The 40th Anniversary of

THE HONG KONG INSTITUTION OF ENGINEERS ELECTRICAL DIVISION

The 35th Annual Symposium

Thursday

12th October 2017

ENGINEERING A CLIMATE-READY CITY

at

Ballroom
Sheraton Hotel
Nathan Road
Kowloon
Hong Kong

SYMPOSIUM PROGRAMME

08.30 Registration and Coffee

09.00 Welcome Address
- Ir Dr Edward W.C. Lo
  Chairman, Electrical Division, The HKIE

09.05 Opening Address
- Ir Ringo S.M. Yu
  Vice President, The HKIE

09.10 Keynote Speech
- Ir Paul W.Y. Poon
  Vice Chancellor
  CLP Power Academy

1. Green Power Systems

09.40 Greener Hong Kong with New Gas-fired Generation
- Ir Y.L. Kwan, Chief Mechanical Engineer
- Ir S.N. Li, Senior Mechanical Engineer
- Ir K.L. Kwong, Mechanical Engineer
  Projects Division
  The Hongkong Electric Co., Ltd.

10.00 Smart Power Enabling Smart City
- Ir Dr Anthony C.W. Lo, Deputy Director – Smart Grid
- Ir Victor K.W. Lam, Senior Manager – BP &TT
- Ir Leo C.K. Ng, Senior Engineer – BP & TT
  Smart Grid Programme
  CLP Power Hong Kong Limited

10.20 Harnessing the Sun – Hong Kong's Largest Solar Farm
- Ir Dr Ricky C.L. Li
  Chief Electrical and Mechanical Engineer
  Electrical and Mechanical Projects Division
  Drainage Services Department
  The Government of the HKSAR

10.40 Discussion

11.00 Coffee Break

2. __Retro-commissioning__

11.30 Driving Retro-commissioning as a Mainstream Practice in Hong Kong
- Ir Cary W.H. Chan, JP
Executive Director
Hong Kong Green Building Council

11.50 Technical Guidelines on Retro-commissioning
- Ir K.W. Kong, Senior Engineer
- Ir Carson C.W. Yiu, Engineer
Electrical & Mechanical Services Department
The Government of the HKSAR

12.10 Discussion

12.30 Lunch

3. __Climate-ready Buildings & Services__

14.00 Consideration of Well-beings of Occupants and Neighbourhoods in Sustainable Built Environment
- Ir Wing W.H. Ho, Associate Director
- Ir Ryan W.T. Cheung, Associate
- Ms Curie W.Y. Hau, Engineer
AECOM Asia Company Ltd.

14.20 Pioneering BIM-AM Application for Green and Sustainable Building Operation and Maintenance
- Ir C.K. Lee, Chief Engineer
- Ir Steve H.Y. Chan, Senior Engineer
- Mr Francis P.H. Yuen, Assistant Engineer
Project Division
Electrical & Mechanical Services Department
The Government of the HKSAR

14.40 Building Services Design for the Revitalization of Valued Existing Buildings
- Ir K.F. Ho, Chief Building Services Engineer
- Ir Judy O.W. Lau, Building Services Engineer
Architectural Services Department
The Government of the HKSAR

15.00 Discussion

15.20 Coffee Break

4. Environmentally Friendly Transportation

15.50 Green Design of Express Rail Link High-Speed Trains

- Ir C.L. Leung, General Manager – XRL E&M
- Ms Candy H.M. Leung, Engineer I – Rolling Stock
  MTR Corporation Ltd.

16.10 Challenges and Opportunities of E-bus in Hong Kong

- Dr W.T. Hung, Fellow, Hong Kong Society of Transportation Studies
- Ir Kane Y.H. Shum, Member, Society for the Environment, UK
- Ir Prof. C.S. Cheung, Professor, Department of Mechanical Engineering,
- Ir Dr Edward W.C. Lo, Associate Professor & Associate Head,
  Department of Electrical Engineering
  The Hong Kong Polytechnic University

16.30 Discussion

16.45 Summing Up

- Ir C.F. Chan
  Symposium Chairman
  Electrical Division, The HKIE

Closing Address

- Ir C.S. Ho
  General Manager
  Hong Kong BEAM Society Ltd.

Acknowledgement

The Electrical Division of The Hong Kong Institution of Engineers would like to express its sincere appreciation and gratitude to the following persons and organizations for their contributions to the Symposium.

Speakers/Authors

Ir Paul Y.W. Poon
Ir C.S. Ho
Ir Y.L. Kwan
Ir S.N. Li
Ir K.L. Kwong
Ir Dr Anthony C.W. Lo
Ir Victor K.W. Lam
Ir Leo C.K. Ng
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Ir C.L. Leung
Ms Candy H.M. Leung
Dr W.T. Hung
Ir Kane Y.H. Shum
Ir Prof. C.S. Cheung
Ir Dr Edward W.C. Lo

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Hong Kong Electrical Contractors' Association Ltd.

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Paper No. 1

GREENER HONG KONG WITH NEW GAS-FIRED GENERATION

Speakers: Ir Y.L. Kwan, Chief Mechanical Engineer
Ir S.N. Li, Senior Mechanical Engineer
Ir K.L. Kwong, Mechanical Engineer
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GREENER HONG KONG WITH NEW GAS-FIRED GENERATION

Ir Y.L. Kwan, Chief Mechanical Engineer
Ir S.N. Li, Senior Mechanical Engineer
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Projects Division
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ABSTRACT

The Hongkong Electric Co. Ltd. (HK Electric) commissioned its first combined cycle gas turbine (CCGT) unit (Unit 9) at Lamma Power Station in Hong Kong in 2006. With 335MW nominal capacity, Unit 9 is an F-class single-shaft base-load machine adopting dry low NOx (DLN) combustion technology with natural gas as primary fuel and light oil as backup fuel. New CCGT units, namely, Units 10 & 11, are currently being planned to meet the environmental challenges in coming years. In order to comply with the very stringent emission limits proposed by the local authority, HK Electric has taken the initiative to conduct feasibility studies on various options to further reduce the NOx emissions from future CCGT units. Through these studies, various important considerations including the as-built constraints, state-of-the-art technologies available in the market, overall plant performance, anticipated new challenges on operations and maintenance (O&M) aspects, local licensing requirements, etc., have been thoroughly evaluated. The studies concluded that the adoption of advanced dry low NOx (DLN) combustion technology coupled with post-combustion Selective Catalytic Reduction (SCR) System would be the most practical solution to meet the new emission limits required by the Authority. This paper serves to share HK Electric's experience in review of the technical and environmental performance of various CCGT Models, and the considerations given in the selection of SCR technologies.

1. INTRODUCTION

Being one of the major power utilities in Hong Kong, The Hongkong Electric Co., Ltd. (HK Electric) has committed not only to providing a safe, reliable and efficient supply of electricity but also maintaining a high standard of environmental care in order to help contribute to cleaner air and blue sky in Hong Kong. Such pledge has been well demonstrated by HK Electric's continual adoption of state-of-the-art emission control technologies for minimizing emissions from both the coal-fired and gas-fired generating units at the Lamma Power Station (LPS) and Lamma Power Station Extension (LMX). The Station originally has a total installed capacity of 3,737 MW comprising eight coal-fired units (3 x 250 MW + 5 x 350 MW), two gas-fired combined cycle units (335 MW + 345 MW) and five simple cycle peak-looping gas turbines (4 x 125 MW + 1 x 55 MW) firing on diesel oil, plus the increasing commercial-scale renewable energy including wind power (800 kW) and solar power (1 MW) as shown in Figure 1. With the retirement of the coal-fired unit L1 in May 2017 after reaching its design life of 35 years and in order to cope with the retirement of other coal-fired units in the upcoming years, HK Electric is currently installing two new CCGT units, namely, L10 and L11 (each of 380MW nominal capacity) for commercial operation in 2020 and 2022 respectively.

HK Electric had been the pioneer in mitigating SOx emission when the first Fuel Gas Desulphurization (FGD) plant in Hong Kong was commissioned for the coal-fired unit L6 in 1993 as the first one in South East Asia, and subsequently two more FGD plants were installed for the two coal-fired units L7 & L8 during their initial development in mid 1990s. Similarly, Low NOx Burner (LNB) combustion systems were installed in L6 to L8 upon their initial commissioning to mitigate NOx emission. In order to support the HKSAR Government's policy objective to further improve the air quality of the Pearl River Delta region, FGD plants were subsequently retrofitted to L2, L4 & L5 and LNB combustion systems to L4 & L5, which as a whole were totally completed in 2010. At present, over 80% coal-fired generating capacity of HK Electric is equipped with FGD plants and 70% with LNB combustion systems. Furthermore, the boiler start-up fuel conversion project for utilizing ultra low sulphur diesel (ULSD) was completed and the use of heavy fuel oil (HFO) was totally eliminated from LPS since end 2011.

In order to further support the revamping of post-2020 fuel mix policy as proposed by HKSAR Government in its public consultation on "Hong Kong's Climate Change Strategy and Action Agenda" and at the same time to satisfy the more stringent new Air Quality Objectives (AQOs) proposed by HKSAR Government in early 2012, it is anticipated that the gas-fired generating units comprising the existing L9 and future L10 & L11 will take more important roles not only in meeting the power system demand but also satisfying the more stringent emission requirements, given also that the earliest-built coal-fired units are scheduled to retire in phases in next few years. This paper serves to share HK Electric's experience in review of the technical and environmental performance of various CCGT Models, and the considerations given in the selection of SCR technologies for L10 & L11.

Fig. 1 - Overview of Lamma Power Station (LPS) and Lamma Extension (LMX)

2. CONSIDERATIONS

2.1 Fuel Mix Policy

The HKSAR Government launched a public consultation on "Hong Kong's Climate Change Strategy and Action Agenda" in September 2010 targeting to reduce Hong Kong's carbon intensity by 50-60% by 2020 as compared with the level in 2005. Among all the measures proposed for mitigating Green House Gas (GHG) emissions, revamping of post-2020 fuel mix for electricity generation in Hong Kong to achieve "50-40-10" proportions [1], i.e. 50% from nuclear import, 40% from natural gas and remaining 10% from coal plus renewable energy, is one of the most important measures given that electricity generation accounts for about 67% of total local GHG emissions. The consultation period was ended in December 2010 and it was revealed by that time that the public would in general support the proposed policy provided that the electricity supply would be safe, reliable, environmentally friendly and affordable. However, after the Fukushima nuclear accident occurred on 11 March 2011, the public had expressed great concern which was then followed by controversial debates on issues related to nuclear power import from China. The divergence of public views had brought up uncertainty for implementation of the nuclear power import policy and the proposed fuel mix policy is yet to be finalized at this stage. Nevertheless, it is the HKSAR Government's policy to use more natural gas for power generation, which will play a more important role in the next decade when power generation from coal-fired units is diminishing regardless of whether nuclear power import is to be implemented or not.

2.2 Review of Air Quality Objectives (AQOs)

Based on the public consultation launched in 2007 on "Air Quality Objectives Review" which was aimed to improve Hong Kong's ambient air quality and to develop long term air quality management strategy so as to align with new guidelines of World Health Organization (WHO) and practices adopted in other developed countries, the Environmental Protection Department (EPD) of the HKSAR Government promulgated in January 2012[2] to proceed with amendment of the Air Pollution Control Ordinance (APCO) with an aim to adopt the proposed new Air Quality Objectives (AQOs) effective in 2014. Among all pollutants, the emission limit for ambient NOx is proposed to be tightened up from the current hourly average of 300μg/m^3 to new 200μg/m^3 by further mitigation of NOx emission from fixed installations such as power plants and mobile sources. In this connection, EPD has proposed among all initiatives to increase the ratio of natural gas in local electricity generation to 50% with additional emission abatement measures, and discussed with HK Electric to review the regulatory limits on NOx emission from gas turbine plants. The proposed new NOx limits for new gas turbine plants will be much more stringent than the existing ones – in the order of single-digit in ppm (hourly average) for both NOx emission and ammonia slip if SCR is installed, while that for existing gas turbine plants will also be further tightened. The on-going review of AQOs, coupled with the revamping of post-2020 fuel mix policy as discussed above, has driven HK Electric to take a proactive role in reviewing thoroughly her own capabilities/ limitations and collecting updated market intelligence in different aspects so as to help formulate appropriate and reasonable strategy for legal compliance.

2.3 Future Development of Lamma Power Station and Lamma Extension

Apart from the emission control projects discussed above for coal-fired units, HK Electric had introduced the intake of natural gas in 2006 from Guangdong Dapeng LNG Terminal located in Shenzhen via a 92 km submarine gas pipeline to fuel the gas-fired combined cycle gas turbine unit (CCGT) L9 (an F-class single shaft base-load machine). Power generation from natural gas has been gradually increasing and has accounted for 33% of HK Electric's total electricity sent out since 2010. As for renewable energy development, after the completion of the 800 kW pilot wind turbine project in 2006 as the first commercial scale wind turbine built in Hong Kong, HK Electric is exploring a wider application of wind power by pursuing the development of a 100 MW offshore wind farm in Hong Kong waters. HK Electric is also marking another milestone by commissioning the city's largest solar power system in July 2010 with a capacity of 550 kW comprising 5,500 thin film photovoltaic (TFPV) modules which has currently been expanded to 1 MW capacity. With such a diversified mix of generation units and the anticipated fluctuation in daily renewable energy output, HK Electric's power system will face more dynamics than ever before. This, alongside with some old coal-fired units to be retired in 2017-2018, will impose much more challenges on HK Electric to satisfy all regulatory requirements and to address new operation & maintenance concerns.

2.4 De-NOx Options

Since the majority of coal-fired units had already been equipped with emission control devices such as FGD plants and LNB combustion systems and there is limited space to accommodate additional emission control devices, it is foreseen that retrofit of new emission control facilities to the coal-fired units will be extremely challenging. In fact, power utilities in Hong Kong are not allowed to build new coal-fired units since 1997 and the earliest built coal-fired units commissioned in 1980's are approaching their design lives within the next few years. Therefore, installation of new NOx mitigation facilities such as selective catalytic reduction system in coal-fired units cannot be economically justified. Under these circumstances, the Authority will only focus on emission control of new gas-fired units.

3. DISCUSSIONS AND RESULTS

HK Electric had taken initiatives since 2010 to explore available, proven and technically competitive technologies of NOx mitigation for gas-fired CCGT units L10 & L11. In the sections below, the selection of gas turbine technology and post-combustion NOx removal facilities will be discussed.

3.1 Gas Turbine Technology Selection

The F-class CCGT technology is so far the most widely adopted and mature design for gas-fired power plants commissioned worldwide in the past decade. Considering the relatively small grid size of HK Electric's power system, F-class machine of single shaft design is the preferred configuration for the new units L10 & L11 with unit size of around 380MW. Adoption of more advanced gas turbine technology such as G-class, H-class and J-class has been ruled out due to its high power output and relatively limited operating record. Several major technical considerations of the latest F-class single shaft CCGT models available from the four major players in the prevailing market including plant performance, NOx emission performance, adaptability to fuel gas property fluctuation and maintenance requirements are discussed below. Generally all the four models are considered technically acceptable for consideration in L10 & L11.

3.1.1 Plant Performance

The performance of the latest F-class single shaft machines is revealed to have better efficiency ranging from 2~3% (abs) and higher output when compared with that of the existing unit L9 commissioned in 2006, which can offer distinct merit of significant fuel cost saving.

3.1.2 NOx Emission Performance

The NOx emission level of the latest F-class single shaft machines is lower than that of L9. The NOx emission level from either the latest DLN burner or sequential burner technology is achieved by optimizing further the premixing of fuel and air at different combustion stages such that the formation of nitrogen oxide (NO or NO_2) could be further reduced down to 15-25 ppm within certain load range. These figures are subject to adjustment by considering other site-specific factors including detailed fuel gas specification, etc. However, it is believed that NOx emission of single-digit in ppm could hardly be achieved solely by the latest DLN combustion system without the aid of post-combustion de-NOx facility such as selective catalytic reduction system.

3.1.3 Adaptability to Fuel Gas Property Fluctuation

There is possibility that new gas supply sources will be secured for L10 & L11, which might be required to be mixed with existing gas source during emergency situation. The mixing ratio might vary periodically and the compositions of the mixed gas would fluctuate gradually. It is important for the new gas-fired units to come with reliable combustion system that could satisfy the fluctuation in Wobbe Index without the need of carrying out any off-line combustion tuning. Among the four models under consideration (described as Models A, B, C & D hereafter), Models A & B can be operated with ±10% fluctuation in Wobbe Index, Model C might even be able to tolerate a wider fluctuation range and Model D can tolerate a maximum allowable fluctuation of ±5%.

3.1.4 Maintenance Requirements

Maintenance costs of CCGT plant are predominantly for the hot gas path (HGP) components of the gas turbine as a combination of repair costs as well as costs for new replacement components.

Model A and Model B combustion system are of relatively simple annular design without individual combustor baskets or transition pieces. On the other hand, Model C and Model D combustion system consists of cannular combustors. For Model A, it requires only visual borescope checking of compressor/turbine blades and combustor chamber without the need of machine disassembly during normal inspections while gas turbine disassembly for thorough inspection and parts replacement are required for a normal overhaul. No rotor de-stacking is required for Model A as the rotor is of welded construction. For Model B, de-stacking of rotor for thorough inspection is made possible in-situ at the turbine hall. For Model D, roll-in and roll-out of certain HGP components during each inspection are required. It is noted that the maintenance requirements for Model C and Model D are similar.

3.2 Post-Combustion NOx Removal Technology

3.2.1 Working Principle of SCR and SNCR

Three are two main streams of post-combustion de-NOx solutions for fossil fuel power plants, namely, the Selective Catalytic Reduction (SCR) System and the Selective Non-Catalytic (SNCR) System. The SCR is designed to apply an oxidation catalyst in the flue gas path to accelerate and promote the chemical reaction between NOx and inject reducing agent such as ammonia gas (NH_3) to form water and nitrogen:-

$$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O$$
$$2\ NO_2 + 4\ NH_3 + O_2 \rightarrow 3\ N_2 + 6\ H_2O$$
$$NO + NO_2 + 2\ NH_3 \rightarrow 2\ N_2 + 3\ H_2O$$

There must be certain amount of excessive ammonia to sustain the de-NOx reaction. As a result, a trace amount of un-reacted NH_3 would leave the reaction zone and release to the atmosphere as “ammonia slip” in the order of a few ppm. The SNCR could also enable such reactions without the presence of catalyst but under a higher flue gas temperature range (900 ^oC – 1150^oC). The SCR system with lower working temperature range (280 ^oC - 350^oC) had been widely adopted in coal-fired units for years while SCR for gas-fired application is less popular since NOx emission level from gas turbine is generally much lesser than that from coal-fired units. Not until the CAA (Clean Air Act) in the US and similar programmes in EU were promoted over the last decade, SCR for gas application had been installed downstream of heavy duty gas turbines in some developed countries for further NOx abatement in addition to the DLN combustion system. Judging from the typical flue gas temperature ranging from 600^oC to 650^oC at the HRSG inlet of an F-class CCGT unit, it will be impossible to implement SNCR in the HRSG inlet. Therefore, SCR is evaluated as the best practical option for installation at suitable location inside HRSG of L10 & L11 for optimized de-NOx efficiency.

3.2.2 Catalyst for SCR

The catalyst designed for NOx removal is fabricated from a mixture of various oxides which are coated to a steel plate surface as plate type catalyst or directly casted in honeycomb shape as honeycomb type catalyst as shown in Figure 2. Both plate type and honeycomb type catalysts have openings in the cross section with passage aligned with the flue gas flow. The detailed composition of the catalyst varies from one manufacturer to another but essentially it consists of titanium oxide (TiO_2), molybdic oxide (MoO_3) in case of plate type and tungsten oxide (WO_3) in case of honeycomb type. Additionally, both catalyst types have vanadium pentoxide (V_2O_5) as the active component. The use of TiO_2 makes the catalyst also suitable for the treatment of flue gases containing acidic components such as SOx [3]. The pore structure on the surface of the catalyst creates active sites where the chemical reactions take place to convert the NOx into water and nitrogen.

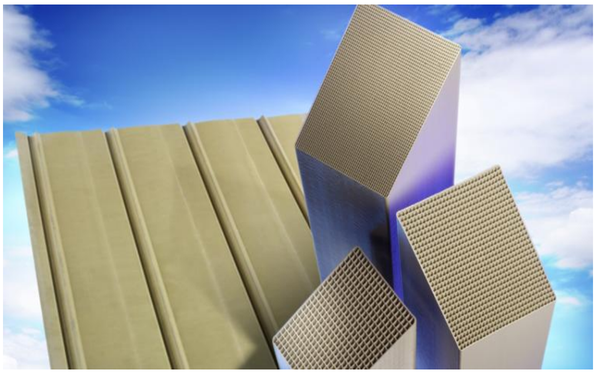

Fig. 2 - Plate Type Catalyst (left) and Honeycomb Type Catalyst (right)

The plate type catalysts are assembled in a metal carrier with suitable spacing called “pitch”. Smaller pitch can produce more surface area for a fixed volume. Similarly, the honeycomb type catalysts are extruded by special machine to form compact honeycomb shape with smaller pitch size as compared with plate type catalysts and so they have relatively higher ratio of “surface area per unit volume”. Unlike the plate type catalysts having a metal sheet presented as the core under the layer of oxides (so-called “non-homogenous” structure), honeycomb type catalysts have homogeneous structure with oxides for both the surface and the core thus requiring careful handling and transportation. For both catalyst types, the single elements are packed within a metal carrier which is then further assembled within a larger case called “module”. In general, working life of plate type catalysts is 2-3 years for coal-fired application in which there is high dust and SOx contents which could react with the injected ammonia to form ammonia sulphate and block the active sites, and thus decreasing the activity of the catalysts. For gas-fired plants like CCGT, honeycomb type catalysts are widely used for this clean flue gas application with low dust and low sulphur content and therefore their working life could be over 5 years generally or even up to 10 years under ideal operating conditions. Deteriorated plate catalysts could be regenerated in suitable facilities with special mechanical and chemical processes to clean up the dust and undesirable contaminants from the active sites, and to re-coat new layer of active oxides on the cleaned-up surfaces such that the activity of catalyst could be recovered to the design level. On the other hand, regeneration for honeycomb type catalysts might not be cost-effective at the present moment and hence they are generally disposed of for landfill upon receiving approval from local authorities based on local disposal criterion, such as toxicity of the concerned waste as per relevant regulation like the “40 CFR Part 261 Subpart C”[4] as adopted in U.S.

By making reference to some typical CCGT plants adopting horizontal-flow HRSG equipped with SCR, the periodical inspection of catalysts could easily be carried out by accessing through the sideway man-door located at the bottom of the HRSG. A sampling tray containing the sample catalyst is installed at men-height level of the catalyst bed which could be easily extracted out manually for subsequent laboratory analysis of the catalyst. Activity test would be conducted when the efficiency and/or ammonia slip is found deteriorating and approaching the guaranteed level so that the residual life could be evaluated. On the other hand, SCR application for vertical-flow HRSG is comparatively less common.

3.2.3 HRSG Design for SCR

Having studied the prerequisites for effective mixing between flue gas and ammonia inside the appropriate temperature zone for SCR operation, it is found that the minimum space required at downstream of a typical F-class gas turbine would be 6-7 meters at the vicinity downstream of the high pressure evaporator (HP EVA) where the flue gas temperature is around 320^{o}C which is an ideal operating temperature for most honeycomb type catalyst under base-load condition. Ammonia Injection Grid (AIG) could be installed at further upstream from this location at a distance of around 3-4 meters.

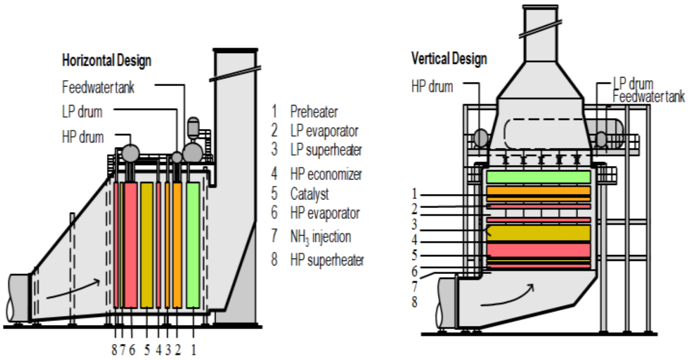

Fig. 3 - Horizontal and Vertical Flow HRSGs

For L10 & L11, HK Electric is open to accept either horizontal-flow or vertical-flow HRSG as long as all our specified and functional requirements could be met. It is noted that the prevailing market trend for single-shaft CCGT plant is to adopt horizontal-flow HRSG which can offer distinct merits in operational flexibility under both base-load and cyclic operation regime (e.g. faster response time in start-up and transient states attributed to higher circulation ratio) and relatively lower installation cost (as the casing is self-supported on ground rather than top-supported as usually adopted in vertical-flow HRSG). The vertical-flow HRSG typically requires smaller footprint but this translates into higher flue gas path with exhaust duct located at top which requires more stringent structural design as illustrated in Figure 3. In fact, the footprint requirement for horizontal-flow HRSG has been greatly minimized nowadays by optimization of gas flow path design. Another distinct merit of horizontal-flow HRSG is the allowance of easy access for installation/replacement of SCR catalyst modules and AIG from HRSG top by vertical lifting and unloading, while the vertical-flow HRSG must be accessed from the two sides of HRSG by manual pulling/pushing movement with the aid of special sliding mechanisms. Based on the above, horizontal-flow HRSG is preferred among the two if SCR is required.

3.2.4 Direct Ammonia vs Urea-to-Ammonia

As explained above, reducing agent must be injected into the gas stream to facilitate the chemical reaction for de-NOx mechanism. Among all gaseous reducing agents available such as CO, CH_4 or other HCs, NH_3 and various derivatives of NH_3 [5], ammonia (NH_3) is the most popular which is colourless but with a very pungent smell. It is lighter than air and exposure to high levels of ammonia in air may be irritating to skin, eyes, throat, and lungs and cause coughing and burns. Lung damage and death may occur after exposure to very high concentrations of ammonia. There are two main types of ammonia available for industrial use, viz aqueous ammonia solution with concentration at 20 - 35%(wt) or anhydrous ammonia with concentration at 99.5%(wt) or higher. Anhydrous ammonia is poisonous to humans, animals and aquatic organisms, while ammonia solution is less poisonous but it is still dangerous as the ammonia vapour released from the solution could be explosive in a closed environment when reaching 15-28% concentration. Ammonia is statutorily regulated as dangerous goods in many countries as well as in Hong Kong, and it is thus undesirable to handle or transport large quantity of ammonia on site for the SCR operation. There is a safer alternative to produce ammonia on site on as-need basis by converting urea to ammonia (U2A) through thermal hydrolysis (or so called thermal cracking) in which the urea molecules are reacted with water under heat to produce ammonia gas, CO_2 and water vapour [6]:

$$NH_2CONH_2 + x\,H_2O \rightarrow NH_2CO_2NH_4 \rightarrow$$
$$2\,NH_3 + CO_2 + (x-1)\,H_2O$$

Urea is not classified as dangerous goods and it is much safer to handle and transport urea in solid form in either granular or prill shape, or liquid form as urea solution of concentration from 32.5%wt to 40%wt. For SCR or SNCR application, normally urea solution at 40% concentration is used for thermal hydrolysis but concentration of 32.5% or lower may be required at

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some locations with cold climatic condition where the urea solution is easily crystallized. Another advantage of using urea solution of 40% concentration is that the ammonia vapour released from the solution is not flammable through the entire mixture range in air [7].

Currently, the two most popular U2A conversion technologies available in the market are Hydrolyser and Thermal Decomposer. For Hydrolyser which is designed as a horizontal pressure vessel equipped with steam heat exchanger coils and/or electrical heater outside, the urea solution is heated for hydrolysis process and the lighter ammonia gas, CO_2 and water vapour flow out from the top of the converter and enter into the AIG for ammonia gas injection. The U2A process occurred in Thermal Decomposer is similar to that of Hydrolyser but with the exception that the urea solution is in direct contact with the heating medium, usually hot flue gas tapped from HRSG. The hydrolysis products like NH_3, CO_2 and water vapour will flow together with the flue gas back to the flue gas path. In general, Hydrolyser is installed horizontally (larger footprint) while Thermal Decomposer is installed vertically (smaller footprint). Thermal Decomposer has slightly faster response time than Hydrolyser due to direct contact/mixing between urea and flue gas, and is considered best suit for unitized installation for one unit. Hydrolyser is preferably installed as centralized ammonia supply serving several AIGs of different units.

4. CONCLUSION

HK Electric has contemplated the possible change in regulatory limit for NOx emission that will be resulted from the fuel mix policy and AQOs newly proposed by the HKSAR Government, and taken proactive steps in evaluating/identifying the best practicable means to face the anticipated challenge and plan for the next step forward. At this moment with the related environmental policies and regulatory frameworks in place, the NOx emission limit for new-built gas-fired plants has been reduced to 5mg/m^3 which is beyond the capability of even the most advanced DLN combustion system. As such, the adoption of post-combustion Selective Catalytic Reduction (SCR) System of 50-90% NOx removal efficiency is evaluated as the best practical solution to meet the challenges in Hong Kong.

With the supports from the community and joint efforts given by the HKSAR Government and the industry, HK Electric will continue its commitment in providing safe, reliable, environmental friendly and affordable power supply to the community and building a low carbon society in the future.

ACKNOWLEDGEMENT

The Authors wish to thank the management of The Hongkong Electric Co., Ltd. for the permission to publish this paper.

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Paper No. 2

SMART POWER ENABLING SMART CITY

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SMART POWER ENABLING SMART CITY

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ABSTRACT

CLP Power (CLP) is dedicated to supporting the Hong Kong SAR Government in its vision of transforming Hong Kong into a smart city. While there is no common definition for "smart cities", they share a common attribute of utilising Information and Communication Technologies (ICT) and data analytics to enable the interconnection of the relevant systems for building a more livable and people-oriented environment. A smart electricity grid is a good example that demonstrates the essential role of ICT in ensuring a reliable energy supply for the smooth running of a smart city. CLP is actively adopting ICT to transform our conventional power grid into a smart grid, which covers all aspects, including power generation, transmission and distribution, as well as customer services, and forms an integral part of a smart city. Moreover, various smart initiatives have been implemented to support the key dimensions like smart environment, smart mobility and smart living of being a smart city. In this paper, the smart initiatives implemented by CLP and the trend of smart technology will be discussed.

1. INTRODUCTION

CLP operates a vertically integrated power supply business in Hong Kong, covering electricity generation, transmission and distribution, and retail, and has been serving Hong Kong for over 115 years. Now, it supplies highly reliable electricity to over 80% of Hong Kong's population. Between 2014 and 2016, the average unplanned customer minutes lost per year was 1.48 minutes and the electricity supply reliability was at a world-class reliability of over 99.999% [1].

As one of the major electricity supply companies in Hong Kong, CLP is dedicated to supporting the Government to transform Hong Kong into a smart city.

2. SMART CITY ELEMENTS

Definition of a smart city evolves over time. In general, it is a multi-disciplinary urban development vision that uses ICT to monitor, manage and enhance public services. This covers a wide range of services including energy, water, healthcare, transport and traffic management. With innovative applications of ICT in connecting and integrating various components across the city, it allows a more efficient use of resources and improves people's quality of life.

One of the frequently referenced illustrations of smart cities is the "Smart City Wheel" developed by Boyd Cohen. Cohen categorized six key elements in a smart city: Smart Mobility, Smart Living, Smart Environment, Smart Governance, Smart Economy and Smart People [2], Figure 1 refers.

Fig. 1 – Six Key Elements of a Smart City

3. EXPENDING SMART CITY LANDSCAPE

Smart city projects are fast developing globally. Although the themes and targets of the projects are different in the countries, their overall goals are to develop a smart city from their conventional city, so to improve their city operational efficiency and effectiveness, and finally citizens' quality of life.

In Hong Kong, as proposed in the 2015 Policy Address by government, a smart city pilot project is implementing at Kowloon East. Further, in June 2017, the Office of the Government Chief Information Officer released the 'Report of Consultancy Study on Smart City Blueprint for Hong Kong', which advises and provides recommendations for formulating a blueprint for long-term smart city planning and development in Hong Kong.

4. INITIATIVES IMPLEMENTED BY CLP TO SUPPORT SMART CITY

CLP strives to support Hong Kong on smart city development by implementing initiatives in smart grid, smart environment, smart mobility and smart living.

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4.1 Smart Grid

Smart grid is the integration of ICT with conventional power grid, from electricity generation to retail, and forms an integral part of a smart city. It can open up many new opportunities, such as engaging customers in energy saving and demand side management. It also enhances the electricity supply reliability, efficiency and safety.

To facilitate those new smart city initiatives to operate seamlessly, it is crucial to have a flexible and robust power grid. Smart grid itself already has those distinguishing features to enable a smart city. Figure 2 shows the breakthrough features of smart grid and the following paragraphs illustrate the examples of self-healing feature of Intelligent Transmission Substation and 11kV Overhead Line adopted [3].

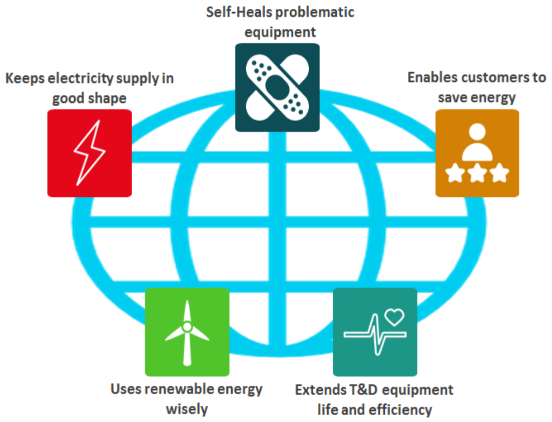

Fig. 2 – Smart Grid Distinguishing Features

4.1.1 Intelligent Transmission Substation

As a pilot scheme, two intelligent transmission substations, namely Chui Ling Road Substation and Eastern Road Substation were successfully implemented by 2014.

Inside these two intelligent transmission substations, dedicated Intelligent Electronic Devices per IEC61850 standard were used to develop the 11kV switchboard Numerical Auto-switching Scheme (NAS). The NAS will be activated when either one of in-service 132/11kV transformers tripped, and it will then operate the pre-defined bus-coupler, bus-section and inter-connector under the programmed sequence to restore power supply to affected equipment within 250ms.

The NAS can also be programmed remotely by System Control Engineer to suit both normal and contingent system configurations and, therefore, the grid supply reliability can be greatly enhanced, especially during equipment failure outage condition.

4.1.2 11kV Overhead Line (OHL) Automatic Supply Restoration System

Similar to intelligent transmission substations, Fault Detection Isolation Restoration (FDIR) has been applied in 11kV overhead line network to improve the distribution system supply reliability.

This OHL self-healing application coordinates intelligent re-closers and load-break switches by an automated OHL supply restoration scheme to restore supply to non-faulty equipment. When an OHL fault occurs, the automated OHL supply restoration scheme is able to locate and isolate the faulty section, then to restore supply to those non-faulty parts.

4.2 Smart Environment

Many smart environment initiatives have been implemented to improve the environment we live, such as diversified fuel mix, green transmission substation and emission control.

4.2.1 Diversified Fuel Mix

CLP has an Energy Vision to provide a reliable electricity supply by clean energy at reasonable costs, through the diversity of fuel types [4]. As early as 1990s, the company spearheaded the introduction of nuclear energy and natural gas for power generation.

Nuclear Power

In 1985, the Chinese Government and the company joined hands to develop the nation's first large-scale commercial nuclear power station at Daya Bay in Guangdong Province in the Mainland. As of year 2016, nuclear energy accounts for about a third of its fuel mix in Hong Kong and has been safely supplying about 25% of Hong Kong's electricity needs for more than 20 years. To ensure that more clean and cost-competitive energy is provided to Hong Kong, an agreement was reached with Daya Bay to provide an additional 10% of the electricity output to Hong Kong from late 2014 to 2018.

Natural Gas

Natural gas produces lower levels of emissions of sulphur dioxide, nitrogen oxide, particulates and carbon dioxide than most other fossil fuels. In 1996, CLP was the first electric utility to bring natural gas to Hong Kong for power generation to improve Hong Kong air quality.

The company started importing gas from Yacheng Gas Field in 1996 at a very attractive price. With the depleting Yacheng gas fields, a Gas Supply Agreement with PetroChina was signed for supplying Second West-East Natural Gas Pipeline (WEPII) gas for 20 years starting from 2013.

In supporting the Government's environmental policy of increasing natural gas to around 50% in the fuel mix target for 2020, an additional Combined Cycle Gas Turbine is being built in the Black Point Power Station, which will be operated at the end of 2019 tentatively. Further, the company has also explored to build offshore Liquefied Natural Gas Terminal, which will be discussed in the coming sections.

Renewable Energy (RE)
CLP is supportive to development of community RE projects and we strive to explore development of practical local RE opportunities. The company has developed Hong Kong's first commercial-sale renewable energy micro-grid on Town Island, which is located in Sai Kung [4]. This micro-grid comprises of 672 solar panels, two wind turbines and 576 batteries, with a generation capacity up to 192kW. By the second quarter of 2016, it had generated more than 340,000kWh of electricity, which equivalent to 970 household monthly consumptions and nearly 140,000kg reduction in carbon dioxide emissions.

Fig. 3 – Micro-grid on Town Island

Apart from the Town Island project, there are over 250 small-scale distributed RE generations connected to the company's grid at the end of 2016. Examples of these projects are including: Science Park's building integrated photovoltaic and wind turbine systems on its facades and roofs, and the Drainage Services Department's biogas generators at the sewage treatment works.

4.2.2 Green Transmission Substation [4]
CLP teamed up with the University of Hong Kong in 2006 to study on Sky Woodland. In May 2013, the concept of Hong Kong's largest Sky Woodland was brought into reality in Chui Ling Road transmission substation. It covers 520m^2 on the rooftops of two substation blocks, together with 500m^2 of vertical greening on the substation walls.

The Sky Woodland is far more than a planting project on a substation, refer to Figure 4. It replicates a natural woodland environment on a transmission substation, hosting 80 trees made up of 32 native species. After its launching, it has attracted abundance species of birds and insects. In additional to its ecological benefits, the Sky Woodland improves the nearby air quality and reducing the indoor and outdoor temperature through solar heat absorption and transpiration. Further, inside the substation, low-noise and low-loss transformers and oil-free cables are used to minimize environmental impact, such as noise impact to surroundings.

The Gold Award for the Transmission and Distribution Project of the Year at the Asian Power Awards in 2013 was presented to the Sky Woodland project to appreciate its distinctive feature and sustainable design.

Fig. 4 – Sky Woodland at the Chui Ling Road Substation

4.2.3 Emission Control [4]
CLP has successfully met the increasing stringent emission caps for our power plants set by the Government. From 2010 to 2011, we retrofitted the largest four units of the coal-fired Castle Peak Power Station with large-scale desulphurization and nitrogen oxide reduction facilities which have significantly improved the emissions performance of the station.

After the retrofit, more than 85% emissions reduction in sulphur dioxide, nitrogen oxide and respirable suspended particulates have been achieved since 1990, while electricity demand has grown by over 83% during the same period.

4.3 Smart Mobility

Electric vehicle promotion is an important element in smart mobility. It improves roadside air quality, has higher energy efficiency as comparing with gasoline counterpart, and is quieter and smoother while the engine running.

4.3.1 Electric Vehicle Chargers
To support keen demand of electric vehicle chargers, the "Trial Network of Charging Stations" programme was launched in 2009 and so far set up 31 standard/semi-quick and 16 quick charging stations in CLP's supply area by March 2017, with a total of 148 charging points [5]. Through those charging stations, drivers can charge their EVs for free until the end of 2017. Supported with the "CLP Hong Kong App", EV drivers can locate nearby charging stations through the mobile app.

Different brands of electric vehicle have their owned standard of electric vehicle charging facilities. In response to different charging needs, the company introduced the first multi-standard EV charger in Hong Kong in June 2015, refer to Figure 5, and now 19 multi-standard EV chargers are installed to suit different charging requirements.

Fig. 5 – Multi-standard EV Quick Charger

4.3.2 EV Charging Infrastructure Development
Smart Charge (HK) Limited is formed under CLP joint venture to offer total EV charging solutions in Hong Kong to meet the increasing market demand [6]. It builds both public and private charging stations in Hong Kong and the charging infrastructure is constructed with advanced supervisory, control and automation technologies and intelligent network management solution to achieve safe and reliable operation.

4.3.3 CLP Electric Vehicle Fleet
To support the smart mobility development in Hong Kong, since 1984, CLP has been introducing electric vehicles into fleet. Various types of electric vehicle chargers were also installed at different offices and depots to support the fleet charging. Some quick chargers are even opened to public to offer 7 x 24 charging services.

Fig. 6 – CLP Electric Vehicle Fleet

4.4 Smart Living

Engaging customers in energy saving and demand side management is the most essential element to promote smart living which helps achieve greater environmental and economic benefits. To engage customers to use energy in a smarter way, smart meter is the key component being deployed by utilities around the world.

4.4.1 Smart Metering
Smart meters allow the utility to collect near real-time information from the customer-end to implement both Demand Side Management such as reducing power system critical peak and empowering customers to conserve energy, and benefit Supply Side Management such as improving supply reliability, safety and operation efficiency.

To explore the potential benefits for our customers by applying smart meter enabled features in Hong Kong, an end-to-end AMI solution was implemented in 2013[4]. About 4,400 customers participated in the myEnergy pilot programme, they could gain timely access to their consumption information via multiple channels, such as dedicated web portal and mobile applications on smartphones. Customers could then adjust their electricity usage behaviour in accordance with the time-varying tariffs, and save on energy use at peak times and energy bills.

To further promote smart living and explore the feasibility of a wider implementation of smart metering, we have launched the Smart Energy Programme – a one-year demand side management study – for about 26,000 residential customers in June 2017.

4.4.2 Smart Energy Experience Centre
CLP has given its customer service centre in Yuen Long a major facelift to transform it into a Smart Energy Experience Centre. The company has also partnered with the Hong Kong Science and Technology Parks Corporation to introduce smart home devices suitable for small flats in Hong Kong at the centre.

The centre features a miniature home featuring smart home products and devices, including a smart home security system and a smart device which controls air conditioners and fans from a mobile app, introducing smart and low-carbon lifestyles to customers.

4.4.3 Eco Power 360
Eco Power 360, an online assessment tool, helps customers understand more about their electricity consumption pattern and benchmark with similar families. Customers can redeem gifts with the Eco Points rewarded by saving energy and joining designated activities under the Eco Rewards Scheme.

5. EMERGING SMART CITY TECHNOLOGIES

Innovative technology development and adoption are the key factors to the success of smart city implementation. In this section, several latest smart city technologies are discussed.

5.1 Offshore Liquefied Natural Gas (LNG) Terminal

Offshore Liquefied Natural Gas Terminal is more economical, has less environmental impacts and of shorter construction duration as compared with the land-based LNG terminal.

It enables direct purchase of LNG from the worldwide market, and therefore improving the future Hong Kong LNG buyers' overall negotiating position, and

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diversity of gas supply sources. The additional gas supply sources also enhance power supply security in Hong Kong.

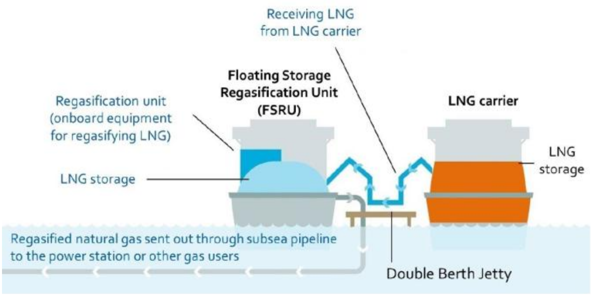

Fig. 7 – Operations of an Offshore LNG Terminal

5.2 Landfill Gas

Landfill gas is released as solid waste decomposes in landfills. It consists of approximately 50% of methane, which is flammable and a type of greenhouse gas. To avoid fire risk, it was burnt directly at the landfill site before. Now, it is regarded as a waste-to-energy source. If the landfill gas extraction rate is large enough, a gas turbine or internal combustion energy can be used to produce electricity to sell commercially or use on site. Further, the greenhouse gas emission can be controlled.

5.3 Condition Monitoring and Asset Health Analytics

There are many emerging real-time condition monitoring technologies to be employed to monitor different equipment status, such as power transformers, reactors and switchgears. Integrating those condition monitoring data with the equipment specific health analytics, equipment health can be evaluated and the appropriate maintenance strategy or actions can be formulated accordingly to optimize the maintenance cost and minimize equipment downtime.

5.4 Energy Platform

With different types of renewable energy connected to smart grid, low carbon society can be realized. Energy Platform is built to link up and control those intermittent generations and finally to optimize the power plant infrastructure investment requirements.

6. CONCLUSION

CLP has been proactively utilizing Information and Communication Technologies to transform the conventional power grid into a smart grid. With the latest smart grid technologies, electricity supply reliability and safety are enhanced. Advanced and innovative technologies can also be offered to enrich customer experience. Moreover, emerging technologies and solutions have been being explored continuously to support the government’s strategy to turn Hong Kong into a greener and smarter city.

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Paper No. 3

HARNESSING THE SUN – HONG KONG'S LARGEST SOLAR FARM

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HARNESSING THE SUN - HONG KONG'S LARGEST SOLAR FARM

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ABSTRACT

The Drainage Services Department (DSD) has been advocating the use of solar technology since 2003. In December 2016, DSD commissioned Hong Kong's largest solar farm at Siu Ho Wan Sewage Treatment Works (SHWSTW). The solar farm uses photovoltaic (PV) panels to convert solar energy into electricity, which is a form of renewable energy suitable for Hong Kong. The solar farm is equipped with innovative designs to enhance operation and monitoring of the PV system. Together with the renewable energy from bio-gas produced in the course of operating the sewage treatment works, a significant proportion of energy consumed by DSD is generated by renewable energy.

The solar farm has gained significant environmental achievements by raising public awareness on climate change and serving as an education centre for the public since April 2017.

1. INTRODUCTION

Combating climate change relies on the collaborating effort between the government and the stakeholders of various sectors in the society. To safeguard the general public against flooding, DSD designs and constructs stormwater drainage systems with reference to international standards, and carries out regular inspections and timely maintenance works. To safeguard the quality of Hong Kong waters, DSD operates some 300 sewage facilities, treats about 1 billion cubic metres of sewage and handles about 393,000 tonnes of sludge every year. In providing these services, DSD consumes enormous amount of energy, which accounts for about 10% of the total electricity consumption of the whole government. In this regard, DSD is dedicated to doing its part in mitigating the impact of climate change through a series of energy conservation and emission reduction measures at its facilities, such as introducing energy-efficient sewage treatment technologies, using renewable energy and utilizing biogas for electricity generation.

In the past three years, different types of renewable energy, such as solar energy and biogas, supplied an average of 27 million kWh of energy annually.

2. PHOTOVOLTAIC TECHNOLOGY

Given the lack of available open space for PV panel installation coupled with competing uses of space, such as equipment installation, in DSD's plants, space is always a constraint which limits large scale implementation of PV systems. In general, possible glare caused by PV panels, remoteness of PV panels from electricity loads and their susceptibility to physical damage are amongst the constraints to be coped with.

Nevertheless, DSD has over the years endeavored to make full use of the open spaces in its sewage treatment works (STWs) and pumping stations to capture solar energy for subsequent use as far as practicable. Since 2003, various large-scale standalone and grid-connected PV systems for supplying electricity to equipment have been installed on the roofs of some major facilities. Furthermore, DSD has installed hybrid lamp posts, each equipped with a solar panel and a mini wind turbine, to capture both solar and wind energy in its STWs and pumping stations. Currently, the total capacity of the hybrid lamp posts is over 40 kW.

To fully utilize the available open space in SHWSTW, DSD had installed a PV system using poly-crystalline silicon. Commissioned in December 2016, it is currently the largest PV panel installation of the government as well as the largest in Hong Kong, adding up the combined generation capacity of all PV systems in DSD's sites to about 1,250 kW.

3. THE LARGEST SOLAR FARM

The solar farm (Figure 1), comprising 4,237 polycrystalline PV panels, covers an area of 11,000 square metres.

Fig. 1 – Solar Farm at SHWSTW

The installed generation capacity of 1,100 kW can generate about 1.1 million kWh of electricity each year, which is equivalent to the annual electricity consumption of about 230 households and reduces carbon dioxide emission by 770 tonnes per year. The electricity generated, which accounts for about 25% of the current annual electricity consumption of SHWSTW, is fed through an internal power distribution network to various facilities inside the plant, including screening facilities, a workshop, an administration building, an ultra-violet disinfection system and sludge treatment facilities.

3.1. Innovative Designs

The solar farm has four major features:

(a) an intelligent automatic detection system;
(b) prefabricated concrete supports;
(c) a solar farm monitoring room; and
(d) an aerial view of DSD logo.

3.1.1. Intelligent Automatic Detection System

Operating and maintaining a large quantity of PV panels is the major challenge for operators. As a pilot trial, DSD introduced an intelligent automatic detection system (Fig. 2) to a part of the solar farm, which facilitates the operators to identify malfunctioning PV panels quickly and effectively. With the proven effectiveness of this detection system, which was the first of its kind implemented in Hong Kong, there is a plan to extend this intelligent automatic detection system to other parts of the solar farm.

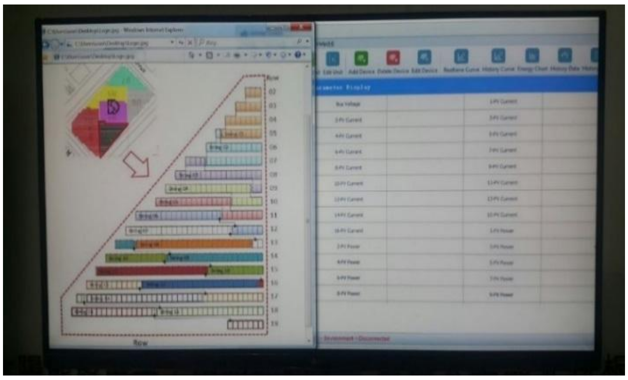

Fig. 2 – Intelligent Automatic Detection System

3.1.2. Prefabricated Concrete Supports

Instead of using traditional steel frame supports, the PV panels at the solar farm are installed on movable prefabricated concrete supports (Figure 3). As there is no mechanical anchorage onto the ground, the PV panels are readily movable and can be relocated easily to cater for future expansion or redevelopment of SHWSTW.

3.1.3. Solar Farm Monitoring Room

The solar farm monitoring room (Figure 4) provides real-time centralised monitoring of the operation and power generation of the solar farm. As an information hub for visitors, the room also features educational materials about different types of renewable energy (e.g. biogas, solar energy, etc.) adopted by DSD.

Fig. 3 – Prefabricated Concrete Supports

Fig. 4 – Solar Farm Monitoring Room

3.1.4. Aerial View of DSD Logo

To showcase the government's commitment in combating climate change, amorphous thin-film PV panels were used to form a highly visible collage in the center of the solar farm. Visitors flying in and out of Hong Kong are able to see aerially the logo of DSD (Figure 5).

Fig. 5 – The Aerial View of the Solar Farm

3.2. Public Education and Achievements

Apart from the environmental benefits, the solar farm project also aims to raise the awareness of the general public on climate change challenges. The commissioning ceremony of the solar farm on 9 December 2016 was widely publicized in 22 journals and the solar farm has been opened for visits by the general public since April 2017. The benefits and achievements of the project were also reflected by the external recognitions, including the awards of CarbonCare® Action Label 2016 by the CarbonCARE InnoLab and the Certificate of Merit of 2017 Environmental Paper Award by the Environmental Division of the Hong Kong Institution of Engineers.

4. CONCLUSION

The solar farm at SHWSTW is only one of the many measures undertaken by DSD in mitigating climate change. DSD will continue to enhance the total energy management strategy for its facilities, extend the application of renewable energy in its new projects and implement effective emission reduction measures, with a view to developing Hong Kong into a low-carbon, sustainable and liveable city.

Paper No. 4

DRIVING RETRO-COMMISSIONING AS A MAINSTREAM PRACTICE IN HONG KONG

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DRIVING RETRO-COMMISSIONING AS A MAINSTREAM PRACTICE IN HONG KONG

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ABSTRACT

Retro-commissioning for existing buildings is regarded as instrumental in meeting the carbon reduction target for Hong Kong. The Hong Kong Green Building Council is planning to run an ACT-Shop programme with the aim to enhance the technical competence of practitioners in carrying out retro-commissioning for central air-conditioning plants.

In order to invite a wider adoption of retro-commissioning in existing buildings, we need to explore the commercial interests of potential market players and suggest practical technical solutions.

The presentation will provide a brief on the ACT-Shop programme and Active trainings, and discuss on the values to facility and property management companies in providing such services to their clients. The presentation will also look at the need to integrate knowledge of practitioners with the emerging technologies.

1. INTRODUCTION

In response to the Paris Agreement reached in the COP21[1], the Government has launched The Hong Kong's Climate Action Plan 2030+ [2] targeting an absolute carbon reduction of 26-36% by 2030. Retro-commissioning for existing buildings is one of the key initiatives that the Government is driving in order to meet the target. The EMSD has carried out pilot projects in Government buildings and published the "Technical Guidelines on Retro-commissioning" [3] in July 2017.

The Hong Kong Green Building Council ("the HKGBC") has been engaged by the Government to drive retro-commissioning within the private sector. To this end, the HKGBC has initiated the "ACT-Shop" programme with the aim of building up the capacity of the industry and training up competent persons with the skill sets of retro-commissioning to bring changes to the industry.

Whilst the ACT-Shop programme is effective in transferring the necessary knowledge to a small number of practitioners, there are limitations if the key objective is to make retro-commissioning the mainstream for the industry. To enable more practitioners to receive trainings on retro-commissioning, the HKGBC is planning to run an "Active training".

Drivers for multi-owned buildings including those managed by facility management companies are often not strong enough to convince the owners to spend resources on retro-commissioning. However, facilities management companies could, if their staffs have the capability to carry out retro-commissioning themselves, carry the work at a much lower cost. The facilities management companies could therefore, become one of the major drivers for retro-commissioning multi-owned buildings in Hong Kong.

It is not practical to carry out works manually daily like collecting data, making analysis, etc. even the technical staffs are knowledgeable enough in retro-commissioning. There have been lots of technological advancements recently like building analytics, mobile technologies, internet of things, etc. which have made retro-commissioning a much easier job for practitioners. Retro-commissioning relies on and will be driven by technologies. To move this forward, emphasis should be placed on how to customize such technologies to suit the building systems and its operation and maintenance staffs.

This paper will give a brief on the ACT-Shop and Active training being operated by the HKGBC, and discuss on what the HKGBC is working on to explore the feasibility of enabling facilities management companies to drive retro-commissioning in buildings that they manage. Also how the adoption of the latest technologies by the industry can be accelerated.

2. ACT-SHOP PROGRAMME

2.1 Objectives of ACT-Shop

The HKGBC has initiated the "ACT-Shop" Programme with the aim to build up the capacity of the industry on retro-commissioning by adopting "knowledge-based" approach.

The key feature of the ACT-Shop is on training participants through using the buildings that they are managing as living laboratories. Real operating data are collected and analysed to generate the necessary information for evaluating the performance of their

HVAC systems and identify opportunities for enhancements. Data are collected after improvement measures for verifying the savings.

For the participants, the objectives would be:

1. Actively supporting HK government's energy saving plan

2. Building up the competence for the industry on retro- commissioning through:

   a. developing the data/knowledge base;
   b. developing a systematic approach for retro-commissioning;
   c. demonstrating the value of retro-commissioning;
   d. transferring the knowledge and skills to the industry; and
   e. establishing a practical operation & management system

3. Promoting the adoption of best practices to the industry

2.2 The ACT-Shop process

The process of ACT-Shop can be divided into the following stages:

1. Evaluation of site conditions and document
   A site visit will be carried out to have a general understanding on the condition of the building and systems, the HVAC system design, the functionalities of various of equipment, the availability of operating data and any past information on equipment performance.

2. Data collection
   Participants would be asked to collect the necessary data either from past log records or if unavailable to obtain it through available meters and gauges. It will not be necessary to collect a large volume of data. If such instruments were not available, alternative means would be worked out with the participants.

3. Data analysis
   The collected data would be analysed together with the participants and the results would be shared with the group to facilitate learning through peers. Tools would be provided to facilitate the evaluation of the performance of their equipment/systems or identify any abnormality.

   Opportunities for improvements through no/low cost measures were identified and discussed. Justifications such as saving estimation, cost and potential risk, if any, would be worked out and followed by implementing the improvement measures.

4. Implementing the improvement measures
   Participants would then go through their internal process for obtaining the approval and resources to have the improvement works done.

5. Measurement and verification
   After the improvement works have been done, data are collected to verify the savings.

2.3 Progress and results

The buildings selected to participate in the ACT-Shop programme are mostly self-owned commercial buildings that are owned by developers with high energy consumptions by their portfolio.

Up to this writing, two batches of buildings have gone through the process. It covered nine commercial buildings and two hotel with a total GFA of 1.3 million m^2. The third batch includes five commercial buildings, one hotel and one multi-owned building managed by a facilities management company. The total GFA is 0.29 million m^2 has just started.

2.4 Potential energy savings identified

The total potential savings identified in the first two batches of buildings and hotels have been accumulated to 13 million kWh per annum which is about 7-10 % of their total consumption.

2.5 Feedback from participants

A preliminary survey was done for the ACT-Shop pilot Scheme, all participants were satisfied with the scheme and agreed that they gained HVAC & retro-commissioning knowledge, especially in terms of "Key parameters for system control" and "Regular retuning" throughout the process. They also rated the contents of ACT-Shop Pilot Scheme as "Absolutely Necessary". It shows that this participative approach can effectively build up the competence of the industry practitioners in terms of knowledge-based energy management.

2.6 Limitations of ACT-Shop

Whilst the ACT-Shop programme has been proved to be effective in building up the capacity of the operating team participated in the programme, it has the following limitations in achieving the mission of driving retro-commissioning as a mainstream practice for the industry:

- It takes a long time to complete the whole process – Usually there are equipment/meters found faulty and it can take time to rectify those before the process can move forward. The process of getting internal approvals and getting the works done would often take months to complete.

- Limited to small groups – Each batch can only be limited to a small group of up to 5 - 7 buildings in order to have a high level of participation and interaction among participants.

- Only interested to owners of self-owned buildings – Energy consumption is normally their second largest outgoing next to staff cost and so the savings would directly affect their bottom line. But for owners of multi-owned buildings, the savings would not be so significant comparing to the efforts of getting all owners to agree on the additional resources needed for retro-commissioning and the stringent procurement process they need to go through by Incorporated Owners. Also it is often difficult to know the exact savings beforehand and makes the justification for retro-commissioning difficult.

Due to the above limitations, the ACT-Shop programme alone would not be sufficient to drive for a wider adoption by the industry except for self-own buildings. Hence, the HKGBC has therefore come up with the following initiatives.

3. ACTIVE TRAINING

Active training can be considered as a condensed ACT-Shop programme. More participants in each class can be allowed. Same as ACT-Shop, participants must be personnel operating or managing the building. Other than the transfer of theories and practices, participants will be asked to do exercises using the real data from their buildings. A project on an improvement measure is also required to be submitted to qualify for receiving a full certificate. The Active training would consist of about 10 classes and can be finished in about three months. With the Active Training programme, it is expected that more people can be trained within a much shorter time. Most important is that it can maintain relatively high interactions between the facilitator and peers which is considered to be a critical success factor for the programme.

4. FACILITIES MANAGEMENT COMPANIES AS A DRIVER FOR MULTI-OWNED BUILDINGS

A large proportion of buildings in Hong Kong are multi-owned buildings. As mentioned above, the drivers are not strong enough to initiate retro-commissioning in their buildings. Also those buildings are usually managed by facilities management companies that provide staff for mainly the daily management and operation only.

Retro-commissioning focuses on retuning existing systems and equipment which could be handled by the site staff of the facilities management companies if they have received adequate trainings. This can significantly reduce the cost to the owners and efforts of getting the consensus among all owners and going through the procurement process.

The benefits of retro-commissioning should be sufficient to drive the facilities management companies to influence their clients. The followings are some examples:

- There is virtually no additional cost to them if their site staffs can do the work.

- If there are retro-fitting or rectification works found necessary, usually facilities management companies can get an add-on fee for the works.

- There is growing interest or concern among their clients regarding sustainability especially all listed companies now have to publish Environmental, Social and Governance (ESG) reports.

- Facilities Management companies could build up their competitive edge and core competence to secure their existing contracts or marketing for new ones.

- Facilities Management companies could demonstrate that they are a socially responsible company and which could make them eligible for joining local and international sustainability indexes.

The HKGBC has recently included a building that is managed by a Facilities Management company in the latest batch. Together we will try to test out if Facilities Management companies would have enough interest to influence their clients to do retro-commissioning.

5. EMERGING TECHNOLOGIES

Retro-commissioning if properly done, would require the continuous collection and analysis of large amount of operating data, monitoring and interpreting the information, and turning those into decision for actions. Even though a staff has acquired the capability of carrying out the work, it would not be practical to do all of those manually.

With the recent advancements in technology in both hardware and software, it is now possible to handle those through latest building analytic tools, mobile technologies and internet of things.

Data can now be collected much more easily through the cloud platform and internet-connected devices. Data collected can be analysed through data analytic tool by artificial intelligence (AI) or expert rules to generate useful information that can be displayed and communicated for the direct use of different types of users. Additional instruments can be added without running conduits and cables throughout the building.

Services providers are becoming one of the enablers and biggest drivers for energy efficiency including retro-commissioning.

The HKGBC is now working with buildings participating in the ACT-Shop programme to pilot the customization of technologies to suit the building systems, and the management and operation team requirements. The work aims to test out the customization process, and understand the type of information each individual needs and the format of display. More importantly is to reveal the value of those technologies to the client.

6. SUMMARY

To make our contribution in meeting the carbon reduction target, it is important to achieve the ultimate objective of making retro-commissioning the main stream practice for the industry, we need training programmes that can effectively enhance the knowledge and experience of related professionals.

We need different enablers and drivers for the different types of buildings and building owners. Facilities management companies should explore the ways and measures that can influence their clients to move forward on this on a win-win basis.

Technology is advancing quickly and no doubt we would have more choices, options and solutions from suppliers and all that could make retro-commissioning easier and more cost effective.

The HKGBC is working closely with the government and the industry through pilots like ACT-Shop programme that will not only transfer knowledge and experience but also explore further drivers through the participating buildings as living laboratories

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SIEMENS

Paper No. 5

TECHNICAL GUIDELINES ON RETRO-COMMISSIONING

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TECHNICAL GUIDELINES ON RETRO-COMMISSIONING

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ABSTRACT

Hong Kong is a densely populated metropolitan city crowded with high-rise buildings. More than half (55%) of Hong Kong's total annual energy end-use is in the form of electricity consumption and buildings take up about 90% of the citywide total electricity consumption. As most of the existing buildings in Hong Kong were designed and built at a time when energy saving was not a foremost consideration, one of the key initiatives for energy savings in existing buildings is to improve their energy performance through Retro-commissioning (RCx).

RCx is a cost-effective process to periodically check the system and energy performance of an existing building. The process identifies operational improvements that can save energy, improve efficiency performance of the buildings and thus lower energy bills. The process can be performed alone or with a retrofitting project, such as replacement of less energy efficient appliances with more efficient ones and fitting meters to measure operations.

EMSD has developed Technical Guidelines on Retro-commissioning, TG(RCx) in order to drive the wider spread of RCx in existing buildings. By government taking the lead, it is hoped that the public and private sectors can work hand-in-hand to improve overall energy performance of buildings and transform Hong Kong into Smarter Green Metropolitan City.

1. INTRODUCTION

Hong Kong consumed about 80,000 million kWh of energy in 2014, in which around 55% energy end-use is in form of electricity consumption. With more than 7 million people squeezed within small stretch of 1,100 km^2 land, the fulfilment of living needs and city operation has indeed resulted in making Hong Kong the most vertical city in the world. It is thus not surprising that buildings take up about 90% of our total electricity consumption, and is roughly 50% of total energy end-use (Figure 1).

It is imperative that reduction of electricity use in buildings can help combat climate change.

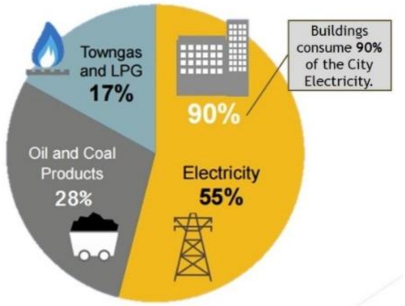

Fig. 1 – Energy Consumption Percentage in Hong Kong

2. ENERGY SAVING TARGET

To this end, the Environment Bureau published the Energy Saving Plan for Hong Kong's Built Environment 2015-2025+(ESP) in May 2015 to set the target of reducing Hong Kong's energy intensity by 40% by 2025. In January 2017, the Environment Bureau published sister document, Hong Kong's Climate Action Plan 2030+ which set another target to reduce our carbon intensity by 65-70 per cent by 2030 compared with the 2005 level. With this ambitious vision, the whole community has to endeavour further effort to achieve energy conservation with concrete supporting measures.

3. BEEO and EE(LP)O

The Government has been pursuing various energy efficiency policies and initiatives to reduce energy use in buildings. In 2012, the Buildings Energy Efficiency Ordinance, Cap 610 (BEEO) came into full operation. It requires 4 types of building services installation in new buildings as well as existing buildings undergoing major retrofitting to comply with the energy efficiency standards and requirements specified in the Building Energy Code (BEC). Meanwhile, by specifying the energy performance of 5 types of "plug-in" domestic electrical appliances under the Energy Efficiency (Labelling of Products) Ordinance, Cap 598 (EE(LP)O) with full implementation in 2009, large amount of electricity consumption in residential sector can be regulated. These two pieces of legislation already govern the "built-in" system and "plug-in" appliances in buildings.

Moreover, the Government is leading by example. In particular, we have set a new target of 5% saving in the electricity consumption of government buildings in the next five years from 2015/16 to 2019/20. With other green building initiatives being rolled out in full steam and relevant energy efficiency regulations being continuously enforced with further tightened requirements, various energy saving initiatives have been in place. However, there will still be a gap to achieve the energy saving target. It is therefore important to trigger contribution from private sector towards the energy saving target.

4. 4Ts

Following Climate Action Plan 2030+, an operational framework on climate change was established. The Environment Bureau created a Dialogue Platform to collaborate with the key stakeholders of the building sector in 2016. Through several rounds of gatherings and information exchanges with the top management from different stakeholders, a broad consensus has been reached for the building sector to partner under the voluntary 4Ts framework which includes four elements, namely Targets, Timeline, Transparency and Together.

The partnership is openly welcome to everyone in Hong Kong built environment. All stakeholders play an important role in setting energy saving targets and timeline. For new buildings and major retrofits, the stakeholders are the key to work with Energy Assessors, consultants and contractors to outperform the Building Energy Code. For existing buildings, we need the stakeholders to carry out building energy audits, implement energy management opportunities and conduct retro-commissioning.

5. TECHNICAL GUIDELINES ON RETRO-COMMISSIONING

Retro-commissioning is a cost-effective process to periodically check the performance of an existing building. The process identifies operational improvements that can optimize energy efficiency performance of the buildings and thus lower energy bills. The process can be performed alone or with a retrofit project, such as replacing less energy efficient appliances with more efficient ones and fitting meters to measure operations.

Although RCx has been adopted in some overseas countries, it has not been widely implemented in Hong Kong due to insufficient local guidelines on RCx and lack of real life examples to demonstrate the benefits of RCx. To overcome these obstacles, Electrical and Mechanical Services Department (EMSD) has been taking the lead to develop Technical Guidelines on Retro-commissioning (TG(RCx)) and carry out pilot projects in order to drive the wider spread of RCx in existing buildings.

In 2016, EMSD developed a draft TG(RCx) for the use by building owners, building operators and other stakeholders. A number of government buildings with varying size, usage, age and annual energy consumption have been selected for pilot projects on the implementation of the RCx. The feedback and experience gained from both consultation and pilot projects was used to fine-tune the draft TG(RCx).

The 2017 edition of TG(RCx) has been formally launched on 30 June 2017.

6. FRAMEWORK OF TG(RCx)

In the TG(RCx), retro-commissioning consists of four work stages:-

Stage 1 – Planning;
Stage 2 – Investigation;
Stage 3 – Implementation; and
Stage 4 –Ongoing commissioning stages.

6.1 Stage 1 – Planning

6.1.1 Collect Building Documentation

When a building is going to conduct RCx, the first step is to collect building information such as building layout plans, buildings services (BS) schematics diagram (e.g. waterside/airside schematic diagram of Mechanical and Ventilation Air conditioning (MVAC) system, electrical schematic diagram etc.), BS layout plans, BS design document, Operation and Maintenance (O&M) manual, operating logs, user requirements, electricity bills and energy audit report as much as possible. A "Building Design Information Checklist" has been formulated in the TG(RCx) to facilitate the RCx Team to collect relevant building documentation.

6.1.2 Interview and Meeting with O&M Staff and Building Occupants

Having familiarized with the current building operation, the RCx team will conduct interview and meeting with O&M staff and building occupants to find out the building operational pattern, operational deficiencies and unsatisfactory indoor environment etc. Relevant Interview Forms have been developed to facilitate the RCx team to carry out this interview.

6.1.3 Carry out Initial Building Walk-through

Following the interview, the RCx team together with O&M staff will perform an initial building walk-through to observe actual operational conditions and discover any operational problems. The data obtained from initial walk through can facilitate the RCx team to verify correctness of collected information and to identify defective sensors/equipment and abnormal settings etc.

6.1.4 Conduct Initial Equipment and System Checking
In this step, the RCx team compares actual operational condition against the design condition or general engineering practices. The comparison can reveal if operating condition of equipment/systems are drift-off from original design condition and identify the areas of potential improvement.

6.1.5 Develop a RCx Plan
Then, the RCx Team formulates a RCx plan by summarizing observation and findings in planning stage including actual building operational condition, energy consumption, operational problem, prioritizing improvements etc. RCx plan would highlight the areas for further study. A sample of RCx plan has been developed in the TG(RCx).

6.2 Stage 2 – Investigation

6.2.1 Conduct Site Survey and Measurement
To start Stage 2, activities include:

(a) Proceed the site survey for the areas and the equipment/systems to be investigated;
(b) Allocate tasks among the RCx team;
(c) Assess if separate groups are needed for the areas and the equipment/systems. The grouping should also be based on the quantity of measurement instrument available;
(d) "Data Collection Form" has been developed in the TG(RCx) to facilitate the users to carry out the site survey and measurement;
(e) Plan ahead on the site measurement to supplement or verify the information collected.

6.2.2 Analysis of Data Collected
The RCx team analyses the collected information such as:

(a) Equipment/system characteristics obtained from site surveys;
(b) Equipment/system performance data obtained from O&M logs;
(c) Equipment/system performance data obtained from site measurement; and
(d) Equipment/system operating conditions of equipment/ systems based on the design and/or general engineering practices

6.2.3 Equipment investigation test
Based on the above information, the RCx team should screen and spot the parameters with values or trends that deviated from what would be anticipated or required respectively.

6.2.4 Identification of Potential Improvement and Optimization Opportunities
If energy saving opportunities is identified, summary of potential improvement and optimization opportunities with estimated energy savings, cost and benefits analysis and estimated payback period could be formulated. The benefits of retro-commissioning should be fully demonstrated to building owner if resource is required. With communication with relevant concerned parties, the RCx team is encouraged to implement energy saving opportunities in coming stage.

6.3 Stage 3 – Implementation

6.3.1 Implementation of Selected Energy Saving Opportunities
At this stage, an implementation plan should be developed to carry out those selected improvements and optimization opportunities that identified in the previous stage. The building owner may propose a staged implementation plan to suit their budget or to minimize the disturbance to the current operation of the building.

6.3.2 Performing Verification
After carrying out the implementation, measurement and verification should be conducted to verify the effectiveness of the implemented items. The measurement and verification method should be agreed with the building owner and stated in the implementation plan.

6.3.3 Develop a RCx Final Report
A RCx final report is prepared to record all activities conducted in the RCx implantation plan. Apart from improvement attained through the RCx, the report should also include the recommended frequency of RCx works on specific system or equipment, RCx training materials for operator and a list of improvement items and optimization opportunities for building owner's further investigation.

6.4 Stage 4 – On-going commissioning

6.4.1 Develop an Ongoing Commissioning Plan
In order to ensure that the benefits of RCx can be maintained and building services systems are operated in high energy efficiency condition, the RCx team should include an ongoing commissioning plan:

- Developing a plan to keep track on energy performance of building services systems
- Developing strategy to maintain the energy performance

6.4.2 Conduct Training for O&M Staff

Building managers and operators should have knowledge to maintain the benefits of the RCx throughout the life of building. As such, the RCx team should conduct training for the operators before the end of the RCx Project.

In post-handover stage, one of the major goals is to ensure the building services system after the RCx would be maintained at “good” energy performance. As such, a retro-commissioning plan to include key energy performance indicators should be developed for the operators to keep track on “good” energy performance.

6.5 Common Operation and Control Issues in Pilot RCx Project

After conduction of four workstages of various RCx pilot projects, some energy saving opportunities can be identified. The presences of these opportunities are mainly due to the some common operation and control issues. It is suggested to review on the below issues during the RCx process:-

6.5.1 Accuracy of Sensors

As part of the RCx process, selecting critical elements of a building and its energy-using equipment for assessment is an effective way to achieve RCx objectives. On the other hand, making simple repairs or quick fix can also help the RCx process. Small adjustments, such as a sensor calibration, not only improve the system operations but also increase the effectiveness of monitoring and testing. After reviewing the data obtained, calibration of critical sensor such as thermostats, humidistats, flow meter, pressure and temperature sensors may require.

6.5.2 Review Building Operating Schedules

HVAC controls must be adjusted to heat and cool the building properly during occupied hours. Occupancy schedules can change frequently over the life of a building, and control schedules should be adjusted accordingly. Operating schedules should also be adjusted to reflect daylight saving time. When the building is unoccupied, set the temperature back to save cooling energy.

6.5.3 Chilled Water Temperature Reset

The chilled water supply temperature reset is to adjust the chilled-water set point of a chiller such that the efficiency of the chiller can be improved and the energy consumption of the chiller can be reduced. Usually, this chilled water reset strategy raises the set-point temperature when the building load is not at full design load condition. Producing warmer chilled water lessens the burden on the compressor, resulting in less energy consumption of chiller. The chiller water supply temperature shall be reset inversely proportional to outdoor dry-bulb temperature. On the other hand, the chiller water supply temperature reset can be a load-based reset which increases linearly from the design value up to 2.5^{o}C higher than the design value.

However, higher chilled water supply temperature will reduce cooling coil performance at the load side. As a result, under the same load, the coils at load side will demand more chilled water and delta-T will be lowered. The increased demand of chilled water will increase pump energy consumption in variable flow chilled water distribution systems. Higher chilled water temperature will degrade the delta-T of cooling coil.

Therefore, the implementation of chilled water supply temperature reset should be implemented in the case that the gain in chiller energy saving can offset the loss in extra pump energy use, which are dependent on the chiller performance characteristics and the nature of coil loads.

6.5.4 Condenser Water Temperature Reset

Most of the energy consumed by a chiller is used to move refrigerant vapor from the evaporator (low pressure) to the condenser (high pressure). As the pressure differential between the evaporator and condenser increases, the chiller compressor must work harder to move the refrigerant. Lowering condenser water temperature decreases this pressure differential, so the compressor does less work.

In order to lower condensing water temperature, the cooling tower is often operated at full fan speed and flow until ambient conditions allow the minimum condenser water temperature limit to be reached. A common approach to controlling cooling towers is to reset condenser water supply temperature based on outdoor air wet-bulb temperature. When outdoor air wet-bulb temperature is sufficiently low, lowering the condensing water temperature setpoint by increasing fan speed or operating more cooling towers can drive the condensing water even lower, without incurring higher costs in condition that the increased tower fan power penalties do exceed the savings at the chiller compressor.

6.5.5 Temperature Difference (Delta-T) of Supply and Return Chilled Water Temperature

Variable-flow chilled water plants are designed to maintain a relatively constant delta-T, the difference between return and supply chilled water temperature. But in real operation of chiller plant, delta-T falls well short of design levels. The load-based control system would not start a new chiller until the operating chillers were loaded. As delta-T degrades, secondary flow increases, causing water in common leg to flow from the secondary return back into the secondary pumps. This causes the secondary supply water temperature to rise, which in turn causes coil performance to degrade, which in turn causes control valves to open more to demand more flow, which in turn causes ever increasing flow in the secondary and ever warmer supply water temperatures. Eventually, both pump energy and chiller energy increase accordingly.

Another possible reason for low delta-T is the degraded coil heat transfer effectiveness by water-side fouling (e.g., slime, scale, or corrosion on the inside of coil tubes), air-side fouling (e.g., dirt buildup on coil fins), and airside deterioration (e.g., deteriorating fins). Any reduction in coil effectiveness increases the flow rate of water required to deliver the desired leaving water temperature, thus reducing delta-T.

To mitigate the low delta-T situation, RCx can be conducted to review the operating condition of control valves for balancing of chilled water flow through the coil. At the same time, periodic water treatment and maintenance of air filter can minimize the fouling on the coil and maintain the coil heat transfer effectiveness.

6.5.6 Calibration of Thermostats and Review of Dampers

When carrying out retro-commissioning for improving the performance of an air distribution system, it is important to remember that zone level performance with regulation on the temperature, humidity and air quality will not be sacrificed. Some of the most common opportunities at the zone level are:-

For temperature-based control air conditioning system, the periodic calibration of thermostats should be typically performed every 6 to 12 months in order to regulate space temperature more accurately. Though thermostat calibration should be checked if a comfort complaint exists, it is preferable to evaluate the thermostats on a regular basis as a proactive maintenance measure.

For air distribution systems with zone dampers, periodically inspect the damper, linkage, and actuator for proper operation. For those aged buildings without proper maintenance, it is likely that some of the zone dampers are frozen in position, rendering them ineffective at regulating comfort. Evaluation and repair of non-functional zone dampers can be time-consuming and costly, especially in large buildings that may have hundreds of zones, it is suggested to select those dampers in major air distribution branch for assessment.

6.5.7 Calibration of Lighting Control System

According to Hong Kong Energy End-use Data 2016, electricity consumption of lighting can contribute up to 15% of total electricity consumption in commercial sector. The current Building Energy Code (BEC) sets out the minimum statutory requirements of the energy efficiency standard on lighting installation design, which focus on the lighting power density and lighting control. For government buildings, the lighting is designed to meet the international design standard on the recommended space illumination level as well as the maximum allowable lighting power density. In addition, lighting control by time scheduling system, occupant sensor or daylight sensor are extensively adopted to achieve energy saving. These lighting control systems should go through periodic retro-commissioning to ensure that they are functioning properly and meet the updated operational need.

There are common cases that occupancy sensors become obstructed by a new furniture arrangement, light sensors may require adjustment if interior surfaces are changed to materials with new reflectance values, or a new building nearby interfering the incoming daylight patterns. Daylight responsive controls need occasional cleaning of the photosensitive surface. Scheduling controls that use relays need to be checked periodically to ensure that they are not permanently overridden. Maintenance personnel should carry out RCx on the lighting controls with these areas at least annually to verify proper operation.

6.5.8 Review Power Quality of Electrical Distribution Network

The total power factor (TPF), a ratio ranging from 0 to 1, is used to describe the extent of the productive work of a load. The ratio is given by the real power doing productive work to that of the apparent power that performs both productive and non-productive work, a close to 1 power factor implying an energy efficient load.

When TPF is lower than the minimum requirements of electricity suppliers, relevant correction devices shall be provided. Beyond the minimum requirements, TPF can be further enhanced with appropriate size of correction devices. The achievable energy saving by improving TPF of a circuit will be equal to the reduction of magnitude of the apparent power.

Harmonic currents, generated by non-linear loads (such as fluorescent lamp control gear, frequency invertor, personal computer etc.) installed in building, increase energy losses in the electrical distribution network. Harmonic currents also heat up conductors and apparatus that increase cooling demand of the air-conditioning system, as well as causing other harmful effects to the electrical distribution network. Harmonic currents can impose significant impact on electrical distribution network and waste energy.

Harmonic correction devices shall be provided when the total harmonic distortion (THD) overs the specified limits. The lower the THD, the lesser is the power or energy wastage.

6.5.9 Review of Tariff to Minimize Maximum Electric Demand

Electric load management allows end-user and utility to benefit from the efficient use of the network and power generation plant without adversely affecting the energy service. The electric load management considers the shifting of certain amounts of energy demand from some time periods to other time periods with lower expected demand.

Pre-cooling of building at night time is one of the examples of load shifting. In many climates, night temperatures are cool even when daytime temperatures exceed economizer limits. Taking advantage of this resource, the air handler and economizer can flush the building with night air to cool down the building mass, which diversifies the maximum electric demand in peak period. The cool mass then acts as a heat sink in the following day and reduces the major electric demand required by air-conditioning installation.

6.5.10 Metering and Monitoring of Electrical Distribution Network

Electricity bill only provides overall electricity consumption of the building on monthly basis. Understanding the power quality and electricity consumption profile of building services installation are important for carrying out retro-commissioning. Metering facilities and monitoring provisions facilitate the analysis of electricity consumption and power quality of a building services installation, and measurement and verification of energy saving after implementation of energy saving measures and assists the building owner to monitor the on-going energy performance of the building.

6.5.11 Review of Traffic Demand and Zoning of Lift Installation

Lift groups are designed to respond optimally to heavy traffic demand situations, such as during up-peak or down-peak demand. During interfloor traffic, the capacity of the installation is never fully used. Therefore, considerable energy savings can be achieved by disabling some of the lifts in the same lift bank during this low demand periods, without significantly lowering the traffic handling performance of lift system. By reducing the number of lifts in use, the car load is increased, moving closer to the counterbalancing ratio, the efficiency of lift can be also increased.

On the other hand, in high-rise buildings, it is desirable to group the lifts to serve particular zones of floors. This creates the need for people travelling to floors within that zone to use the same lifts, thereby reducing the number of start/stop cycles made and avoiding unnecessary energy losses. Appropriate zoning arrangement will not only improve the energy performance of the lift installation, but it will also improve the handling capacity and the quality of the service due to a shorter Round Trip Time.

Since there are still many different energy saving opportunities that could be identified in RCx, we would collect and consolidate these successful cases, upkeep those technology data base of RCx, update the technical guidelines and share with all stakeholders.

7. BENEFITS FROM RCx

The implementation of RCx is often based on a cost/benefit analysis. In general, the benefits derived from the RCx include but not limit to the following: -

(a) Optimize system performance
This applies directly to the savings made in energy;

(b) Reduce operational risks
The RCx will enhance the reliability of the plant and equipment as well as system performance

(c) Ensure the equipment operates at the most-efficient condition
The RCx makes the plant and equipment working at optimal performance will save on maintenance costs

(d) Provide a healthy indoor environment
The RCx improves the indoor environment quality (IEQ) of buildings leading to improved productivity of occupants

(e) Increased knowledge
The RCx ensures that operators are better trained and understand how to operate the system at better efficiency level

(f) Improve documentation of building system
The RCx improves the record and system or equipment performance data

EMSD will continue to promote RCx to stakeholders in private sector, liaising with professional institutions and trade associations for training on retro-commissioning and development of retro-commissioning technologies database enhancing the energy efficiency and reducing greenhouse gases emission. We hope that both public and private sectors can work hand-in hand and transform Hong Kong into Climate-ready city.

ACKNOWLEDGEMENT

Sincere thanks are extended to HKGBC and members (including representatives from HKIE, ASHRAE, CIBSE & PolyU) of the Technical Taskforce on Mandatory Implementation of the BEC and its working groups in offering their expertise advice and support in the development of TG(RCx).

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Paper No. 6

CONSIDERATION OF WELL-BEINGS OF OCCUPANTS AND NEIGHBOURHOODS IN SUSTAINABLE BUILT ENVIRONMENT

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CONSIDERATION OF WELL-BEINGS OF OCCUPANTS AND NEIGHBOURHOODS IN SUSTAINABLE BUILT ENVIRONMENT

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ABSTRACT

Upon the extensive discussion of climate change issues, "sustainability development" has become one of the major aspects for the continuity of human species and resources. As part of sustainability development of a city, sustainable built environment or sustainable design for buildings, commonly captioned as "green building", is of great interest to governments, urban planners, developers and citizens. Conventionally, green building design covers passive design, high performance energy systems, water recycling and indoor environmental quality as well as green construction practices.

However, these general green design practices did not focus much about well-beings or users' experience. Evidence shows that there is an increasing expectation in innovative building design to enhance quality of life and develop a healthier lifestyle for building occupants. This paper focuses on some of the new elements to be considered in green building design and illustrates through case studies to demonstrate how building designs can interact with human well-beings and health.

1. INTRODUCTION

The concept of sustainable development arose only few decades ago, evaluated based on the idea of resources conservation. In 1950s, Harrison Brown published "The Challenge of Man's Future" and thereafter the break-out of concerns on, namely, population bomb, world food problem, oil crisis, desertification, decrease in biodiversity, greenhouse effect and the Antarctic ozone hole, had popularized the term "Sustainable development" in 1987 [1]. The sustainable development was defined as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" by Gro Harlem Brundtland [2] since then. The main focus of this paper is to evaluate the trend of the sustainable design for buildings.

Figure 1 has highlighted some of the important development milestones in Green Building Leadership and green initiatives.

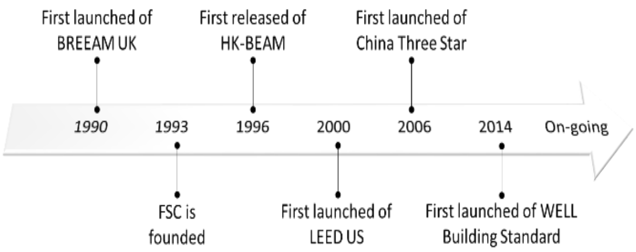

Fig. 1 – The Brief Timeline of Green Building Development

Within three decades, the green building assessment has become more sophisticated and a common practice worldwide to reduce the environmental impact of the whole building life cycle. In 2014, the WELL Building Standard was launched. This expresses the concern about the comfort and well-being of the occupants. This is a migration of the green building standards that provide assessments of the indoor environmental quality and design from the point of view of biological needs of man. For example, the conventional standards give credit to introducing natural light into the building for energy saving purpose, meanwhile WELL Building standard further ensures the daylight introduced is of suitable level in terms of time and amount that give comfort to human eyes. This is called Biophilic design [3]: *to create good habitat for people as a biological organism in the modern built environment that enhances people's physical and mental health, fitness and wellbeing*.

Kellert [4] also suggested the concept of potential Biophilic Urbanism [5]: *to make the experience of the natural world an integral part of ordinary city life, to be the next chapter in sustainable development*. This paper reviews the evidence and case studies on the latest trends of well-being building design and explores the potential sustainable building development tendency.

2. DESIGN APPROACH

Indeed, since the beginning of human species, human history has been written in response to natural system. Human evolved during adaption to the environment whereas nature was our neighborhood.

Kellert and Calabrese [6] constructed a timeline showing that human spent more than a thousand of centuries with nature, before human started to have massive agricultural production and followed by the invention of “City” which established a wall between mankind and our “neighborhood”. The history of industrial and electronic technology development has begun no more than five centuries. For once, human believed that the separation and development was a pledge of civilization and could extend the history of species.

With the ring of energy crisis, climate changes, and public health problems, numerous researchers questioned the recent development approach of setting up the wall between mankind and nature, and are interested in the association in between. It is trivial that nowadays threats are about weapons and wars, however, Ohman [7] has found that fear stimuli of human is more reactive towards snakes than handguns. Recent studies conducted by Harvard University’s T.H. Chan School of Public Health collaborated with SUNY-Upstate Medical School proved that green building conditions can enhance people’s cognitive performance [8] as well as occupants’ physical and physiological health [9]. Harvard University has also started their “Living Lab” initiative and has proven that workers in green-certified buildings experienced fewer sick building symptoms and had better slept at night [10].

The framework of WELL Building Standard covers wide range of aspects that design for the body systems. Figure 2 has illustrated the systems applied to the WELL features. The WELL Building Standard summarizes the impacts of built environment on daily health and the productivity, and provides a comprehensive design guide for addressing the individual needs of occupants.

The design framework includes seven concepts: air, water, nourishment, light, fitness, comfort, and mind (Figure 3). These concepts are comprised of variety of features and considerations.

The strategies of “Air” aim at source reduction of indoor air pollutants. The indoor air quality can be affected by outdoor air quality, indoor emissions (e.g. cooking and building materials), ventilation system, or aggregation of airborne micro-organism and mold on surfaces.

The intention of “Water” seeks the optimal quality of water, pinpointed to filtration of the potential source of contaminations (e.g. additives during treatment and pharmaceuticals), taste and accessibility of drinking water, and periodic water quality testing.

For “Nourishment”, it emphasizes on the influences of built environment to occupants’ lifestyle, such as to grant the access to healthy food and limit the options of unhealthy ingredients. It also stresses on the importance of provision of detailed ingredients information so as to promote a change in eating habits and food culture.

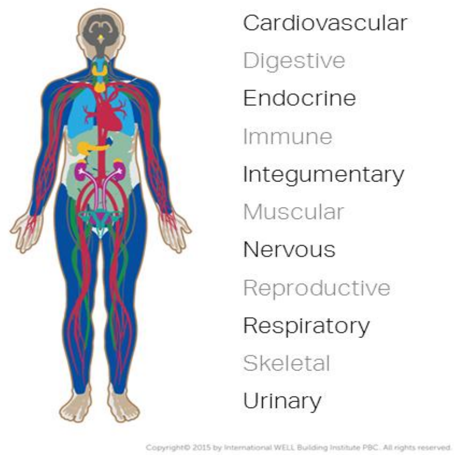

Fig. 2 – The Body Systems Applied to WELL Features (Photo © 2015 International WELL Building Institute)

Fig. 3 – The Seven Concepts of WELL Building Standard

The features of “Light” express the concerns of good visual acuity which include lighting design (e.g. visual lighting and circadian rhythm), glare controls (e.g. surfaces design, solar and electric light glares), and lighting color quality.

“Fitness” focuses on exploring the opportunities to encourage daily exercise in the built environment against the human’s physical inactivity pose that being one of the leading threats to health nowadays.

The design for a place of “comfort” should take acoustic, ergonomic, olfactory, and thermal environments into consideration.

The physical and mental health are subjected to the “Mind” of a body which requires stimulus of human senses. One of the popular design features is the biophilic building design. Although the idea is introduced as a few features under “Mind” only, its coverage is broad and many researchers are interested in it.

Basically, biophilic design should align with the five principles listed below [6] [11]:

a. Biophilic design requires repeated and sustained engagement with nature.

b. Biophilic design focuses on human adaptations to the natural world that over evolutionary time have advanced people’s health, fitness and well-being.

c. Biophilic design encourages an emotional attachment to particular settings and places.

d. Biophilic design promotes positive interactions between people and nature that encourage an expanded sense of relationship and responsibility for the human and natural communities.

e. Biophilic design encourages mutual reinforcing, interconnected, and integrated architectural solutions.

The design strategies which depend on the project’s nature and limitations, such as project size, landscape uses, cultural and ecological conditions, should adhere to the principles noted. An effective practice of biophilic design is able to build a connection between occupants and the nature within the built environment, the attributes that facilitate the connection are categorized into three kinds of experience [6] [12]:

3. APPLICATIONS of WELL-BEING DESIGN

The well-being design involves a wide range of factors and concerns. Therefore, in this section, this paper concentrates on two examples, the circadian lighting design and the biophilic design, to discover how these features benefit the wellness and health of human beings.

3.1 Circadian Lighting Design

Besides the visual effect of lighting, human receives information from the external lighting and compiles the biological clock accordingly.

The word “circadian”, comes from a Latin, means “approximately a day”. Human’s physiological functions work with a 24-hour cycle is thus called the circadian rhythm. Under the survival basis, the circadian rhythm is responsible for keeping the body and brain functions aligned with varying surroundings.

Therefore, lighting designers have proposed simulating natural light in a built environment by the circadian lighting system (Figure 4). During daytime, the cool and blue light should be provided to give the body a signal of “daytime”. This can keep the body alert and trigger the release of serotonin, a neurotransmitter, that acts as antidepressant [13]. In the evening, warm and red light should be the dominant tone to cue for the resting period and stimulate the release of melatonin, a hormone, that contributes to good sleeping quality [14]. This is how the circadian system entrained with human sleep and wake cycle.

When synchronized with circadian rhythm, the body is able to strive for the balance period of bright and dark, evenly for the night shift workers, occupants can work fully functionalized and have a better sleeping quality at night.

	Type of Experience		
	(a) Direct Experience of Nature	(b) Indirect Experience of Nature	(c) Experience of Space and Place
Design Attributes	Light	Images of nature	Prospect and refuge
	Air	Natural materials	Organized complexity
	Water	Natural colors	Integration of parts to wholes
	Plants	Simulating natural light and air	Transitional spaces
	Animals	Naturalistic shapes and forms	Mobility and way finding
	Weather	Evoking nature	Cultural and ecological attachment to place
	Natural landscapes	Information richness	
	Fire	Age, change, and time	
		Natural geometries	
		Biomimicry	

Fig. 4 – The Conceptual Diagram of Circadian Lighting Design (Photo © HowToGeek)

Technology
In practice, the colour temperature ranges from 2200K to 6500K, and the intensity can be adjusted depending on space zone type. Figure 5 has illustrated the use of tuneable light emitting diodes (LED) technology to achieve lighting with different white balance and intensity.

Fig. 5 – Illustration of Tuneable LED Lighting (Photo © USAI Lighting)

Another factor to take into consideration is the lighting profile. A lighting control system should be able to gradually adjust the dosage (i.e. the frequency and duration of light exposure) and the gradient of the changes within a day and even a year.

The implementation of circadian lighting involves mainly three steps [15]:

a. Choose a tuneable LED luminaire with a control protocol (e.g. DALI or DMX)
b. Install a control processor with astronomical time clock that supports data curves for setting the lighting profile
c. Select a user friendly interface to facilitate the control and enhance flexibility (e.g. on electronic devices)

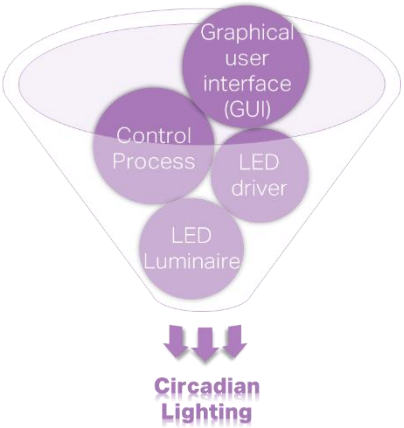

Fig. 6 – The Components of a Circadian Lighting System

3.2 Biophilic Design

The idea of biophilic design is that all the experiences are meant to reconnect the human and nature through various sensation of human, such as vision, hearing, smell, taste, touch and movement. Some of the attributes of biophilic design are included in the building design nowadays, but some are still a step far. The followings are the brief descriptions of each attribute, including current practices and the elements that are conceptual.

3.2.1 Direct Experience of Nature

Light & Weather

Introducing natural light into the building for well-being is fundamental. There are ways to introduce daylight, through glass walls, sun pipe, etc. The Global Headquarters of Heerema Marine Contractors B.V. (HMC) (Figure 7) has adopted a design that integrate natural lighting into the office.

The design that optimizes daylighting and views also provides an experience of the outdoor weather. This kind of perception of weather in the indoor environment induces a sense of satisfaction and stimulus. In addition to visual impact, the experience can be enhanced by stimulating the weather-like conditions, such as airflow, temperature and humidity.

Fig. 7 – The Design of Optimize Views and Natural Daylight of Global Headquarters of Heerema Marine Contractors B.V. (HMC) (Photo © Delta Development Group)

Air & Plants

Fresh air is another fundamental element that provides human comfort and supports their productivity. Fresh air in a built environment is usually done by introducing natural ventilation or variation in airflow, temperature, etc. Besides, the concentration of air pollutant is another important factor to keep people in a sense of freshness. Bringing plants into built environment is one of the solutions that could enhance the indoor air quality and, at the same time, provide the direct touch of nature. The presence of plants, as a portable green wall, in the conference room of Stok's headquarters (Figure 8) has reduced the concentration of carbon dioxide within the enclosed space under constraints of increasing ventilation. Yet, researchers suggested that the landscapes in buildings should not be single or solely plant, instead it is supposed to be abundant and cover varities of native species [6] (Figure 9).

In 2015, a team at Harvard University's T.H. Chan School of Public Health collaborated with SUNY-Upstate Medical School investigated the effects of indoor air quality on workers' cognitive performance [8]. Participants followed a routine of six-day- work and each day for eight hours in a controlled indoor environment without acknowledging them the condition on the day. They were exposed to four different conditions in different days. They were high volatile organic compound (VOC) concentration, low VOC concentration, and high outdoor air ventilation rate, later refer to Conventional condition, Green condition and Green+ condition respectively.

Researchers found that in Green condition, the cognitive scores on average increased 61% when compared to Conventional condition. For Green+ condition, the average cognitive score was two times of that of Conventional condition. They recently carried out further study on the impact of working in a green-certified building than in a non-certified building to workers [9]. The results give evidence that green buildings would result in healthier conditions and enhanced cognitive function for occupants (Figure 10).

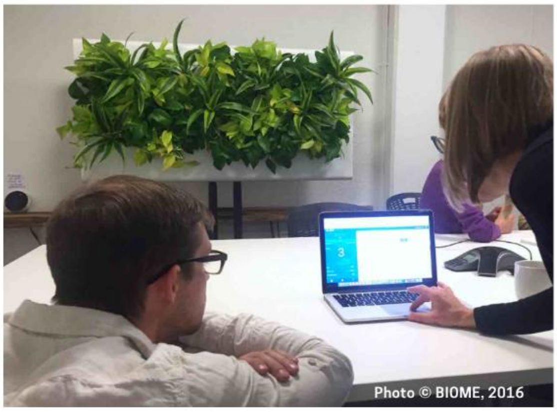

Fig. 8 – The Installation of Portable BIOME Green Wall at the Conference Room of Stok's Headquarters (Photo © BIOME)

Fig. 9 – Green Walls inside One Bryant Park Office Tower (Photo © AECOM)

Fig. 10 – The Results of the Cognitive Study in Green Building (Extracted from WGBC2016 report [16])

Water
It is essential to include water in a built environment as water is the hub of all lives. Therefore, improving the potable water quality by installation of filtration system and maintaining the suitable distance to the water dispenser would be important to encourage occupants' consumption.

In addition, the presence of water elements itself is stress relieving (Figure 11). The design should emphasize on the consideration of hygiene, motion and sound of water, and thus the maintenance and sound level control of the feature might be a challenge and limitation depending on the building type.

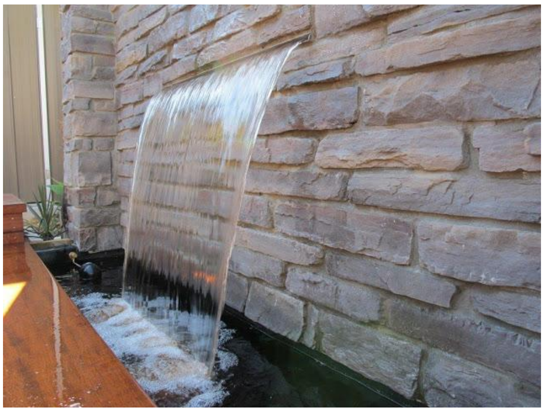

Fig. 11 – Example of Indoor Waterfall in Kansas City (Photo © Anthony D'Rock Reyes)

Animals & Natural landscapes and ecosystems
The integration of nonhuman animal life and self-sustaining ecosystems into a built environment would be challenging in terms of spatial, costs and safety concerns. Therefore, the development and investigation of self-sustaining ecosystems in small scale such as aquaponics systems, which contains serval biophilic attributes:

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water, plants, animals and ecosystem, are essential to promote the sustainable built environment.

At the moment, the installation of indoor aquarium can be one of the solutions (Figure 12).

Fig. 12 – Example of Indoor Aquarium: Kitchen Ocean (Photo © Robert Kolenik)

3.2.2 Indirect Experience of Nature

The indirect experience of nature is about integrating the nature's characteristic into decorative or structural components.

There are four different forms: representational artwork, ornamentation, biomorphic forms and the use of natural materials. The followings are some examples.

Images of nature, Natural materials, Natural colors & Naturalistic shapes and forms

The images of nature in the built environment can be easily achieved through paintings, photographs, and even video. The current interim office of Toronto and Region Conservation Authority (TRCA) has included large images of nature into the built environment (Figure 13). The design of the Salin Liu Performing Arts Centre - Rockport Concert Hall in Rockport, Massachusettes has demonstrated the use of wood and rock as material choices (Figure 14). Extracting and applying the texture, pattern and color of organic matters elicit positive responses.

Fig. 13 – The Inclusion of Large Images of Nature in TRCA Interim Office (Photo © Ward99 Architects)

Fig. 14 – The Use of Nature Materials in Salin Liu Performing Arts Centre – Rockport Concert Hall (Photo © AECOM 200x Photography by Robb Williamson)

Simulating natural light and air & Age, change, and time

The smart building technology allows the dynamic control of lighting and airflow which combined the change in time. For instance, the circadian lighting discussed previously in Section 3.1 is one of those.

3.2.3 Experience of Space and Place

The experience of space and place is about how the spatial configurations affect human psychologically and physiologically. There are some examples:

Organized complexity

Complexity is often confusing and chaotic. However, an ordered and organized complexity pleases human by its networking.

Examples are the roadmap of the MTR system (Figure 15), and an overview of the developed urban (Figure 16).

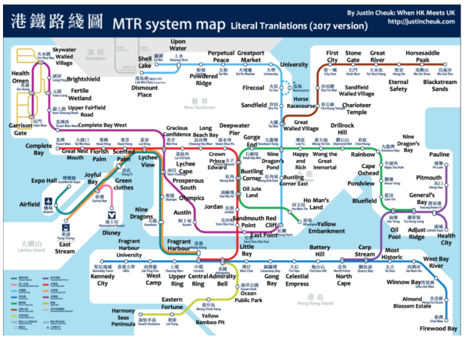

Fig. 15 – The roadmap of the Hong Kong MTR system

Fig. 16 – The overview of Las Vegas (Henderson), Nevada (Photo © Mathieu Helie)

Prospect and refuge
Prospect means the wide angle that allows people to see beyond their immediate surroundings. It premises the perception of dangers and chances. Refuge refers to the protection of the environment that should limit the visual access into the site. In other words, prospect is the openness (Figure 17) and refuge is the enclosure of the space (Figure 18). These are based on the survival philosophy.

Fig. 17 – The JWT Office in Atlanta
(Photo © Eric Laignel)

Fig. 18 – The Hubspot's Headquarter in Cambridge
(Photo © Robert Benson)

4. CONCLUSION

The history of sustainable development is not long but the development is fast within a few decades. The implementation of WELL standard has initiated the awareness on human health and well-being in building design. The participation of companies and the continuous exploration done by researchers support the necessity of biophilia in sustainable development and increase its popularity.

Besides interior biophilic design, the concept of biophilic urbanism that promotes the integration of nature and human as a whole would be the ultimate goal. When the scale increases to urban size, the biophilic design expands to whole building life cycles and the consequences to its neighborhoods in the point of view of citizen living in that district.

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Paper No. 7

PIONEERING BIM-AM APPLICATION FOR GREEN AND SUSTAINABLE BUILDING OPERATION AND MAINTENANCE

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Ir Steve H.Y. Chan, Senior Engineer
Mr Francis P.H. Yuen, Assistant Engineer
Project Division
Electrical and Mechanical Services Department
The Government of the HKSAR

PIONEERING BIM-AM APPLICATION FOR GREEN AND SUSTAINABLE BUILDING OPERATION AND MAINTENANCE

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ABSTRACT

Building Information Modelling (BIM) has rapidly emerged in recent years in architecture, engineering and construction (AEC) industry. There is no doubt that BIM enables green design and construction through energy simulation and prefabrication. In addition, BIM could serve as a digital common platform for multi-disciplinary services coordination and clash detection to effectively reduce unnecessary rework and construction waste. However, BIM applications in the long building lifecycle operation and maintenance (O&M) is little investigated.

This paper is to present a novel architecture and our development works for green and sustainable building O&M by visually intuitive integration among BIM, asset management and various electronics systems.

1. INTRODUCTION

Tracing and identification of building facilities using 2D computer-aided design (CAD) drawings are complicated and inefficient particularly where there are overlapping layered services. Inconvenient cross-reference among different 2D CAD drawings also hinders a clear visualisation of concerned service like duct and pipe works of Heating, Ventilation, and Air Conditioning system. A better visualisation of service drawings is therefore always desirable from O&M perspective. In recent years, BIM, a digital model and process being conceived as an object-oriented CAD system supporting the representation of building elements in terms of their geometric and functional attributes as well as their inter-object relationships, has rapidly emerged in AEC industry to facilitate early coordination among different disciplines, leading to significant shrink of construction schedules and project costs.

However, the approach and application of adopting BIM for green and sustainable building asset management is yet to be investigated. Whilst there are many research studies and real-world applications of adopting BIM in facility management (FM) / asset management (AM), most of them focus on data population from BIM to FM/AM software [1,2,3,4] either by proprietary add-ins, open BIM standard in IFC format [5], or a spreadsheet / an XML file for Construction Operations Building Information Exchange (COBie) [4,6,7]. Albeit that there are researches involving information exchange between BIM and FM/AM system with Building Management System (BMS) integrated [8] and integrating Radio Frequency Identification (RFID) technology with BIM [9], they are in essence not considered as full and seamless integration among BIM, FM/AM software and multiple O&M systems in terms of their integration diversity and extent, as compared with our developed BIM-AM System. Owing to the utmost importance of information accessibility for efficient O&M, asset related information that can be obtained by maintenance engineer should not be limited to static asset attributes of each building element residing in the BIM model. To close the gap between direct adoption of BIM and day-to-day O&M practice for green and sustainable asset management, we have investigated the appropriate approach for integrating/interfacing BIM with a variety of O&M systems/tools.

Having selected the Electrical and Mechanical Services Department (EMSD) headquarters building as a showcase project, an integrated BIM-AM System has been developed to implement the novel architecture. The System offers paperless and smart O&M working tools for providing an intuitive way to access heterogeneous assets information such as photos, attributes, equipment relationships, manuals, e-forms, drawings, maintenance records, live view of Closed Circuit Television (CCTV) System, real-time sensing data from a BMS and wireless ad-hoc sensors, as well as location information of moving asset from a Real Time Location System (RTLS) in one single integrated mobile platform. All these information is readily accessible simply by asset repository, manoeuvring throughout a BIM model, or even triggered from a handheld RFID scanning tool.

Moreover, to further try-out the BIM use for green building application, various energy-saving initiatives aided with BIM were adopted for an Alterations, Additions, Repairs and Improvements (AA&I) works of Customer Service Centre of EMSD headquarters. The results have successfully demonstrated the potential system capabilities in facilitating green and sustainable building O&M.

2. SYSTEM ARCHITECTURE

As far as our knowledge goes, full and seamless integration of BIM with an AM system as well as a variety of O&M systems/tools including BMS, CCTV system, RFID scanning tool, and RTLS has not been realised. Figure 1 depicts the proposed system architecture in which the dotted line indicates the integration that may have been implemented in some other FM/AM software applications whereas the solid line indicates the full and seamless integration that was first implemented by EMSD.

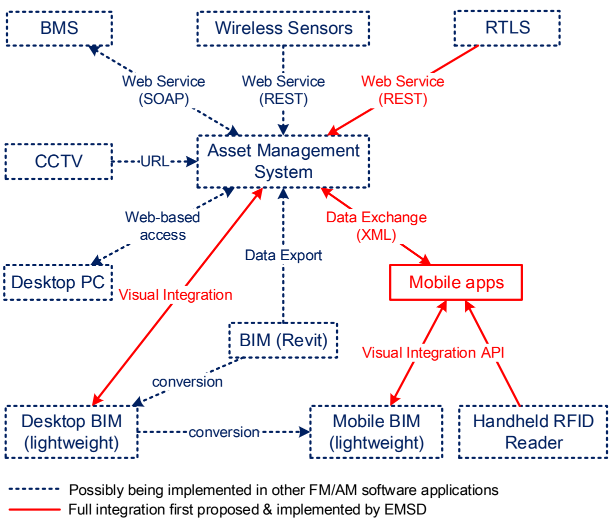


Fig.1 – The Novel Architecture for BIM-AM System

Under this architecture, AM system is considered as an O&M software application for building asset management, preventive maintenance and corrective maintenance management including workflow for fault reporting, handling and monitoring. One of the most distinctive differences is that the AM system in the proposed architecture serves as a middleware to integrate/interface with other systems/tools whereas other research works take BIM as a middleware for information exchange with other systems/tools, thus increasing the integration complexity. This is because direct integrations between BIM and other systems/tools would result in high complexity in the Application Programming Interface (API) development on BIM software and the systems/tools. Moreover, BIM cannot replace the role of AM system in storing and upkeeping AM-related information as well as performing other comprehensive AM features. Another distinctive difference between our works and other researches is that the visual integration between BIM and AM system is in a seamless and intuitive manner, in the sense that the BIM-AM System allows locating and visualising any particular asset with its real-time asset information by manoeuvring freely throughout the BIM model in one single integrated system, instead of mere data exchange between BIM and AM system.

2.1 Visually Intuitive Cross-reference among Real-world, BIM Model, and Static Asset Information

The BIM-AM System enables visually intuitive cross-reference of real-world physical objects to BIM model and even to asset attributes, maintenance records, asset relationships, system topologies, manuals (including animated repair manuals, if any) and system drawings at a mobile terminal. As shown in Figure 2, a VAV box can be visualised and quickly located in its approximate real-world physical location, enabling easy cross-reference to a BIM model for pre-diagnosis.

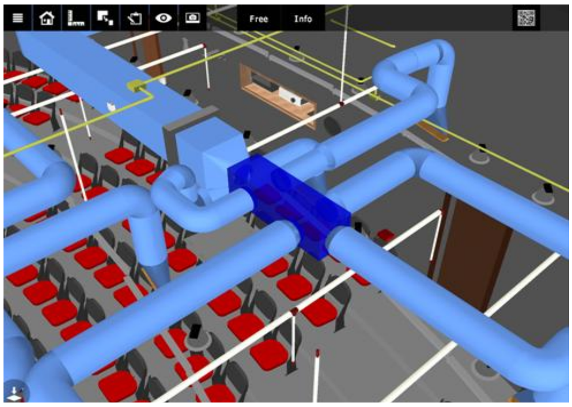


Fig. 2 – Georeference of a VAV Box in a BIM Model

System topology generation was purposely developed to visualise the asset relationships within a particular system for further cross-referencing among assets information during fault locating. The system topology as shown in Figure 3 provides a graphical view of the asset relationships of the VAV box within the overall system.

In addition, we have established sets of BIM-AM asset templates for asset information requirement (AIR) of mechanical, electrical and plumbing (MEP) systems. Apart from typical system specific attributes, the AIR also contains the information of asset relationship, wireless tag ID and geometric related attributes for system topology generation, RFID/RTLS application, and BIM visualisation respectively.

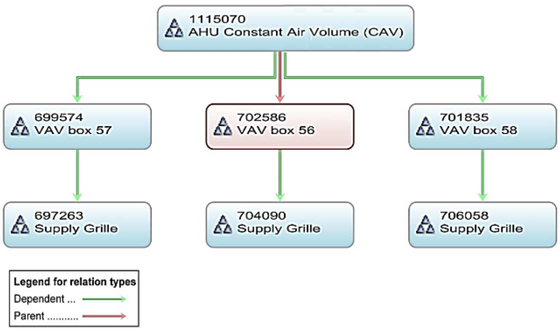


Fig. 3 – System Topology Visualizing the Asset Relationships of a VAV box within the Overall System

2.2 Pre-diagnosis and Condition monitoring based on Real-time Asset Information from BMS, Wireless Ad-hoc Sensors, and CCTV System

Integrating BIM-AM System with BMS and fixed CCTV system for accessing real-time remote site information with control functions at a mobile terminal could facilitate efficient offsite pre-diagnosis and possible rectification. Based on the pre-diagnosis, maintenance engineer would be able to bring necessary tools / spare parts to the site in one go. Figure 4 is the mobile screen capture showing the real-time BMS monitoring sensor values of an Air Handling Unit (AHU).

Code	Meter	Reading date-time	Reading value
1028778	DAHU706.TSP2, Return Temp Set PT (EMSD)	10/12/2015 15:22	24
1028779	DAHU706.PSP, Static Pressure Set PT (EMSD)	10/12/2015 15:22	430
1028781	DAHU706.PSP, Static Pressure Set PT (EMSD)	10/12/2015 15:23	445
1028786	DAHU706.TSP2, Return Temp Set PT (EMSD)	10/12/2015 17:50	27
1028787	LTG_RM7153, Rm 7153 Lighting Control (EMSD)	10/12/2015 09:52	1
1028789	LTG_RM7153, Rm 7153 Lighting Control (EMSD)	10/12/2015 09:54	100
1028832	VAV7F_55FDS, VAV Damper Status	16/12/2015 21:23	38.13
1028834	VAV7F_55FLW, VAV Flowrate	16/12/2015 21:23	0

Fig. 4 – BMS Monitoring Interface of an AHU in the BIM-AM System

Fig.5 – Live Feed of a Wireless Camera in the BIM-AM System

In addition, wireless ad-hoc sensors, such as temperature sensor, humidity sensor, power metre, and wireless camera over WiFi, Bluetooth, and cellular networks, were developed for prompt installation and monitoring. These wireless ad-hoc sensors are considered useful in incident handling, condition monitoring, generation of pre-fault alerts, or energy management. Figure 5 shows the live feed of a wireless camera available at the mobile terminal for monitoring the subject plant room. In this pilot, web services have been employed for the data communication from BMS and wireless sensors to the AM system and vice versa.

2.3 Efficient Locating of Fixed and Movable Assets

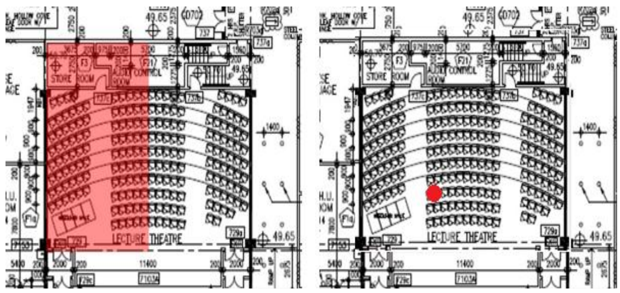
Having integrated the mobile terminal platform of BIM-AM System with a handheld RFID scanning tool, maintenance engineer could efficiently and effectively locate critical equipment for further enquiry of asset information even if the equipment is hidden above a false ceiling or underneath a raised floor. Figure 6 shows a mobile screen capture of RFID scanned results listing nearby assets.

ScannerName HW SW Battery 0%
29 Scan Search By ID

Equipment ID	Description	Location	System Type	Signal
000258	AHU supply 1.4 - 2.8 m3/s	LOBBYZone 1	HVAC	90 %
000244	Airco Unit	AHU RoomZone 4	HVAC	80 %
000243	Emergency lighting decentrally fed	Common AreaZon...	LIGHT	70 %
000253	Splitting system VAV	Hub RoomZone 5	HVAC	60 %

Fig. 6 – RFID Scanned Results listing Nearby Assets

To extend the locating feature from fixed assets to movable assets such as working platform and biomedical equipment, RTLS over WiFi and Ultra-Wide-Band (UWB) technologies, as shown in Figures 7(a) and 7(b) respectively, were piloted in EMSD headquarter building. The latter was adopted and installed because of higher positioning accuracy.



(a) RTLS over WiFi (b) RTLS over UWB

Fig. 7 – RTLS Piloted in the BIM-AM System

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2.4 Efficient and Effective O&M Workflow Management

Coupled with four key generic user interfaces for client, helpdesk, supervisors and frontline, the BIM-AM System can facilitate efficient and effective O&M workflow in fault reporting, handling and monitoring not only for in-source but also out-source arrangement. As shown in Figure 8, the user interface for the maintenance engineer provides readily accessible asset information, such as asset attributes, maintenance record, equipment relationship, system topology, manual, and system drawing as well as creating service request and cross-referencing to BIM model. Additionally, the System can timely notify users to fill in an electronic pre-work safety check form such that the safety compliance can be easily achieved.

Moreover, the System can cater for highly dynamic and versatile interactions among different parties in the client, maintenance contractor and our organisation by assigning respective features to different parties to facilitate efficient and effective O&M services, supervision and communication at all times.

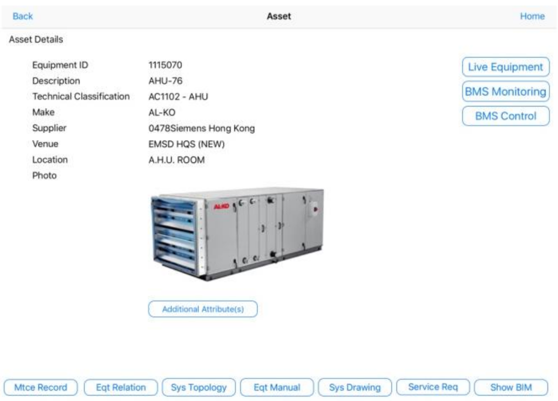

Fig. 8 – User Interface for the Maintenance Engineer at the Mobile Terminal

3. DEMONSTRATION

Simulated maintenance showcases using an AHU model, a fire sprinkler system model, an emergency lighting model, and a general lighting model in the BIM-AM System were recorded in videos for demonstration purpose [11]. The results demonstrated that the BIM-AM System can improve productivity in fault response, workflow management, safety compliance, retrieval and appending of maintenance record, access of asset details, relationships and manuals, and so on. Significant time-saving of more than two hours can be achieved on fault localization in a typical air conditioning fault situation as compared with the current practices. In fiscal year 2015/2016, the total number of maintenance orders was about 639,000 in all buildings maintained by the EMSD. Projecting the potential time-saving without real trials would lead to inconclusive findings, but the benefits of the full rollout are foreseeable.

4. GREEN APPLICATION FOR O&M AND AA&I WORKS

With getting every required tools/parts ready in one go when attending to fault requests, the BIM-AM System does not only enhance O&M efficiency, but also enables green operation by reducing avoidable air pollution and energy consumption generated by vehicles due to the back-and-forth visits. In addition, the BIM-AM System stores electronic manuals, system drawings, and BIM models for easy access as well as documenting service order, maintenance records, safety risk assessment, etc. in paperless form, which in-turn reduces unnecessary carbon footprint during O&M.

Another green application facilitated by BIM in the EMSD headquarters project was to conduct energy analysis of various energy-saving initiatives for an AA&I work of Customer Service Centre of EMSD headquarters. Aided with BIM, virtual design of different MEP systems (with and without energy-saving initiatives) and associated power consumption were simulated. The following energy-saving initiatives during design stage of the AA&I work were employed: (i) adopting LED lights instead of T5 fluorescent tubes for lighting; (ii) adopting variable speed drive ventilation instead of constant speed drive ventilation; and (iii) adopting intelligent room control (such as occupancy sensors, zone lighting for day and night time, and cooling control) instead of manual room control. Simulation results using BIM indicated that the estimated power-saving of the MEP design with the above energy-saving initiatives was 10%, as compared with the traditional one.

5. CONCLUSION

We have proposed a novel system architecture exploiting BIM in asset management and realized the concept in an integrated BIM-AM System featuring multiple O&M systems/tools in one single platform. A summary of the System features is exhibited in Figure 9. The integrated platform has proved effective in streamlining workflow, facilitating responsive incident handling, green operation, and sustainable asset management. As EMSD has been currently operating and maintaining about 5,800 government buildings, the tool has great potential to bring major benefits including long-term cost savings in the O&M building lifecycle. Moreover, the results also showed that the

AA&I work of EMSD headquarter building aided by BIM could yield a power-saving of 10% which may be considered insignificant in value, but the potential green benefits enabled by BIM are too important to be ignored when taking into account the increasing adoption of energy-saving initiatives and the long time-span of building O&M. Though the successes arising from the architecture and pilot BIM-AM System are only on a limited scale, we hopes the integrated BIM-AM System would not only benefit our O&M services, but also encourage and facilitate the construction industry in Hong Kong to better deploy this new technology for sustainable building asset management, particularly O&M services, ultimately benefitting the public.

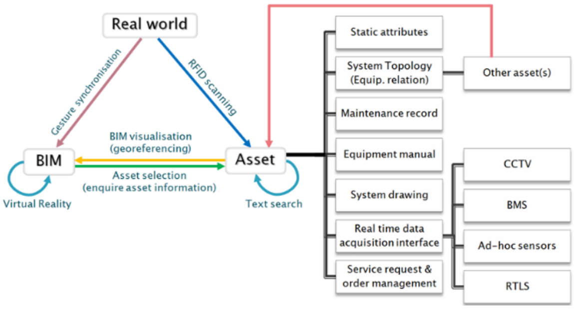

Fig. 9 – Summary of the BIM-AM System Features

6. WAY FORWARD

EMSD would collaborate with the Construction Industry Council (CIC) to explore the green application in Zero Carbon Building (ZCB) by data/energy analytics of sensor data collected from the existing BMS and new wireless Internet-of-Things IoT sensors (e.g. via LoRA network) to be installed in ZCB. All these would help transform conventional O&M to green and sustainable O&M, and engineer Hong Kong to a climate-ready city.

ACKNOWLEDGEMENT

The authors wish to thank the Director and senior management of Electrical and Mechanical Services for permission to publish this paper. Any opinions expressed or conclusions reached in the text are entirely those of the authors.

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Paper No. 8

BUILDING SERVICES DESIGN FOR THE REVITALIZATION OF VALUED EXISTING BUILDINGS

Speakers: Ir K.F. Ho, Chief Building Services Engineer
Ir Judy O.W. Lau, Building Services Engineer
Architectural Services Department
The Government of the HKSAR

BUILDING SERVICES DESIGN FOR THE REVITALIZATION OF VALUED EXISTING BUILDINGS

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ABSTRACT

This paper aims at introducing the challenges usually encountered in the design of building services systems in revitalization project involving valued existing building in particular where new facilities are to be added to transform the building for its new use. More often than not, the existing BS systems have to be upgraded or completely replaced to comply with prevailing statutory requirements and to meet new functional needs without compromising fundamental principle of building conservation. The paper will cover the comprehensive design considerations in planning electrical supply and distribution system, lighting system and lightning protection system to overcome site constraints in valued existing buildings. Other services installations like lift, mechanical ventilation & air conditioning system, fire service system and plumbing & drainage system will also be briefly described to explain how different BS elements can be integrated together to make a valued existing building operating efficiently under its new look.

1. INTRODUCTION

In Hong Kong, there are a total of 114 declared monuments and 1,444 historic buildings accorded with Grade 1, Grade 2 or Grade 3 status up to mid-2017. Valued existing buildings were meticulously graded to reflect their value assessed against six criteria: historical interest, architectural merit, group value, social value and local interest, authenticity and rarity[1].

During the revitalization process of buildings, upgrading of building services systems to meet the current statutory requirements and the operational needs of the future occupancy with up-to-date provisions is necessary. Inevitably, this will call for the alteration of some parts of the building to suit. In order to minimize the impact to valuable heritage elements, building services design in these buildings must be carefully considered before implementation.

In gist, the idea is to upgrade the building services installations with minimal alteration to the building elements while providing green and maintainable facilities to meet stakeholders' expectations and users' operational needs, as well as restore the building to enhance their cultural significance and give the building a new glamour.

This paper will focus on the West Wing of the former Central Government Offices to illustrate the design considerations and challenges on building services design. The West Wing was originally designed by the Architectural Office of the Public Works Department and built in 1959 with the upper-most storey added in 1964. The L-shaped building displays features of the functionalist style of architecture, prevalent during the early to mid-20th century. It is constructed on a flat land at the east end that slopes away towards the west, resulting in a building that ranges from 7 storeys at the east end to 14 storeys at the west end where it fronts Ice House Street. The building was occupied by different government bureau and departments for office use until renovation works commences in October 2016. On completion of the works, the building will be transformed into a modern office accommodation that fits the unique needs of the Department of Justice and law-related and law-related organizations.

2. DESIGN CONSIDERATIONS AND CHANLLENGES

2.1 Site Survey for Existing BS Installation

As with all revitalization projects, it is very important to preserve and restore valued existing buildings in such a way to reveal the original spatial setting and building fabric which are identified to be of high significance. Building services installations that are properly designed and thoughtfully installed play a crucial role in helping to preserve and restore these buildings.

Comparing with new projects, revitalization of valued existing building takes a longer time to prepare and conduct the detailed surveys and investigations. Generally, before the commencement of building services designs, the first step is to carry out survey and investigation works, which are essential in handling revitalization project, as the outcomes might turn down the proposed designs on both architectural and building services. The work shall not only cover surveys on the existing spatial setting and structure conditions, but also surveys on the following building services related areas that are essential to determine the extent of installations and plant rooms to be preserved or modified:

a) Underground utility survey to check the routing of utilities in the vicinity of the building;
b) Closed-circuit television (CCTV) survey to check the condition of existing underground drainage pipes;
c) Building services condition survey to determine whether the existing installation can be retained and reused; and
d) Structural dimension survey to explore all the existing openings which can be reused for building services installation, etc.

Based on the findings of these surveys and investigations, not only the current conditions of the existing building services installations can be determined, but the feasibility of utilizing existing building features to accommodate new building services installations can be assessed. In the project under discussion, it is decided that the existing building services installations are to be demolished and totally replaced by new ones to meet current regulations, design standards, user requirements and/or architectural design.

2.2 Minimum Disturbance

As both the building envelope and selected interior features will be restored to their original form as far as practicable based on the available records and information, new building services installations are designed to integrate with the existing building elements while giving the building an atmosphere that suitably reflects its functions. In addition, all installation methods shall be worked out carefully to avoid damage to the existing internal finishes and façade of the building, especially Character Defining Elements (CDEs) with high significance. A good example is the lighting design in the existing canopy of the building. In order to avoid disturbing the building facades, new light fittings can only be installed at existing locations by making use of the original concealed conduits as far as possible. For places where the existing conduits cannot be reused due to their poor condition, new exposed conduits have to be fixed along routes that are carefully chosen to minimize the impact on the appearance of the facades.

2.2.1 Normal Power Supply

Electricity supply is the fundamental provision for enabling the normal operation of a building. At the early design stage, estimation of both normal and essential electricity consumptions is carried out, and the respective loads will tell whether the capacity of the existing transformers can meet the anticipated operational needs. In our project, upgrading of the existing transformers is not necessary according to the electricity consumption estimate and hence, the quantity and capacity of transformers can remain unchanged.

However, as the building is erected many years ago, the configuration of the transformer room cannot meet the current requirements of the utilities company. A case in point is the floor to floor height of the existing transformer room which is just around 3.35 m against the current requirement of 3.4 m minimum clear headroom under beam. There are also other non-compliant issues like double-slab ceiling construction, separate compartment for high voltage (HV) switchgear, underground cable trench and cable draw pit for incoming cables need to be addressed. All these non-standard provisions have been identified at early stage of the project and discussed with the power supply company and exemption sought from them in order to minimize the extent of alteration works to the transformer room in our project. After lengthy negotiations, the company finally agreed to adopt the existing transformer room to accommodate their new transformers.

However, the existing incoming cables to the transformer room are routed through openings in the retaining wall at the site boundary and run via the car park area into a cable chamber room at a level just below the transformer room. These cables encased by fire rated enclosure could only give a maximum clear headroom of 1.88 m in part of the existing car park area that is to be converted into the main switch room and the FSI switch room under this project. To allow maximum possible headroom in these two switch rooms, the incoming cables are re-routed and a new cable route is mapped out as directly as possible through an inconspicuous area in the building. The extent of cable re-routing work is shown in Figure 1.

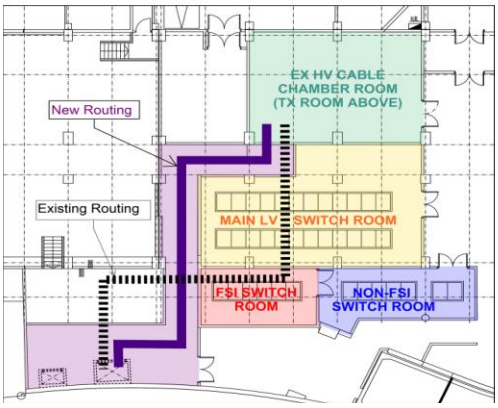

Fig. 1 – Lead-in Cables Routing

2.2.2 Main Power Distribution

Electrical power main distribution will be fed from the L.V. main switch room, FSI switch room and non-FSI switch room and finally to the respective sub-main switch rooms on each floor.

Three sub-main switch rooms are provided on each floor of the building, which are located at east, middle and west of building. The sub-main switch rooms at middle and west are converted from existing sub-main switch rooms and pipe ducts, thus eliminating the need for new openings for cable ducts. The remaining sub-main switch rooms at the east are new ones and are placed at locations where there is no critical constraint on making slab openings for cable ducts.

Final sub-circuits are then distributed from the respective sub-main switch rooms to different parts of the floor. Such arrangement could avoid exten sive power interruption to each floor when there is a fault in any sub-main power distribution system.

The electrical risers for main power distribution from the main switch room to various loads for lighting, air-conditioning units and office equipment, etc. on each floor will run through the existing openings in the sub-main switch rooms as far as possible. In this way, the need for new or enlargement of existing slab openings can be eliminated. Also, the strategic location of the electrical risers and sub-main switch rooms in the building can help to reduce volt drop and, in turn, the size of busducts and cables.

On the same token, horizontal cable run and other building services routing, especially those requiring large openings, such as air ducts and trunkings, shall reuse the existing openings as far as possible (Figure 2).

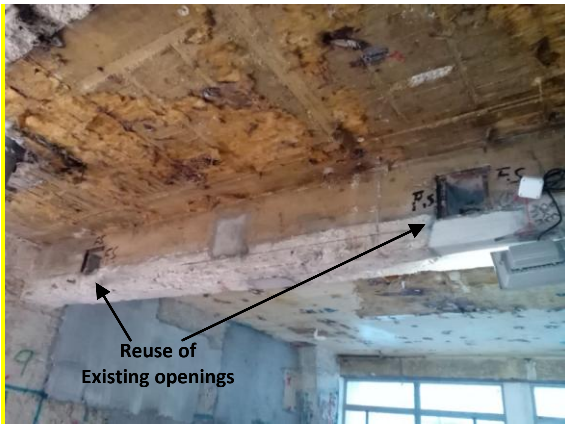

Fig. 2 – Reuse of Existing Openings

2.2.3 Final Circuits Distribution

Since raised floor system cannot be provided in our valued existing building due to the limited headroom, final power distribution circuits for open plan office have to be installed in concealed conduits or power columns with additional dry wall. Additional efforts are needed to plan the final circuit distribution and coordinate with the architectural team to achieve an aesthetically pleasing office environment.

2.3 Visual Impact

Minimal alteration on the façade of the existing buildings is one of the main goals for restoration as the external façades of the valued existing building is identified as CDE. Hence, all previously installed exposed conduits, down conductors, flue pipes and air ducts for building services system are to be demolished. However, this has to be done with care as some essential building services systems cannot just be taken down without replacement.

2.3.1 Essential Power Supply

Generally, there is a need to provide both essential power supply to fire service installations and other critical installations/equipment that demand secured operation during failure of normal power supply. For the current project, the location of the two generator rooms have to be carefully considered, as the flue pipe, makeup air and exhaust air louvers will have critical visual impact to the building façades, which is one of the great concerns of the Antiquities and Monuments Office (AMO). Hence, as with other buildings, the generator rooms are located at less prominent positions in the building, which is roof floor, in order to minimize visual implication on the building façades.

2.3.2 Mechanical Ventilation

In order to comply with the latest ventilation requirements, mechanical ventilation system will be installed to provide sufficient air change rate in toilets and pantries. Since centralized exhaust systems will require new large-size openings for the installation of air ducts, it is not preferable in this project. Local exhaust systems are therefore provided to serve these areas. Inevitably, there is still a need to install additional louvers on the building façades and their impact to the building appearance cannot be underestimated. In view of this, the design and location of louvers have to be considered carefully, and they have to be well integrated into the design of existing windows to soften the visual impact on the façades.

2.3.3 Lightning Protection System

Though the existing West Wing building is surrounded by high-rise buildings, a lightning risk assessment has been carried out and concluded that the lightning systems in its neighbourhood cannot adequately cover our subject building and a new lightning protection system has to be provided.

Since the building façade is defined as CDE of the valued existing building, the fixing of down conductors in accordance with IEC 62305: 2013[2] will adversely affect the appearance of the CDE, not to mention the need for additional earth pits. This design is unlikely acceptable by AMO. As an alternative, non-radioactive early streamer emission (E.S.E.) type lightning protection system with two lightning poles to French Standard NFC17-102[3] will be provided to protect this valued existing building.

2.4 Building Constraints

2.4.1 Location of Air-conditioning Plant on Roof

It is well established that water-cooled chillers are more energy efficient than air-cooled ones. And this is also the reason behind the use of a water cooled chiller plant in this building. But for revitalization projects, one of the dominating factors in the selection of air-conditioning system is the structural constraints as the building structure may not be able to support a substantial increase in building load. For the current project, the existing seawater-cooled chillers will be replaced by fresh water cooled ones in view of the adequacy of reliable fresh water supply. The new fresh water-cooled chillers will be installed in the existing chiller plant room which is on-grade while the associated cooling towers will be installed on the roof. The cooling towers are located on the top of a lift shaft, which is the core of building and hence, the need for structural strengthening will be minimized.

Furthermore, screens that match the building façades are added to shield the cooling towers from view for aesthetics reason.

2.4.2 Ceiling Supports for Building Services Installations

According to the structural record plan, a rib beam and hollow block floor slab design is adopted in almost all office areas of this valued existing building. The direct fixing of supports for building services installation to hollow block could not provide sufficient strength to bear the weight of the installations, hence, specific mounting details for various ceiling mounted building services installation is required to develop in the design stage so as to ensure all mountings are fixed onto rib beam instead of hollow block (Figure 3). This will mean more on site coordination and verification work to determine the exact location of rib beams before installation.

2.4.3 Location of Additional Lifts

With the anticipated increase in demand for vertical transportation when the renovated building is put into new uses, additional lifts have to be provided. These extra lifts are also meant for the meeting of statutory requirement for fireman's lift. Besides, the original provision in this old building cannot comply with the latest requirement in the Design Manual – Barrier Free Access 2008[4] in that not every floor of the building can be reached by lifts.

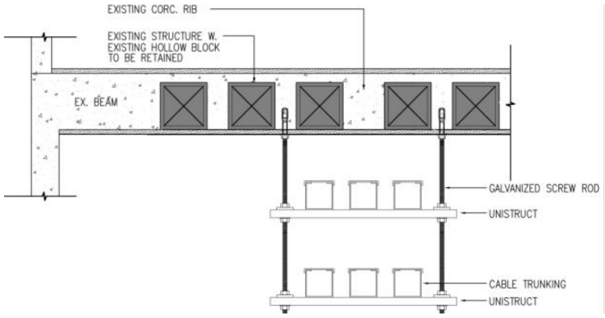

Fig. 3 – Installation Design for Ceiling Mounted Services

In deciding the location of the new lift, attention shall be paid to the dimensions of lift pit and lift overrun. New lift pit to be formed in any existing building will likely crash with the building foundation. The depth of lift pit for one of the new fireman's lift is marginally acceptable based on the available foundation record and lift suppliers' requirement. Hence, additional opening up inspection for lift pits is conducted to verify the suitability of the selected location. For the lift overrun, its height shall be so designed to avoid causing any visual impact on the building façade, and to integrate with other plant rooms on the roof as far as possible.

2.4.4 Rainwater Discharge System

One of the big challenges in revitalizing valued existing building is to upgrade its rainwater discharge system to comply with the up-to-date rainfall intensity with minimal alteration to the underground storm-water connections. Before starting the design of the rainwater discharge system, an assessment of the effectiveness and efficiency of the existing system was conducted through underground utility survey and CCTV survey. The outcomes of the surveys revealed that the existing rainwater pipes to public sewer can be retained. However, in view of the higher frequency of having extreme weather in Hong Kong in recent years, the handling capacity of the system have to be increased to cope with the likely increase in rainwater intensity. An additional stormwater terminal manhole will be provided for the building to cater for the increased rainwater intensity.

In order to suit the design, some underground pipes have to be diverted and the existing manholes within the site boundary are required to be re-constructed. However, the existence of numerous footings in the raft foundation system of the building has restricted the location of the new manholes and underground drainage pipes and extra effort is required to identify a feasible solution to this design issue in the design stage.

2.4.5 Services Coordination

In this project, the floor to floor height is just about 3.35 m, which is lower than that normally provided in recent new modern office buildings. To achieve a clear headroom of about 2.45 m for office and 2.25 m for corridor, the up-to-date services provisions for office such as cable containment facilities, air ducts and air conditioning equipment must be well coordinated and integrated with other building features.

With ceiling voids of depth ranging from 0.3 m to 0.8 m, extra care has to be taken in selecting luminaires in office areas and conference rooms to optimize the available ceiling void space. Also, the location of the light fittings needs painstaking coordination work so that maximum clear headrooms can be attained while other services can be accommodated orderly inside the ceiling void without sacrificing any maintenance needs. In addition, fan coil units instead of all air system are adopted in office areas to take advantage of their compact equipment size. Such system also requires smaller openings to be formed in the existing structure for chilled water distribution. The lighting luminaires together with sprinkler pipes are designed to install along the center of corridor, leaving both sides for running of trunkings for power and ELV cables. Apart from giving the highest possible headroom along the corridor, such arrangement can leave sufficient space for cable installation and/or maintenance. (Figure 4)

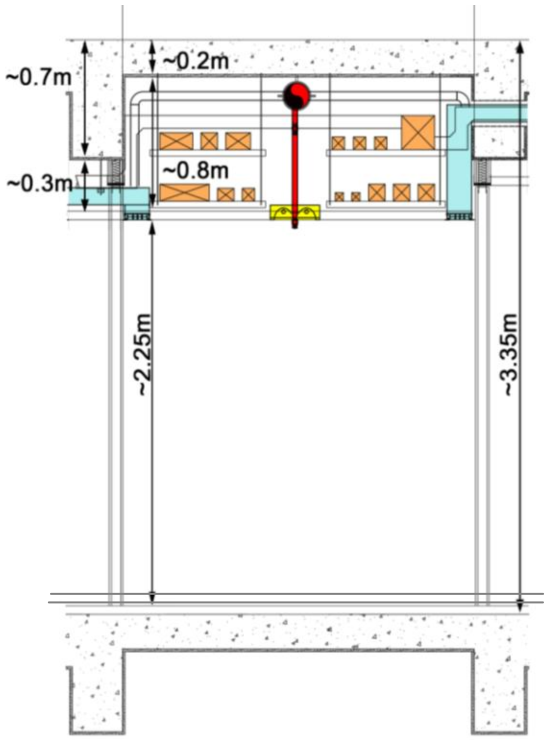

Fig. 4 – Typical Section for Corridor

Moreover, an array of surface channels will be provided on the roof floor to convey rainwater to designated locations so that horizontal run of all drainage pipes at the floor below can be minimized; giving it a higher clear headroom.

2.5 Fire Safety

No less important is the need to upgrade existing fire safety provisions in the building to meet the current fire safety requirements. Provisions like means of escape, fire resisting construction, access for fire fighting and rescue, emergency vehicular access as well as fire service installations will need to be upgraded. In this project, the original sprinkler water tank and pump room on G/F cannot meet the latest requirement, so a new sprinkler water tank with a larger capacity and pump room will have to be provided. However, they have to be located elsewhere due to spatial constraint of the original location. In view of the heavy weight of this 94 m^3 water tank, it is highly undesirable to place it together with its pump room on the roof floor, which will entail extensive structural strengthening works. Taking advantage of the building geometry and site layout, the new sprinkler water tank and pump room is therefore relocated to 6/F of the building which is on-grade; thus no structural strengthening works is required. As the pump room is located at mid-level, multi-stage multi-outlet sprinkler pumps are adopted to serve upper and lower zones of the building.

3. ENERGY EFFICIENCY

Incorporation of energy efficiency and green features is one of our main design themes adopted in this revitalization project. Some energy efficiency and green features are introduced below.

3.1 Lighting Control

In general, light-emitting diode (LED) lamps, high efficiency T5 fluorescent lamps, and LED type exit sign and directional signs are used in public buildings for energy saving purpose. And this is exactly what will be provided for this building.

Photo sensors capable of controlling the light output of artificial lighting from 30% to 100% of its full value are provided at areas where natural daylight is available in order to maximize the utilization of natural light source. In addition, occupancy sensors with 15 minutes adjustable time delay function are provided for the automatic on/off control of lighting as well as the fan coil units for energy saving in office areas, conference rooms and training rooms.

To further minimize the consumption of lighting energy, task lighting design approach will be adopted for open plan office areas. For cellular office areas with higher demand for lighting uniformity, a special lighting arrangement is proposed. Two T5 tubes in a light fitting at task area will be controlled by circuitries under two separate switches at the room entrance. In normal condition, the lighting intensity of these cellular offices is maintained at 300 lux by turning on one of the lighting switches. When the end-users carry out more visually demanding tasks, they could turn on the remaining tube to give a general lighting level of 500 lux. This control system just performs similar to the task lighting design approach, but with a better uniformity to meet client's needs while achieving saving in energy use. (Figure 5)

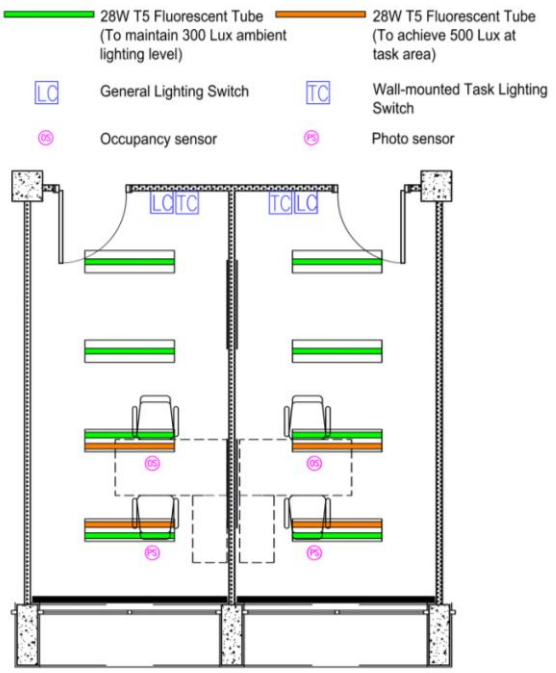

Fig. 5 – Lighting Control in Cellular Offices

3.2 Building Energy Management

Building Energy Management (BEM) system will be provided to collect electricity energy consumption data, and to monitor and record the energy consumption in the building by digital multifunction power meters or digital power analyzers at various feeders and sub-main circuits. The microprocessor based digital power meters or analyzers can measure electrical parameters including current, voltage, power factor, active and reactive power and frequency of power, lighting and air-conditioning equipment energy consumption, etc. These meters will also be able to communicate with Centralized Control and Monitoring System (CCMS) via a common open protocol. Data collected from the BEM system can facilitate the future monitoring of building energy performance.

4. CONCLUSION

This paper introduced the practical solution in the design of building services installations in revitalizing a valued existing building, in particular, ways to overcome challenges posed by existing site constraints. Architect, structural engineer, building service engineer, user and other stakeholders shall work closely to identify critical constraints and requirements at early stage of the project and formulate feasible and practical design solutions that can meet users' operation needs within a tight budget.

Integration of contemporary building services systems into the building with minimum alterations and disturbances while complying with the latest statutory requirements tops the lists of main challenges faced by the building service design team. There shall be no irreversible or adverse impacts to the existing building fabric, which is in line with the original aim of preserving and restoring the building to its original form as far as practicable.

Other attributes like maintenance needs, reliability and resilience, though not explicitly mentioned in the paper, shall continue to form part and parcel of the guiding principles in building services design achieving an environmental friendly, reliable and cost effective building facility.

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Paper No. 9

GREEN DESIGN OF EXPRESS RAIL LINK HIGH-SPEED TRAINS

Speakers: Ir C L Leung, General Manager – XRL E&M
Ms Candy H.M. Leung, Engineer I – Rolling Stock
MTR Corporation Ltd.

GREEN DESIGN OF EXPRESS RAIL LINK HIGH-SPEED TRAINS

Ir C L Leung, General Manager – XRL E&M
Ms Candy H.M. Leung, Engineer I – Rolling Stock
MTR Corporation Ltd.

ABSTRACT

The MTR Corporation is entrusted by the HKSAR Government on the construction of the 26-km Hong Kong Section of the Guangzhou-Shenzhen-Hong Kong Express Rail Link (XRL), including the procurement of 9 high-speed trains for the operation between Hong Kong and Guangzhou. It is the connection of Hong Kong to the Mainland's 20,000km high-speed rail network which plays an important role in enhancing economic development, culture and social exchanges between the Mainland and Hong Kong.

The high-speed rail network provides not only more efficient mean to connect cities in the Mainland, but also more environmental friendly transport mode. Comparing high-speed train with airplane and coach, the energy consumed and carbon dioxide emission per passenger-km is much lower. This paper will introduce various green designs of high-speed trains such as aero-dynamic and noise mitigation measures, and also train testing & commissioning to assure safe and reliable train operation.

1. INTRODUCTION

XRL is a part of the gigantic 20,000km National High-speed Rail Network, which will be further expanded to 8 north-south corridors, and 8 east-west corridors (八縱八橫) with a total length of 38,000km in 2025. It is the last phase of the planned Beijing-Guangzhou-Shenzhen-Hong Kong High-Speed Railway. The whole length of the XRL is 142km, of which the Hong Kong Section is a tunnel of 26km.

The Mainland Section of the XRL is constructed and built to suit the specific operation environment of the National High-speed Rail Network. To maintain the technical compatibility and interoperability of the network, the Hong Kong Section is also constructed to align with the National Code of High-speed Railway requirements.

The XRL adopts proactive safety measures and is fully protected by the signalling system equipped with "Automatic Train Protection" (ATP) function. It can achieve safe operation by ensuring sufficient train separation to avoid collision and also adopting fail-safe design concept. The ATP is highly reliable with another backup signalling system. In addition, the XRL adopts dedicated passenger line operation. It is a segregated line without mixed traffic with freight trains or sharing with the road vehicles, hence it is also named GSG Dedicated Passenger Line (廣深港客運專綫).

Various types of high-speed trains have been approved by National Railway Administration to operate in the National High-speed Rail Network. They are all named under the family of Hexie Hao (和諧號) at two classes of operating speeds:

- CRH1A, CRH1B, CRH1E, CRH2A, CRH2B, CRH2E, CRH3A and CRH5 with a maximum speed of 250km/h;
- CRH2C, CRH3C, CRH380A/AL, CRH380B/BL, CRH380C/CL, CRH380D, CR400AF and CR400BF with a maximum speed of 350km/h.

The 8-car XRL high-speed trains were manufactured on the basis of CRH380A high-speed Electric Multiple Unit (EMU) technology platform and will operate between West Kowloon Station and Guangzhou South Station as shuttle service. The XRL trains have been designed and developed by CRRC Qingdao Sifang (中車青島四方) in accordance with the "Technical Specification for New Generation EMU running at 350kph" (時速 350 公里新一代動車組技術條件) issued in 2009 by the China Railway Corporation (CR) – formerly known as Ministry of Railways (MOR).

Fig. 1 – XRL High-speed Trains

2. MAIN GREEN DESIGN FEATURES

2.1 Energy Consumption

Comparing with other means of transportation including airplane and coach, high-speed train is more environmental friendly no matter on energy consumption or carbon dioxide emission due to the following reasons:

- Comparing with coach, travel time is reduced which reduced energy consumption of on-board systems such as lighting and air-conditioning.
- Comparing with airplane and coach, high-speed trains use electricity, a mix of sources including renewable energy, which produce less CO_2 than fossil fuels.

The XRL high-speed train has excellent energy efficient design. The train is characterized by low running resistance and high regenerative braking utilization. The energy consumption per 100km per passenger is less than 4.38kWh, which is lower than other high-speed trains of similar type. The regenerative braking achieves a maximum energy feedback rate of 90%.

2.2 Aluminum Alloy Carbody

There are three main types of train carbody – carbon steel, stainless steel and aluminum alloy. Carbon steel usually adopts in conventional railway vehicles, which has low manufacturing cost but high maintenance. Stainless steel widely adopts in metro and trains with operating speed below 250 km/h, which has high manufacturing cost but low maintenance cost. Both carbon steel and stainless steel are too heavy for high-speed trains.

Similar to other worldwide high-speed trains operating with speed of above 300 km/h, carbody of XRL high-speed trains are formed by welded aluminium alloy extrusion panels. Aluminium alloy provides light weight carbody with the required strength for use in high-speed trains.

Fig. 2 – Aluminium Alloy Train Carbody

2.3 Streamlined Head Shape

The aerodynamic design of high-speed train is critical to running resistance, stability and riding comfort. The XRL train has incorporated a slender nose of 12-meter long, enhancing the degree of streamlining, featured with rotary parabolic surface to optimize the aerodynamic performance. The cross sectional area of the nose changes linearly in the nose section to reduce the pressure pulse generated during trains passing. Moreover, the shape of nose faring can effectively reduce the pressure pulse as well as end-car lifting force by guiding the airflow downwards. To select the most suitable train head design, computer simulation and wind tunnel test were used. Conventional wind tunnel test cannot simulate the interaction of two fast moving trains in opposite direction on adjacent tracks, also between train and tunnel portal. Hence, the train head design was tested by scaled down models.

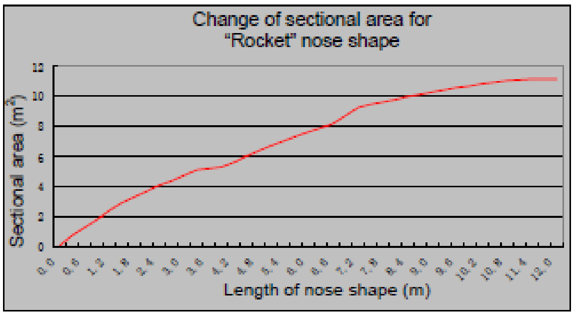

Fig. 3 – Change Rate of Sectional Area for the Nose Shape of XRL High-speed Train

The double-arched curved surface at the cab exterior portion can also reduce the aerodynamic noise at the top of the train cab. Comparing to the previous design of trains running at 200km/h, the streamlined head design for the XRL train brings further reduction in aerodynamic drag, noise, lifting and lateral force. Apart from streamlined head design, other components such as pantograph, underframe equipment and bodyside doors have streamlined design as well. All these streamlined design plus light weight carbody can reduce energy consumption.

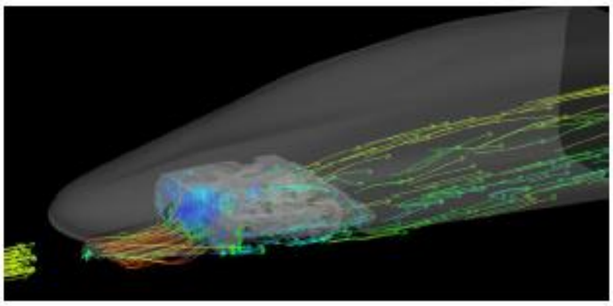

Fig. 4 – Complex Flow Simulated in Bogie Area

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Fig. 5 – Guiding Cover of Pantograph (Simulated on Train Model)

2.4 Vibration and Noise Control

As the running speed increases, the aerodynamic noise, pantograph and wheel-rail noise will increase dramatically. Effective mitigation on noise generation and propagation for high-speed train is therefore critical to ensure excellent riding comfort and minimize the environmental impact. Straight track is adopted in most high-speed alignment wherever possible sections to avoid chance of inducing wheel-rail noise in curves. For reducing aerodynamic drag and noise generation, XRL train head shape and pantograph with good aerodynamic performance are used, and the exterior surfaces of the bodyside doors and windows, roof equipment, bogie area and inter-car connection are also smoothened to streamline the air flow on the train.

For medium-to-high frequency noise propagation, it is mainly tackled by enhancing sound insulation performance of the multi-layer construction and applying new types of acoustic insulation and absorption materials so as to improve the entire sound insulation/ absorption performance. For low frequency noise propagation, it is mainly tackled by increasing stiffness of structural members, improving resilient mounting connections and damping characteristic of materials. With the mitigation measures implemented, the XRL high-speed train can meet both the interior and exterior noise performance requirements.

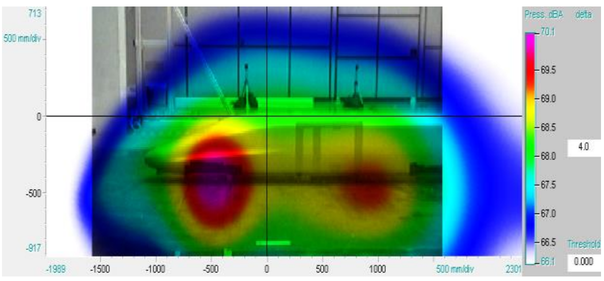

Fig. 6 – Noise Measurement Result of High-speed Train

2.5 Traction and Braking

The capability and efficiency of the traction and braking systems are crucial for safety performance at high speed safe running. To achieve the operating speed of 350km/h, the XRL train is equipped with a traction system having a total traction power of close to 10,000kW.

The hybrid braking system consisting of electrical regenerative braking and pneumatic braking, and priority is given to the regenerative braking so as to recover energy and minimize the brake pad wear. The regenerative braking of XRL train can achieve an energy feedback rate of up to 90% and thus reduces the brake disc and brake pad wear and consumption. In addition, due to good alignment design, high speed trains can run with more coasting and thus reduce energy loss caused by braking.

Same design of the traction and brake system in CRH380A attained very high reliability figure since its introduction to National High-speed Rail Network in 2010. It has already accumulated a safe operation mileage of over 770 million-km, with a fleet of over 400- trainsets (including the 16-car version CRH-380AL) as of August 2017.

3. KEY TESTING & COMMISSIONING REQUIREMENTS

3.1 Train Testing

The majority of high speed type tests were completed in Hukun Line Hangzhou to Changsha section (滬昆綫杭州至長沙段) in Year 2014 at a maximum speed of over 380 km/h. The type tests were witnessed by the representative of the HK statutory regulatory authority (i.e. Electrical and Mechanical Services Department – Railway Branch). Tests in Guang-shen and Hong Kong section included:

- Static tests
- Low speed dynamic test
- Gauging check
- Low speed and high speed tests in mainline with Signalling system
- All remaining types tests such as full load test, pull/push-out test, etc.

3.2 Infrastructure Testing

To verify thousands of kilometre of tracks efficiently, there is a Comprehensive Inspection Train (CIT) which was modified from a CRH380A train equipped with various on-board testing instrument, including:

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- Fibre optic sensors
- Laser & microwave testing system
- Image recognition system
- Signalling and GSM-R communication verification equipment
- Vibration, pressure waves, ride comfort measuring equipment

There are more than 10 CITs being used daily in the Mainland for comprehensive inspection on railway infrastructure at operational speeds. Major items inspected by CIT including:

- Trackwork
- Overhead Line system
- Signalling system
- Communication system
- Dynamic response performance
- Aerodynamic performance

Fig. 7 – CIT Inspection at the Hong Kong Section of the XRL

3.3 Integration Test

High-speed railway is an open and complex mega system, while integration testing itself is complex system engineering. Cross-boundary high-speed railway integration test includes a series of comprehensive testing and verification on various interfaces including wheel-rail, pantograph and overhead line, vehicles coupling, communication systems, signalling systems and trackside systems for system optimization according to the test results. In addition, operational safety, stability and applicability were assessed to ensure that the newly built high-speed railway can meet all the necessary operational requirements.

Cross-boundary high-speed railway integration test involves huge technical complexity and close collaboration between the test teams from the Mainland and Hong Kong is needed. The complex nature of extending an operational high-speed line between Guangzhou South and Futian (廣州南<->福田) to West Kowloon justified the establishment of dedicated Integrated Testing & Commissioning Command Centre (聯調聯試指揮中心) to plan all the test train activities, daily time table & boundary control formalities through systematic approach and management structure. With comprehensive coordination of the parties across the Shenzhen River & optimal deployment of test resources, the integration testing and commissioning will be completed on time in an orderly, high quality and smooth manner.

4. CONCLUSION

The XRL is an integral part of National High-speed Rail Network, which connects Hong Kong with the major cities in the Mainland. The design of the high-speed train procured for this project is based on technology platform of CRH380A. There are a number of design aspects in high-speed train which make it different from mass transit or regional train. The CRH380A train type has excellent track records since its operation in 2010.

Several green designs, including light weight carbody, streamlined head shape, vibration and noise control measures and its traction and braking system, adopted on XRL high-speed trains to reduce the energy consumption and carbon dioxide emission. In addition, comprehensive and sophisticated train testing and integration regime were implemented to ensure the XRL high-speed trains will deliver safe, reliable, fast and comfortable journey to passengers travelling between the Mainland and Hong Kong. This key infrastructure will strengthen Hong Kong as the Southern gateway of the Mainland.

Paper No. 10

CHALLENGES AND OPPORTUNITIES OF E-BUS IN HONG KONG

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Department of Electrical Engineering,
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ABSTRACT

Electric bus, as one of the most effective means to improve roadside air quality, has been proactively trialed and widely used in urban cities in the major countries especially Mainland China. Since 2009, Hong Kong has been trying to introduce E-bus; many trials have been funded by Government. However, successful demonstration of E-bus has yet to be seen. The bus operators who undertake the trials have not been satisfied with the E-bus performance so far. This paper reviews the challenges encountered in these E-bus trials including the battery performance, availability of charging facilities and cost differential compared to conventional diesel bus. Despite these challenges, there are opportunities leading to the successful introduction of E-bus to Hong Kong, leading to the potential huge benefits to operators, manufacturers and the public. A strong supporting policy of the Government is an essential condition for the success.

1. OVERVIEW

Electric vehicle (EV) technology is not new and the operational principle is simple; the rotation of vehicle wheel shaft is driven not by the energy generated from a conventional internal combustion engine but an electric motor driven by a battery. The core technologies of EV are five, i.e., battery, battery management system (BMS), motor control, battery charging and vehicle body (Chan, 2016). Since 1990s, the EV technologies, driven by environmental concerns on conventional vehicles, have improved drastically. The battery energy/power density increases, the weight and volume decrease and the cost reduces. The BMS can now effectively control the battery operation safety, including mechanical, electrical, functional and chemical safety. The vehicle body weight reduces to match the statutory overall vehicle loading requirement, same for conventional vehicles. The charging system can have options of on-board charging (hybrid vehicle), plug in charging, overhead charging (pantograph) and underneath charging (induction).

With the strong support of EV development from Central Government of China since 2007, EV is not a dream now and becomes a reality. There are now numerous vehicle battery and EV manufacturers in China. China has over 331,000 EVs including small to large sized vehicles on the roads as at the end of 2015. The US small EV Tesla compete very strongly especially in urban cities. Hong Kong alone has over 3000 Tesla.

Environmental Protection Department has been actively pursuing EV applications on public transport because they run huge mileage in crowded urban areas. Reduction of emissions from buses, minibuses and even taxis will help improve roadside air quality significantly. A trial programme was launched on electric minibus and taxis as early as 1999. The battery then was too heavy, the BMS could not control the safety of the battery to an acceptable level as well as the driving range was too short, the trial was not successful. A new round of trial on taxis and minibus were initiated under the Pilot Green Transport Fund (PGTF) which was set up in 2011. As at the end of October 2016, 3 taxis, 3 minbuses and 11 buses were funded under PGTF (Chow, 2016). Government also separately funds a trial on 36 electric buses (28 battery driven and 8 super-capacitor driven). The funds cover the installation of charging points as well.

BYD has trialed around 50 taxis in Hong Kong in 2015-2016; 3 under the PGTF scheme and others under its own initiative. The trail was not successful as only one remains running at the end of 2016 although the PGTF trial report concluded that the e-taxi can save running costs and reduce emissions. The major culprits, according to the taxi drivers, are that the driving range of the e-6 model (around 200 km) was not adequate, the charging time was too long (around 45 minutes to top up and 4 hours to fully charge) and the maintenance service was poor (takes days to repair). The BYD buses are now still on the trial but the operators were very cautious to allow the e-buses to operate even with some minor mechanical faults. It takes time to draw any conclusion.

While Hong Kong now has 6860 EVs on the road (nearly all are private vehicles), there is still very few e-buses and e-minibuses running commercially. With over seven million people, Hong Kong has 7193 single-deck buses, 5779 double-deck buses and 7431 minibuses as at the end of 2015. Many of these vehicles are still pre-Euro IV models which emit significantly more than the prevailing new Euro VI models; thus require replacement. In view of the available EV technologies and wide applications of EV on public transport especially in Mainland and Europe, it is believed that EV should be applicable to single-deck buses and minibuses as a first stage in Hong Kong.

2. WORLDWIDE ELECTRIC BUS & MINIBUS PROGRAMMES & BATTERY TECHNOLOGIES

2.1 Noticeable E-bus Programmes

The strongest e-bus programmes are no doubt in cities of mainland China. A very comprehensive report on "Investigation report of pure electric bus - 2012" was issued by the find800 group (www.find800.cn). The report covers 19 major Chinese cities including Beijing, Hengzhou, Guangzhou, Shanghai, Tianjin, Qingdao, Chongqing and Shenzhen. The reports provide observations of reporters in various cities. It gives positive and negative reflections from operators, passengers and drivers such as the battery life span was short (2-3 years), heavy battery resulting in energy wastage, battery temperature too high, charging time too long, and inadequate charging facilities. Chongqing was reported to have the best performance regarding the stability of the vehicle and the battery.

The wide spread of e-bus programmes in Chinese cities was sparked off by the EV policy evolved after the 2008 Beijing Olympics when the first generation of Chinese EVs were used to carry passengers in the sport grounds. Tax has been put on conventional petrol and diesel vehicles in 2008. The first set of financial policy was announced by the Ministries of Finance and Technology in January 2009 to support the development of new energy vehicles (NEV). It covered the period from 2009 to 2012. The target was to have 500,000 NEV production by the end of 2011 and 10% of NEV in new vehicle market penetration by the end of 2012. Capital and running costs of e-bus programmes were subsidized in at least 10 cities; each city would have 1000 e-buses on the road. Beijing, Shanghai and Chongqing were the first batch of cities involved.

A strengthened e-bus policy was announced in 2012. Ministry of Finance, Ministry of Science and Technology, Ministry of Industry and Information Technology (MIIT), National Development and Reform Commission were engaged. MIIT is the key agent to approve e-bus models warranted subsidies which are awarded directly to the vehicle manufacturers upon sales. The target was to have not less than 10,000 and 5,000 e-buses in mega cities and other cities in the country in the period of 2013-2015. Local governments are charged to provide charging infrastructure. The target of NEV development by 2020 is to increase the battery energy density to 300 Wh/kg, improve the life charging cycle to 3000 but reduce the costs to 1.5 RMB/Wh. The subsidy for e-bus in 2016 ranges from RMB24,000 to 500,000 per e-bus. There will be at least 200,000 e-buses in the country (Meng, 2016).

Apart from China, India and Malaysia in Asia have been active in promoting EVs. The FAME (Faster Adoption and Manufacturing of Electric (& Hybrid) Vehicles) plans of India for 2014-2020 and targets to achieve self-sustenance by developing hybrid and electric vehicles. The Malaysian Green Technology Corporation is responsible for the national electric mobility project. It targets to achieve 10% market share of EV in transportation sector, involving 2000 e-buses mainly in Kuala Lumpur.

The European Union funds the International Association of Public Transport (UITP) EUR22.5 million to launch the ZeEUS (zero emission urban bus system) programme (2013 – 2017). The programme targets at developing fully-electric solution to the core part of the urban bus network composed of high capacity buses. It will evaluate the economic, environmental and societal feasibility of electric urban bus systems through live operational scenarios across Europe. It will facilitate the market uptake of electric buses in Europe with dedicated support tools and actions as well as support decision-makers with guidelines and tools on "if", "how" and "when" to introduce electric buses. Ten European cities including Barcelona, Bonn, Cagliari, London, Munster, Paris, Plzen, Randstad, Stockholm and Warsaw are engaged. Approximately 70 electric buses of different makes are being trialed. The revealed challenges of e-bus are that the upfront cost is much higher at around double the price of conventional bus and the battery is around 45% of the cost. The charging infrastructure is costly and the local total cost ownership models are uncertain.

Across the ocean in Canada, the mayor of Windsor city launched an e-bus trail as one of the city's green energy initiatives since 2015. It targets to position Windsor as a pioneer of e-buses within its public transit system and to assist the city with its cost reduction initiatives.

In the US, the California Air Resources Board (CARB) and the National Renewable Energy Laboratory funded the Foothill Transit Battery electric Bus Demonstration program. The program was to evaluate the technology of e-buses meeting the service requirements operating in selected Foothill routes. The program concluded a success. In 2015, the US Department of Energy Resources – the Commonwealth of Massachusetts initiated the "Vehicle-to-Grid Electric School Bus" pilot program. It targets to test the feasibility of electric school bus use. Schools are funded to purchase e-bus for trials.

2.2 Observable E-bus and E-minibus Models and Charging Facilities

The observed e-bus and e-minibus models are plenty during the technical visits in mainland China and Europe conducted by the research team leaded by the author. The e-buses are single deck buses with length ranging from 8 m to 12 m; capacity ranging from 50 to 70 passengers and battery capacity ranging from 64.3 kWh to 285 kWh depending on the type of battery installed. The e-minibuses have the vehicle length ranging from 6.4m to 7.0m with capacity ranging from 10 to 36 passengers. The battery capacity ranges from 68 kWh to 76kWh.

There are slow (Lithium Iron Phosphate battery), fast (Lithium NMC battery) and ultra-fast (Lithium Titanate battery) charging facilities.

For slow charging, the charging electric current is 63-150A at 380-400V; the charging time is around 3-8 hours. For fast charging, the charging electric current is 260A at 600V. For the ultra-fast charging, the charging electric current is 400A at 700V and takes around 10 minutes to charge each time. The 12m e-bus in Chongqing was observed to take 9 minutes to charge from SOC at 60% to 100%.

There are plug-in battery charging, inductive charging and pantograph charging facilities. The plug-in charging gun requires the bus driver or an operator to serve the charging while the other two facilities are automatic when the alignment is correct.

Super-capacitor buses (12-meter-long carrying 70 passengers) were observed in Shanghai. The super-capacitor has 30 kWh capacity. The buses were charged with pantograph at bus stops and termini. The charging current was 150-200A at 600V. The charging time is around 3 minutes.

2.3 Battery Types and Characteristics

Battery determines the e-bus performance. It is crucial to make a correct choice of type and size of the battery to ensure the best bus performance along service routes.

Lithium titanate and *lithium iron phosphate* are the safest battery types with minimum thermal runaway. Lithium titanate has the least specific energy, the highest cycle use (longest life span) but the most expensive type of battery. Lithium iron phosphate is the most popular because of its lower cost and its specific energy is roughly 50% higher than that of lithium titanate; however, its cycle use is much less. The other three types of battery all have problems of thermal runaway which have to be controlled to achieve the safety standard. They are cheaper than lithium titanate but more expensive than lithium iron phosphate. However, they can have higher power and better performance than lithium iron phosphate. The cycle use of *lithium NMC* can achieve a few times longer than lithium iron phosphate but still shorter than that of lithium titanate.

There are five charging modes: ultra-fast, fast, slow, battery swapping and overhead cable (trolley bus). The charging rate of ultra-fast, fast and slow charging mode is over 6C, 1C and less than 0.5C resulting in charging time of 10-15 minutes, 0.5-2 hours and 4-8 hours respectively. The battery swapping mode requires the battery to be charged at dedicated stations with special handling equipment; the operation takes around 15 minutes. The overhead cable charging mode charges the e-bus battery when the bus antennae connect the cable.

With these characteristics, one ultra-fast charging point, similar to that in conventional gas stations, can serve many buses while one slow charging point can only serve one bus during the overnight charging. Cost and land requirements vary significantly in installing charging infrastructure for different modes of charging, probably in the order overhead cable, ultra-fast, fast, slow and battery swapping.

Cities choose various battery charging modes taking their major advantages which may meet their needs better. The major disadvantage of ultra-fast charging is that the battery requires more frequent charging in the day time which may affect the power supply especially at the peak demand of the city. The slow charging battery will have heavier weight on the bus and thus reduce its energy efficiency per passenger carried while battery swapping and overhead cable have their constraints in land, equipment and aesthetic issues.

3. MAJOR BARRIERS

Major barriers to electric commercial vehicle (ECV) adoption can be divided into three main categories, namely technology, finance and operation. Financial/ operational and technological aspects of ECV adoption are equally important in decision making. The ECV technology has improved significantly over the years. The performance of energy storage in terms of power and energy capacity, which was the biggest technological barriers, is greatly enhanced by the more mature lithium-ion battery technology (Burke and Miller, 2011; Scrosati and Garche, 2010). Power and energy capacity improvement enhance the feasibility of electric commercial vehicle operation. However, the energy efficiency has considerable variation depending on driving cycle and bus configuration (Lajunen, 2014).

Uncertainty over total cost of ownership (TCO), lack of supporting legislation and no financial incentives are the major financial barriers (Conti, Kotter and Putrus, 2015; Lajunen, 2014 and Kühne, 2010). The uncertainties were derived from manufactured price, maintenance cost, end of-life, infrastructure, emission and insurance. Procurement intention is reduced by the significant uncertainty over TCO, as TCO of each e-bus cannot be properly quantified and applied in business model. Bae et al. (2011), Kaplan et al. (2016), Kirk, Bristow and Zanni (2014) and Sierzchula (2014) studied the barriers of purchase of ECVs in firm level and important role of government in ECV adoption. The theoretical model created by Bae et al. (2011) shows that government subsidies, energy price shocks, energy savings and environmental regulations can be drivers towards EVC adoption, while Sierzhcula (2014) shows that governmental grants and first-mover advantage could have great impact on profit-seeking companies. It is found from the interviews of 17 stakeholders (Kirk et al., 2014) that fuel costs, refueling infrastructure, vehicle purchase cost and residual value, the removal of the London congestion charge exemption, lack of knowledge regarding EV and vehicle weight are possible motivating factors and barriers underlying purchase of ECVs. A model based on Theory of Planned Behaviour with the basis of 1443 responses from a large-scale survey in Austria, Denmark and Germany (Kaplan et al., 2016) shows that energy cost savings, environmental benefits, parking benefits, good company image and driving ease are relatively important in purchase intentions of ECVs. The attitudes of stakeholders towards innovative measures are studied as part of the European Bus System of the Future (EPSF) project. The result is clear that innovative measures, leading to reduced fuel consumption or improved service efficiency, might be accepted and applied on condition that operation costs are not increased (Musso and Corazza, 2015).

Specific ECV models for different routes are required in order to maximize performance and cost efficiency (Lajunen, 2014 and Pihlatie et al., 2014). As specific ECVs are only energy/cost-effective in specific route, it reduces the flexibility in scheduling and operation comparing to diesel vehicles. Battery electric buses (BEBs), in particular, are questioned in flexibility in operation due to the influence of charging time on schedule (Miles and Potter, 2014). Miles and Potter (2014) estimated that all electric buses provide the similar performance as diesel bus based on range extension by 5min refueling/ recharging, except overnight BEB. It seems BEB opportunity charging has smaller impact on operation than overnight BEB, as it can be achieved by various choices of charging infrastructure including charging spots, pantograph charging and inductive charging (Mahmoud et al., 2016). Although only minor modification to the current infrastructure is needed for BEB opportunity, the considerable number and distribution of infrastructure is a barrier to implementation (Kakuhama et al., 2011).

To confirm these barriers to e-bus introduction to Hong Kong, local bus and minibus operators (individual operators and associations) were consulted through series of meetings, seminar and public forum. The major barriers in the Hong Kong context are summarized in Table 3.1. To the bus and minibus operators, there are two major uncertainties, one is technical and the other is financial. These uncertainties, to a very large extent, are derived from the lack of knowledge of the prevailing technological levels of the e-bus technologies and performance and the unhappy experience of previous e-bus and e-minibus trials in Hong Kong.

4. POLICY RECOMMENDATIONS

It is clear that:

1) The e-bus technology composes of a) vehicle, b) battery, c) BMS and d) charging technologies. These technologies are mature and ready to apply in large scale as reflected in the cases of mainland China and Europe.

2) The e-bus manufacturers in mainland China have invested significantly in developing b), c) and d); however, a) is the weakest while manufacturers elsewhere (in particular EU) are good at a) as they have lots of experience in vehicle design and manufacturing.

3) Although the battery and vehicle technologies are mature but the design and manufacturing of e-bus, i.e., determining the optimum type and amount of battery and vehicle compartment configuration to meet prevailing specification to suit bus operation requirements, is still at a developing stage. Apparently, no e-bus manufacturer is good at all the 4 component technologies to ensure an e-bus meeting the operators' requirements. As such, there are ample rooms for collaborations among these manufacturers.

4) For the case of Hong Kong, there is a big knowledge gap in e-bus technologies and total cost in ownership (TCO) especially among the bus operators. The e-bus knowledge is over-shadowed by negative reports of battery thermal runaway in early trials in mainland China and the unsuccessful experience in very small-scale ill-organized local trials.

5) The limited number of e-buses trialed or being trialed in Hong Kong have not been properly designed to meet the operating conditions for Hong Kong. And, there is no local technical support to oversee and drive the trials to a success. Trials so far disappoint the operators and give rise to the ill impression of e-bus.

6) The e-bus and e-minibus manufacturers are not willing to design, manufacture and provide maintenance service to e-bus if the ordered number for these vehicles is too small. With the Government's financial supports to e-bus and e-minibus trials, the e-bus and e-minibus dealers in Hong Kong are very active to sell available vehicle models (all from mainland China). However, these models can only be picked out of the shelf. It would be extremely lucky if an e-bus model can meet the operational requirements of the local operators.

7) There are some parties (academic, HKPC and GMI) in Hong Kong exploring e-bus and e-minibus technologies. There are some successes in developing charging facilities; for examples, the SmartCharge and the HK EV-Power. HKPC tries to collaborate with manufacturers from mainland China to develop an e-minibus; GMI has developed an e-minibus charged on board by a diesel engine. There is no collaboration between all key stakeholders, i.e., government, bus operator, e-bus manufacturer, battery manufacturer and charging facility provider to ensure a successful e-bus programme.

8) The bus and minibus operators have desire to try e-bus/ e-minibus because of the obvious savings and fuel and maintenance costs; However, the high capital costs; uncertainties of downtime are major hurdles.

There is a golden opportunity for Hong Kong in developing e-bus models and programmes to meet local operation requirements. The opportunity exists in the following areas:

1) Hong Kong is good at forging collaboration between mainland China and the other parts of the world to formulate good business models. There is a huge market in world cities for e-bus. Mainland China is very strong now in battery and charging technologies but weak in vehicle design. Europe is the reverse.

2) Hong Kong can be the first world city to fully implement a successful e-bus programme in market economy. This can be achieved through a properly designed and supervised e-bus trial with a sizeable fleet. As an exemplary city in public transport and electrified public transport system, Hong Kong is in the best position to become a trading centre of e-buses for other parts of the world. The Chinese battery and e-bus manufacturers as well as local e-bus charging facility providers and vehicle dealers will be benefited.

3) With proper education and training, Hong Kong can become a base to service e-bus programmes locally and overseas. Hong Kong is good at formulate value added services. This will create significant job opportunities.

To grasp this golden opportunity, the Government should adopt the following policy:

1) To strengthen the current supports, including financial, land provision and technical supports, to e-buses. In the first stage, Government should formulate a new e-bus programme (described below) to ensure the right policy direction.

2) To enable a good business environment for forging collaborations among battery and e-bus manufacturers in mainland China and European vehicle manufacturers. The relevant policy bureaus, in particular the Transport and Housing Bureau, the Environmental Bureau and Commerce and Economic Development Bureau have to be charged with definite responsibilities to create collaborative opportunities for e-bus trade sectors in Hong Kong, Mainland and Europe.

3) To support education and training of professionals and technicians for the e-bus and e-minibus service sectors to ensure adequate manpower for this new trade.

To push the policy on electrifying public transport ahead and based on the experience of successful e-bus programmes elsewhere, a sizable trial of e-bus and e-minibus should be properly mounted up. The number of vehicles has to be sizable to ensure the manufacturers' willingness to collaborate. The main purpose of the trial is to demonstrate the major technical and financial barriers to e-bus perceived by operators can be tackled. To overcome the technical barriers, the vehicles together with the battery and charging infrastructure have to be properly designed, manufactured and serviced. There must be a competent driving force to ensure the success of the trial.

In order to facilitate the trial programme, the Government should a) bear the monetary cost of e-bus/ minibus in trial; b)install the charging facilities for the e-bus programme, an option is to employ the "Build, Operate and Transfer" (BOT) model to tender out to charging facilities providers as long as the locations of charging points are agreed with bus operators and c) issue temporary licenses for e-bus/ minibus in trial if necessary. Assuming 100 e-buses and 100 e-minibuses in the trial, the total financial commitment (excluding the land requirements) for e-buses ranges from HKD207 million to HKD640 million depending on the vehicle make (Chinese or foreign) and the charging mode (ultra-fast of slow). The total costs of e-minibus trial programme is HKD113 million (a Chinese make and slow charging).

Technological Obstacles		• Battery Safety • Driving Range Anxiety
Operational Obstacles	Obstacles to Charging	• Relatively Long Charging time (Insufficient Charging Facility is one of the reason • Lack of Space in Termini for charging facilities • Limited numbers of Public Charging Facilities
	Obstacles to Fleet Management	• Pressure on Operation due to Uncertain Downtime • Uncertainty over Scheduling • Limitation on Vehicular Licenses • Spare Buses are needed (more) • Availability of service support
	Others	• Lack of Maintenance Technicians Specialized on EV • Battery/ Electric Component Waste Management • Safety of Pedestrians and Cyclists due to Reduced Operational Noise,
Financial Obstacles		• High Upfront Cost • Trade-offs between Efficiency, Size and Price (Battery Types, Interior Volume) • High Uncertainty over TCO

Table 3.1 – Major Barriers to E-bus Programme in Hong Kong

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