RGC Ref. No.:
UGC/FDS24/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

Theoretical Investigation and Control Scheme Development of a Compact Desiccant-enhanced Evaporative Cooling System

(一種緊湊的乾燥增強型蒸發冷卻系統的理論研究和控制方案開發)

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

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	Prof LEUNG Chun-wah / Professor	Director Office / PolyU SPEED
Co-Investigator(s)	Prof YANG Hongxing / Professor	Department of Building Environment and Energy Engineering / PolyU
	Prof CHEN Yi / Associate Professor	College of Marine Equipment and Mechanical Engineering / Jimei University
Others	Dr ZHANG Irene Yanling / Research Assistant	General Office / PolyU SPEED

3. Project Duration

	Original	**Revised**	**Date of RGC / Institution Approval** *(must be quoted)*
Project Start Date	01/01/2021	N/A	N/A
Project Completion Date	31/12/2023	N/A	N/A
Duration *(in month)*	36 months	N/A	N/A
Deadline for Submission of Completion Report	31/12/2024	N/A	N/A

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

Figure 1 Test Rig for Desiccant-enhanced Evaporative Cooling System Experiments

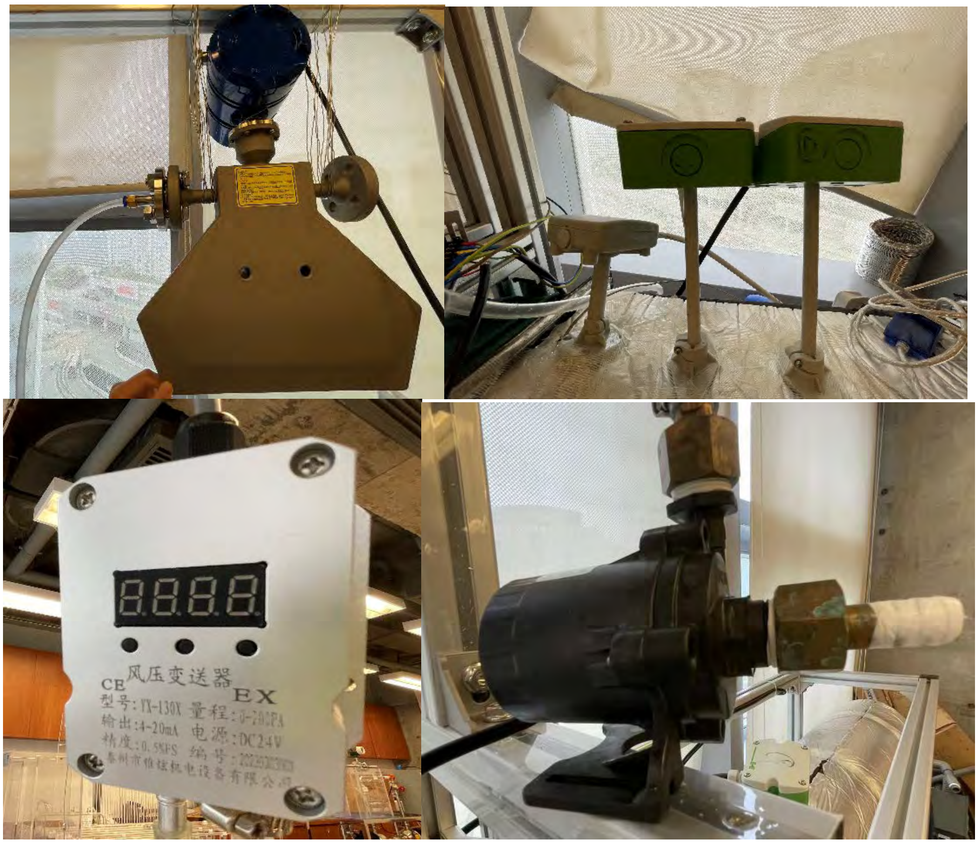

Figure 2 Electronic accessories for the test rig

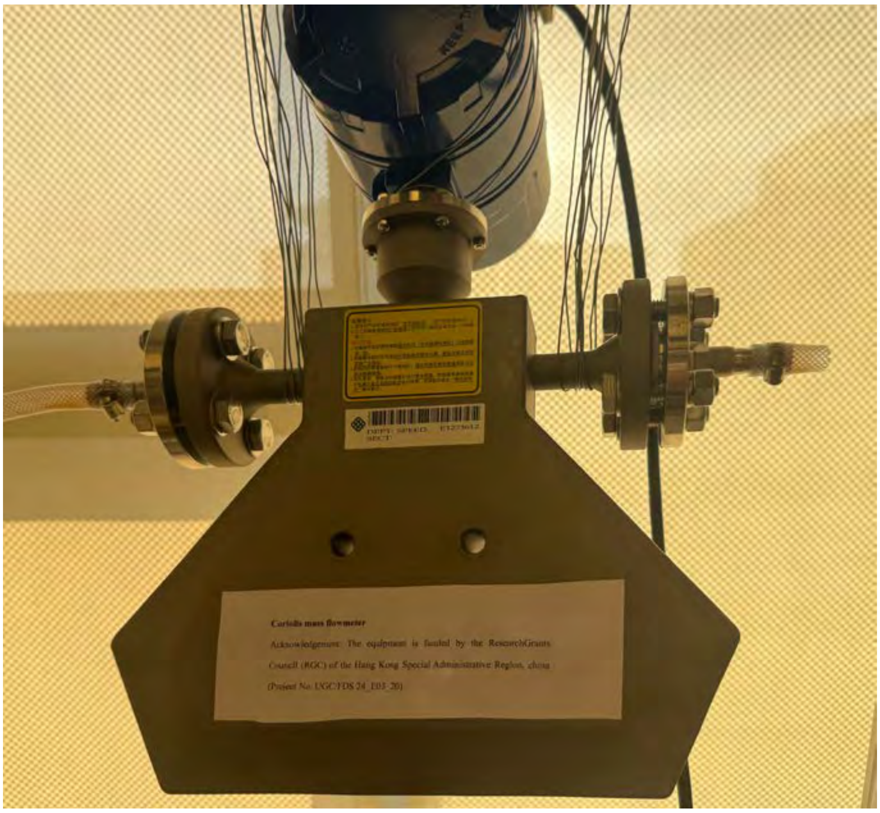

Figure 3 Coriolis mass flowmeter

Figure 4 Auxilary humidifier

Figure 5 Datalogger

Figure 6 Humidifier

Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

1. *To establish the heat and mass transfer model of a desiccant-enhanced evaporative cooling system, considering the closed-loop interaction among the indoor thermal condition, dehumidifier, and evaporative cooler. The novel evaporative cooling-assisted internally cooled liquid desiccant dehumidifier (LDD) is adopted in the system.*

2. *To validate the simulation model by experiments. The validated simulation can be used for thermal and energy performance evaluation and comprehensive parameter study. The coupled sensible cooling and dehumidification capacity of the system under a wide range of operating conditions can be explored.*

3. *To propose optimal design and operational parameters and guidelines for desiccant-enhanced evaporative cooling systems in different regions and applications.*

4. *To establish an experimental-validated predictive model for system regulation and control under changeable ambient environment and indoor cooling load for better thermal comfort.*

5.2 Revised objectives

Date of approval from the RGC: N/A

Reasons for the change:

1.

2.

3. ....

5.3 Realisation of the objectives

(Maximum 1 page; please state how and to what extent the project objectives have been achieved; give reasons for under-achievements and outline attempts to overcome problems, if any)

Objective 1 (Fully achieved): A dedicated numerical model for Desiccant enhanced evaporative cooling system (*DEVap*) to conduct a comprehensive parameter study for performance prediction and parameter optimization. A hexagonal plate heat exchanger (*PHE*) consisting of both counterflow and cross-flow was used as a core in a counter-crossflow *IEC*-assisted *LDD* (*ECLD*) to ensure efficient heat transfer and facilitate easy installation simultaneously. A numerical heat and mass transfer model was established and validated, and an intensive parameter analysis of the thermal performance of the dehumidifier was conducted. The newly developed *ECLD* fully used the return air and worked on improving the cooling capacity to reduce the volume of the combined IEC and *LDD* system. Comparing the heat exchange performance of the PHEs with multiple flow patterns at different aspect ratios may provide references for optimizing the PHEs.

Objective 2 (Fully achieved): A test rig based on the system design was built. The simulated model was validated experimentally. This involved the test rig established according to the design and conducting controlled tests to verify the model predictions and system efficacy. The validated simulation can be used for thermal performance evaluation and comprehensive parametric studies. The coupled sensible cooling and dehumidification capabilities of the system under various operating conditions can be explored.

Objective 3 (Fully achieved): A numerical model of an evaporative cooling-enhanced compact desiccant dehumidification system is developed. A combined system consists of an internally cooled liquid desiccant dehumidification (*ECLD*) and a regenerative indirect evaporative cooling (*RIEC*) that can operate without a power-intensive compressor. The internally cooled *LDD* initially removes the latent heat from hot and humid air before it is cooled by the *RIEC*. The parameter analysis and sensitivity analysis were used to optimize and assess the potential and performance of the system. The validated response surface model is used to optimize six critical environmental and operational parameters. An optimized operational scheme was proposed for the outlet parameters of the system and an optimization strategy for its operating parameters, as well as the potential and energy performance, was assessed through parameter analysis and multifactor optimization. The regional capability was demonstrated in three selected hot and humid regions.

Objective 4 (Fully achieved): Based on the response surface method (*RSM*) and multi-objective optimization, a prediction model was established and can be used to optimize and assess the potential and performance of the system. The validated response surface model is used to optimize six critical environmental and operational parameters. An experimental study was conducted to validate the response surface model, analyzing the energy consumption and air handling capacity of the *DEVap* system under various hot and humid conditions. The proposed system achieves *COP* values ranging from 11.3 to 18.4 without compromising indoor comfort or facility compactness. Experimental studies of this new system provide the possibility of achieving high efficiency in air handling over a wide range of temperatures and humidity.

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 establish the heat and mass transfer model of a desiccant-enhanced evaporative cooling system, considering the closed-loop interaction among the indoor thermal condition, dehumidifier, and evaporative cooler. The novel evaporative cooling-assisted internally cooled liquid desiccant dehumidifier (LDD) is adopted in the system.	√	100%
2. *To validate the simulation model by experiments. The validated simulation can be used for thermal and energy performance evaluation and comprehensive parameter study. The coupled sensible cooling and dehumidification capacity of the system under a wide range of operating conditions can be explored.*	√	100%
3. *To propose optimal design and operational parameters and guidelines for desiccant-enhanced evaporative cooling systems in different regions and applications.*	√	100%
4. *To establish an experimental-validated predictive model for system regulation and control under changeable ambient environment and indoor cooling load for better thermal comfort.*	√	100%

6. Research Outcome

6.1 Major findings and research outcome

(Maximum 1 page; please make reference to Part C where necessary)

<u>*Design and development of a novel system:*</u> The introduction of a novel system incorporating an improved counter-cross flow internally cooled liquid desiccant dehumidifier (*LDD*) serveed as the core component. This innovation effectively managed temperature increases, enhancing humidity control compared to traditional adiabatic *LDD* systems. The proposed system includes a new dehumidification heat exchanger with counter-cross flow internal cooling, introducing a compact counter-cross flow heat exchanger that effectively manages indoor heat and moisture loads in challenging conditions. (Journal publication 5: C (8), training students: C (10))

<u>*Development of a numerical model:*</u> A dedicated numerical model for the counter-crossflow *IEC-assisted LDD* (*ECLD*) system was developed. Integrating a regenerative evaporative cooler within the DEVap system enhances energy performance through return air heat recovery. This model improved dehumidifier performance by 16% and mitigated the rise of the liquid desiccant temperature by 2.07°C. Optimization strategies indicated that adjusting air velocity and solution parameters can enhance cooling capacity by 23.6%. The system's adaptability to different climatic conditions was validated using 17 years of meteorological data from Hong Kong. (Journal publication 4: C (8), conference paper and presentation 1: C (9))

<u>*Empirical model based on response surface method:*</u> An empirical model base on response surface method (*RSM*) predicted the properties of product air and estimated the coefficient of performance (*COP*) based on regenerative energy consumption using solar collectors. Increasing extracted air ratio and air velocity by 30% enhanced system *COP* from 5.66 to 7.82. The regional applicability analysis showed promising potential for deployment in hot and humid regions, achieving a 57.25% improvement in *COP* compared to traditional *MVCR* systems. (Journal publication 3 and 4: C (8), conference paper and presentation 2: C (9))

<u>*Validation of theoretical models and optimization strategies:*</u> Experimental studies validated the theoretical models and optimization strategies based on the prediction model, demonstrating the system's practical viability. The *DEVap* system effectively managed indoor heat and moisture loads, achieving a minimum supply air temperature of 18.44°C and an effective cooling capacity of 0.46 kW under challenging conditions. The experimental findings highlighted a trade-off between temperature reduction and cooling efficiency, emphasizing the system's capability to outperform existing *ECLD* systems. Detailed performance and applicability analysis of the *DEVap* system for typical hot and humid urban environments, demonstrating its capability to efficiently handle indoor heat and moisture loads without compromising comfort or compactness. (Journal publication 2: C (8), training students: C (10))

<u>*Multivariate optimization strategy for pv/t assisted devap system:*</u> An experimental validated multivariate optimization strategy was investigated for a photovoltaic/thermal (*PV/T*) assisted *DEVap* system tailored for high-density, hot, and humid urban environments. By integrating a *PV/T* system with the DEVap, the proposed derivative system configuration and optimization scheme (*RSM* and *NSGAIII*) include maximizing cooling capacity, minimizing energy consumption, and reducing emissions. This research executes multivariate hyperplane optimization to balance technical, environmental, energy, and financial goals by employing a novel operational strategy tested under local climatic conditions. The system achieves a 58.1% reduction in energy consumption and a 61% decrease in carbon dioxide (CO_2) emissions compared to conventional systems, providing an effective cooling capacity of 22.9 kW and generating annual savings of 22,766 HKD. (Journal publication 1: C (8))

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

While this research has demonstrated the application of the proposed system in hot and humid environments, several avenues for future work could facilitate its broader application.

Firstly, this study primarily focused on the air treatment capabilities of the DEVap system. In real-world applications, leveraging waste heat or integrating hybrid regeneration methods (combining solar, natural gas, and electricity) could enhance energy efficiency and reduce operational costs. Future studies should explore the integration of other renewable energy sources, such as wind or geothermal, to further reduce dependency on traditional energy sources.

Secondly, while lithium chloride is an effective desiccant, its corrosive nature poses challenges that could reduce the system's lifespan. Future research should aim to develop less corrosive and more cost-effective desiccant materials.

Thirdly, this technology can be utilized in the development of precision temperature and humidity control systems for industrial air conditioning, particularly in sectors such as biopharmaceuticals and lithium battery production. These industries are experiencing rapid growth, with increasing demand for equipment. However, traditional technologies face challenges such as high energy consumption and the coupling of temperature and humidity control, which affects precision. Compared to conventional air conditioning systems, this technology offers significant energy-saving and emission-reduction benefits in the development of precision temperature and humidity control systems.

Lastly, experimental findings indicate varying performances of different liquid desiccants in cooling, dehumidification, and absorbing harmful substances, suggesting potential for new desiccant formulations. Future research could explore innovative desiccant materials that enhance environmental and health benefits, particularly in applications demanding high air quality, such as healthcare and precision agriculture.

7. Layman's Summary

(Describe <u>in layman's language</u> the nature, significance and value of the research project, in no more than 200 words)

Traditional air conditioning systems have excessive energy use and subpar cooling performance in regions plagued by hot and humid conditions. Addressing this challenge, the research develops the Desiccant Enhanced Evaporative Cooling (*DEVap*) system, an innovative air conditioning solution tailored for demanding climates. The DEVap system ingeniously merges evaporative cooling with liquid desiccant dehumidification. This combination allows precise control over indoor temperature and humidity, ensuring superior comfort. Central to the system is a specially designed heat exchanger that optimizes the handling of heat and moisture. Moreover, the system capitalizes on reusing waste heat from indoor spaces, enhancing its energy efficiency.

Experimental validation of extensive computer simulations and empirical tests shows that the DEVap system outperforms conventional cooling methods. It significantly cuts energy consumption and elevates indoor air quality, steering buildings towards greater sustainability. This research also introduces an optimized operation approach to the system, offering enhanced comfort, reduced energy expenses, and a minimized environmental impact, particularly suited for challenging weather environments.

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									
Year of Publication	**Year of Acceptance** *(For paper accepted but not yet published)*	**Under Review**	**Under Preparation** *(optional)*	**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)*	**Ackn owl-edged the Support of RGC** *(Yes or No)*	**Accessible from the Institutional Repository** *(Yes or No)*
2025				Yanling Zhang, Yi Chen*, Hongxing Yang*, Hao Zhang, Chun Wah Leung	Multivariate hyperplane optimization of integrated photovoltaic/thermal – Assisted desiccant evaporative cooling system. Energy Conversion and Management	No	Yes [Full Paper: Appendix 1]	Yes	No
2025				Yanling Zhang, Yi Chen*, Hongxing Yang*, Hao Zhang, Chun Wah Leung	Experimental performance investigation on a desiccant-assisted two-stage evaporative cooling system in hot and humid areas. Applied Energy, 377, 124704.	No	Yes [Full Paper: Appendix 2]	Yes	No
2023				Yanling Zhang*, Hao Zhang, Hongxing Yang, Yi Chen*, Chun Wah Leung	Response surface modeling and optimization scheme of an internally cooled liquid desiccant air conditioning system. Journal of Building Engineering Volume 76, 1 October 2023, 107371	No	Yes [Full Paper: Appendix 3]	Yes	Yes
2023				Yanling Zhang*, Hao Zhang, Hongxing Yang, Yi Chen*, Chun Wah Leung	Optimization of the Liquid Desiccant Cooling Systems in Hot and Humid Areas. Sustainability 2023, 15(18), 13511; https://doi.org/10.3390/su151813511	No	Yes [Full Paper: Appendix 4]	Yes	Yes
2022				Yanling Zhang*, Hao Zhang, Hongxing Yang, Yi Chen*, Chun Wah Leung	Counter-crossflow indirect evaporative cooling-assisted liquid desiccant dehumidifier: Model development and parameter analysis. Applied Thermal Engineering Volume 217, 25 November 2022, 119231	Yes	Yes [Full Paper: Appendix 5]	Yes	Yes

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)*
08/2022/ US	Energy Performance of Internally Cooled Desiccant Enhanced Evaporative Cooling System in Hong Kong	MIT-AB	2024	Yes [Full Paper: Appendix 6]	Yes	Yes
06/2023/ US	Optimization of the liquid desiccant cooling systems in hot and humid areas	2023 ASHRAE Annual Conference	2024	Yes [Full Paper: Appendix 7]	Yes	Yes

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

This research project has significantly enhanced the teaching and learning experience in the fields of sustainable technologies and air conditioning systems. The insights and methodologies developed through this project have been directly transferred to undergraduates, particularly those studying mechanical engineering and environmental technology.

Undergraduate students involved as research assistants gained practical experience in advanced applications of heat and mass transfer, air conditioning, and renewable energy courses, including data analysis and system design. This participation not only enriched their practical skills but also deepened their understanding of integrated energy systems and mitigating environmental impacts.

Moreover, the new knowledge acquired from this research has been integrated into relevant courses, such as SEHS4626 Air Conditioning for Indoor Thermal and Environmental Quality and SEHS4673_SPD4673 Heat and Mass Transfer. The development of the heat exchanger and dehumidifier within this project provided excellent practical materials for studying the principles of heat and mass transfer. These components, as real-world applications, demonstrate the theoretical concepts taught in the classroom, enabling students to understand how these principles operate under actual conditions. This combination of theoretical knowledge and practical exposure enhances the teaching experience, helping students connect theoretical learning with practical applications, improving their learning outcomes, and preparing them for future professional challenges.

Also, technical staff also benefited immensely from participating in the assembly, operation, and maintenance of the newly developed air conditioning system. This experience enhanced their technical expertise, which is crucial for supporting laboratory activities and student projects related to energy systems and thermal engineering.

In summary, this project has not only advanced research in the field of sustainable air conditioning but also made significant contributions to the academic development of students by providing a practical, application-based learning environment, thereby enhancing the overall educational standard of the institution.

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
N/A			

12. Other Impact

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

The experience gained, equipment acquired, and the physical laboratory facilities developed under this project significantly enhanced the laboratory teaching of the subjects ‘Air Conditioning for Indoor Thermal and Environmental Quality’ and ‘Heat and Mass Transfer’ at Poly SPEED. These improvements not only enabled students to better understand and grasp the relevant theoretical knowledge but also provided more opportunities for hands-on practice, helping them consolidate what they have learned through practical application. Additionally, the modernized laboratory equipment and advanced facilities have sparked students' interest in learning, increased their engagement and participation, and further promoted the overall effectiveness of the teaching process.

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	5	2	0	0		

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