Research Assessment Exercise 2020
Impact Case Study

University: The Hong Kong Polytechnic University (PolyU)
Unit of Assessment (UoA): 16 – Civil Engineering and Building Technology

Title of case study: Building energy technologies – Building life-cycle optimization and diagnosis

(1) Summary of the impact

The UoA team have conducted research into reducing building energy consumption and enhancing energy efficiency, mainly in connection with air-conditioning systems. They have also sought to improve the uptake of renewable energy resources. The team's research outputs have resulted in innovative methodologies and technologies which have had significant impact through both technology transfer and direct industrial applications in well-known building projects as well as the adaptation in governmental assessment schemes. These known direct applications have delivered energy savings ranging from 15% to 42% that delivered for over 20 buildings a total of over 25 million kWh annual savings, currently valued at about HK$25 million. The research has also resulted in successful establishment of three technology-driven start-up companies and one licensed patent.

(2) Underpinning research

Buildings contribute over 40% of overall energy consumption worldwide, and over 80% of the overall energy consumption and over 90% of electricity consumption in Hong Kong. Research by our UoA's Building Energy Group shows that energy savings of up to 42% can be achieved through more advanced system design and management/control technologies. The underpinning research conducted by the five members of our Energy Group (Prof. Shengwei Wang, Prof. Hongxing Yang, Prof. Ling Lu, Dr. Fu Xiao and Dr. Wai-Ling Lee) led to 68 PhD students graduating over the last 20 years. These studies have progressively formulated a comprehensive approach to tackle building energy consumption which employs innovative methods/technologies to support energy system design and control optimization, diagnosis and commissioning over the life-cycle of new buildings and also for the retrofitting of existing buildings. The research achievements in building energy systems can be categorized into: (i) optimal energy system design and integration of renewable energy generation; (ii) optimal control methods and strategies; and (iii) system assessment, diagnosis and commissioning. Brief summaries are given below of the underpinning research that has led to impact in each of these areas. Outputs from the research have also generated significant impact in the academic field concerned, including over 15,000 citations, 15 highly cited publications and two top-150 highly cited scholar mentions since 2005.

Optimal system design and integration of renewable energy generation. The UoA's Building Energy Group has pioneered uncertainty quantification in enhancing the optimal design of building air-conditioning and district cooling systems. A novel robust methodology has been developed adopting a probabilistic approach [R1]# that addresses uncertainties in design inputs and the relative reliabilities of equipment operating, adding also flexibility to optimize on-site adaptive commissioning. This research won 2 best paper awards and attracted 3 keynote invitations in international conferences. Strategies and technologies have also been developed to optimize the design of solar and wind generation systems integrated into buildings [R2]# and to improve their efficiency. This research won 4 best paper awards and attracted 6 keynotes in international/national conferences.

Optimal control methods and strategies. The Building Energy Group has also developed of a series of smart and energy-efficient control strategies for large/complex cooling and air-conditioning systems that integrate in-situ validations and real applications in super-large systems. These include robust chiller sequence control, adaptive optimal control and optimal control of chiller cooling water

systems [R3]#. These strategies cater to the current need for optimization of the building-grid interoperation/responses and the future need for smart grids. This research won 3 best paper awards and attracted 5 keynotes in international/national conferences.

System assessment, diagnosis and commissioning. The Group's third major element of underpinning research comprises building energy performance assessments and system diagnosis methods to improve the energy efficiency. These methods quantify the energy performance and identify the energy saving opportunities/solutions. For existing buildings, these methods address (for example) the challenging situations of the diagnosis of information-poor buildings [R4]# and building Big-Data analytics. The Group's work on Big-Data research is the first example of which we are aware of the need to address the effective use of the huge amount of data in modern 'information superrich' buildings [R5]#. These research achievements resulted in 3 best paper awards and attracted 4 keynotes in international/national conferences. The Group's comprehensive energy performance assessment methods for new building designs [R6]# have now been adopted by the authorized building design assessment scheme in Hong Kong.

(3) References to the research

R1. Gang WJ, Wang SW*, Xiao F and Gao DC, "Robust optimal design of building cooling systems considering cooling load uncertainty and equipment reliability", Applied Energy, V159, 265-275, 2015

R2. Peng J.G. Lu L and Yang H.X. "Investigation on the annual thermal performance of photovoltaic walls mounted on a multilayer façade", Applied Energy, V112, 646-656, 2013

R3. Sun YJ, Wang SW and Huang GS "Chiller Sequencing Control with Enhanced Robustness for Energy Efficient Operation", Energy and Buildings, V40(11), 1246-1255, 2009

R4. Yan CC, Wang SW, Xiao F and Gao DC, "A multi-level energy performance diagnosis method for energy information poor buildings", Energy, V83, 189-203, 2015

R5. Fan C, Xiao F and Wang SW, Development of Prediction Models for Next-Day Building Energy Consumption and Peak Power Demand Using Data Mining Techniques. Applied Energy, Vol. 127, pp.1-10, 2014.

R6. Lee WL, Yik FWH and Burnett J. Assessing energy performance in the latest versions of Hong Kong Building Environmental Assessment Method (HK-BEAM). Energy and Buildings, V39(3), 343-354, 2007

(4) Details of the impact

Significant impact has been generated beyond academia as summarized below under four headings:

4.1 Successful implementations and significant energy savings

The outputs/technologies developed from the underpinning research are implemented directly through Professional Consultancy projects (valued at HK$ 13 million, see [S1]) and collaborative research (valued at HK$ 7.5 million) in over twenty building projects, including well-known projects such as: (i) the International Commerce Center (ICC, the tallest super-high-rise building in Hong Kong); (ii) redevelopment of New World Centre (New World Group); To Kwa Wan Station (establishing the model for MRT's the next generation underground station air-conditioning systems); and (iii) water energy recovery turbine technology at Pik Wan Road [S2] (establishing the new model for the power supply of the monitoring systems network in Hong Kong). The direct implementation of optimal system design and control delivered a total of over 25 million kWh annual savings, currently valued at around HK$25m, for the owners of over 20 buildings.

Further evidence of the positive impact includes:

- The PolyU team contributed an annual saving of 10 million kWh (18%) [S3] to ICC since 2013 by implementing the technologies of the Group on the air-conditioning systems, with an accumulated saving of about 70 M kWh. The efforts and resulting energy saving have received

over ten international and local awards, which have been well received by local and international profession and widely reported by the local media.

- Application of our technologies on the Holiday Inn Express SoHo air-conditioning system has achieved the energy saving of about 27% [S4], led to the building being recognized by the HK Green Building Council as a green-building model;
- Implementation of diagnosis and optimal ventilation control strategies in two existing Jacobson Pharma's production buildings led to substantial savings, i.e., 40% and 27% respectively as reported in source [S5];

4.2 Technology transfer

A further impact of the team's building energy research is the establishment of one technology transfer firm and two technology-driven firms founded by PhD graduates, namely:

- REC Green Energy Solutions, which was established using the robust and optimal control software packages as core technologies via contracted research with You Lee Group [S4];
- PhD graduate, Dr. Zhengyan Xu, founded Shenzhen Junzhi Hi-Tech Co. Ltd, a firm focusing on building automation, in 2009 shortly after his graduation. Since Oct 2013, this well-recognised BA & Energy Optimization Services company has undertaken a number of impactful projects in China, including Dongguan Tai-Xin Hospital, Sheraton Hotel, and High-speed Rail Building in Beijing etc. [S6];
- PhD graduate, Dr. Wei Zhou, founded Shenzhen Smartrans Photoelectric Co. Ltd, a firm focusing on PV products and technologies, in 2017 [S6];

A patent created from the Group's research has generated further impact through a licensing agreement signed with Sunlight Eco-tech Limited for "Nanocomposite Paste for Self-Cleaning Coating for Glass Panels", in 2016 [S7]. Other than establishments of startup companies by our PhD graduates or by technology transfer via financial agreements, a few partners in building energy field, which are very successful and influential today in South China, have also received great benefits from our research and the collaboration with us particularly at the early stage of their establishments, such as Guangzhou I-mec Technology Co. Ltd (*http://www.i-mec.cn/main.aspx*) and Shenzhen Jialida Energy Saving Technology Co. Ltd (*http://www.coolead.com/index.html*).

4.3 Prestigious technology awards

Ten international awards have been received over last 15 years in recognition of the technologies developed by the team and particularly their applications. Two representative examples are:

- 2014 ASHRAE Technology Award (Category I - New Commercial Buildings) for the achievement in improving energy efficiency of ICC [S8]. The case was published as the "cover story" of the ASHRAE Journal in July/2014 (Fig-2), distributed to over 57,000 members in over 130 countries worldwide;
- TechConnect 2017 Global Innovation Award for the technology of "Transparent thermal insulation coating for window glass" [S9].

4.4 Adaptation and impacts in/on government codes and authorized assessment

Building-related energy performance assessment methods developed by the group members have been adopted from 2004 in the building performance assessment methods authorized by the SAR government, which are designated as HK-BEAM and BEAM Plus [S10], that apply to all new buildings, and recently extended to existing buildings. This implementation has implemented the team's energy budget approach covering integrated energy performance for low-cost housing in assessments of over 150,000 building cases.

(5) Sources to corroborate the impact

S1. Reference letter (1) of PolyU Technology and Consultancy Company Limited
S2. Reference letter of Water Supplies Department
S3. Reference letter of International Commerce Centre management Services Office

S4. Reference letter from Yau Lee Holdings Limited
S5. Reference letter from Jacobson Pharma Corporation Limited
S6. Reference letters from two PhD graduates who established their own firms
S7. Reference letter (2) of PolyU Technology and Consultancy Company Limited
S8. ASHRAE Technology Award 2014 (Category I – Commercial Buildings – New)
S9. TechConnect 2017 Global Innovation Award
S10. Reference letter from Hong Kong Business Environment Council Ltd