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Economic Cooperation

Workshop to Support the Development of National Lighting Design Centers in APEC Region

Final Report

Energy Working Group
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INTRODUCTION

The energy used in the operation of buildings contributes to almost 40% of greenhouse gas emissions. Electric lighting accounts for 20-25% of this overall energy use; as such, best-practice lighting strategies and technologies represent one of most effective near-term opportunities for energy efficiency and greenhouse gas mitigation. Adaptive lighting controls, daylighting and solid-state technology (LED) represent a few of the emerging technologies and best practices that can achieve very large savings.

However, the uptake of new technologies and design practices has typically been slow, principally due to knowledge and experience barriers within the lighting design industry. Universities are in an ideal position to bridge these barriers by engaging both the profession and the industry in a range of activities; these may include research, demonstration, testing, education and training. In developed economies, university-based research and demonstration centers have proven to be effective at translating lighting design research into practice and accelerate broader adoption of best-practice technologies.

The APEC Expert Group on Energy Efficiency and Conservation (EGEEC) has supported this US led workshop. The two-day roundtable conference was hosted by King Mongkut's University of Technology Thonburi (KMUTT) in Bangkok, Thailand on 5-6 September 2013. It aims to understand how to effectively translate lighting design research into practice with a university research center model based on input from regional experts and stakeholders – government agencies, utilities, lighting industry and professional associations. Our long-term objective is to establish such a regional center at KMUTT and other APEC economies.

The first day of this roundtable conference was organized around a series of presentations on current lighting design research and operational models by successful lighting centers; energy efficient lighting policies and implementations by government agencies. On the second day, through group discussions, all stakeholders were invited to give input on shared vision, mission, strategies and recommendations on next steps to the development of lighting design centers in APEC region was developed. Forty speakers and participants from 12 APEC economies contributed to this US led APEC workshop (Australia; China; Indonesia; Japan; Malaysia; New Zealand; The Philippines; Singapore; Chinese Taipei; Thailand; USA and Viet Nam).

This report presents the outcome from presentations and discussions, and is organized in three themes 1) The opportunities of lighting design research for sustainable development 2) Research focus areas in APEC region 3) Recommendations on a model for effective lighting design center as well as a framework on next steps for the development of national lighting design centers in interested APEC economies. As part of the framework a supporting system and activities are also proposed in order to assist the developing process as well as to allow for sharing and exchanging resources of lighting research community in the APEC region. Finally, the last chapter reports on main findings from the workshop and the first steps of the development of national lighting centers at KMUTT in Thailand and other three APEC economies.

The workshop agenda can be found at the end of this report. Full list of presentations can be downloaded from: www.apec-lightingworkshop.org

CHAPTER 1

Opportunities of Lighting Design Research

This chapter provides a summary of presentations and inputs by lighting experts and key stakeholders. It gives an overview of energy efficient lighting policies and how lighting design research and translational activities, particularly demonstrations and education for practitioners, can support those policies in each economy. This helps to identify the opportunities of lighting design research for sustainable development as well as research focus areas for prospective regional lighting design centers in APEC region.

1.1 APEC and Lighting Energy Efficiency Overview[1]

APEC was created in 1989 to promote trade liberalization, trade facilitation and technical assistance. APEC economies account for more than one-third of the world's population, 60% of the world GNP, and 50% of world trade. APEC implements its activities through 14 working groups. The Energy Working Group (EWG) is one of them and is supported by 8 sub-fora groups, including Expert Group of Energy Efficiency and Conservation (EGEEC). As of April 2013, there were 6 ongoing APEC funded projects and a signature initiative is the APEC Energy Standards Information System (ESIS).

APEC EGEEC projects related to energy efficient lighting include Harmonization of LED Standards (Australia), Street & Outdoor LED Lighting Initiative Asia (SOLLIA) (USA), and self-funded APEC Workshop for the Promotion and Application of LED Technology (Chinese Taipei). Some of other building-related projects also involve energy efficient lighting and lighting design best practice, These include, for example, APEC Cooperative Energy Efficiency Design for Sustainability (CEEDS) implemented by Japan. It aims to promote "high-performance" energy efficiency policy measures in developing economies in a specific sector; Appliance energy efficiency standards and labeling and Building Energy Codes and Labeling are part of this project.

1.2 Experiences and Input from Stakeholders

1.2.1 Energy efficient lighting policies and roles of lighting research

Thailand

The final energy consumption in Thailand costs nearly 20% of the country's GDP and electricity use in building sector accounts for approximately 20% of the total energy use[2]. By 2030, the government has a long-term plan to reduce the energy use by 25%, based on the consumption of 2010, and aims to increase the number of zero-net energy buildings to 20%. The lighting power density (LPD) is set to reduce from 14 W/m^2 in 2012 to 2 W/m^2.

[1] *Introduction and overview of activities of the APEC Expert Group on Energy Efficiency and Conservation.* Presented by Dr Cary Bloyd, Electricity Infrastructure & Buildings Division, Pacific Northwest National laboratory, Richland, Washington, USA.

[2] *Energy Efficiency Policies and Strategies in Thailand.* Presented by Dr Twarath Sutabutr, Deputy-Director General, Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand.

Three main strategies have been implemented to promote energy efficiency 1) Law and regulations: the new building codes have been introduced in 2012. 2) Financial support: ECCO companies 3) Social awareness: to educate the public and to support the design professionals. According to the new building code two out of six building design parameters, namely building envelop and artificial lighting design, are heavily influenced by architects and lighting engineers and designers. Building Code Service center has been set up by Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy to support the design professionals with software that can evaluate the building energy use of their design.

For energy efficient lighting projects, the government policy is to promote wider use of LED by supporting large-scale replacement of conventional lamps in government buildings. The projects have been implemented by DEDE in collaboration with Electricity Generating Authority of Thailand (EGAT)[3], Provincial Electricity Authority (PEA) together with the Department of Highway, and Ministry of Defense. EGAT has also implemented voluntary labeling programs on MR16 LED for halogen substitutes.

For lighting design research and education, lighting experts at KMUTT have focused on daylighting and daylight harvesting, task-ambient lighting, and urban lighting[4]. Knowledge has been transferred to design professionals through teaching and training, and translated into real practice through consultant work for individual projects. Although these activities have been supported by the university and lighting industry, the impact of research on influencing building codes and real practice is still very limited. This agrees with the suggestions from lighting industry and Thai Illuminating Engineering Association (TIEA) that building codes and standards on lighting requirements should take into account the local context and be informed by scientific research[5]. They also agreed that there is a good potential that a national lighting center could support the R&D of innovative LED and OLED products, thus increasing the competitiveness of Thai lighting industry.

United States

California Lighting Technology Center: Lab to Marketplace.[6] California Global Warming Solutions Act (AB 32) aims to reduce GHG emissions to 1990 levels by 2020. For lighting energy consumption Huffman Bill (AB 1109), signed in 2007, aims to reduce statewide indoor residential lighting consumption not less than 50% and indoor commercial lighting as well as outdoor lighting not less than 25% from the 2007 levels by 2018. The *Vision for California 2020* targets at 60% reduction in net electrical lighting energy consumption and supports zero-net-energy buildings.

The energy efficient programs have started in the mid 1970's and so far California has avoided building 30 new power plants. This has been supported by 3 pillars: building standards, appliance standards, and utility programs - mostly lighting. California's annual energy savings in 2003 was around 40,000 GWh/year. Around 50% of the savings was the results of the utility efficiency programs, and the other half was from the building and appliance standards for California (Title 20 and Title 24).

[3] *Thailand Voluntary Labeling Program by EGAT.* Presented by Mr Pitarn Chaichinda, Director of Demand Side Implementation Division, Electricity Generating Authority of Thailand (EGAT), Thailand.
[4] *Lighting Research and Future Vision in Thailand- KMUTT.* Presented by Dr Acharawan Chutarat, School of Architecture and Design, King Mongkut's University of Technology Thonburi, Bangkok, Thailand.
[5] *Lighting Design Center: Needs from Professionals.* Presented by Mr Kitti Sukutamatunti, The Illuminating Engineering Association of Thailand (TIEA), Thailand.
[6] Presentation by Prof. Michael Siminovitch, Rosenfeld Chair, California Lighting Technology Center, University of California at Davis, California, USA.

Lighting is very important, not only because it consumes 25% of the total electricity use and is one of the largest single contributors to GHG. It is a also significant component for business cost and has important consumer impact such as in retail and hospitality sector. Equally important, new lighting technologies are developing rapidly. Efficient lighting design is therefore regarded as one of the largest near term opportunities to address energy issues. In 1998 the state, lighting industry, and the university agreed to create a lighting innovation center. In 2003 the California Lighting Technology Center (CLTC) was established at University of California Davis.

Mission of CLCT includes R&D, lighting demonstrations, education and training, and building codes and policy. It was emphasized that lighting research and product development can be successfully introduced into the market through well synchronized activities among partners, particularly the utilities and industry. New lighting technologies are developed and tested in the laboratory, those which have been proof to work in the controlled environment and economically viable will be demonstrated. These full-scale demonstration projects are needed to allow building users to experience the luminous-environment and energy consumption monitoring.

The demonstration projects are essential tool for education and training of related professionals. The results and evidence from the field monitoring and occupant's evaluation are useful in supporting the adoption of the new technology. It was highlighted that, to accelerate the adoption of these new technologies into real projects, the results should be developed into building codes and standards as well as inform the policies. Multi-disciplinary team of academics, designers/architects, engineers, and business development have contributed to the center's success.

Lighting Design Centers: Recipe for Success[7]. Working in collaboration with CLTC is Sacramento Municipal Utility District (SMUD), the US 6th largest publicly owned utility. It has a long history of conservation and committed to providing innovative strategies to energy efficiency and renewable energy such as Solar Shares and PV Pioneers. Other key strategies include promoting community engagement and providing public outreach through classes and seminars for schools and universities as well as regular public events. Education for public, in particular, is seen as the most sustainable form of energy conservation as it can influence people's attitudes and ultimately behaviour changes.

SMUD has its own state-of-the-art energy and technology center, where the public can get hands-on experience on innovative energy efficient technologies. Exhibitions include interactive display, a walk-in house, and other full-scaled demonstrations. For lighting research, it has partnered with CLTC to study and to test new lighting technologies in the laboratory and then demonstrate them to the public. It has also supported field demonstrations using LED with advanced controls, so local businesses can achieve large energy savings. These achievements such as Surf Extreme, a well-known retailer, are then advertised to encourage even a wider adoption of best practice.

China

Lighting laboratory at College of Architecture and Urban Planning at Tongji University in Shanghai, China has the mission to provide professional education and training for design professionals and lighting industry; conduct scientific and academic research in advanced and emerging lighting issues and technologies[8]. It also provides social and design service for national and provincial projects as well as product innovation and development for the lighting industry.

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[7] Presentation by Mr Alan Suleiman, L.C. LEED AP, Energy and Technology Center Director, Sacramento Municipal Utility District (SMUD), Sacramento, California, USA.

[8] Lighting Research and Professional Practice in China. Presentation by Prof. Luoxi Hao, College of Architecture and Urban Planning, Tongji University, Shanghai, China.

The team of lighting experts from Tongji University have contributed to evaluation and testing and designing services for several high profile projects, especially during the Beijing Olympics and the Shanghai World's Expo. It was pointed out that the added benefit of having a university-based lighting design center is to use the real projects for student assignments, then the results are applied in practice. The lighting laboratory has a wide range of light sources and lighting systems with flexible arrangement - to provide hands-on experiment and learning experiences. These facilities are also used for professional trainings. Research focus areas are LED in urban areas (SPD and visual recognition), light and health (circadian system), and non-visual effects of light on moods and well-being - this has been implemented in the operation room at the hospital. Product innovation includes flexible LED luminaire with different light distributions and colour.

Another prominent lighting laboratory in China is based at the Key Laboratory of New Technology for Construction of Cities in Mountain Area, Chongqing University (NTCCM).[9] It comprises four specific labs: 1) Architectural Optics Laboratory for photometry lab 2) Architectural Lighting Laboratory for lighting design system for architecture and design 3) Tunnel lighting Laboratory 4) Healthy lighting laboratory. In particular, the tunnel lighting lab is needed due to the natural landscape around Chongqing areas.

The multi-disciplinary team of researchers have worked on physiological, psychological and biological effects of light in various applications, including classrooms and factories. For research on health effects of light, the lighting experts collaborate with the medical team from Chongqing Medical University. Other research focus areas include urban lighting design, which is similar to the lighting lab at Tongji University. The lighting expert pointed out that although the research is on similar topics, the methodologies used are different. It was suggested that there should be sharing and exchanging of information among lighting laboratories, while each lab still maintain its unique approach.

Singapore

In Singapore, electricity use for building accounts for almost 50% of the total electricity use[10]. The largest consumptions are from air-conditioning and lighting, which account for 30% and 11% of the total electricity use respectively. Thus Singapore Green Building Council (SGBC) has the mission and programs to promote sustainable design best practice and to provide outreach and education to the public. This include Building and Construction Authority (BCA) Green Mark labeling, a green building rating system to evaluate buildings for their environmental impact and performance launched in 2005. Energy efficiency is one out of five key assessment criteria. As of July 2013, 1,655 buildings are certified; this accounts for some 20% of total existing building floor space.

As lighting constitutes a large percentage of electricity use in buildings, there is an initiative to establish Singapore lighting research center with the mission to advance the effective utilization of lighting technologies and design strategies for achieving energy saving, while enhancing visual performance and comfort. SGBC, BCA, industry, Nanyang Technological University (NTU) and Singapore-Berkeley Building Efficiency and Sustainability in the Tropics (SinBerBEST) are among the stakeholders. As a stakeholder for the proposed lighting research center, SinBerBEST has

[9] *Lighting Research and Innovation in China.* Presented by Prof. Yan Yonghong, Department of Building Science&Technology, Faculty of Architecture&Urban Planning, Chongqing University, China.
[10] *Research efforts in lighting technologies in Singapore.* Presented by Prof. TSENG King Jet, Nanyang Technological University and Dr CHIEN Szu-Cheng, Berkeley Education Alliance for Research in Singapore (BEARS) Center. Singapore.

currently focused on the utilization of daylight to replace or supplement the use of electric lighting in office buildings.

A research project 'Living Lab' has started in January 2013 to evaluate daylight performance in tropical office buildings. Apart from daylight performance and energy efficiency, it aims to provide comprehensive understanding of visual performance and occupant comforts, using a parametric approach. The results indicated that the interior surface reflectance, the visible light transmission of the glazing, and internal shading control's behaviour have stronger influences on daylight performance and visual comfort than the light shelves. Phase two of this study will explore other parameters and develop a network-control system to optimize the quantity and quality of daylight for office buildings in the tropics.

Malaysia

Green building policies are an important agenda for the government of Malaysia. Some key initiatives involved the studies of energy saving potentials of a newly designed green building compared to a base-case, then followed by the construction of demonstration projects[11]. These low-energy and zero-net energy buildings (LEO and ZEO) were built to demonstrate advanced green building technologies, including the use of external shadings, energy-efficient and smart control lighting. It was hoping that these best practices together with green building labeling will encourage the private sector to invest in more green buildings.

For lighting research, daylighting in the tropics has been a main focus because it has direct impact on the quantity and quality of lighting in the buildings. At the same time, it has influence on the design of building envelop and overall building energy use. With the support from Public Works Department of Malaysia, the lighting experts conducted research on optimized daylighting in selected public buildings. The lit-environment from both daylight and artificial light as well as occupants' responses in several government office buildings were quantified.

Extensive field measurements, computer simulations, and scale model studies were carried out in order to understand the current design parameters and to propose design guideline that can improve daylighting performance and occupant's comfort for government office buildings. The research outcomes were also used to develop a simplified daylighting design guideline for architects. The guideline was tested during the workshop with the potential users and their feedbacks were then used to improve its contents.

Indonesia

The Indonesian government has committed to a long-term plan to reduce 26% of greenhouse gases emission by 2020 - employing legal, fiscal, institutional, and financial instruments[12]. The government has also initiated channels to educate and to disseminate knowledge to the general public by setting up the Energy efficiency and conservation information center. It was suggested by the Indonesian expert that in the future the information and knowledge on energy efficient lighting could be part of this center. For building sector, the government also aims towards net-zero energy buildings and Green building Council of Indonesia (representing World Green Building Council – WGBC) has played an important role. At the local government level, Jakarta province green buildings code aims to achieve 30% of CO_2 reduction by 2030.

[11] *Daylighting and Green Building Research and Policies in Malaysia.* Presented by Assoc. Prof. Mohd Zin Kandar, Faculty of Built Environment, Universiti of Teknologi Malaysia and Mr Fadli Arabi, Public Works Department of Malaysia.

[12] *The Status of Lighting Programs in Indonesia.* Presented by Mr Totok Sulistiyanto. Indonesia.

According to the energy efficiency guidelines, Energy Efficiency Indexes for main building types are provided; three out of five building system components (envelope optimization, lighting optimization, and control systems) involve architects and lighting design professionals. As lighting energy consumption is around 20% in commercial buildings, thus the focus for energy efficient building is on effective daylighting and lower lighting power density. Technical design procedures for daylighting and artificial lighting systems are available; computer simulations have been employed at the design stage and field monitoring is used to verify the energy savings after the building operation. Best practice buildings designed with daylighting and energy-efficient lighting have been reported to save energy between 30-45% compared to a base case. The lighting power density in these buildings is between 4.5-6 W/m^2, only 50% of the levels recommended by ASHRE Standard 90.1 (2010).

Chinese Taipei

Chinese Taipei is among the world's leading suppliers of LED and the government has led several major programs to increase the competitiveness of the LED lighting industry[13]. Research and large scale demonstration as well as installation projects have been supported by the Bureau of Energy (BOE) MOEA, while the Industrial Technology Research Institute (ITRI) has carried out the R&D activities. Similar to other APEC economies in Asia, some early programs involved the replacement of conventional lamps with LED streetlights in towns and cities across the country. In 2013, it also promotes the use of LED (A19) for indoor lighting application to replace the inefficient incandescent. The large-scale installation of streetlights in various towns and cities provides the opportunity for long-term monitoring of product performance and investigating how to improve quality and to reduce failure. The government's support on the development of national standards and certification scheme also played an important role in improving LED lighting products and building a stronger LED lighting industry.

The latest research trend includes a prototype of an intelligent iLE technology, integrating unique optical package, advanced thermal management technology and high efficacy LED chip together with intelligent driver IC. This will enhance the competitiveness of LED industry through better light engine efficiency, lower cost and intelligence of the system. Another trend is research on human factors have also been carried out and highlighted as an unique opportunity for LED lighting to take up market share by better understanding how innovative products can improve our lighting experiences. These include the Just-perceptible-colour temperature and Just-acceptable of two adjacent LED panels in office environment, which will have an impact on the building user's acceptance of the new LED lighting systems.

Viet Nam

In 2000 the Viet Nam Energy Efficiency Public Lighting Project (VEEPL) was approved by the United Nations Development Program and co-funded by the Vietnamese Government. The program supported the plan to install and promote the use of energy efficient lighting in streets, schools, and hospitals across the country[14]. Main achievements (2006-2011) included providing technical assistance for Vietnam's energy efficient lighting policy development; technical assistance for lighting industry of Vietnam; demonstration projects and communication of EEPL models[15]. By 2013,

[13] *The Research, Deployment, and Standardization in Chinese Taipei.* Presented by Mr Shiaw-Jiun Bor, Bureau of Energy, MOEA, Chinese Taipei and Dr Ming-shan Jeng, Industrial Technology Research Institute (ITRI) Chinese Taipei.
[14] Available at: http://www.c40.org
[15] *Urban Lighting Research and Implementations in Vietnam.* Presented by Dr Luong Thi Ngoc Huyen, Architect and lighting expert, Coninco, Vietnam.

the cumulative CO_2 emission reductions and energy efficiencies are estimated to be 568 KTons and 1,321 GWh respectively.

Next step for public lighting is set by Viet Nam Urban Lighting Development Plan by 2025. The Ministry of Construction also made the decision to integrate public lighting into city's construction master plan. Urban lighting has been recognized as a tool not only for energy efficiency, also for creating urban identity and boosting tourism and local economy. Thus, the government has supported the development of urban lighting design and management guidelines, based on several international and national standards such as CIE, IESNA and BSI. Due to the lack of qualified lighting designers in Viet Nam, it was hoping that the design guidelines will change the current practice and contribute to a better quality lighting and more sustainable urban development.

Japan

In 2009, Japanese government implemented a large economic-stimulus package that included the Eco-point Program to stimulate consumer purchases of energy-efficient household appliances, including LED products[16]. Japan high LED lighting adoption has continued due to electrical power limitations and energy-saving efforts after the tsunami and nuclear crisis in 2011. The country's market share for LED bulbs was 63% in 2011 and will remain the biggest lighting market until 2014.

The Institute of Energy Economics, Japan (http://eneken.ieej.or.jp/en) reported on the electricity-saving potential of LED lighting and concluded that if all lighting in Japan was switched to LEDs, the total potential savings would amount to 92.2 TWh/year, equivalent to 9% of Japan's current total energy consumption. The breakdown of the savings shows that the greatest potential exists in offices and commercial buildings.

For lighting industry, as the price downtrend persists, LED lighting firms have been exploring other markets such as convenient store lighting and office lighting, aiming to increase their products' added value and increase their market acceptance[17]. Lighting product research and development as well as application centers (i.e. showroom) in Japan are provided mainly by lighting manufacturers. The emphasis is on new generation LED luminaire with improved efficacy and colour rendering properties; LED products with integrated smart and wireless network controls are also being promoted[18]. Lighting industry also supports lighting education through workshops for leading universities including Tokyo University of Science and University of Tokyo.

1.2.2 Recommendations on lighting education for practitioners

Lighting education has been well-established in the APEC economies, particularly in Australia and the United States. Post-graduate degrees at the University of Sydney and Queensland University of Technology (QUT) in Australia are among the leading programs available. According to Prof. Cowling, post-graduate lighting programs at QUT are supported by three pillars: education, research, and testing services[19]. The current trend of lighting education is now moving to Continuing Profession Development (CPD) type, which should suit the practitioners better. It was suggested that the students should learn the basic science of vision and colour, photometry, and daylighting,

[16] *Japan's Eco-point Programs Transforms Market for LED lamps.* Article by Philip Jessup. LEDs Magazine, July/August 2011. Retrieved from: http://ledsmagazine.com/features/8/7/6
[17] *What is next for Japanese Lighting Industry.* Article by Lowy Chang, Published on September 2012. Retrieved from http://ledinside.com/outlook/2012/9/whats_next_japan
[18] *Thoughts on Future Vision and Challenges for Lighting Industry.* Presented by Mr Yoshio Takamori, General Manager Asia-Pacific, ENDO Lighting Corp, Japan.
[19] *Lighting at QUT.* Presented by Assoc. Prof. Ian Cowling. School of Chemistry, Physics and Mechanical Engineering. Science and Engineering Faculty, Queensland University of Technology, Brisbane, Australia.

as well as the issues of human factors and controls. The basic knowledge is essential to the application to energy efficient and good quality lighting design.

Current research at QUT is design-related and includes daylighting, energy efficient light sources, photometry, environmental effects of light, and human factors in lighting. For prospective lighting centers in APEC region, QUT would be glad to collaborate in both teaching and research; common interests include lighting in the tropics - daylighting and lamp performance.

Mr Cuttle[20], an experienced educator and a lighting designer, also agreed with the significance of the basic knowledge. In addition, he suggested that the students should be encouraged through project work to discover the shortcomings of current practice, and search for better solutions through research. Some failures to relate to human response to illumination include: visual adaptation, circadian response, colour rendering of light sources, spatial distribution of light and temporal distribution in the space. It was proposed that for project works, the students should be encouraged to explore alternative ways of measuring illumination for closer correspondence with typical human response. At least one location should be equipped to provide a range of controlled illumination conditions for subjective assessment studies.

Additionally, Prof. Mohd Zin Kandar also highlighted the lack of basic education for architects in daylighting and energy efficient lighting. This situation may also reflect what has happened in other developing economies such as Thailand. It represents the general discrepancy between the expectation of the architect, who have significance and direct influence on building energy use, and their capability in designing low-energy and sustainable buildings. This may require that the contents and tools for teaching and training for practitioners are developed to suit each group of users and their level of basic understanding.

1.3 Research Focus Areas for APEC Region

1.3.1 Daylighting and Daylight Harvesting

Daylighting Design

Many APEC economies in this region (see Figure 1.1) including Thailand, Malaysia, Singapore, Indonesia, the Philippines and part of Australia have tropical climates. Due to the luminousity of sky, daylight offers a great potential for illumination in buildings. In Thailand, for example, it was reported that the daylight illuminance on window during normal working hours (8:00-17:00) exceeds 5000 lux more than 90% of the time regardless of orientation[21]. Despite the available daylight, its excessive amount and the presence of direct sunlight could contribute to heat gain in the buildings. This is particularly the case for most commercial buildings where large areas of glass facade are used without proper design of external shading and fenestrations to keep out direct sunlight and redirect daylight deep into the building interiors. The interior layouts and shading devices are also not effective in providing quality lighting and visual comfort; most window blinds are drawn down most of the time and rarely adjusted. Thus daylight is generally underutilized and, according to the lighting experts in the region, daylighting in the tropics is among the most common focus areas. Currently daylighting research has been conducted in Malaysia, Singapore, Thailand, and Australia, while the experts from the Philippines agreed that there should also be daylighting study and promotion in the

[20] *Proposals for National Lighting Design Centre.* Mr Christopher Cuttle, New Zealand.
[21] *Daylighting in the Tropics: daylight availability, sky luminance distributions, daylight application with automated window-blind* Pipat Chaiwiwatworakul. Lambert Academic Publishing. 2011.

economy[22]. Additionally, it was suggested that daylighting research in the tropics should focus on the optimum design of building envelop, shading devices, interior layout, and occupants' control behavior. The local context such as culture and expectations of daylight and sunlight should also be considered.

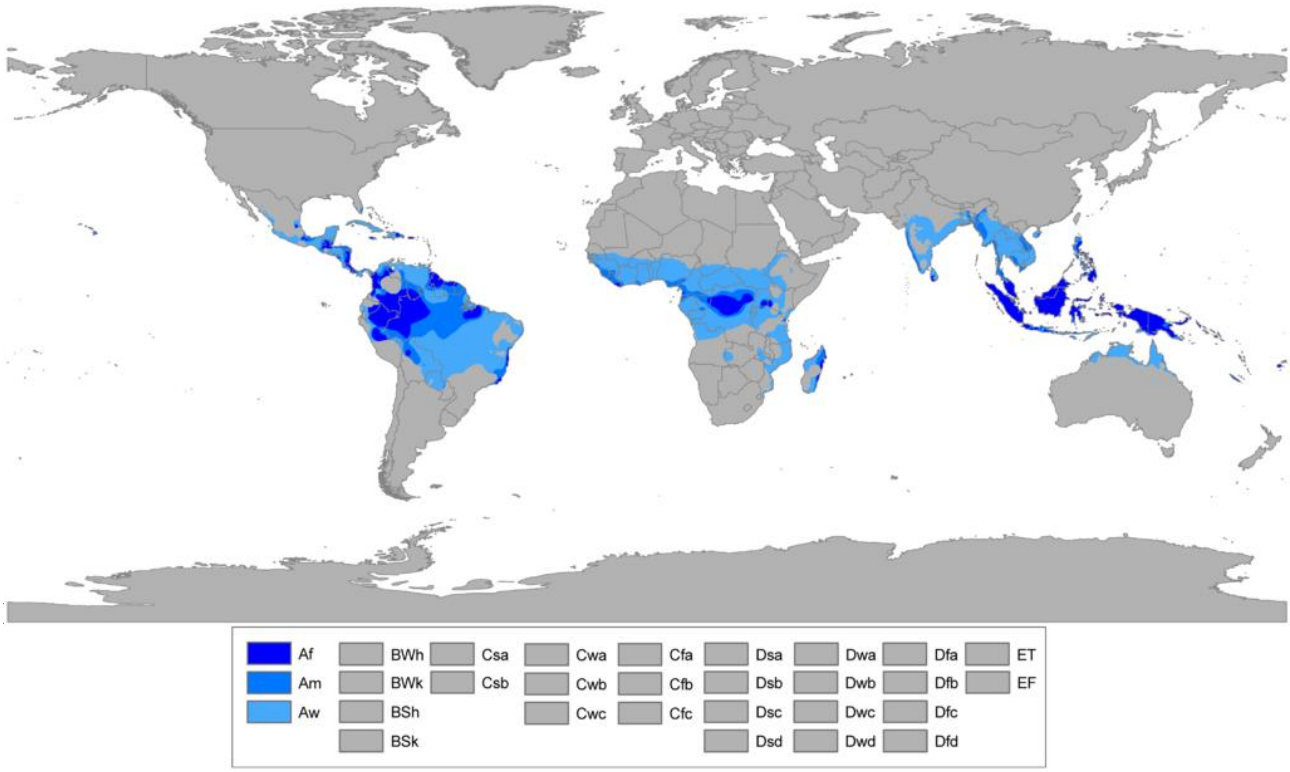


Figure 1.1 Map of the Tropics
(available at http://en.wikipedia.org/wiki/Tropics)

effect of daylight availability in each location on the amount of daylight in the interior may be less significant. This is particularly the case for existing buildings where little can be done to alter the building façade and fenestrations. It was suggested that lighting design research could look into how to benefit from the incoming daylight. On-going research and demonstration projects at University of California include the use of bi-level switches for private offices, where occupancy sensors automatically turn on 50% of room lighting, then occupants could either manually switch it off if they feel daylight is sufficient or top it up to 100%. The development of simplified daylight dimming systems is also needed because of errors due to the commissioning of the photosensor and occupancy sensors as well as the high costs of the continuous dimming systems.

1.3.2 Energy Efficient Lighting Products and Design

With current lighting technologies and design strategies, the lighting power density (LPD) for most commercial buildings can be reduced up to 50% compared to the AHRAE Standard 90.1. However,

[22] *A Proposal to the APEC Workshop to Support the Development of National Lighting Design Centers in APEC Region*. Presented by Dr Enrie A Mendoza and Mr Alessandro Abbate, ILDAP Founder of the Lighting Designer Association in The Philippines.

to achieve the long-term goal towards net-zero energy building where LPD is near zero, great effort is still needed. LED's performance and colour quality should be improved.

The full potentials of advanced LED technologies in combination of information technology have to be realized; the adoption of current lighting system design has to be accelerated. According to the lighting experts, two main areas of research on energy efficient lighting emerged: the development of better performance and intelligent LED luminaire and the efficient lighting design systems**.** While the first involves lighting product innovation based on rapidly developing LED technologies, the latter requires the integration of efficient lighting design and control systems with architecture and interior.

Better and Smarter LEDs

Although the penetration of LED lighting product has increased dramatically in recent years, there are still several barriers to its wider use. These mainly due to its relatively high initial cost and the following performance issues: system efficacy and its actual life as opposed to expected life time; colour appearance and colour rendering properties. The colour properties of LED are very essential to the application where atmosphere of the place and colour accuracy of the object displayed is the priority. These include retails and hospitality applications which typically use a large number of inefficient tungsten halogen (CRI > 95), thus require higher lighting power density than general commercial space such as offices. Other performance such as luminaire efficiency and lifetime still depends on other factors, particularly the optical design of lens and luminaire; and heat dissipation system.

Apart from the improvement of LED performance and colour properties, to take full advantage of LED technologies, LED product is being developed to be more intelligent and flexible. This is also another approach to add value to the LED products in the time of strong price competition. As presented by the expert from Chinese Taipei a prototype of the new integrated Light Engine (iLE) technology has been developed using IC technologies for driving the light engine. It can receive feedback and send the signal to the luminaire for heat management and multiple beam angles adjustment. The development of such an innovative product not only needs technical study, but also the application requirements from the design practitioner.

Task-ambient Lighting Systems

For commercial buildings where typically a uniform light distribution to the entire space is provided, regardless of whether visual tasks are being performed, lighting consumption is around 25-25%. Task-ambient lighting systems, which reduce light intensity for the general area and provide more task illuminance or localized lighting at the work space, can reduce the lighting electricity use by up to 50%. In addition to the energy saving, it could also improve the luminous environment and the user can have fine adjustment of light levels to suit their visual needs. In principle this strategy may sound simple and has been recommended by most design guides. However, in practice there are still several issues that have slowed down its widespread use.

The reduction of general lighting also reduces the luminance of major surfaces such as walls and ceilings, which has a direct effect on the building occupants' brightness perception of the space. As a result, this can have negative impact on occupants' acceptance of the system. According to study at KMUTT[23], the acceptable light level of general lighting for a typical office use should be between 250-300 lux, and additional vertical cove lights to the walls could compensate for the reduced

[23] *Lighting Research and Future vision in Thailand-KMUTT.* Presented by Dr Acharawan Chutarat, School of Architecture and Design, King Mongkut's University of Technology Thonburi, Bangkok. Thailand.

ambient light. However, it was found that the poor quality of task lights on the mass market and the high cost of good quality ones is also another barrier. In addition, due to the limited surface area, the presence of a task light on workstation may cause an inconvenience to the user. The integration of LED task light into the design of workstation can help solving this issue.

Adaptive Lighting Systems

Lighting is often left on full power during the time that the space is rarely used due to safety and security reasons. In the US, smart control systems with high and low light levels setting that respond to the presence of users have been proofed to reduce the energy being wasted, while improving users' perception of safety and satisfaction[24]. Public areas such as corridors, bathrooms, parking lots, and pathways are good candidate for such systems. However, the application of smart control systems in other economies should take into account the local context and expectation of users. For example, the optimum and acceptable light levels of high and low setting as well as light distribution within the users' field of view that still provide good visibility and perceived safety can be the subject of further study.

1.3.3 Urban Lighting

Due to rapid urbanization, by 2030 some 5 billion of world population will live in urban areas of towns and cities (http://www.unfpa.org/pds/urbanization.htm). This is particular the case for developing economies in Asia such as China and Viet Nam. While urbanization brings favorable setting for better quality of life and accessibility to job and education, the challenge for sustainable development is the increasing demand for energy use and other resources. To facilitate the urban life at night-time lighting for public infrastructure such as roads and bridges is required for providing safety and security as well as serving recreational purposes in public parks and squares. At the same time, energy-efficient lighting design strategy that also minimizes light pollution into the atmosphere is an essential topic.

Additionally, urban lighting has also been used to boost local economy and tourism by highlighting significant landmarks and enhancing the image and local identity of towns and cities. This usually requires a collaborative study with other stakeholders of the cities in order to establish a coherent lighting strategy or light plan, which will provide design guides for specific element of the cities. This is especially important for towns and cities with cultural heritage where its historical and architectural values can be either enhanced or undermined by the application of lighting. Thus experts in China, Vietnam, and Thailand have been actively involved in this relatively new area of urban lighting research.

1.3.4 Light and Health

Since the discovery of the third type of photoreceptor in the retina of human eyes about a decade ago, we've learned that processing of light information by the circadian (24-hour biological clock) and classical visual systems is different. These photosensitive retinal ganglion cells (pRGCs) do more than regulate the biological clock, and are involved in other irradiance detecting tasks that regulate sleep, alertness, hormonal rhythms and pupil constriction[25]. The effects of lighting application on the rhythm of melatonin and cortisol hormones, which influence the sleep quality and levels of alertness, has been the subject of interest of many lighting experts. More studies are still

[24] *California Lighting Technology Center:lab to marketplace.* Presented by Prof. Michael Siminovitch, Rosenfeld Chair and Director California Lighting Technology Center, University of California at Davis, USA.
[25] *Cambridge Neuroscience Public Lecture: Light, clocks, and sleep: the discovery of a new photoreceptor within the eye.* Public lecture on 20th March 2012 at University of Cambridge by Prof. Russell Foster, Retrieved from http://www.neuroscience.cam.ac.uk/news/article.php

needed on the effects of some specific wavelengths e.g. blue and amber, light intensity and duration of light exposure for certain type of application such as residential, nursing homes, and hospitals where there are night-shift workers. Benefits also include better sleep quality, work performance, general health and well-being.

Although this is not directly related to the energy saving, the experts believe that research in this area will gain more importance as people are more concerned about better health and well-being. Thus the knowledge in this area could provide specific design guidelines and generate lighting products that tailored to each specific application such as hospitals, nursing homes, and schools.

Also, with rapid development and strong emphasis on the promotion of LED in both outdoor and indoor applications, there is a common concern among the experts for the potential harmful effects of blue spectrum from the use of white LED, when the phosphor deteriorates near its end of life. This could cause irreversible damage to the retina. The experts agreed that a long-term study of this effect is needed; and the application of LED for indoor lighting should be considered with care as most people tend to spend more time in the buildings, thus increasing the time exposure to the blue spectrum.

1.4 Opportunities for Lighting design Research for Sustainable Development

1.4.1 Reduce Energy Use and Environmental Impact

Most APEC economies have common energy efficiency policies and long-term goals toward green buildings and zero-net energy buildings by 2020 and 2030. To achieve these goals, some of the main strategies include codes, standards, green labeling programs for appliances and buildings. Demonstration projects have also been implemented; the replacement of conventional light sources with LED for streetlights and government buildings is among the most prevalent. In some cases where lighting best practice such as daylighting and energy efficient lighting design are integrated with the design of building, the energy use can be reduced by 30-45% and lighting energy use decreased by at least 50%.

Further lighting energy savings, however, can be achieved with the integration of advanced LED lighting, smart controls, daylighting design, and daylight harvesting. For exterior lighting, appropriate design technique and luminaire with well-control optic can minimize light pollutions or wasted light into the sky. Efficient lighting design is, therefore, one of the largest near term opportunities to address energy and environmental issues. To realize its full potential, however, more studies on these topics are still needed. They should consider not only the technical aspects, but the visual perception and other human factors such as control behavior.

1.4.2 Social and Economic Development

In addition to the reduction of lighting energy consumption and GHG emissions, the opportunities of lighting design research also include social and economic development. Good exterior lighting could help promote safety and security, and provide well-lit and pleasant night-time environment. As presented in the previous section (1.3.3) urban lighting research could provide lighting master plan or guidance for coordinating town and city planning and public lighting. In many cities, well-coordinated urban lighting has been used as a tool to promote tourism and local businesses at night.

For economic development, as seen in Chinese Taipei, lighting design research has played an important role in building competitiveness for its LED lighting industry by supporting the development of national standards as well as more intelligent and innovative LED products. The added values

are particularly important for the lighting industry when the price of LED has been in the downward trend. Research on human factors in lighting such as psychological perception of the luminous environment are considered as a unique opportunity to the development of innovative products as it can shorten the time-to-market.

CHAPTER 2

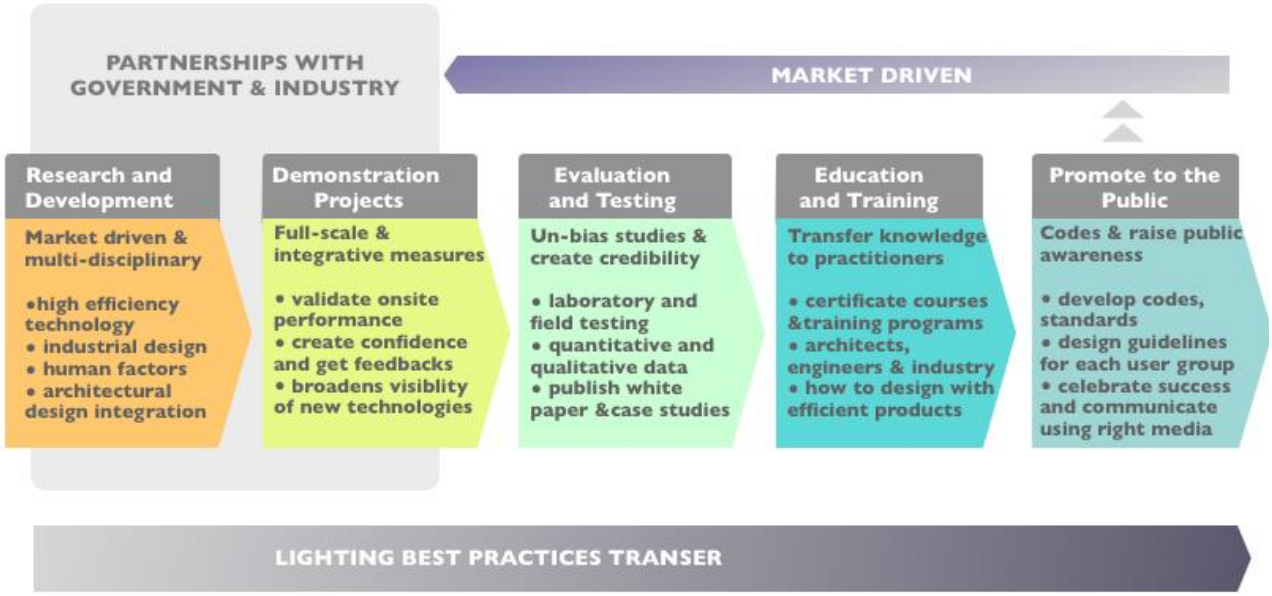
Recommendations and Framework for Next Steps

This chapter presents recommendations on a process and main activities for a university-based lighting center to effectively translate lighting research into practice, based on strong partnerships with government and industry. These have been developed into a framework for next steps in developing lighting design centers in interested economies, which will be supported by initiatives proposed by the participating experts.

2.1 Shared Vision and Key Activities

2.1.1 Shared Vision and Mission

'Light for Life Towards net-zero energy building and better lighting for health and well-being', the shared vision for lighting design centers in APEC region was developed at the workshop. The vision clearly reflects the participants' holistic view of energy-efficient lighting research and its potential beyond energy savings. The experts were in agreement with the general mission that it should support technological and design innovation; support business opportunities; advance education and training; and support more insightful policy and effective building codes. They also put an emphasis on raising public awareness on the importance of energy efficient and quality lighting.



2.1.2 Key Activities and Objectives

For a university-based lighting center to effectively translate lighting design research into practice, a process and key activities as shown in Figure 2.1 is proposed. It was adapted from the model

originally put forward by Prof. Siminovitch[26] and subsequently refined to include strategies and recommendations obtained from the workshop. It was strongly suggested that the process and activities are market-driven and supported by partnerships with key stakeholders. Objectives and strategies for each main activity are described below.

R&D technology, Products and Design

The aim of R&D activity is to develop a broad cross section of new products and systems that address lighting needs with new high efficiency technology. It should be market-driven and supported by requirements from stakeholders such as policies, codes, and new advanced technologies. It can include the following: optical, electrical, and mechanical design; industrial design and human factor; architectural and interior design integration.

The experts also recommended that lighting research should be of multi-disciplinary nature in order to achieve novel solutions and to strengthen integrity of the study. A lighting center should seek allied partners and institutions that have mutual interests to provide supports, academically and financially. They also emphasized that energy efficient lighting research should address the human factors and behavior as many research confirm that these could have as significant impact on building energy use.

Demonstrations

It was suggested that demonstration projects should be developed in partnership with utilities and/or industry partners. The objective is to translate research results into full-scale initial installation in real buildings, in order to validate on-site performance. Demonstrations also create confidence and provide feedbacks from real users regarding lighting quality and acceptability, which can then be used for further improvement. They also increase visibility of new lighting technologies among potential users and specifiers, especially for successful demonstrations with well-known partners where large savings on lighting are achieved[27]. Another strategy recommended by the expert is that demonstration projects should address integrative measures such as building envelope design, smart controls, and users' behavior.

Evaluation and Testing

With its impartial role, a university-based lighting center has an advantage to create credibility by engaging in un-bias studies and testing of new products and efficient lighting applications. The objective is also to develop quantitative and qualitative data on the performance attributes of the new technologies and system. This can include laboratory and field testing. It also covers quantitative photometric indicators, energy efficiency, cost effectiveness, and subjective evaluation/human factor issues. It was recommended that a base-line of electricity use for lighting in each type of application can be created as a basis for future comparisons with the application of new lighting technologies. Where possible, the lighting experts suggested that results from the evaluation and testing should be published as white paper and case studies.

Education and Training

The objective here is to educate practitioners such as architects, engineers, and facility managers as well as end-users on how to design with efficient products. Knowledge transfer can be offered

[26] *"California Lighting Technology Center: lab to marketplace"*. Presented by Prof. Michael Siminovitch, Rosenfeld Chair, Director California Lighting Technology Center, University of California at Davis, USA.
[27] *"Lighting Technology Centers: recipe for success"*. Presented by Mr Alan Suleiman, Director of Energy and Technology Center, Sacramento Municipal Utility District (SMUD), California, USA.

through hands-on workshops, certification classes and training programs. These courses could be organized to fulfill continuing professional development program (CPD), in collaboration with professional organizations such as national architect and engineer associations.

Technology Transfer to the Public

This activity aims to transfer knowledge and experiences to a wider audience of practitioners and industry. It also aims to educate and raise awareness on energy efficient lighting and lighting quality to the general public. The activity can include building standards, product design guides, application design procedures, industry partnerships, Intellectual Property Rights (IPR) and license agreements. The experts recommended that knowledge should be translated into suitable forms for each target group such as design guideline for architects and quick tips for home-owners. Another interesting strategy is to explore new channels for distributing and promoting the knowledge such as mobile apps in order to reach different target group effectively. In addition to the main activities described above, another important strategy proposed by the experts is sharing knowledge and information among lighting experts in the APEC region, which has now been integrated into the framework for next steps described later in this chapter.

2.2 Recommendations on a Lighting Center Facilities and Management

Requirement for Laboratories as Part of a Lighting Center

Laboratories as part of a lighting center should consist of three parts: 1) the main experimental space for research 2) the area for laboratory equipment, computers, and servers 3) the area for basic lighting education and training. The main area for research should have empty space with flexible layout and adjustable interior design parameters[28], particularly wall and ceiling reflectance and heights as shown in Figure 2.2. There should be possibilities to black-out windows, if any, in order to create dark room for testing and measurement of light sources and luminaire. It is also essential for setting up experiments where the effects of daylight have to be excluded. Lighting systems should be flexible and have ability to link with advanced control systems.

For lighting education and training area, it should address the issues of visual perception, lighting technologies and architectural integration such as comparison of light sources, luminaire distributions, colour qualities, lighting techniques on objects and applications. Basic equipment for

Figure 2.2 Flexible space for lighting research at Tongji University

[28] *Lighting Research and Professional Practice in China.* Presented by Prof. Luoxi Hao, College of Architecture and Urban Planning, Tongji University, Shanghai, China.

lighting education and research should include digital luminance and illuminance meters as well as photocells for data-logging over a period of time.

With rapid development on LED and OLED technologies, illuminance spectrophotometer[29] should also be useful for evaluation of these next generation light sources. It can measure illuminance, color temperature, CRI (Color Rendering Index), chromaticity, and spectral power distribution, and S/P ratio of scotopic illuminance and photopic illuminance[30].

Other facilities and space requirements depend on specific mission and research focus of each center, target groups, and methods of study. As presented by the expert from Chongqing University, where there will be testing of lighting for tunnels and bridges around the area, the space needed is relatively higher and larger than other laboratories[31]. Also if the mission is to provide product testing and calibrating measuring equipment for industry, the lab should be certified to national or international standards[32].

For daylight research, apart from a weather station for measuring sky luminance and daylight availability, full-scaled mock up rooms with flexible fenestration design, visible transmission of glazing, and facade orientations will be needed to validate the results from computer simulations and scaled-model studies. This is particular important for the study of glare perception and occupant behavior such as the control of window-blinds and acceptability of daylight-linked dimming controls.

Relationship with Lighting Design Profession

A lighting design center based at a university has an advantage on being impartial, which is essential for establishing credibility for research results and design suggestions that will be provided to the design profession. Lighting is a fast changing technology and new issues have arisen such as latest LED and health effects of light; at the same time, there is so strong competition on lighting market that a flux of products and information can create uncertainty among the design professionals.

Facts and figures from un-bias performance testing, systematic evaluation or field study on the new products and system integration are needed as a basis for their design decision. Thus a lighting center can provide a credible, reliable, and timely study as their source of reference on new technologies and innovative system application. In this regard, a lighting design center could bridge a gap between scientific and applied research and the practice by translating that knowledge and develop it into case studies and design guidelines; organizing courses and training programs to transfer the knowledge.

Relationship with Industry and the Government

As emphasized at this workshop, successful lighting centers have established and maintained good relationship with the government, utilities, and lighting industry. Each economy and government has common policy and mission towards sustainable development; there are strategies, programs, laws and regulations put in place to promote energy savings and industry competitiveness. Industry also strives for business opportunities and competitive advantage. A lighting center can support the

[29] http://sensing.konicaminolta.us/products/cl-500-illuminance-spectrophotometer/
[30] *Proposals to Lighting Design Center -KMUTT.* Presented by Mr Chritopher Cuttle. New Zealand.
[31] *"Lighting Research and Innovation in China"*. Presentation by Prof. Yan Yonghong, College of Architecture and Urban Planning, Chongqing University, Chongqing, China.
[32] "*Lighting Education at QUT".* Presented by Assoc. Prof. Ian Cowling. Queensland University of Technology (QUT), Brisbane, Australia.

government and industry by establishing partnerships to develop R&D, design and innovation, based on these requirements.

Through a range of activities including demonstrations, education, and outreach programs, the knowledge and technologies obtained from the studies can be effectively transferred to practitioners and the general public. At the same time, new technologies and design systems that have been proofed to be economically sound and accepted by users can inform policy and influence codes and standards. Thus the process could help accelerating the adoption of best practice and raising awareness of the public. For the industry, this process could provide confidence for users and reassurance for market acceptance of new technologies and products. As a results of the partnership, intellectual property (IP), including patents and design rights, can be an important contributor to the company competitiveness.

Universities to Leverage Opportunities and Maximize their Impact

Universities in the APEC economies could work together and leverage opportunities to maximize their impact by sharing knowledge and experiences as well as collaborating on research and teaching. As learned from the workshop, although some universities have been studying similar topics, each of them has their own strength and employs different methodologies. Some have strong architectural and product design background and are keen on experimental study and field works, while others have engineering approach and mainly use computer simulations. Each of these approaches can complement each other very well and may give different insights into the same topic of study.

It was also proposed that should be a forum where the universities and stakeholders can come together and exchange experiences on their research that have been applied into real projects. Lessons learned from full-scale demonstrations and field studies would also be very valuable. As suggested by the experts from QUT and Chongqing University who have been operating certified lighting labs, some lab equipment can be very expensive to invest and need dedicated staff to operate. Thus well-established lighting laboratories could provide technical guidance on setting up and calibrating laboratory equipment for interested economies.

Funding Models that Will Best Serve the Goals of a Lighting Center

The funding models in each APEC economy may vary depending on the vision and policies of government sector and university as well as direction of lighting industry. In some cases such as the US, the initiative to establish a lighting center comes from the government and utilities, who then sought an appropriate university partner. The initial seed money is provided for investing in space and essential lab equipment as well as key persons such as director and researchers in order to get the lighting center off the ground and for its first few years operation. A similar model has also been used by the government of Singapore to launch its lighting center by 2015.

For personnel and operating costs, such as full-time researchers and lab maintenance, funding could come from government agencies, utilities and lighting industry mainly through research and development projects, demonstrations, and consultant services. The costs of key persons, especially the director who is also a professor, can also be shared between the lighting center and the university. Regular funding could also come from establishing industry partnership packages to cover different levels of benefit they can receive from collaborating with the lighting center. The entity of a lighting center can help fostering a formal collaboration between key stakeholders and thus recognition of the study which should lead to a sustainable support and funding.

2.3 A framework Towards Next Steps

Based on the experiences from successful lighting design centers as well as productive discussions during the workshop, a framework for developing lighting design research centers in the APEC region has been established. The framework can be illustrated as shown in Figure 2.3.

The lower part of the diagram suggests the important steps that should be taken by an APEC economy interested in developing a national lighting center. Along with the development process, the upper part proposes a supporting mechanism and activities that will enable universities to leverage opportunities and maximize their impact on translating lighting design research into practice.

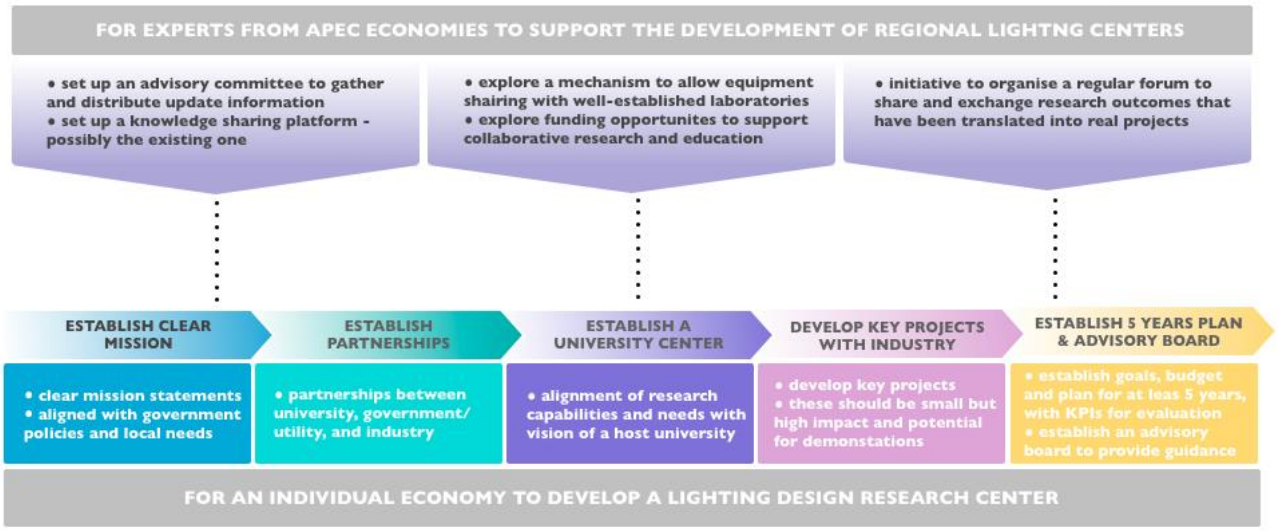


Figure 2.3 A Framework for next steps

2.3.1 Development of a National Lighting Design Center

Apart from Thailand and Singapore, which already have initiated the process, the lighting experts from Malaysia, Indonesia and The Philippines also expressed keen interest in establishing national lighting centers in their economy. The followings steps are suggested:

Establishing Clear Mission

Although the shared vision and general mission have been agreed, each interested economy should establish clear mission by exploring specific needs for a lighting center based on government policies as well as vision of lighting industry in their economy. It was also suggested that a steering committee should be set up from the key stakeholders to provide guidance on the center's mission and roadmap.

Establishing Partnerships

Partnerships between key stakeholders - a university, government and/or utilities, and lighting industry - have been identified as an essential factor for successful lighting centers and should be established. As described in section 4.1.2 (see also Figure 4.1) earlier, the partnerships are

particularly important in supporting market-driven research and development activities, demonstration projects, and knowledge transfer to the masses and public sector.

Establishing a Lighting Center

In case that a lighting center is initiated by the government and/or lighting industry, then an agreement with a university to host the center should be created. Also, there should be an alignment of the lighting center mission, which reflects the government policies and needs from industry, with vision and research capabilities of the host university.

This is especially the case for Indonesia and the Philippines where the experts who plan to initiate a national lighting center are from the government sector and lighting design profession.

Develop Key Projects with Industry

Key projects should be developed through seminars with industry and professional organizations, and matched with the research capability and strength of a lighting center. The projects should be small, but has high impact and potential to be multiplied and also developed into demonstration projects. The first achievement should help building confidence and earning more supports for the center.

Develop a Minimum of 5-Year Plan and an Advisory Board

Establish clear short-term and long-term goals for a lighting center, with KPIs for evaluation. These also include budget and action plan for at least 5 years. An advisory board should also be established to provide specific guidance and support on achieving the center's goals and objectives. A role of advisory boards[33] may include providing an additional resource for sponsorship and creating a link with a specific group of stakeholders, such as government.

2.3.2 Supporting Mechanism and Activities

In addition to the necessary steps described above, the lighting experts also proposed that a supporting system and activities should be initiated after the workshop in order to support the developing process as well as to allow for sharing and exchanging resources of lighting research community in the APEC region.

Set Up an Advisory Committee and a Knowledge-Sharing Platform

It was strongly suggested that an advisory committee should be set up to gather and distribute information and updates on lighting research and the development of lighting design centers in the APEC region. The committees are volunteers among the lighting experts participating in this workshop. For a knowledge sharing platform, it was suggested by Dr Cary Bloyd that there is a possibility to use the existing knowledge sharing platform supported by Chinese Taipei and managed by the US (University of Pennsylvania).

Explore the Mechanism to Allow Equipment Sharing and Collaborations

Sophisticated lighting equipment and certified laboratories can be expensive to invest, especially for newly-established lighting centers. They also require high maintenance and dedicated technician to

[33] http://www.councilofnonprofits.org/advisory-boards

operate. Thus, it was proposed that a mechanism within the APEC framework to allow equipment sharing should be explored. In addition to equipment sharing, more channels and funding to enable exchanges and collaborations on research and education among the lighting experts in the APEC region will be investigated.

Organize a Forum for Translational Projects and Activities

Currently there are several international and regional lighting conferences organized; however their main target is often for scientific and academic papers. It was therefore suggested that a possibility to organize a specific forum for presenting and sharing experiences on translating lighting design research into real projects should be explored. This will complement the knowledge sharing platform and demonstrate the important role of lighting design research to a wider audience.

CHAPTER 3

Conclusion: Main Findings and the First Steps

This final chapter summarizes main findings from the workshop to support the development of national lighting design centers in the APEC region, with the objectives to accelerate the adoption of energy efficient lighting design practice and to improve the quality of lit-environment. It also provides an update on some of the activities proposed by the lighting experts since the workshop; and finally the progress on the development of lighting centers at KMUTT and three other APEC economies.

3.1 Main Findings

The two-day roundtable conference was hosted by King Mongkut's University of Technology Thonburi (KMUTT) in Bangkok. The conference was well received from regional lighting experts, government officials, and lighting industry. Forty speakers and participants from 12 APEC economies contributed to this US led APEC workshop. Workshop activities included a series of presentations and input from all stakeholders as well as group discussions on strategies and recommendations on next steps. Main findings are as follow:

1. It was apparent from demonstration projects in various types of building presented here that at least 50% reduction in lighting energy use compared to ASHRAE 90.1 can be achieved with current energy efficient lighting technologies and best practice. However, the experts agreed that the adoption of lighting best practice has been generally slow due to the knowledge and experience barriers within the design and lighting industry. Thus it supports the need for national lighting design centers to effectively transfer the knowledge and bridge the gap with current practice.

2. New advanced LED is considered by many APEC economies as one of the most promising energy efficient lighting technology; most governments have supported large-scale replacement of conventional lights with LED, especially for streetlights and public buildings. To realize its full potential, however, the experts suggested that more studies and efforts are needed to explore and promote the use of LED with advanced demand-responsive control systems. Also, in order to achieve even higher savings and better lighting quality than the LED lamp replacement, demonstration projects should include appropriate design strategies and system integration of LED with architecture and interior design.

3. In addition to the reduction of lighting energy consumption and GHG emissions, the opportunities of lighting design research also include social and economic development. Good exterior lighting could help promote safety and security, while minimizing light pollutions. For economic development, well-coordinated urban lighting plan in many cities have been used as a tool to promote tourism and local businesses at night. As seen in Chinese Taipei, lighting design research has played an important role in building competitiveness for its LED lighting industry by supporting the development of national standard as well as user-centered and market-driven products.

4. There are common interests among stakeholders in the following research focus areas: 1) daylighting in the tropics and daylight harvesting 2) energy efficient lighting, especially smart LED and controls; task-ambient lighting systems 3) urban lighting - due to dramatic increased in urbanization in developing Asia 4) light and health - because of the recent widespread use of LED and concerns with the potential health risks of blue spectrum from white LED on the retina.

5. *'Light for Life* **-** Towards net-zero energy building and better lighting for health and well-being' is the shared vision for lighting design centers in APEC region obtained from the workshop. The general missions are: supporting technological and design innovation; supporting business

opportunities; advancing education and training; and supporting more insightful policy and effective building codes. Moreover, the experts also recommended that research should be of multi-disciplinary nature and focus more on human factors in lighting.

6. Main activities (see Figure 2.1) for a lighting design center should include 1) R&D of high efficiency technology and industrial design/architectural design 2) demonstrations to provide full-scale installations with integrative measures 3) evaluation and testing to establish credibility 4) education and training to transfer knowledge to practitioners and lighting industry 5) develop codes and design guides that are suitable for each target group, to promote lighting research and raise awareness of the general public. It was strongly suggested that the process of these activities should be market-driven and supported by partnerships with key stakeholders.

7. A framework for developing lighting design centers in APEC region has been established and illustrated in Figure 2.3. It suggests five important steps that should be taken by an APEC economy interested in developing a national lighting center. In parallel to the development process, supporting mechanism and activities that will enable universities to leverage opportunities and maximize their impact on translating lighting design research into practice are also proposed. In particular, establishing an advisory committee and a knowledge-sharing platform to stay connected as a lighting research network are among the recommendations.

3.2 The First Steps

Since the workshop, first few steps toward developing lighting design centers in APEC region have been taken. Firstly, there are 12 lighting experts volunteered as an advisory committee to contribute to the knowledge sharing platform:

Prof Ian Cowling, Australia

Prof Yan Yonghong, China

Mr Totok Sulistiyanto and Mr Herman Endro. Indonesia

Assoc. Prof. Mohd Zin Kandar, Malaysia

Mr Christopher Cuttle, New Zealand

Mr Alessandro Abbate, Philippines

Prof. Tseng King Jet and Dr Szu-Cheng Chien, Singapore

Dr Ming-Shan Jeng, Chinese Taipei

Dr Chanyaporn Chuntamara, Thailand

Dr Cary Bloyd, USA

There have been progress on developing lighting centers in Singapore and Thailand; and there were reports of initial meetings between the lighting experts who participated in the workshop and key stakeholders in Indonesia and Malaysia.

Prof. Tseng King Jet, College of Engineering, Nanyang Technological University reported that Singapore Green Building Council (SGBC) and Singapore's Building and Construction Authority (BCA) is collaborating with The University of California, Davis to develop a lighting efficiency demonstration and training center in Singapore (see Figure 2.4). This new sustainable lighting initiative is expected to reduce Singapore's lighting energy use by 50%. A Memorandum of

Understanding (MOU) was signed on 12 September 2013, with the aim to develop a Lighting Technology Centre in Singapore over a two year period.

Figure 2.4 Singapore Lighting Technology Center to be launched (http://www.apec-lightingworkshop.org/news/)

In Indonesia, shortly after the APEC workshop in Bangkok, Mr Totok Sulistiyanto had discussions with Mr Awang Riyadi, the Ministry of Energy and Mineral Resources (MEMR) and Mr Herman Endro, the Chairman of HTII-ALKI (Illumination Engineering Association of Indonesia). In the near future they will gather stakeholders facilitated by MEMR to prepare for the lighting design center in Indonesia. He and Mr Herman Endro also volunteer as the advisory committee for the lighting knowledge sharing platform. Similarly, Assoc. Prof. Mohd Zin Kandar, Faculty of Built Environment, Universiti Teknologi Malaysia (UTM) also reported that he and Mr Fadli Arabi from the Department of Public Work of Malaysia had organized initial meetings together with the university to explore the possibility of establishing a lighting research center in Malaysia.

In the meantime, existing channels of the university have been used to explore the possibility of future collaboration between universities in the APEC region. Dr Chuntamara from KMUTT (Thailand) was invited as an external examiner to evaluate two doctoral theses on the topics of mutual interests for the experts from Malaysia and China. These are '*Optimizing Daylight Performance by Anidolic Daylighting System in Tropical Area*' at the Faculty of Built Environment, Universiti Teknologi Malaysia and '*Artificial Lighting Design Guides For Religious Buildings in Thailand'* at the College of Architecture and Urban Planning, Tongji University (China). Possibilities of future collaboration on shared teaching assignment and lighting research on innovative LED lighting were discussed with Prof. Luoxi Hao at Tongji University in late November 2013. It was hoping also that the meeting with Assoc. Prof. Mohd Zin Kandar in Malaysia early 2014 will lead to a collaborative research on daylighting in the tropics.

3.3 Progress on the Development of KMUTT Lighting Design Research Center

Lighting design research activities at the School of Architecture and Design, King Mongkut's University of Technology Thonburi (KMUTT) have been active since 2004. Research focus areas include daylighting design, energy-efficient lighting, human factors in lighting, and urban lighting. Most studies are collaborative effort with other institutions locally and internationally. For education and training, it offers a Master of Science in Lighting Design (international program) and regularly organizes public seminars and workshops for design practitioners, lighting industry, and government officials. Additionally it provides academic service as a consultant to energy efficient lighting for

architecture and interior design, mostly for government projects. The program has so far received good supports from the industry and maintained good relationships with the lighting practitioners. Despite the efforts, the impact of these activities on introducing lighting best practice in Thailand is rather limited.

The idea of setting up a lighting design research center that can effectively translate the knowledge and experiences from lighting design research into practice was initiated a few years ago and a suitable model and framework has been explored. Indeed, experiences shared by the experts from successful lighting centers and the framework recommended at this APEC support workshop are very helpful and provide a bright prospect to KMUTT's lighting design center initiative. The working team has since applied the framework into the local context and taken the first few steps to clarify our mission and to establish partnerships and key projects with key stakeholders.

Firstly, the mission has been clarified based on the current activities on lighting research and education; vision and strength of KMUTT in engineering and energy research; the government's policies and requirements of lighting industry. A public seminar with key stakeholders and initial meetings with potential allied partners were arranged (see Figure 2.5). Shortly after the APEC workshop, a public seminar on 'The Future of Municipal and Exterior Lighting" was organized in collaboration with California Lighting Technology Center (CLTC); Prof Michael Siminovitch, Rosenfeld Chair and the Director of CLTC was the invited speaker and Dr Chuntamara was the moderator. The objectives were to share experiences on research and successful demonstration projects using LED technology for exterior applications, particularly the design with adaptive lighting controls. At the same time, it was also the first forum to gather specific requirements and feedback on the potential key projects of KMUTT lighting center from main stakeholders here.

Figure 2.5 Seminar for Stakeholders **Figure 2.6 Exchanges on the Application of LEDs**

The half-day seminar was a success and some 70 practitioners (lighting engineers and designers) as well as lighting industry and government officials responsible for energy efficient lighting attended including Electric Generating Authority of Thailand (EGAT), Provincial Electricity Authority (PEA), Metropolitan Electricity Authority (MEA), Department of Public Works and Town & Country Planning, and Department of Highways. The participants were very much interested in the performance and economics of advanced LED technology and adaptive lighting approach.

There were also questions about appropriate colour temperature for exterior lighting in Thailand and some concerns with quality and standard of LED products, especially when installed in the tropical areas (see Figure 2.6). Finally, they seemed to have a keen interest in research and demonstration

projects on colour temperature for exterior lighting and adaptive lighting application for this context, proposed by KMUTT.

Other meeting was the introduction of KMUTT lighting center to an allied research institution, National Science and Technology Development (NSTDA). Due to the government's policy on energy efficiency and promises of LED technology, NSTDA has carried out several research and development projects on advanced LED and OLED technologies and products such as luminaire and optical lens, and LED lights that also transmit information wirelessly. Some of these projects are collaborations with industry partners.

Most recently, KMUTT lighting center was invited to join the expert panel that NSTDA organized in order to gather requirements on R&D research from lighting industry. The objectives of this project are to increase the industry's competitiveness and business opportunities through advanced LED lighting technology research and development. One of the most common concerns from the lighting industry is the lack of national standard for LED products and the fast changing technology of LED. From the industry's point of view, Thailand should also focus on advanced LED product design and innovation. The seminar and initial meetings were very helpful in gathering requirements from key stakeholders and identifying key projects.

LED adaptive lighting was among the key projects, thus a pilot study was carried out at KMUTT in order to develop a full proposal to the university and key partners. The study was looking into the potentials and users' subjective perception of applying LED adaptive lighting at KMUTT's main campus (see Figure 2.7). After the initial survey, the covered walkway around the main library was selected for the pilot study. The reason was that this type of covered walkway is quite common in Thailand where there need to be some forms of protection from sunlight and rain, thus the results can also be applied to wider applications. The objectives were to investigate the preferred high-levels and low-levels light setting for the adaptive lighting system under two background light levels.

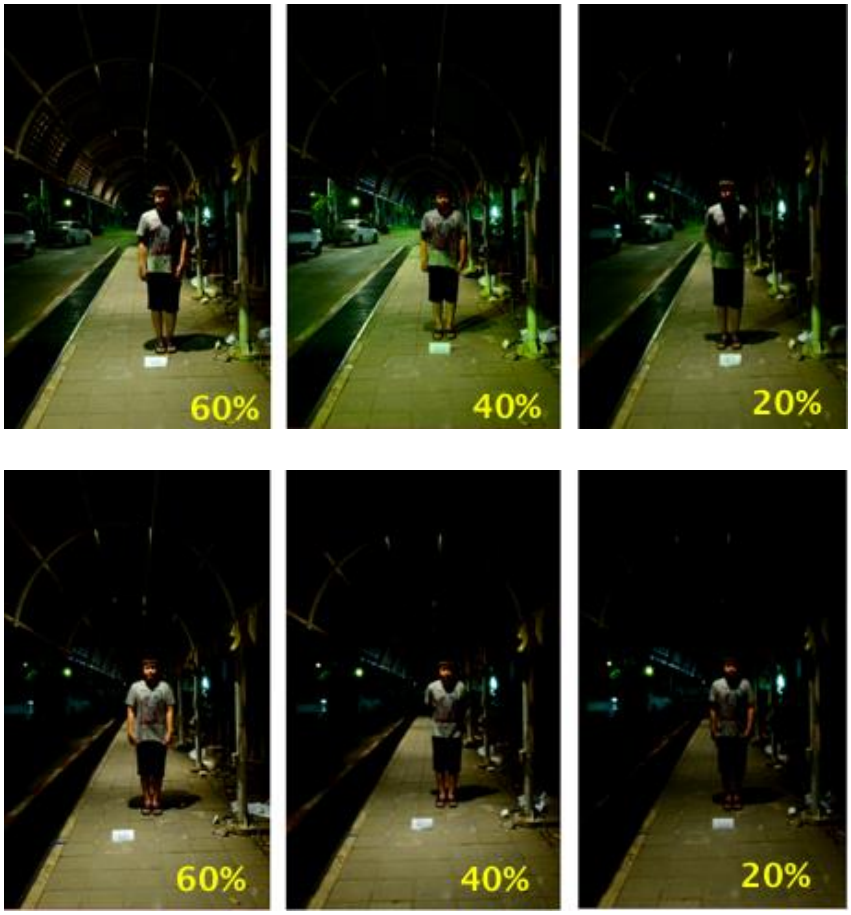
Computer  simulations

Figure 2.7 A Pilot study of adaptive lighting for covered walkway at KMUTT

and then a full-scaled experimental setup at the selected area in the main campus were carried out as shown in Figure 2.8; undergraduate and postgraduate students from various faculties participated in the study and interviews. The initial results suggested the new adaptive lighting system was

preferred and could save the lighting energy use by up to 75% compared to the existing fluorescent battens. The participants also agreed that the new system improved the quality of pathway lighting, particularly the uniformity and visibility, thus their perceived safety and security of the adaptive lighting is much higher than the existing ones.

However, the payback period of the new LED adaptive lighting system is longer than 5 years due to the high initial costs of the luminaire and control systems. The main study should therefore investigate possibilities to reduce the number of luminaire and costs of the occupancy systems. The study also suggested several luminaire design possibilities, which will be proposed at the next meeting with Thai lighting industry, organized by NSTDA in February 2014.



Next step, the results of this pilot study will be discussed with the university and lighting industry in order to establish industry partners, which will later support the main study and demonstration projects. In the meantime, the 5-year plan with goals, budget, and KPI for evaluations is being

Figure 2.8 Field study with high brightness background (Top) and low brighness background (Bottom)

developed; the plan will be refined and included in the full proposal to be submitted to KMUTT in early 2014 for approval and internal supports. Finally, a list of an advisory board has been compiled and will likely to include high-level representations of main stakeholders such as The Thai Chamber of Commerce, The Illuminating Engineering Association of Thailand, and Electricity Generation Authority of Thailand, and Thai lighting industry.

APPENDIX

Meeting of Minds: Translating Lighting Design Research into Practice

A roundtable conference hosted at King Mongkut's University of Technology Thonburi (KMUTT) for the APEC Expert Group on Energy Efficiency and Conservation

Workshop to support the development of national lighting design centers in APEC region
5-6 September 2013; Bangkok, Thailand

Agenda

Purpose of the meeting:

To better understand how to effectively translate lighting design research into practice with a university research center model based on input from regional experts.

Specific agenda items:

1) Understand the potential of lighting design research by examining examples of ongoing lighting research from regional experts
2) Learn from effective collaboration models and operational strategies of the successful translational lighting centers
3) Generate strategies that will allow university's regional lighting technology centers, including the one at KMUTT, to effectively translate lighting research into practice

Driving forces:

The energy used in the operation of buildings contributes to almost 40 percent of greenhouse gas emissions. Electric lighting is a major constituent of this overall energy use; as such, best-practice lighting strategies and technologies represent one of most effective near-term opportunities to reach ambitious goals for energy efficiency and greenhouse gas mitigation.

Advanced lighting technologies and best-practice design have shown great promise for achieving energy efficiency in the operation of buildings. Adaptive lighting controls, daylighting and solid-state technology represent just a few of the emerging technologies and best practices that can achieve very large savings in the operation of buildings.

Despite these compelling reasons to embrace energy-efficient lighting, the uptake of new technologies and design practices has typically been slow. This slow rate of market transformation is principally due to knowledge and experience barriers within the lighting design industry. Universities are in an ideal position to bridge this knowledge barrier by engaging both the profession and the industry in a range of different activities that translate lighting design research into practice and accelerate broader adoption of best-practice technologies. These activities, which include education, research, demonstration, and testing, can all be supported in a regional center of expertise.

Research and demonstration centers have proven to be quite effective at translating lighting design research into practice; our long-term objective is to establish such regional centers in APEC region.

Format and organization:

The roundtable meeting of experts will focus on the two specific components of the two-day program:

1) Lighting design research opportunities for sustainable design
2) Recommendations on how potential universities and KMUTT could develop regional lighting centers

The "Meeting of Minds" roundtable will be organized around a series of presentations from each invited expert, addressing these two components. We are asking that the invited experts talk about their specific experience advancing and developing a lighting research agenda. The concept here is to share experiences and opportunities to achieve sustainable lighting design. Specific focus will be placed on translation and technology transfer and how the individual researchers have moved their research into the professional marketplace.

We would also like each invited expert to specifically address recommendations for establishing and developing activities for national lighting design centers in the APEC region. Here we would like to see specific ideas relative to research directions, activities, infrastructure, programming, and funding that could be helpful in the planning and development of a long-term proposal.

Key questions relative to establishing a university-based lighting center:

What areas of lighting research should the center focus on?

What major activities (research, demonstration, education, etc.) should it engage in?

What kind of laboratories will be required as part of a lighting center?

What relationship should the center have with the lighting design profession?

What relationship should the center have with industry and with the government?

How can universities work together and leverage opportunities to maximize impact?

What funding models will best serve the lighting center in meeting its goals?

Who should manage the center's projects, and who should serve as advisors (board of directors)?

Meeting Agenda

Workshop to support the development of national lighting design centers in the APEC region

Date : **Wednesday, 4 September 2013**
Venue: **Chatrium Hotel Riverside, Bangkok, Thailand**
Time: **6:00 PM - 8:30 PM**
Event: **Welcome dinner** (hosted by KMUTT)

Time	Event
6:00 PM	Registration and welcome drink
6:30 PM	Thai set dinner
20:30 PM	Closing

Meeting Agenda

Workshop to support the development of national lighting design centers in APEC region

Date : **Thursday, 5 September 2013**
Venue: **Chatrium Hotel Riverside, Bangkok, Thailand**
Time: **8:30 PM - 16:30 PM**
Event: **Meeting Day 1**

Time	Event	Presenter
8:30 AM	Registration	All
9:00 AM	Welcome speech by Assoc. Prof. Bundit Fungthamasarn	Vice President of KMUTT
9:10 AM	Introduction and overview of activities of the APEC Expert Group on Energy-Efficiency and Conservation	Dr Cary Bloyd, PNNL
9:25 AM	Keynote speaker: Energy-efficiency policies and strategies in Thailand	Dr Twarath Sutabutr, DEDE
9:45 AM	Overview of the workshop objectives and activities	Dr Chuntamara, C.
10::20 AM	Coffee break	

Presentations (lighting opportunities and center recommendations)

10:40 AM	California Lighting Technology Center: lab to marketplace UC Davis, USA	Prof. Michael Siminovitch
11:00 AM	Sacramento Municipal Utility District (SMUD) - Lighting innovations, USA	Mr Alan Suleiman
11:20 AM	Lighting research and professional practice in China - Tongji University, China	Prof. Luoxi Hao
11:40 AM	Lighting research and innovations in China - Chongqing University, China	Prof. Yan Yonghong
12:00 AM	Lunch break	

Presentations (lighting opportunities and center recommendations)

13:30 PM	Proposals for lighting design center - New Zealand	Mr Christopher Cuttle
13:50 PM	Lighting education & Photometric Laboratory - QUT, Australia	Assoc. Prof. Ian Cowling
14:10 PM	Research efforts in lighting technology for Singapore, Nanyang Technological University, Singapore	Prof.Tseng King Jet and Dr Szu-Cheng Chien
14:30 PM	Daylighting and green building research and policies in Malaysia, Malaysia	Prof. Mohd Zin Kandar
14:50 PM	Coffee break	

Presentations (government agencies and national lighting institutes)

15:10 PM	Urban lighting research and implementations in Vietnamese cities - Vietnam	Dr Luong Thi Ngoc Huyen

Time	Event	Presenter
15:30 PM	The status of lighitng programs in Indonesia, Indonesia	Mr Totok Sulistiyanto
15:50 PM	The research and deployment of standardized LED lighting, Chinese Taipei	Mr Bor and Dr Jeng
16:10 PM	Discussions and summary of the first day presentations	(Moderator)

Meeting Agenda

Workshop to support the development of national lighting design centers in the APEC region

Date : **Friday, 6 September 2013**
Venue: **Chatrium Hotel Riverside, Bangkok, Thailand**
Time: **8:30 PM - 16:30 PM**
Event: **Meeting Day 2 and Thank you dinner**

Time	Event	Presenter
8:30 AM	Registration	All
9:00 AM	Keynote Speaker: Voluntary lighting labeling scheme at EGAT, Thailand	Mr Pitarn Chaichinda, EGAT
9:20 AM	Energy efficiency research and industry partnerships at KMUTT	Vice President of KMUTT
9:40 AM	Lighting research and future vision at KMUTT	Dr Acharawan Chutarat
10::00 AM	Coffee break	
	Input from stakeholders: future vision and goals	
10:20 AM	Requirements for Lighting design center from industry and professional-Thailand	Mr Kitti Sukutamatanti, TIEA
10:35 AM	Proposal for a lighting design center by the Philippines	Mr Abbate and Dr Mendoza
10:50 AM	Future vision and challenges for lighting industry, Japan	Mr Yoshio Takamori, ENDO
11:00 AM	Input from key stakeholders: Future vision and goals for APEC economies	All
12:00 AM	Lunch break	
	Development of framework: Roundtable discussions	
13:30 PM	Review of shared vision and goals for APEC economies	Dr Acharawan Chutarat
14:30 PM	Roundtable discussions: strategies, activities, and partners	All
15:00 PM	Coffee break	
	Framework recommendations: Roundtable discussions	
15:20 PM	Roundtable discussions: strategies, activities, and partners	All
16:00 PM	Framework and recommendations toward the goals	Moderator/Group leaders
16:15 PM	Workshop summary and closing remarks	
	Farewell Dinner (hosted by KMUTT)	
18:00 PM	Meeting at Chatrium Pier and depart for Supatra River House Restaurant	All

Time	Event	Presenter
21:00 PM	Depart from Supatra River House Restaurant back to Chatrium	All

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