RGC Ref.: X-HKU711/14
(please insert ref. above)

The Research Grants Council of Hong Kong
SFC/RGC Joint Research Scheme
Completion Report

(Please attach a copy of the completion report submitted to the Scottish Funding Council by the Scottish researcher (Annex 1.1 and Annex 1.2))

Part A: The Project and Investigator(s)

1. Project Title

Carbon Emission Modelling of Energy Systems for Retrofit Office Buildings

2. Investigator(s) and Academic Department/Units Involved

	Hong Kong Team	Scottish Team
Name of Principal Investigator *(with title)*	Dr Pan, Wei	Dr Liang, Xi
Post	Assistant Professor	Senior Lecturer
Unit / Department / Institution	Civil Engineering / The University of Hong Kong	Centre for Business and Climate Change / Business School / University of Edinburgh
Contact Information	Tel: (852) 2859 2671 Email: wpan@hku.hk	Tel: (44) 131 651 5328 Email: xi.liang@ed.ac.uk
Co-investigator(s) *(with title and Institution)*	Prof Li, Yuguo Mechanical Engineering / The University of Hong Kong	NA

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted*)
Project Start date	09 Jan 2015	NA	
Project Completion date	08 Jan 2016		
Duration *(in month)*	12		
Deadline for Submission of Completion Report	08 Jan 2017		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. Develop a carbon emission model of energy systems for low or zero carbon retrofit office buildings in Hong Kong and Edinburgh.

2. Examine the effects of different energy system options on the 'operational lifecycle' energy use and carbon emissions of retrofit office buildings in Hong Kong and Edinburgh.

3. Develop design and policy strategies for optimising energy systems for retrofit office buildings.

5.2 Revised Objectives

Date of approval from the RGC: _____

Reasons for the change: _____

_____

1. NA
2.
3. ....

6. Research Outcome

Major findings and research outcome
(maximum 1 page; please make reference to Part C where necessary)

The first finding is that there is an urgent and important need for carbon emission models of energy-supply-centric systems for low or zero carbon retrofit office buildings, and that there exist multifaceted challenges to the development of such model. This finding is elaborated below:

- The challenges for carbon emission modeling of energy-supply-centric systems are particularly significant for high-rise buildings in the hot and humid climate of Hong Kong.
- The challenges exist in various aspects, including modeling approach, modelling tools, data availability and atmospheric conditions.
- Essential to addressing the challenges are the collection and verification of building information and specification of thermal zones and schedules for modeling.
- The energy-supply-centric systems fall in three categories: on-site renewable energies; off-site renewables but directly connected with the building; and adaptable 'allowable solutions' and emerging technologies. Appropriate ones to the Hong Kong context include BIPV, rooftop WECS and biodiesel from waste fuelled CCHP systems.

The second finding is that through the utilization of energy-supply-centric system solutions, there is a substantial potential for reducing energy use and a huge potential for cutting down carbon emissions of high-rise office buildings. This finding is elaborated below:

- A carbon emission model of retrofit high-rise office building was developed and tested using various energy systems.
- The annual electricity supply from grid for the case building could be reduced by 8.7% and 0.6% through employing the BIPV and WECS systems, respectively. Accordingly, 8.7% and 0.6% GHG emissions reductions could be achieved.
- For the CCHP systems, the estimated carbon emission reductions can be as much as 69.4%, due to the significantly lower carbon emission conversion factor of bio-diesel from waste cooking oil (0.16 kg CO2-eq/kWh) than that of diesel oil (1 kg CO2-eq/kWh).
- Combining BIPV, WECS and CCHP, the total primary energy use savings can be up to 19% and the total carbon emission reductions can be as much as 78.7%.

The third finding is that the use of energy-supply-centric systems of BIPV, WECS and CCHP should be promoted for achieving low-energy low-carbon retrofit office buildings. This finding is elaborated below:

- Should energy-efficiency technologies be utilised for the building fabrics and HVAC systems (i.e. with building-centric solutions being integrated), there is a promising technical feasibility of achieving net zero carbon of high-rise office buildings in Hong Kong.
- Nevertheless, this achievement of net zero carbon would be based on the use of the much lower carbon conversion factor of bio-diesel from waste cooking oil compared with fuel types. For possibly achieving net zero energy of office buildings, emerging technologies should still be explored.

Potential for further development of the research and the proposed course of action *(maximum half a page)*

The project has been completed with all objectives achieved. Future research should further address several knowledge gaps.

- First is how the multifaceted challenges to the carbon emission modeling of energy-supply-centric systems for retrofit office buildings can be addressed systematically. Future research using bulk building energy use data from a large dataset should help expand the boundary of this project using case study.
- Second is what might be the holistic technical feasibility of achieving net zero or very low-energy low-carbon retrofit office buildings in high-density high-rise contexts. This future research requires the integration of energy-efficiency technologies utilized for the building fabrics and HVAC systems (i.e. with building-centric solutions being integrated) and energy-supply-centric systems examined in this project. Holistic energy modeling should help substantiate the further examination.
- Third is how carbon conversion factors of different fuel types affect the extent of energy savings and carbon emission reductions of retrofit office buildings. Future

research should examine the issues with not only energy systems but energy policy and fuel mix.

- Fourth is what and how emerging technologies will help to meet the increasing demand for energy due to the rising life standard, in two aspects: to reduce buildings' energy demand through energy-efficiency technologies and to further increase renewable energy supply.

7. The Layman's Summary

(describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

Buildings account for 92% of electricity use and 60% of carbon emissions in Hong Kong. The HKSAR government has proposed a carbon intensity reduction target of 50%-60% by 2020 compared to the 2005 level. Previous studies have focused on building-centric solutions, rendering limited knowledge of energy-supply-centric solutions to building carbon reduction, particularly with high-rise. The aim of this project was to identify appropriate energy systems and examine their effects on the 'operational lifecycle' energy use and carbon emissions for retrofit office buildings. The potentials for energy savings and carbon emission reductions of various systems were identified through a reference 30-storey office building using TRNSYS modelling software. The project results show that building integrated photovoltaic and rooftop wind energy conversion technology can help to meet 8.7% and 0.6% of the total electricity demand of the case building, respectively. The use of these on-site renewable technologies and off-site bio-diesel powered combined cooling and power system can help to reduce the carbon emissions relevant to the building's energy use by 9.3% and 69.4%, respectively. The findings discover appropriate energy-supply-centric solutions for achieving low-energy low-carbon retrofit office buildings, and should inform energy supply policy and low-carbon building design decision-making.

Part C: Research Output

8. Peer-reviewed journal publication(s) arising directly from this research project

(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.))

The Latest Status of Publications				Author(s)	Title and Journal/ Book	Submitted to RGC	Attached to this report	Acknowledged the support of this Joint Research Scheme	Accessible from the institutional repository
Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*	***bold** the authors belonging to the project teams and denote the corresponding author with an asterisk*)*	*(with the volume, pages and other necessary publishing details specified)*	*(indicate the year ending of the relevant progress report)*	*(Yes or No)*	*(Yes or No)*	*(Yes or No)*

2015	-	-	-	**Yu, C., Pan, W.*,** Zhao, Y. and **Li, Y.**	Challenges for Modeling Energy Use in High-rise Office Buildings in Hong Kong. *Procedia Engineering (Elsevier)*, 121, 513-520. ISI listed	2017	Yes (Annex 2)	Yes	Yes
2016	2016	-	-	**Liang, X.*, Pan, W., Jiang, M., Guo, Y.**, Lyu, J., Li, J. and Chen, X.	Assessing the Value of Commercial Building Low-carbon Retrofit in Edinburgh City in Scotland. *Zero Carbon Building Journal (CIC)*, 5, 6-16.	2017	Yes (Annex 3)	Yes	Not yet
-	-	2016	-	**Long, H., Pan, W.*, Li, Y.** and **Liang, X.**	Potential of energy saving and carbon reduction of energy-supply-centric solutions for retrofit office buildings in Hong Kong. *Sustainable Cities and Society (Elsevier)*, ISI listed	Not yet; Under blind review	Yes (Annex 4)	Yes	Not yet
-	-	-	2017	**Yu, C.** and **Pan, W.***	Sensitivity Analysis of Energy Use in High-rise Office Buildings in Hong Kong - A Case Study. *Building and Environment (Elsevier)*, ISI listed	Not yet; to be submitted for review early 2017	No	Yes	Not yet

9. Recognized international conference(s) in which paper(s) related to this research project was/were delivered

(Please attach a copy of each delivered paper. All listed papers must acknowledge RGC's funding support by quoting the specific grant reference.)

Month/Year/ Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*

07/2015 /Tianjin, China	Challenges for Modeling Energy Use in High-rise Office Buildings in Hong Kong	9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE)	2017	Yes (ditto Annex 2)	Yes	Yes
06/2017 /Hong Kong	A discussion on potentials of energy efficiency strategies for high-rise office buildings in Hong Kong	World Sustainable Built Environment Conference 2017 Hong Kong (WSBE17 Hong Kong; *accepted for oral presentation and publication*)	2017	Yes (Annex 5)	Yes	Not yet

10. Student(s) trained *(Please attach a copy of the title page of the thesis.)*

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
Yu, Cong	PhD (HKU side)	Sept 2015	Sept 2019 (expected)

As this PhD study is still underway, the thesis will be produced in due course. However, the title of the thesis is "Energy performance of high-rise office buildings with uncertainties in Hong Kong".

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

Other publications:

1. Liang, X., Pan, W., Jiang, M., Guo, Y., Lyu, J., Li, J. and Chen, X. (2016) *Assessing the Value of Commercial Building Low-carbon Retrofit in Edinburgh City in Scotland: Draft for Comments*, University of Edinburgh Business School, UK-China CCUS Centre, and Department of Civil Engineering of The University of Hong Kong, March 2016 (Annex 1.2).

Lectures/seminars delivered:

Date	Venue	Title of Lecture/Speech	Audience	Speaker
25 Sept 2015	University of Edinburgh, UK	Low or Zero Carbon Building: Systems the Lever, Partnership the Fulcrum	MSc students in Business and Climate Change, University of Edinburgh	Dr Wei Pan (HK side PI)
6 Jan 2016	The University of Hong Kong, HK	Assessing the Value of Commercial Building Low-carbon Retrofit in	Colleagues and researchers, Centre for Innovation in Construction and Infrastructure	Dr Xi Liang (Scottish side PI)

		Edinburgh	Development, Department of Civil Engineering, HKU	
6 Jan 2016	The University of Hong Kong, HK	Carbon emission modelling of energy systems for retrofit office buildings	Colleagues and researchers, Centre for Innovation in Construction and Infrastructure Development, Department of Civil Engineering, HKU	Dr Hui Long (HK side researcher); Dr Wei Pan (HK side PI)