**Research Assessment Exercise 2020**

**Impact Case Study**

**University:** The Hong Kong University of Science and Technology

**Unit of Assessment:** 14 - mechanical engineering, production engineering, textile technology and aerospace engineering

**Title of case study:** Towards the Future of Smart Green Buildings

(1) ***Summary of the Impact***

Research led by Professor Chao and his team at HKUST has resulted in several innovative products; new adsorption cooling systems using MWCNT Zeolite 13X/$CaCl_2$ composite adsorbent integrated with $TiO_2$ nanofluid-based micro-grooved evaporators saving around 60% electricity consumption, have now commenced production at Guangzhou Wanbao Group Co. Ltd.; novel low-speed wind turbines using MPPT controllers, cloud services, and online monitoring and control are now a product of major Chinese wind power company, Guangzhou HY Energy Technology Ltd. and have already generated 10 million RMB sales revenue during the census period; newly-innovated and energy-efficient health-focused air cleaners that use acoustic and microfluidics techniques, and micro-pattern structured filters, have been successfully utilized by Raymond Industrial Ltd. for Philips, Honeywell, Blue Air's products have generated 7 million RMB earnings in the census period; and novel passive thermal radiative coolers are used in Kaisa's buildings in China.

***(2) Underpinning Research***

Smart green building development is underpinned by several classical problems: energy efficiency, green energy and sustainability. To facilitate the process of industrialization and marketization of the new technologies, Building Energy Research Center (BERC), Fok Ying Tung Graduate School (FYTGS) was established in mainland China with Professor Chao as Director and Professor Qiu as Associate Director. The main research interests are heating, ventilation, and air conditioning (HVAC), new energy, energy saving reconstruction and environmental protection. BERC has managed government projects with funding of over 15 million RMB with over 17 Chinese patents filed or granted. The team including Profs. Chao, Qiu, Huang and Tso have focused on energy efficient systems described below:

**Energy efficient adsorption cooling system**

We developed a novel composite material (zeolite 13X/$CaCl_2$) as the adsorbent that uses water as the adsorbate for an energy efficient adsorption cooling system (ACS). Compared with the zeolite 13X adsorbent, this new adsorbent operates at a much lower desorption temperature which can be utilized to desorb the composite adsorbent when compared with the conventional zeolite 13X adsorbent [1]. To further improve the energy efficiency, multi-wall carbon nanotubes embedded in the zeolite 13X/$CaCl_2$ composite adsorbent have a 5 times greater thermal conductivity than zeolite 13X. In addition, our research showed that using nanofluids as adsorbates, together with conducting the heat and mass recovery cycles, the ACS specific cooling power has been further improved by 20%, to 401W/kg. Our team also developed a nanofluid evaporator with an externally micro-grooved surface that enhances heat transfer performance by up to 44.6% [2]. The novel multi-wall carbon nanotube embedded zeolite 13X/$CaCl_2$ composite adsorbent and the optimized adsorption cooling system design has impacted the new product development in energy efficient adsorption cooling systems.

**Green energy with an efficient small-scale wind power system**

Small vertical-axis wind turbines as energy saving devices are in great demand. However, Savonius wind turbines require a low torque for starting, but their efficiency is low, while Darrieus wind turbines have high efficiency but are difficult to start. To solve this problem, based on our fundamental research [3], a novel efficient small-scale wind power system combining the advantages of a Savonius

and a Darrieus turbine with a minimal compensation for power efficiency by optimizing the geometric parameters has been developed. Our research showed that the optimum configuration for the combined rotor generating the maximum power coefficient of 0.363 and the required start up torque is less than 0.1 Nm at low wind speed of 2 m/s and, therefore, the key advantage of this innovation is that it can improve max power coefficient while reducing the startup torque, providing guidance for optimization of small wind turbine design.

**Novel technique for energy-efficient indoor air quality control**

Indoor air quality control to prevent disease transmission and reduce infection risk is crucial. However, conventional techniques, such as cyclones and/or filters require powerful blowers which consume a large amount of energy. To minimize the energy consumption during operation, innovative aerosol removal techniques without high pressure drop or high airflow velocity are highly desired. Our team used acoustics, treating the inner surface of the air duct with micro-patterned structures, along with the development of a highly efficient electrostatic precipitation type air cleaner for ultrafine particles, to develop an energy-efficient aerosol removal and virus inactivation technique. [4] We found that the geometry that produced a high vorticity magnitude near the deposition surfaces provided conditions to induce a high occurrence for aerosol deposition (up to 3.5 times the rate caused by natural deposition). [5] The research findings provide a guideline for designing acoustic aerosol manipulation devices that significantly improve the aerosol-removal efficiencies and reduce energy consumption.

**Passive radiative cooler for smart green building**

We developed a smart green wall panel to provide a cooling effect in Hong Kong's hot and humid climate. Our photonic radiative cooler achieved a cooling capacity of 38 $W/m^2$ under a clear night sky. By integrating an asymmetric electromagnetic transmission window with a polymeric based radiative cooler, we achieved a cooling power of 100 $W/m^2$ sufficient to provide chilled water to the relevant building. This was the first successful demonstration of passive radiative cooling in a hot and humid climate. [6]

***(3) References to the Research***


[1] K.C. Chan, Christopher Y.H. Chao, G.N. Sze-To, K.S. Hui, 2012 Performance predictions for a new zeolite 13X/CaCl2 composite adsorbent for adsorption cooling systems, *Int. J. Heat & Mass Transfer,* 55, 3214–3224. https://doi.org/10.1016/j.ijheatmasstransfer.2012.02.054

[2] CY Tso, KC Chan, CYH Chao, CL Wu, 2015 Experimental Performance Analysis on an Adsorption Cooling System using Zeolite 13X/$CaCl_2$ Adsorbent with Various Operation Sequences, *Int. J. Heat & Mass Transfer,* 85, 343-55. https://doi.org/10.1016/j.ijheatmasstransfer.2015.02.005

[3] XT Liang, SC Fu, BX Ou, CL Wu, CYH Chao, KH Pi , 2017 A computational study of the effects of the radius ratio and attachment angle on the performance of a Darrieus-Savonius combined wind turbine, *Renewable Energy*, v.113, p.329-334. https://doi.org/10.1016/j.renene.2017.04.071

[4] WT Yuen, SC Fu, JKC Kwan, CYH Chao, 2014 The Use of Nonlinear Acoustics as an Energy-Efficient Technique for Aerosol Removal, *Aerosol Science and Technology*, 48, 907-15. http://dx.doi.org/10.1080/02786826.2014.938800

[5] W. T. Yuen, S. C. Fu, Christopher Y. H. Chao, 2015 The correlation between acoustic streaming patterns and aerosol removal efficiencies in an acoustic aerosol removal system, *Aerosol Science and Technology,* 50:1, 52-62. https://doi.org/10.1080/02786826.2015.1124986

[6] Shin Young Jeong, Chi Yan Tso, Jimyeong Ha, Yuk Ming Wong, Christopher Y.H. Chao, Baoling Huang, Huihe Qiu, 2019 "Field Investigation of a Photonic Multi-layered TiO2 Passive Radiative

Cooler in Sub-tropical Climate," *Renewable Energy* 146 (2020) 44-55 (accepted on 21 June 2019). https://doi.org/10.1016/j.renene.2019.06.119

### *(4) Details of the Impact*

Smart green building development is focused on energy efficient, green and sustainable technologies. A recent report issued by Market Research Future [S1] in June 2019 predicts that the global green building market of residential green buildings, valued at USD 123,401.5 million in 2018 could go up to USD 206,855.7 million by 2023. The non-residential segment is likely to reach USD 121,270.0 million over the forecast period. In particular, the global adsorption chiller (adsorption cooling system) market size is projected to exceed USD 980.0 million by 2023 (Global Market Insights [S2]), global air purification systems market will reach USD 29.25 billion by 2025 [S3] and global small wind power market size was valued at $3,805.0 million in 2015 and is expected to reach $8,874.0 million by 2022 [S4]. However, the successful exploitation of smart green buildings will require the application of new and innovative key technologies. Based on research findings of Prof. Chao's team, we will describe the details of the impact by energy-efficient technologies below.

**4.1 Guangzhou Wanbao Group Co., Ltd.**

Guangzhou Wanbao Group Co. Ltd. is one of the earliest and largest R&D and manufacturing centers for household appliances and refrigeration equipment in China. [S5] The Group recognized that our new economical, compact and efficient ACS, using the novel special coated composite adsorbent integrated with a nanofluid-based evaporator, [1, 2] offered a good option for wise energy management. Our novel ACS technology has also been applied to new-self-cooling mobile refrigeration systems. As a result of our ACS technology, a collaboration agreement between Prof. Chao's team and Guangzhou Wanbao Group Co. Ltd, was signed in 2013. The company was so impressed by our ACSs that it adopted our innovative technologies into its production line as an alternative to conventional vapor compression cooling/refrigeration systems (See attached letter).

**4.2 Guangzhou HY Energy Technology Limited Corp (China Stock Code: 832160)**

Guangzhou HY Energy Technology Limited Corp is a high-tech manufacturer focused on design, production and application of reliable, high performance small wind turbine products, and is one of the top small-scale wind turbine companies in China. [S6] The novel wind turbine technologies developed by Professor Chao's team include a high-efficiency wind turbine with a new control technology and low-voltage side-connected 20 kW wind turbine are now used in HY's products in different application fields and harsh environments. Our technologies adopted in the projects include hybrid-type wind blades for starting at lower wind speeds, a low cost MPPT control system for maximizing energy harvesting, pulse charging technology for extending battery life and charging efficiency, and APL technology for protection under high wind speed [3]. The control system also features other advanced IT technologies, including cloud services, online monitoring and control, Wi-Fi hotspot, and air quality monitoring. As a result of our research outputs, Guangzhou HY Energy Technology Limited Corp launched high-tech products 'Wind Generator and Wind Power Generation Systems' on the market in 2016, generating a sales revenue of 10 million RMB (See attached letter).

**4.3 Raymond Industrial Ltd. (HKEx Stock Code: 0229)**

Since 2016 Raymond Industrial Ltd. has been cooperating with Professor Chao's team to improve existing designs and to invent new types of air cleaners through the BERC platform.[S7] To improve indoor air quality to prevent disease transmission, and reduce infection risk, the novel techniques developed by the team [4], combined with biological knowledge and engineering expertise, have resulted in an energy-efficient technique for aerosol removal and virus inactivation using acoustics (by treating the inner surface of the air duct with micro-patterned structures), along with the development of a high efficiency electrostatic precipitation type air cleaner for ultrafine particles

(UFPs).[5] Based on our technologies, a number of air cleaner prototypes and measurement techniques have been developed and successfully utilized by Raymond Industrial Ltd for Philips, Honeywell and Blue Air's product development. These techniques have enhanced their products on the market and generated over 7 million RMB in earnings. (See attached letter.)

**4.4 Kaisa Group Holdings LTD (HKEx Stock Code: 1638)**

The outstanding accomplishments of Professor Chao's team have attracted both the investment and cooperation of Kaisa Group Holdings Ltd., a Hong Kong listed company [S8]. The objectives are to create a Shenzhen-HK ecosphere for innovation and a platform for industry, research institutes and cooperation among universities. This promoted the transformation of scientific research and enhanced the integration and operation of green cities. High-tech smart green technologies, including new materials, renewable energy, intelligent devices, smart homes, IoT, information technology, etc., are the main focus. The two parties have established an Innovation Research Platform for Smart Green Cities at HKUST, with Kaisa investing 7 million RMB to support ongoing research. Moreover, a Joint Research Platform for Smart Green Cities has been established in mainland China. Kaisa has invested 29 million RMB over 5 years for the mainland research and demonstration activities. Smart green wall panels have been installed on the external walls of the Kaisa-HKUST Joint Research Building. The polymeric based radiative cooler with asymmetric electromagnetic transmission window has provided chilled water to the indoor environment with a maximum cooling power of 100 $W/m^2$ under a clear sky. Through the smart adaptive control/monitoring system equipped with CMOS MEMS sensors & smart actuators, cold and clean air is supplied to every individual for better monitoring of personal exposure and micro-environmental parameters. $VO_2$ thermochromic smart windows have also been installed to provide a good thermal comfort environment for research staff in the building.

***(5) Sources to corroborate the Impact***

[S1] Market Research Future, "Green Building Market 2019: Global Industry Overview By Historical Analysis, Comprehensive Research Study, Opportunities, Competitive Landscape and Regional Trends by Forecast to 2023" https://www.marketresearchfuture.com/reports/green-building-market-4982;
[S2] Global Market Insights, "Absorption Chiller Market Size, Industry Analysis Report, Regional Outlook, Application Potential, Price Trend, Competitive Market Share & Forecast," 2019-2025, https://www.gminsights.com/industry-analysis/absorption-chiller-market
[S3] Zion Market Research, "Global Air Purification Systems Market," https://www.zionmarketresearch.com/report/air-purification-systems-market
[S4] Allied Market Research, "Global Small Wind Power Market, Opportunities and Forecasts 2014-2022" https://www.alliedmarketresearch.com/small-wind-power-market
[S5] letter from XJ Fang, Deputy Chief Engineer, fangxujun@gzwanbao.cn, Guangzhou Wanbao Group Co., Ltd.
[S6] letter from HY Yu, Director; KH Pi, Deputy Chief Engineer; S Xiao, Engineer, hy@hyenergy.com.cn, Guangzhou HY Energy Technology Limited Corp.
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