RGC Ref. No.:
UGC/FDS16/E03/20
(please insert ref. above)

RESEARCH GRANTS COUNCIL
COMPETITIVE RESEARCH FUNDING SCHEMES FOR THE LOCAL SELF-FINANCING DEGREE SECTOR

FACULTY DEVELOPMENT SCHEME (FDS)

Completion Report
(for completed projects only)

Submission Deadlines:	*1. Auditor's report with unspent balance, if any: within **six** months of the approved project completion date.* *2. Completion report: within **12** months of the approved project completion date.*

Part A: The Project and Investigator(s)

1. Project Title

An investigation of daylight-linked lighting control system in urban area by simulation approach and development of weather database for daylighting assessment

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

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	Dr TSANG Kin Wai / Assistant Professor	Department of Construction and Quality Management, School of Science and Technology, Hong Kong Metropolitan University
Co-Investigator(s)	Dr Li Hin Wa/ Professor	Department of Architectural and Civil Engineering, City University of Hong Kong
Others	Dr CHEN Xi/ Research Assistant Professor	Department of Mechanical and Automation Engineering, Chinese University of Hong Kong

3. Project Duration

	Original	Revised	Date of RGC / Institution Approval *(must be quoted)*
Project Start Date	1/1/2021	1/1/2021	
Project Completion Date	31/12/2023	30/6/2024	30/6/2023
Duration *(in month)*	36	42	30/6/2023
Deadline for Submission of Completion Report	31/12/2024	30/6/2025	30/6/2023

4.4 Please attach photo(s) of acknowledgement of RGC-funded facilities / equipment.

Figure 1 Spectrophotometer CM-25cG

Figure 2 Luminance and Color Meter CS-150

Figure 3 Illuminance meter T-10A

<u>Part B: The Final Report</u>

5. Project Objectives

5.1 Objectives as per original application

1. To devise a new method in modelling photosensor's signal
2. To study the visual and energy performances of daylight-linked control system under heavily obstructed environment
3. To select sky luminance distribution model and establish a weather database for daylighting assessment
4. To develop design guidelines for selecting, locating, testing and commissioning of photo sensor for different lighting system for heavily obstructed urban area

5.2 Revised objectives

Date of approval from the RGC: ______________________

Reasons for the change: ______________________

____

5.3 Realisation of the objectives

Project Objective 1

To understand the relationship between indoor illuminance and response of photosensor. It is need to important to devise a correlation between energy uses, daylight availability. Simulation study was used to study the indoor daylight autonomy under the local climate for different principal orientation (Attachment 1). Another simulation study was conducted to identify the impacts of daylight-linked lighting control (DLLC) system based on different sensors under current T&C method. The implication of using open-loop ad closed-loop proportional control with different photosensor were partly addressed in Conference Paper 2 (Attachment 3). A further paper with classifying the effectiveness of each control type under different sky condition (Based on real measured sky) was addressed in another paper (Attachment 4).

Project Objective 2

The performances of DLLC system based on daylighting prediction and system arrangement is evaluated based on the Commission Internationale de l'Eclairage (CIE) standard sky. The simulation model is further evaluated under heavily obstructed environment to represent urban topography. Parameters including percentage light deficit, percentage intrinsic light excess and percentage light wastage were evaluated, and the annual lighting energy saving was also determined. Open-loop control is always unable to provide the required illuminance level. The phenomenon is more significant observable for less obstructed floor. For closed-loop integral control, a narrower spatial sensitivity photosensor is better in maintaining the indoor illuminance level but light wastage is found for the higher floor. (Conference paper 2, Attachment 4). A detail analysis can be found in journal paper 3 (Attachment 3).

Project Objective 3

Sky luminance distribution pattern and weather data are the other important factors for accurate prediction of indoor illuminance. In 2003, 15 sets of CIE general skies represent all sky conditions around the world. General Sky No. 1, 8 and 13 were the dominated types in Hong Kong and classified sky types according to different climatic parameters. Conference paper 1 (Attachment 1) evaluated the effect of different sky model in building energy and daylighting performance. Machine learning was used to determine the sky type according to the typical year is used. In Conference paper 3 (Attachment 5) has devised and checked the machine learning (ML) approaches based on the CIE general sky classification. The use and implications of the ML for CIE general sky model has been detailly analysis and described in Journal Paper 2 (Attachment 2).

Project Objective 4

The DLLCs are not performed as design intents and cause annoyance to building occupants. The major reasons that occupants did not accept DLLC due to difficulties in design, installation and calibration. Hence, a set of design guidelines is needed. Based on the research results stated in Objectives 1 to 3, a set of rules of thumb is proposed. Journal paper 3 (Attachment 3) and Conference Paper 4 (Attachment 6). The design guidelines cover the sensor view angle, position and control types are covered. The design guidelines specifically address the building located in urban areas facing different level of obstruction.

5.4 Summary of objectives addressed to date

Objectives *(as per 5.1/5.2 above)*	**Addressed** *(please tick)*	**Percentage Achieved** *(please estimate)*
1. To devise a new method in modelling photosensor's signal	✓	100%
2. To study the visual and energy performances of daylight-linked control system under heavily obstructed environment	✓	100%
3. To select sky luminance distribution model and establish a weather database for daylighting assessment	✓	100%
4. To develop design guidelines for selecting, locating, testing and commissioning of photo sensor for different lighting system for heavily obstructed urban area	✓	100%

6. Research Outcome

6.1 Major findings and research outcome

While the DLLC systems have been widely adopted in most newly built commercial buildings, their performances are still far from satisfactory. Hence in this study, some of the problems have been addressed. The research started from determining the daylight availability inside the room. Currently, there are few studies using the useful daylight indicator (UDI) as assessment parameters for indoor daylight environment. However, this factor may not be an effective parameter in daylighting design. Hence a simpler method is required to determine the daylight zone (lighting control zone) for DLLC systems. In Attachment 1, the correlations between point daylight factor (PDF) under overcast sky and UDI were analysed. It demonstrated that for indoor area with a PDF of 2% to 4% is suitable for providing DLLC as an effective energy saving measures. The correlation foreach daylighting performance indicators are determined for each principal orientation. In the second place, the sky luminance distribution is a one of the critical factors in daylight predication. Among several daylight calculation algorithms, split flux method and climate-based daylight modeling (CBDM) are most used calculation methods. Attachment 3 found that split-flux method always provided a higher illuminance value than CBDM. In terms of energy use, the different is only 2% and hence calculation algorithm is more sensitive to illuminance prediction but not energy consumption. Different sky model including ASRC-CIE and all-weather model were evaluated. Zenith region is more sensitivity to the luminance distribution model. To have a better understanding of the effectiveness of using sky luminance distribution models, a machine learning (ML) approach (light gradient boosting machine, LGBM) was developed and use to select appropriate CIE general skies model in Attachment 2. Then in Attachment 6, a few models, the best-fit CIE General sky approach (best-fit), LGBM and the ASRC-CIE and all-weather model. Undoubtedly, best-fit model performs the best and the LGBM is comparable with the best-fit model with a RMSE around 20%. While ASRC-CIE and all-weather models has a RMSE over 30%. It is found that selecting the best CIE general skies is a better option than using other sky luminance distribution models adopted for all-weather condition.

The performance of DLLC systems were evaluated in Attachments 3, 4 and 5. 5 five-storey building facing heavy obstruction were analyzed. The open- and closed-loop control were studied. The open-loop control cannot satisfy most of the situation especially under highly variant daylighting condition (i.e. less obstructed location). The open-loop control tends to underprovide artificial lighting and hence provide a higher light deficit. While for closed-loop control, the sensor with a narrower view angle provide better estimation on the indoor illuminance and the photosensor should be closed to the last row of the dimed lights. Furthermore, a trial study on using artificial neural network (ANN) to provide lighting control can outperform traditional lighting control method. It can lower down the light deficit and light wastage to less than 10% for most of the case. As the intrinsic light excessive is relatively low for ANN approach (smaller base), the actual performance of ANN-DLLC is much better.

6.2 Potential for further development of the research and the proposed course of action

In the future, DLLC systems should leverage the applications of the Internet of Things (IoT) and deep learning (DL), as illustrated in Attachment 5. Artificial Neural Networks (ANN) have the potential to outperform traditional DLLC systems. Currently, this study does not incorporate the implications of internal layouts on DLLC systems. It is crucial to analyze the potential impact of replacing photosensors with cameras. The adaptability of photosensors and cameras in relation to modifications in internal layouts should also be considered. Additionally, the recalibration procedures and minimum resolution requirements for cameras must be evaluated to balance the performance of DLLC systems with privacy considerations.

Another approach involves utilizing sky images as input for deep learning training. While sky scanners provide the most accurate sky luminance distribution data, their installation is often impractical for most commercial applications due to high costs and long scanning times, which do not accommodate rapidly changing weather conditions. Therefore, a fisheye camera that continuously monitors the sky presents a viable alternative. This control method can enhance the determination of indoor illuminance and facilitate the prediction of daylight climate trends. Finally, the interaction between shading and lighting should be considered to achieve a fully integrated passive daylighting design.

7. Layman's Summary

The Daylight-Linked Lighting Control (DLLC) system is a prevalent energy-saving measure employed in modern commercial buildings. However, these systems are frequently overridden by manual controls due to inadequate design guides. This study aims to develop appropriate sky luminance distribution models based on various typical weather data to evaluate the performance of DLLC systems in urban environments during the design phase. We propose specific settings for DLLC systems, including sensor locations, fields of view, and control strategies. By adhering to these principles and assessment methods, building designers and commissioning agents can effectively develop daylighting and DLLC system design schemes at the early stages of design, ensuring satisfactory system performance.

The implementation of suitable sky models, weather data, and photosensor settings represents a promising approach to achieving an adequate indoor lighting environment—both natural and artificial—while maximizing energy savings. This research confirms the feasibility of employing sophisticated methodologies in DLLC system design and opens new avenues for researchers to further enhance DLLC system performance in the presence of various obstructions.

Part C: Research Output

8. Peer-Reviewed Journal Publication(s) Arising Directly From This Research Project

(Please attach a copy of the 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) *(denote the correspond-ing author with an asterisk*)*	Title and Journal / Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this Report *(Yes or No)*	Acknowledged the Support of RGC *(Yes or No)*	Accessible from the Institutional Repository *(Yes or No)*
Year of Publication	**Year of Acceptance** *(For paper accepted but not yet published)*	**Under Review**	**Under Preparation** *(optional)*						
2023				Shuyang Li, Danny H.W. Li, Wenqiang Chen*, Siwei Lou, Ernest K.W. Tsang^	Simple mathematical models to link climate-based daylight metrics with daylight factor metrics and daylighting design implications / Heliyon. 9(5), e15786	No	**Yes (Attachment 1)**	**Yes**	**Yes**
2025				Emmanuel I. AGHIMIEN, Ernest K. W. TSANG*, Shuyang LI	CIE Standard General Sky Model: A Review of Research Landscape, Modelling Techniques and Building Energy Applications / Renewable and Sustainable Energy Reviews, 221, 115897	No	**Yes (Attachment 2)**	**Yes**	**Yes**
2025 (Expected)			**Yes**	Ernest K. W. TSANG, Shuyang LI*,	An analysis of daylight-linked lighting	**No**	**No**	**Will be included**	**Will be available**

				Emmanuel I. AGHIMIEN, Patrick X CHEN	control system in Hong Kong /TBC				

Note: ^ The corresponding author was student of Co-I.

9. Recognized International Conference(s) In Which Paper(s) Related To This Research Project Was / Were Delivered

(Please attach a copy of each conference abstract)

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 RGC** *(Yes or No)*	**Accessible from the Institutional Repository** *(Yes or No)*
08/21 Croatia	Evaluation of daylight prediction algorithms in building energy performances under heavily obstructed urban topography	9th Global Conference on Global Warming	Yes	Yes (Attachment 3)	Yes	Yes
09/21 Tokyo	A simulation study of daylight-linked lighting control under heavily obstructed skies	11th SOLARIS 2021 International Symposium on Solar Energy and Efficient Energy Usage	Yes	Yes (Attachment 4)	Yes	Yes
06/24 Bozen-Bolzano	Integration of Machine Learning-Based CIE Standard Skies Model With Daylight Simulation for Building Energy Performance Analysis	6th IBPSA-Italy Conference	No	Yes (Attachment 5)	Yes	Yes
06/24 Bozen-Bolzano	A Simulation Study on the Performance of Machine Learning Daylight-Linked Lighting Control Under Urban Topography	6th IBPSA-Italy Conference	No	Yes (Attachment 6)	Yes	Yes

10. Whether Research Experience And New Knowledge Has Been Transferred / Has Contributed To Teaching And Learning

(Please elaborate)

The results of the research also presented in the “Joint Symposium 2024 - Innovating and Revitalizing Productivity in Building Services with 3S Solutions towards Carbon Neutrality” held by the Hong Kong Institution of Engineers – Building Services Division on 19 November 2024 (see Attachment 7)

11. 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
	Bachelor Of Engineering (Honours) In Building Services Engineering and Sustainable Development	21/7/2020 24/7/2020 9/7/2020 8/8/2020	May 2022

12. Other Impact

(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, teaching enhancement, etc.)

Nil

13. Statistics on Research Outputs

	Peer-reviewed Journal Publications	Conference Papers	Scholarly Books, Monographs and Chapters	Patents Awarded	Other Research Outputs (please specify)	
					Type	No.
No. of outputs arising directly from this research project	3 (TBC)	4	0	0	Undergraduate thesis	1

14. Public Access Of Completion Report

(Please specify the information, if any, that cannot be provided for public access and give the reasons.)

Information that Cannot Be Provided for Public Access	Reasons