YellowGreen | 4 | 6 | 0 | 10/19 | |
| orange | 7 | 3 | 0 | 10/19 | |
| iColor Flex SLX | 3 | 2 | 2 | 7 | |
| Red | 3 | 0 | 0 | 3/7 | |
| Violet | 3 | 0 | 2 | 5/7 | |
| Blue | 0 | 0 | 2 | 2/7 | 3.4/7≈50% |
| Aqua | 0 | 2 | 2 | 4/7 | |
| Green | 0 | 2 | 0 | 2/7 | |
| YellowGreen | 2 | 2 | 0 | 4/7 | |
| Orange | 3 | 1 | 0 | 4/7 | |

From Table 5.3, we can see that it will take almost half of the maximum power of the RGB LED lights to form the colour changing circulation of the rainbow scheme.
The electricity consumption on every summer festival night is half of the maximum power consumption for each summer night,

50% x 4.158 KWH = 2.079 KWH

The electricity consumption on every spring-fall festival night is half of the maximum power consumption for each summer night,

50% x 7.128 KWH = 3.564 KWH

The electricity consumption on every winter festival night is half of the maximum power consumption for each winter night,

50% x 10.098KWH = 5.049 KWH

Four months winter time, including 65 weekday nights, 45 weekend nights, and 12 festival and event nights. The duration of operation every night is 8.5 hours.
Four months spring-fall time, including 67 weekday nights, 43 weekend nights, and 12 festival and event nights. The duration of operation every night is 6 hours.
Four months summer time, including 66 weekday nights, 48 weekend nights, and 9 festival and event nights. The duration of operation every night is 3.5 hours.

Tab 5.4 Electricity Consumption of the Second Transformative Lighting Strategy

| Season | | Weekday nights | Weekend nights | Festival and event nights |
|---|---|---|---|---|
| Winter | Daily Electricity Consumption (KWH) | 2.437 | 3.366 | 5.049 |
| | Days | 64 | 45 | 12 |
| | Subtotal (KWH) | 155.968 | 151.47 | 60.588 |
| Spring-Fall | Daily Electricity Consumption (KWH) | 1.72 | 2.376 | 3.564 |
| | Days | 67 | 43 | 12 |
| | Subtotal (KWH) | 115.24 | 102.168 | 42.768 |
| Summer | Daily Electricity Consumption (KWH) | 1.004 | 1.386 | 2.079 |
| | Days | 66 | 48 | 9 |
| | Subtotal (KWH) | 66.264 | 66.528 | 18.711 |
| Total | | 779.705≈780 KWH | | |

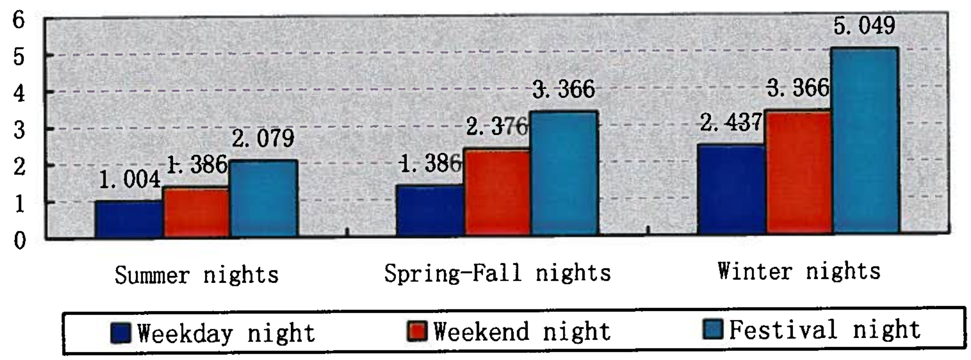



Fig 5.3 Daily Electricity Consumption of the RVH's Building Illumination

The calculation of the existing CFLs' electricity consumption per annum:
Six summer months from April 1 to September 30, total 183 days, from 9:30 pm to 1:00 am, every night 3.5 hours for exterior lights-on,
(110+84+120)x18W/1000=5.652KWx3.5H=19.782KWHx183day=3620.1KWH
Six winter months from October 1 to March 31, total 182/183 days, every night from 4:30 pm to 1:00 am, 8.5 hours for exterior lights-on,
(110+84+120)x18W/1000=5.652KWx8.5H=48.042KWHx182day=8743.65KWH
The total electricity consumption per annum of existing CFLs on the rooftop structure, the front and rear façades of the RVH, is 12363.75KWH≈12364 KWH

The electricity consumption for my experimental lighting design of the second transformative lighting strategy per annum is 780 KWH, about 6.3 per cent of the existing CFLs' electricity consumption. Conversely, from the architectural standpoint, the less electricity consumed, the more vibrant, dynamic, and attractive the lighting effects that can be achieved.

## 5.3 Design Issues

This section identifies the design issues, as opposed to the technical issues, raised by my second transformative lighting strategy. Even though the main design goal is to save energy and reduce maintenance in a sustainable manner, in the architectural research, functional, aesthetic, and budgetary issues have been integrated into the design process and have influenced the design. Good estimations of the efficiencies of each system can be made based on existing constraints. The combination of lighting goals and system efficiencies has directed the design. As with any design, there are many different ways to best achieve the design goals. The section addresses some essential issues that I have taken into account in devising a prototype design best able to respond to the design issues discussed below.

I have analyzed the differences in the appearance of the RVH as seen from various points in the city. With these studies, and considering energy savings, my experimental design proposal aims to demonstrate how artificial lighting can be used when integrated with architecture to illuminate the urban nightscape. My experimental lighting design shows how a new illumination system can be developed on the existing mounting points; how the colours of different LED light fixtures can be integrated into a multi-storey hotel to create a different ambience; and, at the same time, how the costs of maintenance and energy consumption can be reduced. Lighting is instrumental in accentuating these above characteristics, giving form and presence to spaces in the night.

### 5.3.1 Function, characteristics, and constraints

The 19-storey RVH includes 429 rooms and 8 suites. As part of the hospitality business, it provides continuous service to its guests, although there is much slow time, after 2am generally. The nocturnal illumination effects of a hospitality building should establish its identity, attract more guests, and provide way-finding at night. The RVH is a rather elegant modern building, a post-and-beam concrete structure with floor-to-ceiling glass walls. The original mounting points for CFL fixtures, the square-shaped depressions on the building façades, and the rooftop structure, as well as the previously-employed 60 watt incandescent light fixtures, were designed by Vancouver architect Bing Thom in 1987. The rear and front building façades currently show a static CFL lighting array of 194, 18-watt bulbs and 120, 18-watt bulbs on its circular top structure, reflecting Thom's original design concept. The original mounts are inflexible constraints on new light settings because they disallow arrangements different from the existing mounting points and patterns. However, if we were to attempt new mounting points, they would be inconsistent with the original design and it would be hard to set up a new wiring system in the existing building. Therefore the existing lighting array has been respected.

### 5.3.2 Positioning of lighting fixtures

I have taken the RVH's modern building components, and the existing building constraints, and turned the RVH into a "Stage of Light." The benefits of improved LED technology, which will replace the yellowish CFL lighting array with colour-changing RGB LEDs and an intelligent system as proposed in my experimental design are evident in renderings of the RVH. The rendering were produced by 3D software where photorealistic images highlight the difference between the proposed lighting design and its predecessor.

Fig 5.4 The Existing CFLs and Mounting Points on the Façades

### 5.3.3 Color and intensity

The prevailing colours of the proposed lighting design are a blue to aqua series, with a subtle colour-change (contrasted with a rainbow colour animation used occasionally to signify weekend, local events or important dates) and mall reacting to the colour shifts at nearby Canada Place. The Philips Color Kinetics intelligent system is proposed to control LED colours in coordination with those of Canada Place, where the 5 distinctive fabric sails are illuminated by 40 LED Light Wave LX fixtures. The reason for the response to the colour of Canada Place is to respect the whole image of the waterfront urban nightscape and to eliminate inharmonious lighting effects from individual buildings within the waterfront skyline. The system can combine red, blue, and green LEDs to produce up to 16.7 million colours, as well as such effects as fades, washes, and twinkling, with variations in speed and intensity, all of which play continuously and can be set by a timer. In addition, the rooftop rotunda of the building culminates in a crown of LED fixtures, which change and harmonize with the effects on the façade. The intensity of LEDs can be adjusted periodically according to issues raised by the community. "Light should be a material with which we build," declared James Turrell, echoing a suggestion that light designers have formulated again and again throughout the twentieth century.[158]

Fig 5.5 Blue to Aqua Colour Changes on the Front and Rear Building Façades

According to the characteristics of both their structural and visual concepts, the same colour scheme will be applied to the rear and the front façades. Slightly different effects will be observed on the two façades when viewed from a short distance due to their different architectural appearance, orientation, and surroundings. However, observers cannot see both sides at the same time; my design is focused on the rear building façade which faces the harbour, although with some consideration for the front façade as well.

5.3.4 Components and patterns

[158] Neumann (2002) 216.


Fig 5.6 The Proposed Building Illumination's Components of the Rear Façade

The proposed LED lighting components on the rear façade include the rooftop strip of LEDs, dotted LEDs and decorative linear LEDs on the major wall area, and a red-highlighted name sign. Every component's variations can be controlled by the Philips Color Kinetics intelligent system independently, except the lighting of the "Renaissance Hotel" sign, which reflects the original red colour of the signage. Dotted RGB LEDs are the major components of integrated lighting effects, presenting a variety of different patterns in harmonization with other lighting components.

Fig 5.7 The Proposed Building Illumination's Patterns of the Rear Façade

### 5.3.5 Direction

The building features floor-to-ceiling glazing and glass balcony railings. The rear building façade overlooks Burrard Inlet and Stanley Park, so the direction of building illumination on the rear façade faces out on the Inlet where it is able to avoid light trespass and glare through glass into the guest rooms and balconies. The adopted LED light fixtures allow better control of the directional quality of light than do CFL fixtures.[159] (Please refer to the picture below demonstrating the lighting direction of LED fixtures and CFL fixtures). Because every LED fixture is composed of lots of LED chips, which have inherently small profiles, LED light fixtures produce more directional light avoiding the light trespass associated with light pollution and doing so with less energy consumption. The illuminance of the existing CFLs is reduced by the fixture's blunt oval shape, its omni-directional lighting, and its recessed installation. The 18-watt outdoor CFL is a long cylinder of 2-3/8 inch diameter and 6-1/4 inch length. Its frosted circular surface illuminates out, which can be seen as dotted lighting from West Cordova Street from Thurlow Stree to Bute Stree and extending to the Inlet. The rear building façade has the recessed rectangular holes which partially obscure CFL bulbs, so most of the light from the side of the light bulb is wasted in being absorbed within the rectangular holes and by the rough stucco surface of the RVH's façades. Compared with CFLs, LEDs have no such lighting wastage because they are very precise in their beam control and their profiles are quite short and contained without light spilling in unwanted directions.

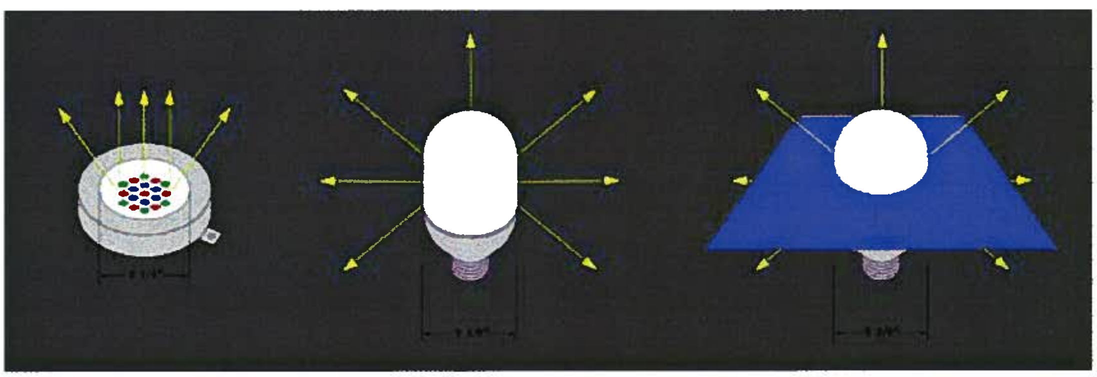


Fig 5.8 The Direction of LED Lighting and CFL Lighting

[159] "LEDs emit light in a less diffuse pattern than conventional light sources. In contrast, standard fluorescent lamps emit light in all directions, and much of the light output is absorbed inside the fixture or escapes in an unintended direction." Cited from "FAQs on Market-Available LEDs" Building Technologies Program: Solid-State Lighting (US Department of Energy), 31 March 2008 <http://www.netl.doe.gov/ssl/faqs.htm>.

5.3.6 Proportion and the daytime effects

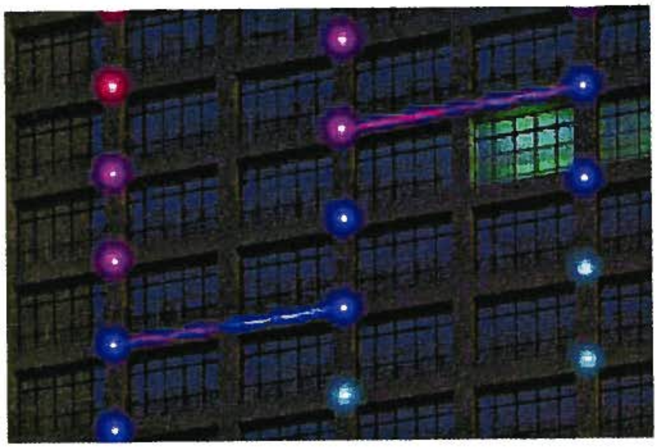


Fig 5.9 The Linear Accented LED Fixtures Connecting Dotted LEDs

My experimental LED lighting design mainly respects the original lighting proportions and positions which allow for easy installation and limited maintenance. The adoption of LED light fixtures with sizes similar to those of CFL fixtures will help to retain the same visual effects of the building façades in the daytime. In addition, LED lights can be adjusted not only to on-and-off but also for a variety of illumination arrays to create different proportions, periodically controlled by computer programs. Six linear accented LED fixtures connecting 12 dotted LEDs' positioned diagonally decorate the rear façade. This special arrangement has been intentionally used to enrich the light effects and to counter the unvaried proportion of dotted LED lights on the rear façade. The six illuminated lines are positioned from the lower left to the top right of the rear façade, representing an upward trend. Even though my simulation of a LED lighting design has not pursued particular, extravagant, and brilliant light effects, it demonstrates the pursuit of a harmonious, dynamic, and versatile waterfront nightscape which respects the existing lighting design.

5.3.7 Intelligent and programmable system

Colour-changing LED lamps, or nodes, are composed of red, green, and blue LED chips. LED is a semiconductor with positive (P) and negative (N) sides. Different chemicals inside the semiconductor produce different colours. Different coloured LEDs require slightly different currents to activate electrons and produce photons, which become visible light. The control system should change power, data, and current intensity, so that the RGB LEDs will alter in colour, brightness and speed. Normally, the lighting industry calls this control system "intelligent," because the colour change also refers to the varying temperatures that the energy supplier constantly reacts to and provides. Individual light nodes need to be equipped with the intelligence to be automatically addressed and controlled.[160]

My design makes use of a technology that is more sophisticated and versatile than other colour-changing control systems. It is called Philips Color Kinetics "flagship technology", which "leverages a layer of digital intelligence to control LEDs, generating millions of colours and a myriad of lighting effects." [162] The underlying technology, which is unprecedented in affording "a microprocessor, network address or user interface to LED illumination devices", [162] was recognized with national patents in many countries. My power supply system, which is on-site photovoltaic electricity generation associated with battery storage, integrates a complete DC voltage power solution with intelligent LED lighting systems: "It surpasses traditional power supply technology by streamlining multiple conversion and regulation stages into a single, flexible, and microprocessor-controlled power stage that rapidly, efficiently, and accurately controls power output to LED-based systems" [162] directly from DC voltage, "eliminating the need for external power supplies."[162] This system increases efficiency, lowers the overall cost, and eases installation of intelligent LED lighting systems. The intelligent control system is "the brain of colour-changing LED lighting that makes possible a host of previously unimaginable applications" for both small and large-scale installations.[161]

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[160] "Core Technologies," Philips Solid-State Lighting Solutions (Philips & Color Kinetics official website), 31 March 2008 <http://www.colorkinetics.com/technologies/core/>.

[161] "Core Technologies," (Philips & Color Kinetics).

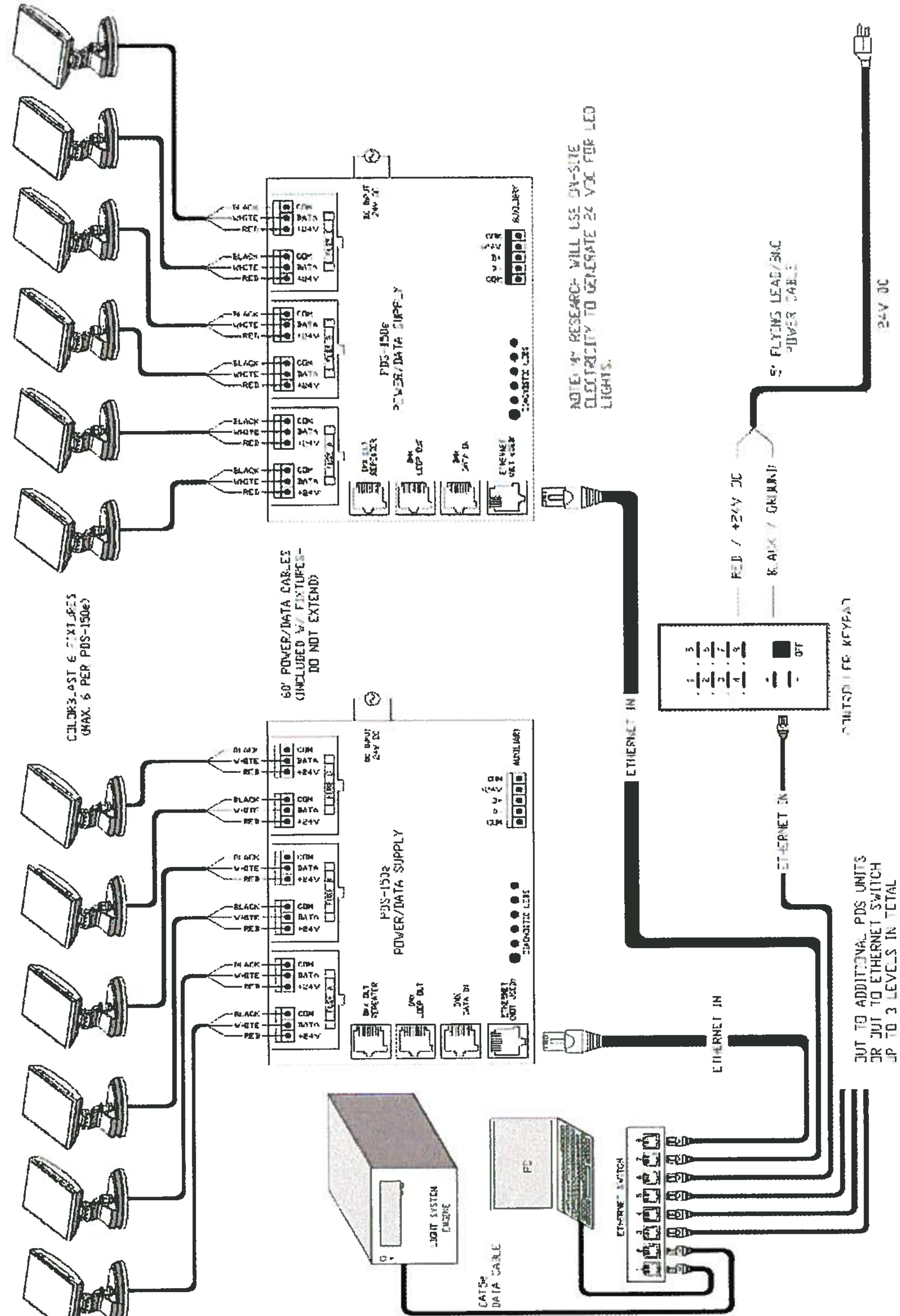


Fig 5.10 The Intelligent System of LED Fixtures, adapted from Philips Color Kinetics

The second intelligent system that has been set out in my proposal is building-responsive lighting. I envision the lighting effect of the RVH as a component of the waterfront skyline of Vancouver. It raises a new need for the development of a functional aesthetic related to the proposal for an integrated urban nightscape by balanced and well-accentuated lighting design which appears especially evident when looking at the city's current grey nightscape.

In order to achieve a balanced waterfront night image, a sensor reacting to all of the colour changes and the illusion of movement at Canada Place, combined with the Philips Color Kinetics system to adjust the RVH's building illumination, would create interesting effects for the Vancouver nightscape. The effect would not be too kinetic, but colourful, joyful, and courteous. Even when the rear façade of the RVH is static with a single 'look,' it can contribute to an enlarged and coherent waterfront image associated with its varying reflection. The façade of the building literally will become a performance, and it can also glow, flash, and change from one colour to another, with LEDs to mirror Canada Place.

Fig 5.11 The Relationship of Canada Place, the Shaw Tower, and the RVH

5.4 Discussion

The reason for choosing the rear building façade as the design focus, rather than the entrance façade that greets arriving guests, is that the rear façade holds an important location facing the waterfront of downtown Vancouver and can be seen from long distances. Despite its low height, compared with surrounding high-rise towers, it is an indivisible part of Vancouver's city skyline. The RVH sits between two neighbouring black-coloured office towers. Since the neighbouring buildings are very close, lighting the adjacent East and West walls of the RVH would cause glare and light trespass on the neighbouring buildings and would be accompanied by energy waste. The front (South) building façade has the same existing lighting fixtures, 18-watt CFLs, mounted on concave structures of the building façade. Using LED RGB light fixtures to retrofit the existing CFLs on the whole building façade of the RVH will encounter the same technical and economic issues as those encountered on the rear (North) waterfront façade. In design terms, the front building façade overlooks residential, office, and commercial buildings and is viewed from about the distance of a conventional street, so lighting intensity will need to be adjusted for the comfort of the surroundings. The rear building façade overlooks Harbourside Park, Burrard Inlet, and Stanley Park. The lighting effect can be seen from different distances, so the light application on the rear façade of the RVH will have more impact than that of the front façade.

Responsive and intelligent lighting is designed to react to "the electro-physical flux of urban environments."[162] The emerging digital technologies and colour-changing LEDs therefore help to build more vivid, dynamic, and lifelike environments in communicating with human beings. The idea of lighting design proposed in this research is derived from the illusion of the "kaleidoscope." The programmable LED lighting can be changed through a computer program to reflect different concepts. Actually, the communication qualities of responsive and intelligent lighting reflect the new trend of uncertainty or non-determinacy in the design field, which means designers give more space to users to think, to involve, or to design their own environments.

The 1986 "Tower of Winds" was a lighting designed by architect Toyo Ito applied to a cubic concrete tower utilized both for ventilation and as a water tower. His lighting design comprised thirty floodlights, 12 neon bands and 1,200 small lamps and was commissioned for the thirtieth anniversary of the Yokohama West bus terminal. The

[162] Bullivant 19.

lighting design broke the static light trends of that era by responding to both the direction and speed of external wind and noise from the street. The tower was transformed with all kinds of illumination transitions and variations at night while it merely showed its perforated metal second surface during the day. Ito's design sought to respond to our physical environment by means of visible electronic media – lighting. However, the Tower of Winds has not (or only partially) been illuminated in recent years due to high electricity bills and required maintenance.[163] It seems that long-term electricity consumption and maintenance are two substantial and influential requirements to sustain the life of a great architectural lighting design, even after initial installation.

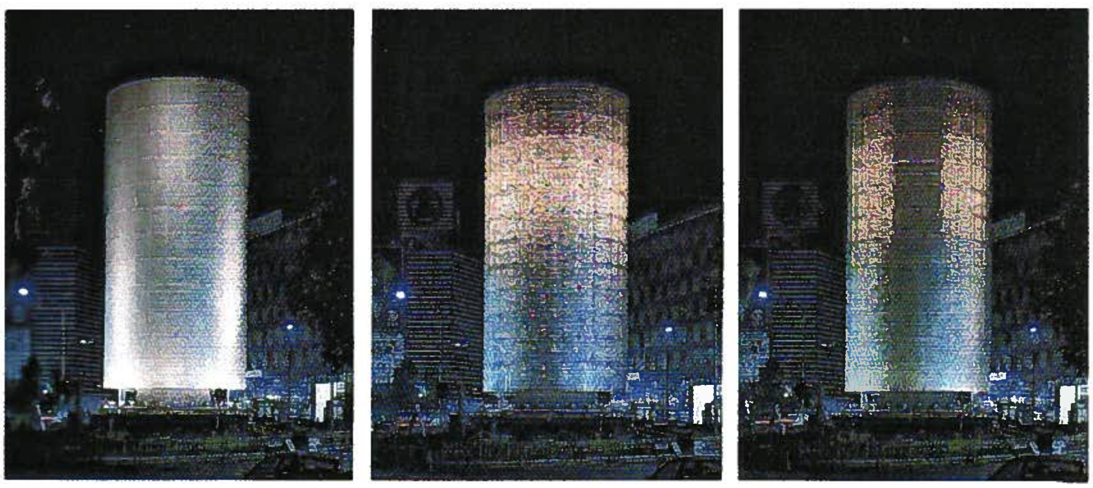

Fig 5.12 Interactive Building Skins, "the Tower of Wind" adopted.[164]

The RVH's light design is facing more constraints due to the aesthetic considerations of its location, its architectural and structural features, functions, and current conditions in business operations, although energy-saving LED technology continues to reveal beneficial effects on building illumination two decades after the debut of the Tower of Winds. My proposal for the RVH's intelligent system has taken the whole waterfront skyline of Vancouver into consideration, as the building illumination of the RVH is just one part of my design. The RVH looks out on the Burrard Inlet, the water and the north. While the illumination of the Tower of Winds interacted with wind and noise from the

[163] Neumann (2002) 203.
[164] Bullivant 19.

physical environment, the illumination of the RVH is reflected by the water variously and randomly, and mirrors the lighting colour of Canada Place. The Tower of Winds was intended as a specific celebration event; the illumination of the RVH is intended to advertise the hotel itself, promote the legibility of Vancouver's waterfront skyline, and demonstrate the sustainability of the urban nightscape so as to help Vancouver promote its tourist industry. In a simple lighting design, we need to consider light technology, architectural structure, initial cost, electricity requirements, maintenance, and design intentions.

Fig 5.13 The Illumination of the RVH Mirrors the Lighting Colours of Canada Place

# Chapter 6:

# The Third Transformative Lighting Strategy

## 6.1 Introduction

Since we all play a crucial part in putting the world onto sustainable development paths, we should put our incremental efforts into developing alternative energy-renewable forms. My third transformative lighting strategy uses on-site micro-renewable energy generation to supply the electricity requirements of the RVH's exterior illumination. Three reasons for introducing on-site micro-renewable energy generation for illumination are to achieve zero-energy requirement from the grid; to anticipate and participate in the trend toward the use of LEDs; and to contribute to the nocturnal waterfront ambience.

My objective is to achieve a zero-energy requirement from the grid system for the building illumination, and to demonstrate an optimized light design and arrangement based on different time settings appropriate to the instability of the singular renewable energy resource.

I expect that when LEDs' technology and prices become more competitive than those of CFLs, and when the existing RVH's interior lights are switched to LEDs, that today's lighting system, combined with on-site electricity generation, storage, and DC-DC conversion, will still be useful and sustainable.

I also expect the nocturnal illumination of Vancouver's waterfront will be more vibrant, attractive, and enjoyable once energy-saving LED technology with its zero energy consumption and an on-site renewable energy network is composed encompassing of all the buildings at Vancouver's waterfront.

I have chosen to explore on-site energy generation for transformative lighting.

## 6.2 The Photovoltaic System

I considered five micro-renewable energy resources: solar photovoltaic (PV) electricity, onshore wind turbines, kinetic energy, earth energy and wave/tidal energy. Among these five forms of renewable energy, solar energy and wind energy are more mature in practice and market availability because it is easy to purchase photovoltaic panels and wind turbines. Considering application feasibility, durability, and the noise issues of renewable energy generation, solar photovoltaic electricity will be more suitable for the RVH building because of constraints that the existing building and urban contexts present, such as surrounding high-rise buildings, limited rebuilt space, and nearby residential and office buildings, eliminate the feasibility of using wind turbines.

Solar photovoltaic electricity is the power produced from panels of light-sensitive cells. Photovoltaic cells can convert the energy of the sun into electricity without thermal processes. "Photovoltaic cells consist of two layers of silicon, each with different electromechanical characteristics, connected to an outside electric circuit through which the generated low-voltage electric direct current (DC) is transported."[165] PV cells can work any time the sun is shining, but when the sunlight is more intense and rays of sunlight are perpendicular to the PV cells, more electricity is produced. PV modules, as a clean, renewable resource, produce electricity without noise or air pollution. With today's growing population and environmental problems, and with the world's energy crisis, industry experts predict that solar photovoltaic will be the next breakthrough industry.[166]

Photovoltaic cells come in many sizes, but most are 10 cm by 10 cm and generate about half a volt of electricity.[167] Cell assemblies, called solar panels or modules, are encapsulated in watertight modules for protection from moisture and impact. The PV modules are composed of glazing, encapsulant, silicon wafers and associated wiring, and a protective back sheet.[168] Solar modules and panels are further linked to systems with power controllers, inverters, and storage devices. Even though PV

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[165] Santamouris 278.

[166] The National Renewable Energy Laboratory, A Consumer's Guide: Get Your Power from the Sun Washington, DC: US Department of Energy, December (2003) DOE/GO-102003-1844 2, 31 March 2008 <http://www.nrel.gov/docs/fy04osti/35297.pdf>.

[167] Solar Energy Society of Canada Inc., "Photovoltaic Solar Energy," 31 March 2008 <http://www.newenergy.org/sesci/publications/pamphlets/photovoltaic.html>.

[168] DuPont Company, "Photovoltaic Solutions: Science of Photovoltaic Energy," 31 March 2008 <http://www2.dupont.com/Photovoltaics/en_US/science_of/index.html>.

panels are not highly efficient, converting only 12 to 15 per cent of the sunlight into electricity, PV modules are technically well proven, and have an expected service time of 30 years.[169] I understand that energy conversion is from one type of energy to another. Wind turbine systems convert kinetic energy to electricity; photovoltaic panels convert photons (light) to electricity. No energy converting system can make a perfect conversion in energy because of material resistance and a system's efficiency etc. Burning fossil fuel to get electricity is only at about 33% efficiency in the US today, which has not been changed since 1958.[170] Buildings with integrated photovoltaic energy systems are of special interest for the electricity generated in cities. Through electricity generation, solar cells do not cause any environmental pollution in terms of emissions and noise, and this efficiency is of extreme importance for cities. Furthermore, modules have a long life span and they do not need a lot of maintenance, as is the case with most construction elements of the building's envelope.[171] PV panels are market-ready, with little maintenance for their 25-30 years' life span, compatible with the LEDs' lifetime because LEDs with a 50,000 hour lifetime, operated 2200 hours per year, will last about 23 years.

### 6.3 The Third Transformative Lighting Strategy

My third transformative lighting strategy explores the potential of on-site generation of electricity instead of purchase from BC Hydro. Photovoltaic panels will generate the electrical requirements of the RVH's decorative exterior LED lighting. This transformation will transfer daytime sun energy to electricity for night outdoor building illumination; therefore, it will encourage outdoor activities in the night time for Vancouverites, as a means to compensate for the limited daytime hours in Vancouver's winter months.

People question the viability of solar systems in Vancouver due to the clouds and rain.

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[169] Solar Energy Society of Canada Inc.

[170] Sarah Lozanova, "Power Plant Efficiency Hasn't Improved Since 1957" Clean Technica. Published on June 26th, 2008 in Energy Efficiency, Fossil Fuels, Politics, 11 July 2008 <http://cleantechnica.com/2008/06/26/electricity-generation-efficiency-its-not-about-the-technology/>.

[171] Mat Santamouris 278.

However, many cities in Germany receive less sunlight than Vancouver, yet Germany has the largest installed solar electric base in the world, with 300 MW. Generally, Vancouver receives 1919 hours of sunlight annually compared with 1837 in Berlin, 1680 in Munich and 1643 in Frankfurt.[172]

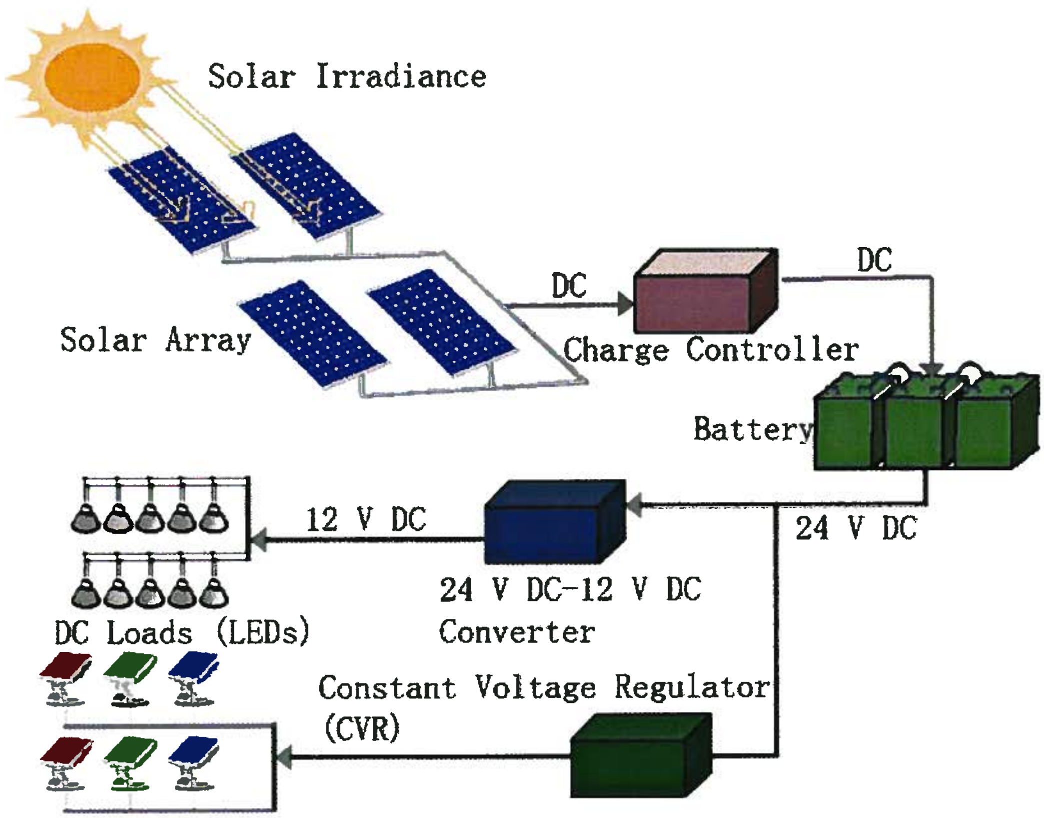


Fig 6.1 Proposed Photovoltaic System of the RVH

From the standpoint of electrical engineering, PV electricity to support LED illumination is a simple circuit without DC-AC conversion. Due to the fact that the electricity will be used at night, the system needs electric storage-batteries. The Figure 6.1 illustrates the whole of the RVH's third transformative system.

In my experimental design, chosen LED lights are supplied by 24 or 12 V DC based

[172] SPEC, "Solar Technology Tours at SPEC," Society Promoting Environmental Conservation (SPEC), 31 March 2008 <http://www.spec.bc.ca/article/article.php?articleID=488>.

on their product specifications.[173] Coincidentally, the photovoltaic system produces DC power and the batteries can store 24VDC through constant voltage regulator (CVR) to 24VDC LEDs (LightWild LW-UP-19-1C), which can be converted to 12VDC because LEDs (Philips Color Kinetics IColor Flex SLX) request the same current. Hence my third transformative strategy will reduce the electricity loss from DC to AC, and then from AC to DC again. Thus, the considerable cost of the DC-AC inverter and the AC-DC inverter will be saved. Compared with the DC-AC inverter, the DC-DC converter is low-priced and effective in reducing electricity loss.

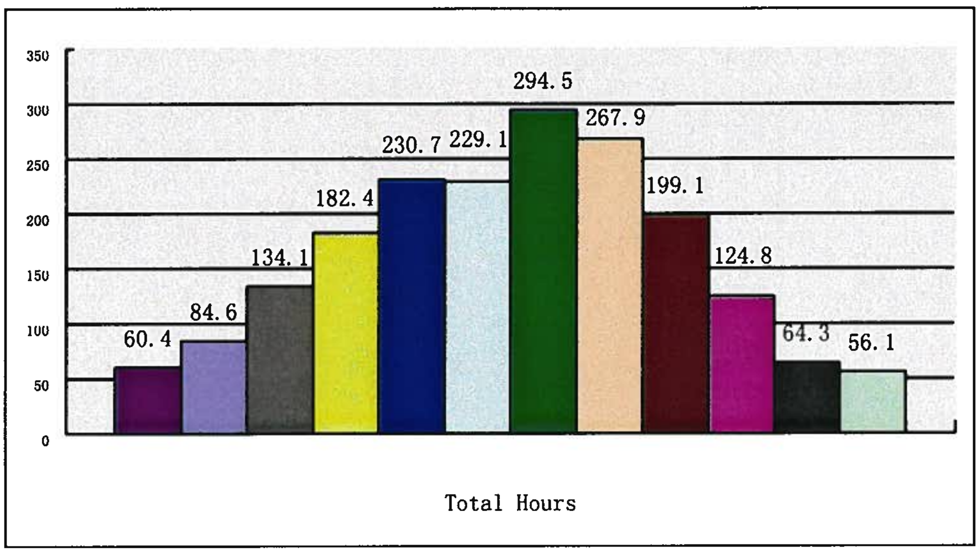


Fig 6.2 Monthly Total Sunlight Hours in Vancouver Tested at Vancouver's International Airport[174]

From the data provided in Figure 6.2 about Vancouver's monthly sunlight hours, we can easily see that December would be the most challenging month for using photovoltaic panels to supply the RVH's outdoor decorative lighting because it has the most limited sunlight hours, 56.1 hours in a month, and the highest electricity

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[173] LightWild LW-UP-19-1C uses 24VDC and Color Kinetics IColor Flex SLX uses 12VDC.

[174] Environment Canada, "Canadian Climate Normals 1971-2000: Vancouver Int'L A, British Columbia," (Environment Canada), 31 March 2008 <http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=ALL&StationName=Vancouver&SearchType=BeginsWith&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=889&>.

requirements – the 6 day festival night arrangement with at least 8.5 hours of operation every night. December will therefore be the month used to determine the feasibility of the system, because it has the greatest demands.

It is easy to find the most advantageous place to install photovoltaic panels on an existing building to maximize sun capture and to avoid unnecessary maintenance or damage. For instance, there is a 55.5ft x 54.5ft rectangular space ideal for photovoltaic panels on the rooftop of the RVH. A standard size of photovoltaic module – 80-watt panel size – is about 47.3 x 21.2 x 1.8 inches. At least 176 80-watt solar panels can be installed on the flat rooftop of the RVH and provide 14 KW per hour under proper sunlight. In December, every festival night requires 5.05 KW of electricity to light the RVH's outdoor LEDs for 8.5 hours, so every hour would require 0.6 KW continuous supply. If we calculate the electricity loss in the circulation from the electricity source, storage and wiring to LED outlets, then we will need to increase the required electricity amount and flux. If we use a sizeable battery to store generated electricity and systematically supply it to LED decorative lighting, we can calculate the total amount of electricity in December as a whole and subdivide by the total sunlight hours, so determining the number of 80-watt photovoltaic panels needed.

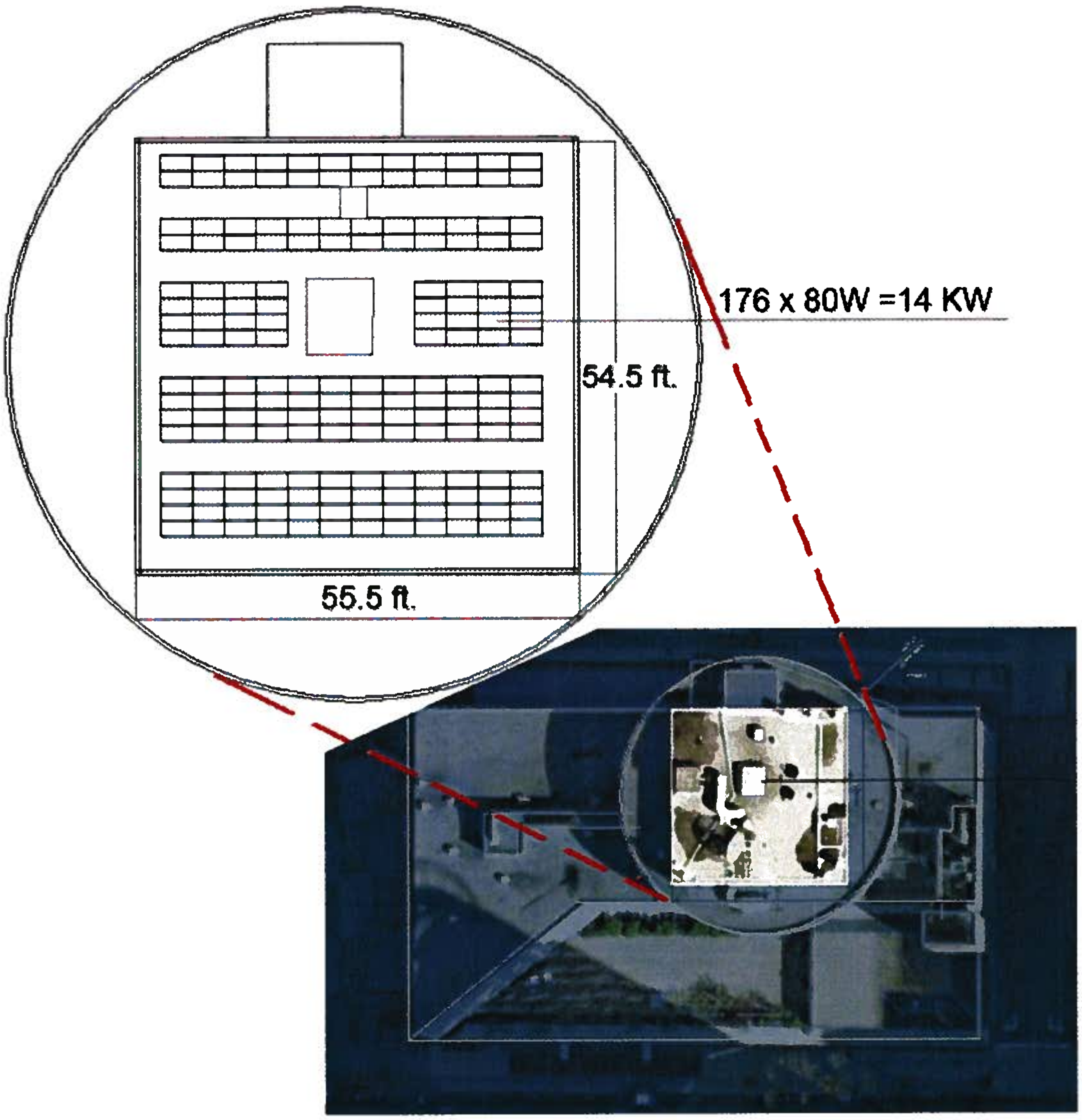


Fig 6.3: PV Panels on the RVH's Rooftop. Map adopted from Google Maps by the author.

The total amount of electricity in December:

16 Weekdays + 9 Weekends + 6 Festival Nights = December

16 x 1.4552 + 9 x 1.819 + 6 x 5.049 = 23.2832 + 16.371 + 30.294 = 69.9482≈70KWH

Directly, the number of photovoltaic panels can be obtained by the following calculation:

70 KWH x 1000 / 56H / 80W = 15.625≈16

According to my calculation, supplying outdoor LED lights will require at least 16 80-watt solar panels without any consideration of the electricity loss in its circulation. If we estimate 30% electricity loss, then we will need 23 80-watt solar panels, equal to the volume of 1840 watts. BC-based EA Energy Alternatives Ltd. supplies a full-time PV system compatible with the RVH's LED lighting. Customization of the PV system named Primary Power1 with extra an 1140-watt solar panels will fulfill the requirements.

Tab 6.1 The Estimated Total Cost of the RVH's PV System

| Item | Unit Price Per watt/panel | Quantity (Watt/ panel) | Cost |
|---|---|---|---|
| Solar panels | $ 5.50/watt * | 1140 | $6,270 |
| Primary Power 1 – Outback 2.5 KW, 24V | $ 16,995 | 1 | $16,995 |
| Total | | | $23,265 |

Note: 1. *A PV panel's wholesale price in the North American market is about $5.50/watt.

2. The battery's storage capacity will be 20KWH at 24 VDC, suitable for 4 days of illumination in December without recharging.

3. Price from EA Energy Alternatives Ltd. and its official website: www.energyalternatives.ca.

## 6.4 Batteries

There are some concerns about using batteries to store electricity on site for the requirement of night lighting. "Batteries are only useful to light up the building during a power outage." And there are "quite a few disadvantages: such as low efficiency (less power), more cost, more maintenance, and pollution from [battery] disposal." [175]

Currently, a power outage in Vancouver's downtown is highly unlikely, but it may happen more frequently if energy sources lessen or an incident happens, so a local

[175] Data from Hiltz Tanner, BEng, System Design Engineer at EA Energy Alternatives Ltd, Victoria, BC. Its official website: <www.energyalternatives.ca>.

supplier of the PV system recommend connecting to the grid with a grid-tie inverter. In this way, BC Hydro would become an infinite "battery" for lots of micro-PV systems; therefore, in the winter time, electricity from the grid will be provided for operation requirements even if less sunlight is available, and in the summer time when generated electricity exceeds requirements, the RVH can sell extra volume to BC Hydro, at least theoretically.

This system would not be very convincing. It is difficult and expensive to store electricity so that it must be produced when we need it with the quantities in demand.[176] Electricity generated by renewable energy going back to BC Hydro's grid system cannot reduce its load. When the grid has a blackout, batteries help the lighting system become independent from the grid. Unfortunately, while I was completing this thesis, downtown Vancouver had nearly three full days of an outrage because of an underground circuit fire causing about $36 million losses by estimate.[177] A lighting system relying on an independent electricity system is more sustainable and constructive in terms of dealing with a catastrophe. Batteries could have longer life if properly maintained. Sealed lead-acid batteries have often been used with a PV system as a better solution for rechargeable maintenance-free batteries. Lead-acid battery recycling is one of the most successful recycling programs in the world, with over 97% of all battery lead recycled.[178] Metro Vancouver has its own lead-acid batteries recycling program.[179]

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176 Monbiot 79.

177 CBC News, "Lights on, But Compensation off, as Vancouver Blackout Ends," CBC 17 July 2008, 17 July 2008 <http://www.cbc.ca/canada/british-columbia/story/2008/07/17/bc-vancouver-blackout-compensation.html>.

178 Gravita Exim Ltd., "Environmenal Friendly Battery Recycling," (Gravita Exim Ltd. official website), 31 March 2008 <http://www.gravitaexim.com/Battery-Recycling/environment-friendly-battery-recycling.html>.

179 Metro Vancouver, "Take-back Program," (Metro Vancouve official website), 31 March 2008 <http://www.metrovancouver.org/services/solidwaste/recycling/Pages/takeback.aspx>.

# Chapter 7:
# Conclusion

## 7.1 Conclusion

### 7.1.1 General Discussion

This research demonstrates that Vancouver's urban context is able to achieve a vibrant and enjoyable nocturnal illumination responsive to a coherent waterfront image and reduce electricity consumption considerably via LED technology and via the introduction of transformative lighting strategies. The first transformative lighting strategy retrofitted existing CFLs on the RVH with LEDs. It reveals LEDs' advantages in the reduction of total cost and maintenance labor for the building façades. This strategy projected a saving, over 50,000 hours, of $32,514 on the total amount of light fixtures, electricity costs, and maintenance costs of the RVH's building illumination, which represented 48 per cent of CFLs' total costs. Furthermore, changing CFL electricity-saving bulbs to LEDs will save at least 223,200 KWH over 50,000 hours, more than 79 per cent of CFLs' electricity consumption.

The second transformative lighting strategy introduced to save more energy demonstrated architectural creativity via versatile LED lighting patterns, and systematically managed the unstable generation of renewable energy by a yearly optimized programming of outdoor LED lighting in accordance with seasonal themes. Through this second transformative lighting strategy, yearly electricity consumption was reduced from CFL's 12,364 KWH to coloured LED's 783 KWH, which saves more than 90 per cent of the electricity consumed by existing CFL bulbs. In 50,000 hours, the implementation of the second strategy can save 264,770 KWH, 94 per cent of the electricity consumed by CFLs.

The third transformative lighting strategy aimed to achieve zero energy consumption by using an on-site PV system instead of purchasing from BC Hydro. Generally, BC Hydro's hydroelectricity is renewable energy, but, as discussed in chapter two, BC Hydro has been in a net importing electricity situation since 2001 and will continue to be so because of growing energy demands as the population increases and lower water inflows persist with global warming. Additionally, this transformation transfers daytime solar energy to electricity for outdoor building night illumination; therefore, it can encourage outdoor activities in the nighttime for Vancouverites, as a means to compensate for the limited daytime hours in Vancouver's winter months.

A summary of the three transformative lighting strategies and their respective electricity reductions is provided in Figure 7.1. This reduction may be met through technological advances, but also through design interventions as addressed in chapters four and five.

Tab 7.1 Electricity Consumption and Reduction

| | Existing CFLs | 1st Strategy | 2nd Strategy | 3rd Strategy |
|---|---|---|---|---|
| Electricity Consumption (KWH) | 282600 | 59400 | 17830 | 0 |
| Electricity Reduction (KWH) | 0 | 223,200 | 264,770 | 282600 |
| Reduction Percentage (100%) | 0% | 79% | 94% | 100% |

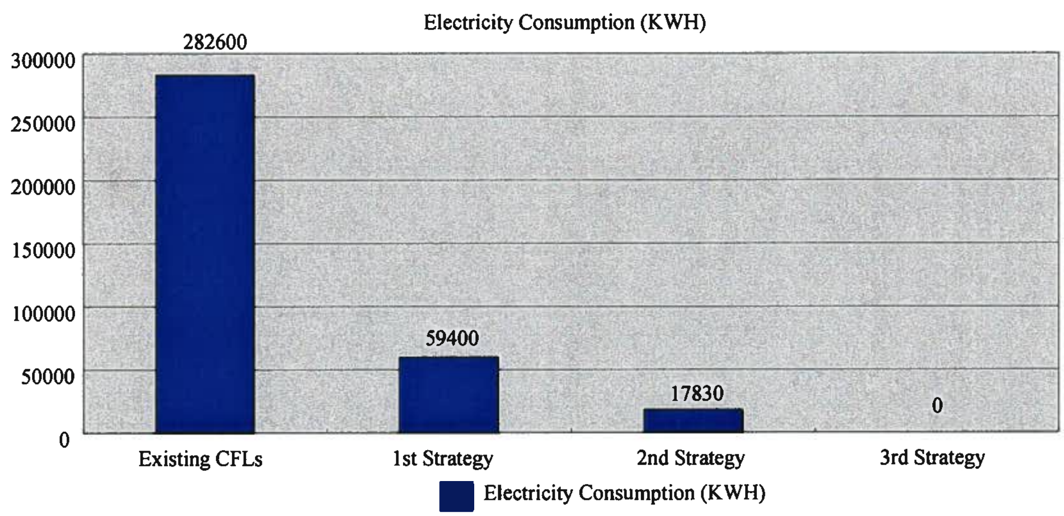


Fig 7.1 Electricity Consumption Comparison

### 7.1.2 Lighting Circuit Efficiency

LEDs are inherently DC outlets, different from most conventional light bulbs, and also on-site solar panels produce DC electricity. However, BC Hydro's grid system supplies its users with 120/240 VAC. There are several problems in the conversion between AC and DC. AC-DC converters add extra costs and require more space; the waste materials from the converter cause environmental pollution; and normally, 80%

efficiency of the converter causes 20% electricity loss.[180] This research involves a design solution to reduce electric waste when converting between AC and DC by adopting DC for the whole circulation. The whole lighting system and PV system should remain DC instead of AC and DC. Since my proposed LED outdoor lighting of the RVH only needs less than 10% of the electricity required by existing CFLs, technically, adding more PV panels will supply all the electricity requirements of the interior and exterior LED lighting for the RVH. When LED technology as general lighting reaches the point where most people accept and can afford it, micro-renewable energy will be able to supply all lights inside and outside of this building just by simple DC electricity with a closed circuit, safer and more efficient compared with the AC system.

### 7.1.3 Design

Gradually, more people start to replace their old light bulbs with LEDs, and also more lighting on building façades have being replaced by colour-changing LEDs. Borrowed from the world of theatre and entertainment lighting, dynamic light effects using both moving lights and shifting colours are now available on a large scale for use in exterior lighting.[181] From a design perspective, when colour-changing LEDs are applied to outdoor environments, especially to those landmark high-rise buildings holding significance for a city's skyline, one of the most crucial concerns is to respect neighbouring architecture to achieve a harmonious image for the city's panorama. A city's skyline is the historic accumulation of its culture, economy, and architecture. If owners or designers pursue the outstanding night visions of their buildings without a whole city picture in their minds, the whole image of a city will fall into gaudiness and disorder. Therefore, serious consideration and design guidelines should be enacted to regulate building illumination design. Due to the RVH's location and geometric form, my proposed intelligent lighting of the RVH proposes to mirror the colour changes of

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[180] Seoul Semiconductor Press Release "Seoul Semi Acriche Attains Efficiency of 80 lm/W," (FlashlightNews.org - 2/11/2008), 31 March 2008 <http://flashlightnews.org/story1183.shtml>.

[181] Carl Gardner and Raphael Molony, Light Crans-Près-Céligny, Switzerland; Hove, East Sussex: RotoVision, (2001) 14.

Canada Place, to which LEDs have been applied since 2004. In Figure 7.2, we can see the balanced image of Vancouver's waterfront via the similar colour tones at Canada Place and the RVH.

Fig 7.2 Proposed Vancouver's Waterfront Panorama

7.2 Limitation of Thesis

The chosen LED fixtures in this thesis are colour-changing RGB LEDs, which are able to achieve white light and rainbow colour series. A colour-changing LED system needs other devices, such as a personal computer (PC), power/data supplies, control panels, and wiring. These facilities have not yet been accounted for in the comparison of total costs via the first transformative strategy because this section only evaluated LEDs producing white light, which require basic wiring as the existing CFLs do. In my study of the first transformative strategy, I just compared the price of lights and their fixtures. The reasons have also been explained in my methodology section.

My second transformative strategy presenting intelligent, dynamic and colour-changing LED lighting effects exceeded the existing yellowish and dull CFL lighting effect. The cost of extra devices to achieve such LED lighting effects could be considered if the CFL lighting effects were colour-changing, which means extra control devices have been used. The costs of colour-changing LED systems and their control systems are higher than those of monochromatic CFL, but are similar to those of colour-changing CFL systems. Currently, the prices of LEDs and their control system are major challenges to massive applications of LED exterior lighting requiring dynamic, colour-changing, and intelligent effects in terms of the creativity and advances of architectural or environmental design.

Generally speaking, one of the benefits of applying LEDs is reducing electricity consumption and maintenance costs. LED technology improvement is ongoing and varied, so people might want to wait for LEDs products with prices competitive to conventional light bulbs, better qualities, and the convenience of purchasing at local stores. People are hesitant to apply them even if they could afford to buy them now. The LED products need to be introduced to potential users and be applied with different design strategies and principles, while improving product quality and quantity.

## 7.3 Further Research

Vancouver's urban context as defined in the thesis includes a variety of architecture and landscapes. Due to the limitations of time, participants, and data collection, the thesis has been narrowed down to the RVH, a hospitality building. Extending research to other types of architecture will implicate different design approaches and evaluation perspectives. Coloured LEDs on the RVH are for decorative illumination rather than functional purposes. The comparison of lumens of the proposed LEDs and existing CFLs would require technical expertise in engineering and electrical equipment beyond the scope of this thesis. However, using equipment to measure luminance and luminous flux technically will be further studies in collaboration with electrical engineers. These fundamental issues regardsing the relationship of nocturnal illumination and Vancouver's urban context. can be extended to more precise and detailed study. In this thesis I may not have been able to discuss and solve all the environmental, economic, and social issues in terms of Vancouver's nocturnal illumination, but I have demonstrated the advantages of employing LEDs in external lighting design for the nocturnal and urban setting through energy-saving design approaches and comparative evaluation methods.

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## Appendix I

### 18 Watt CFL bulb manufactured by "Philips Marathon"


18 Watt Outdoor Energy Saver Bulb

$11.98 (Homedepot Canada)

This 18W outdoor energy saver bulb is ideal for use in weather-protected outdoor fixtures. Save up to 75% in electricity costs.

The 18-watt Marathon bulb provides2700K soft white light similar to a 75-watt incandescent bulb.

Light output (Lumens) is 1,100. Lifespan is 10,000 hours. Its Colour Render Index (CRI) is 82 and its operating temperature ranges from -25℃ to +60℃.

Assembled Length： 6-1/4 inch

Assembled Diameter： 2-3/8 inch

Assembled Weight： 0.3Lbs.

Country of Origin: Mexico

CSA Certified: Yes

Caution: Risk of electric shock. Do not use where directly exposed to water. Not for use with dimmers.

## **Appendix** II

**RGB LED - Color Kinetics iColor Flex SLX**
31 March 2008 <http://www.colorkinetics.com/support/datasheets/iColorFlexSLX.pdf>.

COLOR KINETICS

PHILIPS

# iCOLOR FLEX SLX

POWERED BY CHROMACORE®

Color Kinetics® iColor® Flex SLX is a flexible LED string lighting solution that is brighter and larger than the iColor Flex SL. iColor Flex SLX is an excellent choice for use in the millwork, signage, and amusement industries. Designed for accent or perimeter lighting or as a component of a custom fixture, iColor Flex SLX provides lighting professionals with a "building block" for the design and creation of custom applications. Uses may include: curtain walls, lined building facades, and under- cabinet lighting. Depending on the iColor Flex SLX application selected, you can create custom color changing effects or custom animation. iColor Flex SLX may be used as a traditional string light or can be custom mounted with the optional mounting clips or mounting tracks.

iColor Flex SLX is a strand of 50 individually-addressable LED nodes driven by Color Kinetics' Chromasic® technology. This dynamic integration of power, communication, and control gives the lighting designer extraordinary color flexibility. LEDs are addressed and powered through Chromasic technology—a Chromacore® embedded microchip on every node. Thus, each node can generate virtually any color at any specified time. Node lenses are available in two models; flat and clear, or domed and translucent. Nodes are mounted in small plastic housings and are arrayed in 4 or 12-inch (0.1 or 0.305 m) increments along a three-wire 16 AWG cable. An integral 50-foot (15.2 m) leader runs from the power/data supply to the first node. Standard colors for iColor Flex SLX are white or black. (Custom node spacing schemes and node color options are available by special order.)

iColor Flex SLX receives power and data from a dedicated Color Kinetics 12V Chromasic power/data supply—available with Ethernet control, DMX512 control, or pre-programmed effects. Each power/data supply supports one 50-node strand. The compact size allows for discrete installation.

CHROMACORE® BY COLOR KINETICS

CHROMASIC™ BY COLOR KINETICS

OPTIBIN® BY COLOR KINETICS

DRY

DAMP

WET

CE c UL US

### iCOLOR FLEX SLX SPECIFICATIONS

| | |
|---|---|
| COLOR RANGE | 64 billion (36-bit) additive RGB colors; continuously variable intensity |
| SOURCE | 50 Nodes; each with 3 Red, 2 Green, 2 Blue LEDs— 350 LEDs total |
| AVAILABLE IN | Clear flat lens or Translucent domed lens |
| HOUSING | Polycarbonate, approx.1.10" x 1.22" x .56"H (2.97 cm x 3.12 cm x 1.4 cm) |
| LISTINGS | C-UL US, CE |

### COMMUNICATION SPECIFICATIONS

| | |
|---|---|
| DATA INTERFACE | Color Kinetics data interface system |
| CONTROL | Ethernet, DMX512 or stand-alone |

### ELECTRICAL SPECIFICATIONS (LIGHTS)

| | |
|---|---|
| POWER REQUIREMENT | 12VDC |
| POWER CONSUMPTION | 50W Max. at full intensity (full RGB), per 50 node strand |
| POWER SUPPLY | Color Kinetics PDS-60ca 12V (Preprogrammed 109-000020-00, DMX 109-000020-01, and Ethernet 109-000020-02) |

### ELECTRICAL SPECIFICATIONS (POWER/DATA SUPPLY)

| | |
|---|---|
| POWER INPUT | 100VAC to 240VAC auto ranging (50Hz–60Hz)<br>Power factor correction (PFC) |
| POWER OUTPUT | 12VDC |
| HEAT DISSIPATION | 25 percent of total power output |
| HOUSING | NEMA 4 indoor/outdoor rated enclosure |
| CONNECTORS | Data: RJ45 input/output connectors Power: 4-pin connector |

### ENVIRONMENTAL SPECIFICATIONS

| | |
|---|---|
| TEMPERATURE RANGE | -40°F to 122°F (-40°C to 50°C) operating temperature<br>-4°F to 122°F (-20°C to 50°C) starting temperature |
| PROTECTION RATING | IP66 |

### LED SOURCE LIFE

In traditional lamp sources, lifetime is defined as the point at which 50% of the lamps fail. This is also termed Mean Time Between Failure (MTBF). LEDs are semiconductor devices and have a much longer MTBF than conventional sources. However, MTBF is not the only consideration in determining useful life. Color Kinetics uses the concept of useful light output for rating source lifetimes. Like traditional sources, LED output degrades over time (lumen depreciation) and this is the metric for SSL lifetime.

LED lumen depreciation is affected by numerous environmental conditions such as ambient temperature, humidity, and ventilation. Lumen depreciation is also affected by means of control, thermal management, current levels, and a host of other electrical design considerations. Color Kinetics systems are expertly engineered to optimize LED life when used under normal operating conditions. Lumen depreciation information is based on LED manufacturers' source life data as well as other third party testing. Low temperatures and controlled effects have a beneficial effect on lumen depreciation. Overall system lifetime could vary substantially based on usage and the environment in which the system is installed.

Temperature and effects will affect lifetime. Color Kinetics rates product lifetime using lumen depreciation to 50% of original light output. When the fixture is running at room temperature using a color wash effect, the range of lifetime is in the range of 30,000-50,000 hours. This is LED manufacturers' test data. For more detailed information on source life, please see www.colorkinetics.com/lifetime.

**iColor Flex SLX ITEM#**
**101-000053-00 (4" White, Translucent Dome)**
**101-000053-01 (4" White, Clear Flat)**
**101-000054-00 (12" White, Translucent Dome)**
**101-000054-01 (12" White, Clear Flat)**
**101-000055-00 (4" Black, Translucent Dome)**
**101-000055-01 (4" Black, Clear Flat)**
**101-000056-00 (12" Black, Translucent Dome)**
**101-000056-01 (12" Black, Clear Flat)**

This product is protected by one or more of the following patents: U.S. Patent Nos. 6,016,038, 6,150,774 and other patents listed at http://colorkinetics.com/patents/. Other patents pending.



BR0165 Rev 02

Specifications subject to change without notice. Refer to www.colorkinetics.com for the most recent data sheet versions.

PHILIPS SOLID-STATE LIGHTING SOLUTIONS • 3 BURLINGTON WOODS DRIVE • BURLINGTON, MA 01803 • USA
TEL 888 FULL RGB • TEL 617 423 9999 • FAX 617 423 9998 • INFO@COLORKINETICS.COM • WWW.COLORKINETICS.COM

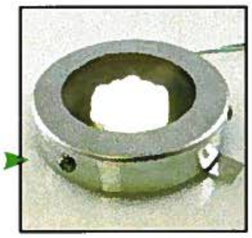
## Appendix III

**RGB LED - LightWild Pixels™ - Part No. LW-UP-19**
31 March 2008

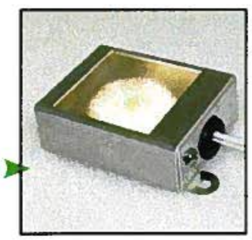
<http://www.lightwild.com/products/ledcomponents_pixels.asp#>.

# Product Data

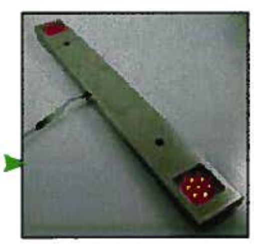
**LightWild's base Project Pixel is delivered with your choice of housings, lenses, and cable lengths**



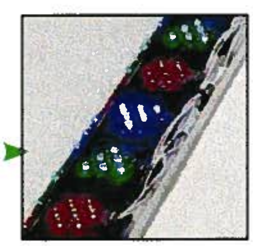
Circular Housing
Part No. LW-UP-19-1C



Rectangular Housing
Part No. LW-UP-19-1R



Custom Housings and Channels
Part No. LW-UP-CUST



## GENERAL INFORMATION

**Description:** LightWild's Ultimate Architectural Pixel™ is a versatile low profile cluster of LEDs delivered with your choice of housings, lenses, and cable lengths. The Pixel is used to wash bottles, objects, acrylics, fabrics, walls, and alcoves with warm or cool white, blue or other single color, or controlled color-changing lighting. Powerful and bright, the Pixel is also effective in delivering animated direct view lighting effects from walls and building and arena facades.

**Available LED Colors:**

| | | | |
|---|---|---|---|
| **RGB Controllable** (19 LEDs) (7 red, 6 green, 6 blue) | **Warm White** 3000K Nominal Color* (18 LEDs) | | **Amber** (19 LEDs) |
| | **Cool White** 7300K Nominal Color* (18 LEDs) | **Blue** (18 LEDs) | **Green** (18 LEDs) |

**Source:** 18 or 19 LEDs (see color list above)

**Beam Angle:** iES files are at www.lightwild.com/products/ledcomponents_pixels.asp

**Connectors:** Self-locking, water-tight connectors

**Housings:** Pixels are available with a circular aluminum housing, square aluminum housing, and custom channels and housings on a project basis.

**Mounting Methods:** Housings include supports or ears for screw-mounting to most any surface.

**Cable Attachment:** Cables enter the sides of housings unless otherwise specified.

**Diffuser:** An integrated lens of clear, lightly frosted, or frosted acrylic is available with the circular and square Pixel housings. Custom housings can also include an integrated lens if specified.

**Listings:**

c UL us LISTED

UL Listed (3KD5, E306264). Suitable for wet locations. Wall, under cabinet, and cabinet mount. Use only with LightWild supplied Class 2 power unit.

## ENVIRONMENTAL

**Temperature Range:** -10 to 150 F (-25 to 65 C)

**Locations:** Dry, damp, and wet location use.

## CONTROL OPTIONS

**DMX (Effects & Shows):** Color-controllable Pixels can be used in a DMX universe and controlled by third party DMX controllers.

**DMX (Dimming & On/Off):** White and single color Pixels can be used in a DMX universe, where they can be turned on and off and dimmed by third party DMX controllers.

**LightWild and DMX:** A third party DMX controller can be used to initiate stored lighting routines in a LightWild MonsterBrain Light Controller. This approach minimizes the number of channels Pixels consume in a universe because each stored routine represents a single channel regardless the number of Pixels used in the installation.

**LightWild:** LightWild can provide a complete, pre-programmed solution for your Pixel installation with its MonsterBrain Light Controller and associated driver boards and controllers.

**Power Only:** White and single color Pixels can be delivered ready for installation into on/off scenarios.

## ELECTRICAL

**Power Requirement:** 24VDC (120/240VAC is supplied to power unit. 24VDC is delivered to fixtures.)

**Power Consumption:** 2 watts (per Pixel)

**Life of Bulbs:** Under ideal environmental and electrical conditions operating normal effects, LightWild's LEDs are expected to last approximately 50,000 to 80,000 hours according to LED manufacturers. As with all light sources, users can expect a depreciation in brightness during the course of this estimated lifetime. A depreciation in brightness can be expedited by a change in environmental conditions, electrical uses, or the types of effects that are used on the Pixels.

* LightWild selects from an LED bin with a range of 2700K-3200K with a goal of matching 3000K for its warm white Pixel product and from an LED bin with a range of 5600K-9000K with a goal of matching 7300K for its cool white Pixel product.

## Appendix IV

**Data from an interview with Mr. Carl Corrigan, Director of Engineering Department of the Renaissance Vancouver Hotel at 10:00 am on December 3, 2007, Monday.**

The Renaissance Vancouver Hotel (RVH), is a 3-star hotel located in downtown Vancouver. It has 19 stories, includes 429 rooms and 8 suites, and is over 30 years old. The decorative arrangement of existing lighting on the top round structure, front façade, and rear façade of the RVH was designed by Vancouver's Bing Tom architecture firm in 1987 for the same building named the New World Hotel. The next buildings on both sides are black while the RVH has its beige-coloured stucco wall finishing. In order to make the hotel outstand from the black background, architect used outdoor decorative lighting to present hotel's welcoming attitude and attractive quality. Recently, 18-watt outdoor CFLs, which give out warm yellowish light, have replaced the former 60 watt incandescent light bulbs for increased energy efficiency and reduced maintenance costs. Photocell and timer have been used to control its outdoor decorative lighting. The RVH currently has a static CFL lighting array of 120 18-watt bulbs on its circular top structure and 194 18-watt bulbs on its façades including 110 CFLs on the rear façade and 84 CFLs on the front. In summer, the operation time starts from 9:30pm to 1:00am; in the winter, the operation time starts from 4:30pm to 1:00am. The whole outdoor lighting has no festival function and no colour/pattern change at different times. The whole hotel pays $20,000 per month on its electricity bill. The commercial rate of BC Hydro's electricity bill is 4.5 cent per KWH, which is lower than most electricity rates in Canada and the United States. The RVH has 3 Green Leaves due to its energy saving action. The RVH has flat roof for photovoltaic cell panel to accumulate electricity.

## Appendix V

### Data from Local Electrical Suppliers, Kris Chemenkoff from Bernard & Associates and Natasha Kennett from CDM2Lightworks

Maintenance cost:

Replacing a light fixture on the rooftop of the RVH costs $7.00/each

The estimated time of replacing light fixtures on a façade of the RVH is 24 hours and two electricians. An electrician costs at approximately $35.00/hour. The labour cost of replacement is equal to 2x35x24=$1680. Miscellaneous equipment rental is about $800.00/day; therefore the equipment rental of replacing light fixtures on a façade of the RVH costs $2,400.00 (Equipment rental day based on 8 hours)

(Adopted from Kris Chemenkoff from Bernard & Associates)

Fixture Cost:

An eW Flex SLX costs $750.00 USD/unit. Its lifespan is expected to last approximately 50,000-80,000 hours

An iColor Flex SLX costs $550.00 USD/unit. Its lifespan is expected to last approximately 30,000-50,000 hours

(Adopted from Kris Chemenkoff from Bernard & Associates)

An LW-UP-18-1C costs $105.00 USD/unit. Its lifespan is expected to last approximately 50,000-80,000 hours

An LW-UP-19-1C costs $105.00 USD/unit. Its lifespan is expected to last approximately 50,000-80,000 hours

(Adopted from Natasha Kennett from CDM2Lightworks)