AU-KFAS Research Grants Publications Report

ACADEMIC YEAR - 2024/2025

EXECUTIVE SUMMARY

This detailed report serves to highlight the Australian University (AU) and Kuwait Foundation for the Advancement of Sciences (KFAS) joint Research Grants achievements across a range of disciplines for the academic year 2024/2025. Over the last few years, research at AU has undergone a fundamental transformation where the university has redesigned its strategy and governance framework to ensure that research is a core function and strategic priority. To support the university's research vision, AU's Scientific Research Center has been establishing thematic lines of research that address areas of priority aligned with the National Development Plan of Kuwait (Kuwait Vision 2035). The university has broadened its research scope and implemented schemes to fund multidisciplinary research that focus on key national priority issues. During 2024/2025, AU faculty members have published a total of 18 research works funded by KFAS (12 journal papers and 6 conference papers) and two journal papers under review. Many peer-reviewed papers were published in Q journals: 9 publications in Q1 journals, 2 in Q2 journals, and 1 in no Quartile. The pages of this report outline the strong research trajectory between AU and KFAS. Please refer to the full report for additional details, figures, and the journal publications.

RESEARCH AT AU

Research at AU has undergone a fundamental transformation within the last few years. The University redesigned its strategy and governance framework to ensure that research with impact becomes a core function and a strategic priority. The University has been focusing on the following research areas: water and environment, energy, materials, mechatronics and automation, learning philosophies and frameworks in higher education, innovation and entrepreneurship, business management and finance, as well as marketing and communication. To better exchange knowledge, the College progressed to establish national and international partnerships to strengthen its research capabilities. These partnerships provided the College with access to resources and networks. For instance, the University signed agreements with its international partners to allow faculty to conduct joint research collaborations. On a national level, it broadened its research scope through collaborations with local funding institutions such as KFAS. Internally, it implemented grant schemes to fund multidisciplinary research that focuses on key national priority issues. Furthermore, incentive plans were designed and executed to encourage faculty to engage in research and publications in renowned journals. AU has diverse, highly qualified faculty members with extensive levels of expertise over a broad range of subject areas. Our faculty members strive to produce graduates at the highest level that can face the constantly changing and challenging demands of the industry

In support of this vision, the Research Center is establishing and sustaining thematic lines of applied research that address priority areas aligned with the National Development Plan of Kuwait (New Kuwait Vision 2035). In addition, the research conducted is focused on real-life problems and is led by a strong engagement with the industry. AU's research program works to increase the impact and productivity of research and scholarly activities across and between the disciplines within and outside the University.

VISION AND MISSION

Vision

Our research vision is to enhance the profile of AU as a higher educational institution by contributing to the pursuit of original research aimed at extending the boundaries of applied knowledge.

Mission

The research mission is as follows:

- To enhance the research profile of AU locally, regionally, and internationally
- To create national and international impact in the field of applied research
- To establish a research program supportive of the applied teaching model at AU
- To create interdisciplinary and collaborative research
- To sustain strong partnerships with research funding organizations such as, KFAS, Kuwait Institute for Scientific Research (KISR), and the industry.

AU-KFAS Research Grants

AU is keen to play an important role in development and capacity building in research and technology through KFAS funded joint research projects with international universities. These proposals address national research priorities aligned with Kuwait National Development Plan. For the academic year 2024/2025, AU faculty members have published a total of 18 research work related to the funded KFAS grants (12 Journal papers and 6 Conference papers) and two journal papers under review as depicted in Figure 1. Many peer-reviewed papers were published in Q journals (ranking based on Scopus) as depicted in Figure 2. According to Scopus, 9 publications in Q1 Journals (research paper published in top 25% of the international journals), 2 publications in Q2 Journals (research paper published in the middle-high position – between top 50% and top 25%), and 1 in no Quartile journals.

Type	Total
Journal Paper	12
Journal Under Review	2
Conference Paper	6
Grand Total	**20**

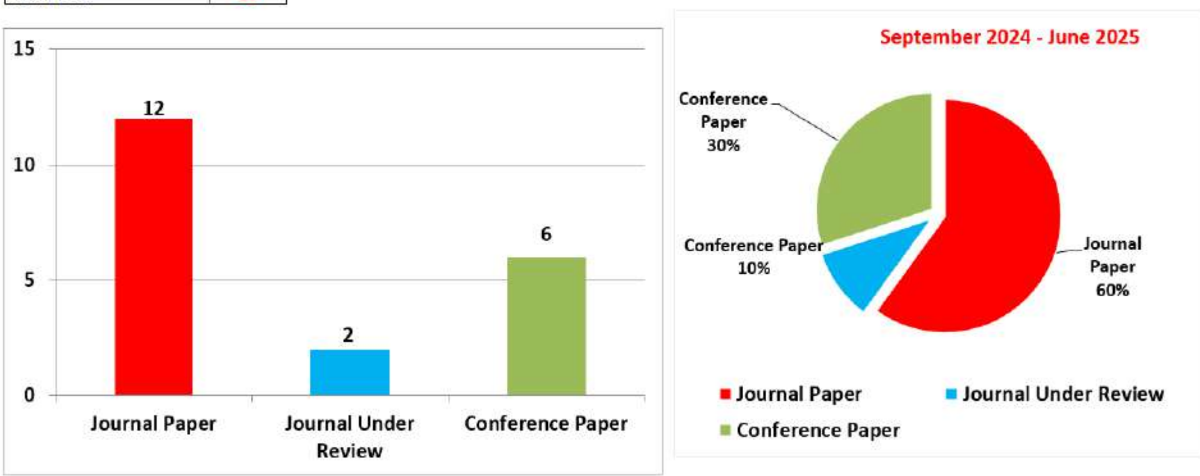

Figure 1. Summary of published research by AU faculty members as related to KFAS grants for the academic year 2024/2025

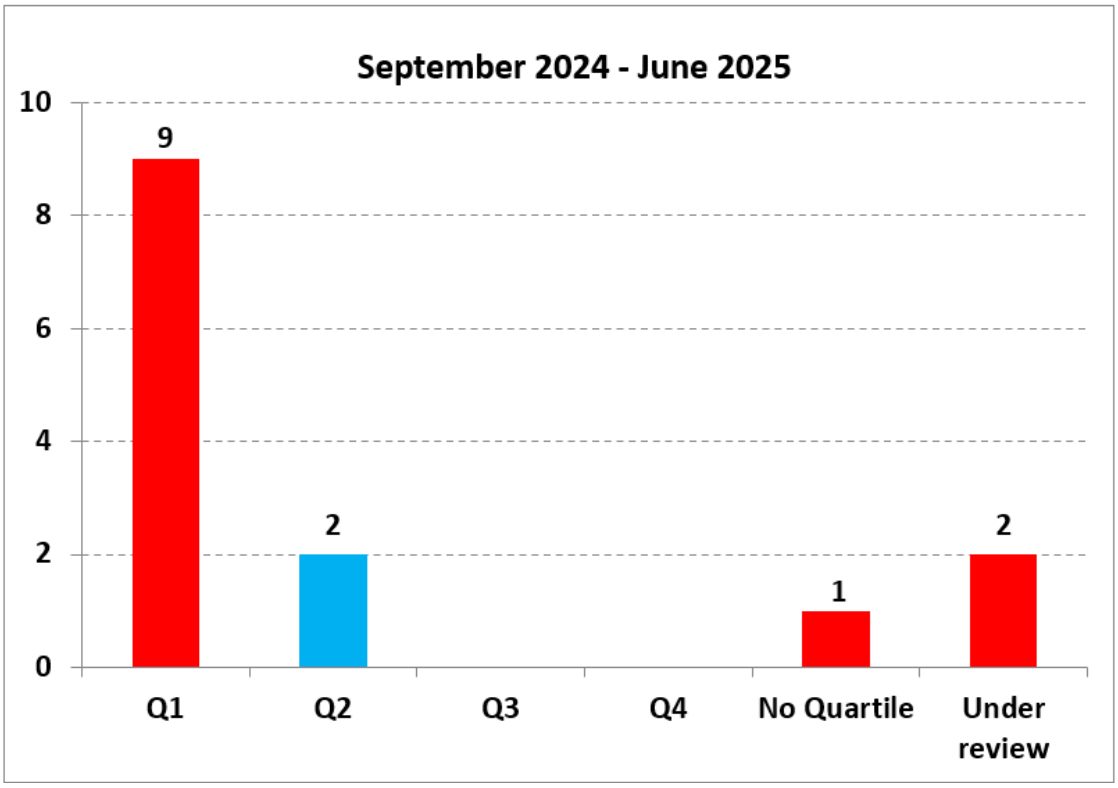

Figure 2. AU Research Faculty Output in Q-Journals for academic year 2024/2025

Full Details of Publications

AU Faculty Research Output, KFAS Grants

Department : **Scientific Research Centre**

Academic Year : **2024-2025**

1 ACK Faculty Research Output

Publications – KFAS Grants (Academic Year 09/2024-06/2025)						
Sr. التسلسل	**Authors** المؤلف	**Publication Title** عنوان النشر	**Name of Journal/ Conference** اسم المجلة/المؤتمر	**Category / Impact Factor** الفئة / عامل التأثير	**Date** التاريخ	**KFAS Grant #**
College of Engineering						
1.	Md Nurun Nabi, **Wisam K Hussam**, Mohammad G Rasul, Ashfaque Ahmed Chowdhury, Md Islam Jahirul, Roksana Yasmin, Peter Brooks, Nahina Islam, Alia H Marafie	Novel Biofuels Derivation and Characterisation From Macadamia Integrifolia, Undaria Pinnatifida and Tree Mulch via Advanced Pyrolysis	International Journal of Energy Research	Journal (Q2: Impact Factor: 4.9)	13/5/2025	CN22-15SE-1612
2.	**Wisam K Hussam**, Md Nurun Nabi, Mohammad G Rasul, Ashfaque Ahmed Chowdhury, Fazlur Rashid, Nahina Islam	Innovative Insights into Engine Performance and Emissions-A Numerical and Experimental Investigation of Aliphatic Hydrocarbons and Renewable Dimethyl Ether	Case Studies in Thermal Engineering	Journal (Q1: Impact Factor: 7.39)	27/5/2025	CN22-15SE-1612
3.	Md Nurun Nabi, **Wisam K Hussam,** Md Islam	Improvement of engine performance, combustion	Case Studies in Chemical and	Journal (Q1: Impact Factor: 8.1)	24/3/2025	

AU Faculty Research Output, KFAS Grants

Publications – KFAS Grants (Academic Year 09/2024-06/2025)						
Sr. التسلسل	**Authors** المؤلف	**Publication Title** عنوان النشر	**Name of Journal/ Conference** اسم المجلة/المؤتمر	**Category / Impact Factor** الفئة / عامل التأثير	**Date** التاريخ	**KFAS Grant #**
	Jahirul, Mohammad G Rasul, Ashfaque Ahmed Chowdhury, Peter Brooks	and remarkable reductions in NOx, CO and unburned HC emissions fuelling with mixed plastic pyrolysis oil and oxygenated additives	Environmental Engineering			CN22-15SE-1612
4.	**Jean H El Achkar**, Suad Al Radhwan, Ahmed M Al-Otaibi, Abdul Md Mazid	Optimizing food waste anaerobic digestion in Kuwait: Experimental insights and empirical modelling using artificial neural networks	Waste Management & Research	Journal (Q1: Impact Factor: 4.6)	5/10/2024	PP22-15SE-1593
5.	**Mohammad Hany Yassin**, Rana Ezzdine Lakys, Zein-Eddine Merouani, Adel Jumah & Mohamad Hussein Farhat	Performance analysis of palm tree microfibers in concrete	Scientific Reports	Journal (Q1: Impact Factor: 3.9)	19/12/2024	PN20-35EV-02
6.	**Mohammad Hany Yassin**, Mohamad Hussein Farhat, Michel Nahas, Ahmad Said Saad	Investigation of fiber Bragg grating sensor measurability in concrete beams under static load conditions	Heliyon	Journal (Q1: Impact Factor: 4.0)	1/11/2024	PR20-15 EE-01
7.	**Yassin, M.H.**, Farhat, M.H., Soleimanpour, R. et al.	Fiber Bragg grating (FBG)-based sensors: a review of technology and recent applications in structural health monitoring (SHM)	Discover Civil Engineering	Journal (N/A: Impact Factor: N/A)	25/11/2024	PR20-15EE-01 & PR19-15EC-09.

AU Faculty Research Output, KFAS Grants

Publications – KFAS Grants (Academic Year 09/2024-06/2025)						
Sr. التسلسل	Authors المؤلف	Publication Title عنوان النشر	Name of Journal/ Conference اسم المجلة/المؤتمر	Category / Impact Factor الفئة / عامل التأثير	Date التاريخ	KFAS Grant #
		of civil engineering structures				
8.	**Majdi M. Alomari**, Hania EL-Kanj, Ayse Topal, Nafesah I. Alshdaifat	Designing an Effective Energy Literacy Course: A Multi-Phase Approach Tailored to Kuwaiti Students' Needs	World Transactions on Engineering and Technology Education	Journal (Q2: Impact Factor: 0.96)	1/12/2024	CN23-42SE-1891
9.	R Kalbasi, **A Sedaghat**, A Al-Masri,	An experimental study on application of phase change materials in a portable cabin in Wintertime of Kuwait under Active/Passive cooling	Applied Thermal Engineering	Journal (Q1: Impact Factor: 6.95)	14/9/2024	CN19-35EM-06
10.	**Ahmad Sedaghat**, Rasool Kalbasi, Ali Mostafaeipour, Mohammad Nazififard	Practical application of machine learning in energy and thermal management: Long-term data analysis of solar-assisted AC systems in portable cabins in Kuwait and Australia	Renewable Energy	Journal (Q1: Impact Factor: 9.0)	5/10/2024	CN19-35EM-06
11.	**Mohammad Hany Yassin**, Zainab Al Hajaj, Rana Lakys, Zein-Eddine Merouanid, Adel Jumaah	The Influence of Palm Tree Fiber Addition on the Physical, Mechanical and Thermal Properties of 2 High Strength Concrete	Materials and Structures	Journal (Q1: Impact Factor: 3.14)	28/1/2025	PN20-35EV-02 CN20-35-EM-04

AU Faculty Research Output, KFAS Grants

Publications – KFAS Grants (Academic Year 09/2024-06/2025)						
Sr. **التسلسل**	**Authors** **المؤلف**	**Publication Title** **عنوان النشر**	**Name of Journal/ Conference** **اسم المجلة/المؤتمر**	**Category / Impact Factor** **الفئة / عامل التأثير**	**Date** **التاريخ**	**KFAS Grant #**
12.	**Mohamad H Farhat**, Youssef Mazloum, Samer Wakim, Wissam Bou Nader, Meshari ALEbrahim, Nader Ghareeb	Energy optimization of parabolic dish solar concentrator coupled to organic Rankine cycle: Experimental and analytical investigation of cavity receiver design and covering effects	International Journal of Thermofluids	Journal (Q1: Impact Factor: 8.71)	16/6/2024	CN22-15EE-1626
13.	Nader Ghareeb, Umar Nimal, Hussein Zughaer, Bader Alshuraiaan	The developments office ergonomics and Human factors – A critical review	Results in Engineering	Journal (Q1: Impact Factor: 9.2)	Under review	CN22-18IQ-1621
14.	Nader Ghareeb, Umar Nimal, Hussein Zughaer, Ammar Alshalabi, Bader Alshuraiaan	Ergonomic awareness and practices: A comparative analysis of trends, challenges and opportunities among diverse demographics	Theoretical Issues in Ergonomic Science	Journal (Q2: Impact Factor: 2.97)	Under review	CN22-18IQ-1621
Conference Publications						
1.	**Wisam K. Hussam**, Asif Jaman3, Raouf Mibarki, Rafid Al Mahmud, and Gregory J. Sheard	Techno-economic and environmental evaluation of integrated microgrid systems for electrification and hydrogen production	HEET2024: The 7th International Symposium on Hydrogen Energy and Energy Technologies Conference Osaka, Japan	**Conference**	14-15/11/2024	CN22-15SE-1612

AU Faculty Research Output, KFAS Grants

Publications – KFAS Grants (Academic Year 09/2024-06/2025)						
Sr. التسلسل	Authors المؤلف	Publication Title عنوان النشر	Name of Journal/ Conference اسم المجلة/المؤتمر	Category / Impact Factor الفئة / عامل التأثير	Date التاريخ	KFAS Grant #
2.	Ahmad Sedaghat, Mohammad Nazififard, and Mo-hamad Iyad Al-Khiami,	Dynamic IoT Determination of Overall Heat Transfer Coefficient in a Portable Cabin in Kuwait	7th IFIP International Internet of Things (IoT) Conference, Nice - Sophia Antipolis, France	**Conference**	6-8/11/ 2024	CN19-35EM-06
3.	Mohamad Iyad Al-Khiami, Sayed Mohamad Soleimani, **Ahmad Sedaghat**, Mahdi Ashtian Malayer	Impact of Phase Change Materials on Temperature Regulation in Passive Cooling Systems	9th International Conference on Sustainable Energy Engineering (ICSEE 2025), Australia	**Conference**	18-20/1/2025	CN19-35EM-06
4.	Arash Mehdizadeh, **Ahmad Sedaghat**, and Sayed Mohamad Soleimani	Thermal Comfort, Humidity, and Air Quality in Passive Cooling Systems Using Phase Change Materials	2nd GCC International Conference on Industrial Engineering and Operations Management, Muscat, Oman	**Conference**	1-3/12/ 2024	CN19-35EM-06
5.	Nader Ghareeb	Understanding office ergonomics and employees well-being in the workplace	2025 AHFE International Conference on Human Factors in Design, Hawaii, USA	**Conference**	8-10/12/2025	CN22-18IQ-1621
6.	**Mohamad Farhat**, Yousef Mazloum, Samer Wakim, Wissam Bou Nader, Meshari ALEbrahim	Optimizing Solar Parabolic Concentrators with Cylindrical and	2025 10th International Conference on Sustainable and Renewable Energy	**Conference**	13-16/5/2025	CN22-15EE-1626

AU Faculty Research Output, KFAS Grants

Publications – KFAS Grants (Academic Year 09/2024-06/2025)						
Sr. التسلسل	Authors المؤلف	Publication Title عنوان النشر	Name of Journal/ Conference اسم المجلة/المؤتمر	Category / Impact Factor الفئة / عامل التأثير	Date التاريخ	KFAS Grant #
	, Nader Ghareeb	Conical Receivers for Improved Thermal Performance	Engineering, Nice, France			

Journal Publications

Renewable Energy 237 (2024) 121539

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Practical application of machine learning in energy and thermal management: Long-term data analysis of solar-assisted AC systems in portable cabins in Kuwait and Australia

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ARTICLE INFO

Keywords:
Building energy-saving
Gaussian process regression
Machine learning
Photovoltaic
Solar-assisted air conditioning

ABSTRACT

Machine learning techniques are advancing rapidly in theoretical grounds, but their practical application and real evaluation in engineering disciplines are limited. This study investigates one-year of experimental data for indoor air conditions and energy monitoring of two identical portable cabins in Kuwait. Additionally, a 9-month period of solar photovoltaic energy production is experimentally obtained for assessing energy saving aspects of a solar assisted air conditioning system in one of the cabins. A transient system simulation tool model is developed and validated for the portable cabins. Both one-year experimental data and the validated simulation data are used for developing machine learning models for six case studies in Kuwait and Australia. In simulations, there are issues related to lack of access to real-time weather data from a locally installed weather station. In experimental works, there were issues related to disruption of data collection due to power or internet shutdowns. To resolve these issues, nineteen regression models are investigated. It was found that all models performed very well although the Matern 5/2 and Exponential gaussian process regression model performed slightly better, with all models achieving high accuracy, as indicated by R-squared values close to 1.0 in all six case studies. Overall, it was found that the photovoltaic solar-assisted air conditioning system could save annually 26.2 % and 75.7 % energy in Kuwait and Rockhampton, Australia, respectively.

Abbreviations

AC	Air Conditioning
ANN	Artificial Neural Network
AU	Australian University
BES	Building Energy Saving
CNN	Convolutional Neural Network
CFD	Computational Fluid Dynamics
COP	Coefficient of Performance
CO_2	Carbon Dioxide
DL	Deep Learning
EGB	Extreme Gradient Boosting
ESS	Energy Storage System
ETM	Event-Triggered Mechanism
KFAS	Kuwait Foundation for the Advancement of Sciences
LCSA	Life Cycle Sustainability Assessment
LED	Light-Emitting Diode
GA	Genetic Algorithm
GCC	Gulf Cooperation Council
GPR	Gaussian Process Regression
IoT	Internet of Things
ML	Machine Learning
MOD	Margin of Deviation
MPPT	Maximum Power Point Tracking
NASA	National Aeronautics and Space Administration
PEB	Positive Energy Building
PV	Photovoltaic
RES	Renewable Energy Source
RL	Regression Learner
SVM	Support Vector Machine
TTM	Time-Triggered Mechanisms

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0960-1481/© 2024 Elsevier Ltd. All rights reserved, including those for text and data mining, AI training, and similar technologies.

the application of phase change materials (PCM) and new solar configurations using flexible PV panels, can be investigated as the continuation of this research to achieve more sustainable and effective energy solutions in different climates or locations.

CRediT authorship contribution statement

Ahmad Sedaghat: Writing – original draft, Supervision, Investigation, Funding acquisition, Conceptualization. **Rasool Kalbasi:** Software, Methodology, Formal analysis, Data curation. **Ali Mostafaeipour:** Writing – review & editing, Resources. **Mohammad Nazififard:** Writing – review & editing, Visualization, Software, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] S. Mousavi, et al., Data-driven prediction and optimization toward net-zero and positive-energy buildings: a systematic review, Build. Environ. (2023) 110578.
[2] Z. Li, et al., Combining physical approaches with deep learning techniques for urban building energy modeling: a comprehensive review and future research prospects, Build. Environ. (2023) 110960.
[3] Z. Chen, et al., Optimization and prediction of energy consumption, light and thermal comfort in teaching building atriums using NSGA-II and machine learning, J. Build. Eng. (2024) 108687.
[4] A. Ali, et al., Machine learning as a surrogate to building performance simulation: predicting energy consumption under different operational settings, Energy Build. 286 (2023) 112940.
[5] F.E. Sapnken, et al., Modeling energy-efficient building loads using machine-learning algorithms for the design phase, Energy Build. 283 (2023) 112807.
[6] P. Anand, et al., Occupancy-based energy consumption modelling using machine learning algorithms for institutional buildings, Energy Build. 252 (2021) 111478.
[7] U. Ali, et al., Urban building energy performance prediction and retrofit analysis using data-driven machine learning approach, Energy Build. 303 (2024) 113768.
[8] P. Stoffel, M. Berktold, D. Müller, Real-life data-driven model predictive control for building energy systems comparing different machine learning models, Energy Build. 305 (2024) 113895.
[9] S. Walker, et al., Accuracy of different machine learning algorithms and added-value of predicting aggregated-level energy performance of commercial buildings, Energy Build. 209 (2020) 109705.
[10] G. Li, et al., A novel method of creating machine learning-based time series meta-models for building energy analysis, Energy Build. 281 (2023) 112752.
[11] M.H. Fouladfar, et al., Adaptive thermal load prediction in residential buildings using artificial neural networks, J. Build. Eng. 77 (2023) 107464.
[12] Y. Zhang, et al., An energy-saving design method for residential building group based on convolutional neural network, J. Build. Eng. 82 (2024) 108291.
[13] Y. Ding, L. Fan, X. Liu, Analysis of feature matrix in machine learning algorithms to predict energy consumption of public buildings, Energy Build. 249 (2021) 111208.
[14] R. Veiga, et al., Application of machine learning to estimate building energy use intensities, Energy Build. 249 (2021) 111219.
[15] L. Wang, et al., Application of the hybrid neural network model for energy consumption prediction of office buildings, J. Build. Eng. 72 (2023) 106503.
[16] M. Rätz, et al., Automated data-driven modeling of building energy systems via machine learning algorithms, Energy Build. 202 (2019) 109384.
[17] A. Ali, et al., A comparative analysis of machine learning and statistical methods for evaluating building performance: a systematic review and future benchmarking framework, Build. Environ. (2024) 111268.
[18] J. Vivian, et al., A comparison between grey-box models and neural networks for indoor air temperature prediction in buildings, J. Build. Eng. 84 (2024) 108583.
[19] M. Zhussupbekov, et al., Forecasting energy demand of PCM integrated residential buildings: a machine learning approach, J. Build. Eng. 70 (2023) 106335.
[20] D.K. Bhamare, et al., A machine learning and deep learning based approach to predict the thermal performance of phase change material integrated building envelope, Build. Environ. 199 (2021) 107927.
[21] S. Yang, W. Chen, M.P. Wan, A machine-learning-based event-triggered model predictive control for building energy management, Build. Environ. 233 (2023) 110101.
[22] Q. Zhou, R. Ooka, Implementation of a coupled simulation framework with neural network and Modelica for fast building energy simulation considering non-uniform indoor environment, Build. Environ. 211 (2022) 108740.
[23] A.Š. Glumac, et al., A multi-fidelity wind surface pressure assessment via machine learning: a high-rise building case, Build. Environ. 234 (2023) 110135.
[24] H.A. Toosi, et al., A novel LCSA-Machine learning based optimization model for sustainable building design-A case study of energy storage systems, Build. Environ. 209 (2022) 108656.
[25] C. Ghenai, et al., Artificial neural networks for power output forecasting from bifacial solar PV system with enhanced building roof surface Albedo, J. Build. Eng. 56 (2022) 104799.
[26] R. Huang, X. Zhang, K. Liu, Assessment of operational carbon emissions for residential buildings comparing different machine learning approaches: a study of 34 cities in China, Build. Environ. 250 (2024) 111176.
[27] C. Zhang, et al., Automated machine learning-based building energy load prediction method, J. Build. Eng. 80 (2023) 108071.
[28] N.-T. Ngo, Early predicting cooling loads for energy-efficient design in office buildings by machine learning, Energy Build. 182 (2019) 264–273.
[29] J. Zhan, W. He, J. Huang, Dual-objective building retrofit optimization under competing priorities using Artificial Neural Network, J. Build. Eng. 70 (2023) 106376.
[30] J. Zhang, et al., Graph neural network-based spatio-temporal indoor environment prediction and optimal control for central air-conditioning systems, Build. Environ. 242 (2023) 110600.
[31] V. Venkatraj, et al., Toward the application of a machine learning framework for building life cycle energy assessment, Energy Build. 297 (2023) 113444.
[32] X. Cui, et al., Energy consumption prediction and household feature analysis for different residential building types using machine learning and SHAP: toward energy-efficient buildings, Energy Build. (2024) 113997.
[33] H.H. Hosamo, et al., Multiobjective optimization of building energy consumption and thermal comfort based on integrated BIM framework with machine learning-NSGA II, Energy Build. 277 (2022) 112479.
[34] X. Liu, et al., Investigating the performance of machine learning models combined with different feature selection methods to estimate the energy consumption of buildings, Energy Build. 273 (2022) 112408.
[35] A. Etemad, A. Shafaat, A.M. Bahman, Data-driven performance analysis of a residential building applying artificial neural network (ANN) and multi-objective genetic algorithm (GA), Build. Environ. 225 (2022) 109633.
[36] M. Lillstrang, et al., Implications of properties and quality of indoor sensor data for building machine learning applications: two case studies in smart campuses, Build. Environ. 207 (2022) 108529.
[37] A. Sedaghat, et al., Implementing cool roof and bio-PCM in portable cabins to create low-energy buildings suitable for different climates, Sustainability 15 (20) (2023) 14700.
[38] A. Sedaghat, et al., Exploring energy-efficient building solutions in hot regions: a study on bio-phase change materials and cool roof coatings, J. Build. Eng. 76 (2023) 107258.
[39] A. Sedaghat, et al., Integrating solar PV systems for energy efficiency in portable cabins: a case study in Kuwait, Sol. Energy 277 (2024) 112715.
[40] G. James, D. Witten, T. Hastie, R. Tibshirani, An Introduction to Statistical Learning, vol. 112, springer, New York, 2013, p. 18.
[41] L.S. Aiken, S.G. West, R.R. Reno, Multiple Regression: Testing and Interpreting Interactions, sage, 1991.
[42] P.J. Huber, E.M. Ronchetti, Robust Statistics, Wiley & Sons. Inc., 2009.
[43] N.R. Draper, H. Smith, Applied Regression Analysis, vol. 326, John Wiley & Sons, 1998.
[44] L. Breiman, J. Friedman, R. Olshen, C. Stone, Classification and Regression Trees, Wadsworth, 1984.
[45] C. Cortes, V. Vapnik, Support-vector networks, Mach. Learn. 20 (1995) 273–297.
[46] N. Cristianini, J. Shawe-Taylor, An Introduction to Support Vector Machines and Other Kernel-Based Learning Methods, Cambridge university press, 2000.
[47] C.K. Williams, C.E. Rasmussen, Gaussian Processes for Machine Learning, vol. 2, 2006, p. 4. Cambridge, MA: MIT press.
[48] J.H. Friedman, Greedy function approximation: a gradient boosting machine, Ann. Stat. (2001) 1189–1232.
[49] L. Breiman, Bagging predictors, Mach. Learn. 24 (1996) 123–140.
[50] C.K. Williams, C.E. Rasmussen, Gaussian Processes for Machine Learning, vol. 2, 2006, p. 4. Cambridge, MA: MIT press.
[51] T.G. Dietterich, Approximate statistical tests for comparing supervised classification learning algorithms, Neural Comput. 10 (7) (1998) 1895–1923.

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Case Report

Improvement of engine performance, combustion and remarkable reductions in NOx, CO and unburned HC emissions fuelling with mixed plastic pyrolysis oil and oxygenated additives

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ARTICLE INFO

Keywords:
Waste plastic-derived fuels
Oxygenated additives
Diesel engine
Engine performance
Combustion
Exhaust emissions

ABSTRACT

Global emissions from the transportation sector are one of the reasons for climate change. This study aims to use waste-plastic-derived pyrolysis oils in a diesel engine to reduce exhaust emissions and improve engine performance. Pyrolysis oils were derived from waste plastics and oils were tested in a diesel engine effectively by blending with diesel and oxygenated additives. The experimental results were validated with simulation results. The key findings are the remarkable reductions in carbon monoxide (CO, 74.4 %), unburned hydrocarbon (UBHC, 62.1 %), and nitrogen oxide (NOx, 18.96 %) emissions without deteriorating engine performance at all engine operating conditions.

1. Introduction

Plastics are indispensable materials for humans and play a key role in the packaging, storage, medical, and transportation sectors [1]. In today's modern societies, the use and production of plastics are rapidly growing due to their versatile, affordable and wide range of applications [2]. It has been reported that yearly 11.2 billion tonnes of solid waste is generated globally. Of this massive amount of solid waste, 13 % is plastics [3]. According to a published report, the worldwide plastic generation was 360 million tonnes in 2018. However, a recent estimate for annual plastic production was 400 M tonnes. If this generation rate continues, the total plastic generation by 2050 will be estimated to be approximately 1.1 billion tonnes [1]. Globally, the per capita average plastic consumption is 28 kg per year. The major share of plastic consumption is in packaging. Around 44 % of plastics are used in packaging [4]. Among the various plastics, a few are widely used because of their chemical stability, low price, flexibility, and lightweight [5]. The most popular plastics used in our everyday life and industrial use are HDPE, LDPE, PET, PP, PS, and PVC. These plastics account for approximately 90 % of the total consumption [4]. A published report indicated that the global demand for different plastics is PET 7 %, polyurethane (PUR) 6 %, PS 7 %, PVC 13 %, PP 19 %, HDPE 12 %, LDPE 17 %, and others 19 % [5]. According to the EPA, only 7 % of plastics go for recycling annually. Furthermore, the report indicated that only 8 % of plastics go into incineration, and the rest go to landfills [1]. One of the key challenges for waste plastics is their sustainable management. Recycling, incineration, pyrolysis, and landfilling are the ways of managing them. However, plastic landfilling poses a huge threat to the environment, as it produces toxic emissions, including methane (a dangerous greenhouse gas component), requires a large amount of land, and can contaminate soil, water, and air. Another way to manage these plastics is to recycle them via pyrolysis. Pyrolysis is the thermal degradation process of organic materials upon indirect heating them in a pyrolysis reactor in an inert and oxygen-free atmosphere. The pyrolysis products are liquid, gas and char. Liquid can be upgraded and used in internal combustion engines. The syn gas can also be used as fuel with some purification processes. The char has versatile uses. Among the various uses, one of them is to use the growth of marine plants even in harsh environments [6].

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emissions. The authors reported a simultaneous reduction in PM and NOx emissions with DYG but realised higher formaldehyde and acetaldehyde emissions.

The crude pyrolysis oils have impacts on the injector performance, atomisation and spray pattern [36]. This is because crude pyrolysis oil has higher viscosity than diesel. The higher viscous oils or fuels will produce larger fuel droplets causing issues with spray pattern and mixing with air. However, the upgraded pyrolysis oils tested in this investigation have almost similar or lower viscosity except 10TYG than diesel fuel. Thus, the issues related to injector performance, spray pattern and or injector clogging were not experienced with the tested engine. The tested engine in this study has been using for several years using biodiesel, biofuels, oxygenated fuels and diesel as a reference fuel. The use of these oxygenated fuels or their blends required no engine or injector modification.

4. Conclusions

An experimental study in a 4-stroke naturally aspirated diesel engine with a novel series of sustainable fuels, including upgraded pyrolysis oils from co-pyrolysis of mixed HDPE, PET, and PS with a ratio of 1:1:1. Six fuels, including reference diesel, were tested in a diesel engine to examine their performance, combustion, and exhaust emission characteristics investigation. Among the five fuel blends, three were binary and two were ternary. Besides the pyrolysis oil, two oxygenated additives were added to the blends to lessen the exhaust emissions further and improve the engine performance. The experimental results were validated using simulation data. The conclusions of this study are as follows.

– A maximum of 82 % oil was obtained from the co-pyrolysis of HDPE, PET, and PS at a ratio of 1:1:1. The oil was then upgraded and characterised. The fuel properties are similar to, and in some cases, better than those of the reference diesel.
– The GC-MS results showed a higher percentage of saturated compounds in the two ternary blends (5PO10DYG and 5PO10TYG) than in neat pyrolysis oil (100 % pyrolysis oil).
– Engine performance results, including BMEP, BTE, and BSEC with binary and ternary blends, are almost similar to those of the reference diesel. With the binary and ternary blends, the increased BMEP ranged from 0.06 % to 1.25 %, while the decreased range was 0.08 %–2.45 %. However, relative to diesel, a maximum increase of 4.36 % and a 3.52 % decrease in BTE was observed with binary and ternary blends, respectively.
– Insignificant variations in the in-cylinder pressure were observed among the six fuels. This was due to the similar energy content of the fuels.
– All five binary and ternary blends reduced the NOx emissions. A maximum of 18.96 % of NOx was reduced with the 5PO10DYG blend compared to diesel. The NOx emissions from the binary and ternary blends were multifold lower. Some of them have a higher NO2/NOx ratio, lower heat release rate, lower exhaust temperature, faster ignition, and better ignitability of the binary and ternary blends.
– Binary and ternary blends reduced CO emissions by a maximum of 70.4 % and 62.1 % in UBHC emissions, respectively, indicating their remarkable performance in reducing CO and UBHC emissions.
– A maximum discrepancy of less than 4 % between the experimental and simulation data demonstrated the high accuracy of the experimental findings.
– The long-term stability and unregulated emissions for binary (diesel-pyrolysis oil and diesel-oxygenated additives) and ternary blends (diesel-pyrolysis oil-oxygenated additives) need further investigation.

CRediT authorship contribution statement

Md Nurun Nabi: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Wisam K. Hussam:** Writing – review & editing, Writing – original draft, Project administration, Funding acquisition. **Md Islam Jahirul:** Writing – review & editing, Writing – original draft, Investigation. **Mohammad G. Rasul:** Writing – review & editing. **Ashfaque Ahmed Chowdhury:** Writing – review & editing. **Peter Brooks:** Writing – review & editing, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cscee.2025.101203.

Data availability

Data will be made available on request.

References

[1] L. An, et al., Research progress in fuel oil production by catalytic pyrolysis technologies of waste plastics, Catalysts 14 (3) (2024).
[2] Y. Vasseghian, et al., A global meta-analysis of phthalate esters in drinking water sources and associated health risks, Sci. Total Environ. 903 (2023) 166846.
[3] Subhashini, T. Mondal, Experimental investigation on slow thermal pyrolysis of real-world plastic wastes in a fixed bed reactor to obtain aromatic rich fuel grade liquid oil, J. Environ. Manag. 344 (2023) 118680.
[4] P. Das, P. Tiwari, The effect of slow pyrolysis on the conversion of packaging waste plastics (PE and PP) into fuel, Waste Manag. 79 (2018) 615–624.
[5] A.L. Andrady, M.A. Neal, Applications and societal benefits of plastics, Philos. Trans. R. Soc. Lond. B Biol. Sci. 364 (1526) (2009) 1977–1984.
[6] Y. Vasseghian, M.M. Nadagouda, T.M. Aminabhavi, Biochar-enhanced bioremediation of eutrophic waters impacted by algal blooms, J. Environ. Manag. 367 (2024) 122044.
[7] G. Liu, et al., Biochar/layered double hydroxides composites as catalysts for treatment of organic wastewater by advanced oxidation processes: a review, Environ. Res. 234 (2023) 116534.
[8] M.N. Nabi, et al., Notable improvement of fuel properties of waste tire pyrolysis oil by blending a novel pumpkin seed oil biodiesel. 7th International Conference on Advances on Clean Energy Research, ICACER 2022 April 20-22, 2022, Will be Archived in Energy Reports, Barcelona, Spain, 2022. Paper ID ER025.
[9] A. Paykani, et al., Synthesis gas as a fuel for internal combustion engines in transportation, Prog. Energy Combust. Sci. 90 (2022).
[10] S.T. Okonsky, N.R. Hogan, H.E. Toraman, Effect of pyrolysis operating conditions on the catalytic co-pyrolysis of low-density polyethylene and polyethylene terephthalate with zeolite catalysts, AIChE J. 70 (12) (2024).
[11] H. Gulab, et al., Copper catalyzed co-pyrolysis of polyethylene terephthalate with low and high density polyethylene for liquid fuel production, J. Chem. Technol. Biotechnol. 98 (1) (2022) 282–295.
[12] H. Gulab, S. Malik, Polyethylene terephthalate conversion into liquid fuel by its co-pyrolysis with low- and high-density polyethylene employing scrape aluminium as catalyst, Environ. Technol. 45 (18) (2024) 3721–3735.
[13] C.A. Rinaldini, et al., Performance, emission and combustion characteristics of a IDI engine running on waste plastic oil, Fuel 183 (2016) 292–303.
[14] S. Maithomklang, et al., Pyrolysis oil derived from plastic bottle caps: characterization of combustion and emissions in a diesel engine, Energies 16 (5) (2023).
[15] S. Padmanabhan, et al., Energy recovery of waste plastics into diesel fuel with ethanol and ethoxy ethyl acetate additives on circular economy strategy, Sci. Rep. 12 (1) (2022) 5330.
[16] A. Pumpuang, et al., The influence of plastic pyrolysis oil on fuel lubricity and diesel engine performance, RSC Adv. 14 (14) (2024) 10070–10087.

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Energy optimization of parabolic dish solar concentrator coupled to organic Rankine cycle: Experimental and analytical investigation of cavity receiver design and covering effects

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ABSTRACT

Concentrated solar power (CSP) systems offer a promising solution for sustainable energy, but achieving high and stable efficiency requires careful design optimization. This study evaluated the overall performance of a parabolic dish solar concentrator coupled to an Organic Rankine Cycle (ORC) system through experimental and analytical assessments. The research examined the impact of cavity receiver shape (cylindrical vs. spherical) and the use of a glass cover on thermal efficiency. Additionally, the effectiveness of a cone structure to reduce spillage losses and improve optical efficiency was explored. Testing showed a significant improvement in system performance, with an increase from 75 % for the open cavity to 90 % for the sealed cavity equipped with the cone structure (15 % increase). This highlights the importance of receiver design in reducing heat loss. To further optimize the system, a numerical model was developed and validated against experimental measurements. The simulation demonstrated that the overall system performance is significantly influenced by the water outlet temperature from the cavity receiver and the pressure drop within it. The model suggests that overall performance could be enhanced from 4.6 % to higher than 6 % by optimizing factors like water mass flow rate, cavity tube diameter, and the selection of a more suitable ORC working fluid (e.g., R245fa instead of R134a).

1. Introduction

Concentrated Solar Power (CSP) is a promising renewable energy technology that utilizes concentrated sunlight to generate electricity. It offers several advantages, including reduced greenhouse gas emissions, integration with energy storage systems, and potential for economic development. This study explores the application of CSP coupled with an Organic Rankine Cycle (ORC) system for electricity production. ORC systems employ organic fluids with lower boiling points than water, allowing them to vaporize at lower temperatures. In a CSP-ORC system, concentrated sunlight is directed onto a receiver, heating a heat transfer fluid (HTF) like oil or molten salt. The heated HTF then transfers its thermal energy to the ORC system, driving a turbine connected to a generator to produce electricity. CSP-ORC systems are attractive due to their high energy conversion efficiency, scalability, and suitability for integrating with intermittent renewable energy sources [1–4].

Parabolic Dish Collectors (PDCs) are highly efficient at converting solar energy into thermal energy. Their applications include power generation, space heating, and desalination. A crucial component of a PDC system is the cavity receiver, which absorbs concentrated sunlight and transfers heat to a Heat Transfer Fluid (HTF). Both the PDC and receiver designs are crucial for maximizing solar energy capture and minimizing optical and thermal losses [1].

Extensive research has been conducted to improve cavity receiver designs and reduce heat losses. Studies by Hassan et al. [2] and Dabbo et al. [3] compared the performance of cylindrical, conical, and spherical cavity receivers. Conical receivers exhibited better thermal and optical efficiencies than cylindrical or spherical. Investigated the impact of using a glass cover on cavity receivers, finding that it can improve

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and revealed that minimizing pressure drops and maximizing hot water temperature are critical for efficiency improvement. Furthermore, using R245fa as the working fluid instead of R134a has the potential to increase system efficiency from 4.6 % to over 6 %. Future research should explore the effects of pressurized water and high-temperature thermal oils on system performance through simulations. These investigations will pave the way for optimizing CSP-ORC systems and promoting their adoption as a clean and efficient renewable energy technology, contributing to a low-carbon future.

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CRediT authorship contribution statement

Mohamad H Farhat: Writing – original draft, Project administration, Methodology, Funding acquisition, Conceptualization. **Youssef Mazloum:** Writing – original draft, Validation, Supervision, Conceptualization. **Samer Wakim:** Methodology, Investigation, Conceptualization. **Wissam Bou Nader:** Methodology, Investigation, Conceptualization. **Meshari ALEbrahim:** Writing – review & editing. **Nader Ghareeb:** Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Data availability

Data will be made available on request.

References

[1] P. Mandal, A. Rajan, K.S. Reddy, Optical and thermal investigation of hyperbolic cavity receiver with secondary reflector for solar parabolic dish collector, Therm. Sci. Eng. Prog. 47 (2024) 102350, https://doi.org/10.1016/j.tsep.2023.102350.

[2] A. Hassan, C. Quanfang, S. Abbas, W. Lu, L. Youming, An experimental investigation on thermal and optical analysis of cylindrical and conical cavity copper tube receivers design for solar dish concentrator, Renew. Energy 179 (2021) 1849–1864, https://doi.org/10.1016/j.renene.2021.07.145.

[3] A.M. Daabo, S. Mahmoud, R.K Al-Dadah, The effect of receiver geometry on the optical performance of a small-scale solar cavity receiver for parabolic dish applications, Energy 114 (2016) 513–525, https://doi.org/10.1016/j.energy.2016.08.025.

[4] D. Azzouzi, B. Boumeddane, A. Abene, Experimental and analytical thermal analysis of cylindrical cavity receiver for solar dish, Renew. Energy 106 (2017) 111–121, https://doi.org/10.1016/j.renene.2016.12.102.

[5] T. Venkatachalam, M. Cheralathan, Effect of aspect ratio on thermal performance of cavity receiver for solar parabolic dish concentrator: an experimental study, Renew. Energy 139 (2019) 573–581, https://doi.org/10.1016/j.renene.2019.02.102.

[6] R. Loni, E. Askari Asli-Ardeh, B. Ghobadian, E. Bellos, W.G Le Roux, Numerical comparison of a solar dish concentrator with different cavity receivers and working fluids, J. Clean. Prod. 198 (2018) 1013–1030, https://doi.org/10.1016/j.jclepro.2018.07.075.

[7] E. Bellos, E. Bousi, C. Tzivanidis, S. Pavlovic, Optical and thermal analysis of different cavity receiver designs for solar dish concentrators, Energy Convers. Manag. X 2 (2019) 100013, https://doi.org/10.1016/j.ecmx.2019.100013.

[8] N.A. Pratik, MdH Ali, N. Lubaba, N. Hasan, Md Asaduzzaman, A. Miyara, Numerical investigation to optimize the modified cavity receiver for enhancement of thermal performance of solar parabolic dish collector system, Energy 290 (2024) 130133, https://doi.org/10.1016/j.energy.2023.130133.

[9] Z. Si-Quan, L. Xin-Feng, D. Liu, Qing-Song M. A numerical study on optical and thermodynamic characteristics of a spherical cavity receiver, Appl. Therm. Eng. 149 (2019) 11–21, https://doi.org/10.1016/j.applthermaleng.2018.10.030.

[10] S. Sharma, A. Sah, C. Subramaniam, S.K. Saha, Performance enhancement of tapered helical coil receiver using novel nanostructured carbon florets coating, Appl. Therm. Eng. 194 (2021) 117065, https://doi.org/10.1016/j.applthermaleng.2021.117065.

[11] J.K. Swanepoel, W.G. le Roux, A.S. Lexmond, J.P. Meyer, Helically coiled solar cavity receiver for micro-scale direct steam generation, Appl. Therm. Eng. 185 (2021) 116427, https://doi.org/10.1016/j.applthermaleng.2020.116427.

[12] A.S. K, G. Muthuvairavan, S.K Natarajan, Numerical investigation of modified conical cavity receiver with different heat transfer fluids, Energy Sources Part Recov. Util. Environ. Eff. 45 (2023) 6964–6980, https://doi.org/10.1080/15567036.2023.2218833.

[13] L. Di Cairano, W. Bou Nader, M Nemer, Assessing fuel consumption reduction in Revercycle, a reversible mobile air conditioning/Organic Rankine cycle system, Energy 210 (2020) 118588, https://doi.org/10.1016/j.energy.2020.118588.

[14] L. Di Cairano, W. Bou Nader, M Nemer, A simulation and experimental study of an innovative MAC/ORC/ERC system: reverCycle with an ejector for series hybrid vehicles, Energy 230 (2021) 120830, https://doi.org/10.1016/j.energy.2021.120830.

[15] J.C. Jiménez-García, A. Ruiz, A. Pacheco-Reyes, W. Rivera, A comprehensive review of organic rankine cycles, Processes 11 (2023) 1982, https://doi.org/10.3390/pr11071982.

[16] J Holman, Heat Transfer, 10th edition, McGraw-Hill Education, Boston, Mass, 2009.

[17] Pagar S.R. Modified solar thermal cavity receivers for parabolic concentrating collector: review 2017.

[18] Dymola. Dassault systèmes 2023. https://www.3ds.com/products/catia/dymola (accessed February 4, 2024).

[19] VDI e. V. (Ed.), VDI Heat Atlas, Springer Berlin Heidelberg, Berlin, Heidelberg, 2010, https://doi.org/10.1007/978-3-540-77877-6.

[20] R. Tillner-Roth, H.D. Baehr, An international standard formulation for the thermodynamic properties of 1,1,1,2-tetrafluoroethane (HFC-134a) for temperatures from 170 K to 455 K and pressures up to 70 MPa, J. Phys. Chem. Ref. Data 23 (1994) 657–729, https://doi.org/10.1063/1.555958.

[21] J.R. C, R.B. D, Guideline On an Equation of State for Humid Air in Contact With Seawater and Ice, Consistent With the IAPWS Formulation 2008 For the Thermodynamic Properties of Seawater, The International Association for the Properties of Water and Steam, Lucerne, Switzerland, 2007.

[22] Y. Mazloum, H. Sayah, M. Nemer, Comparative study of various constant-pressure compressed air energy storage systems based on energy and exergy analysis, J. Energy Resour. Technol. 143 (2020), https://doi.org/10.1115/1.4048506.

[23] C. Zou, Y. Zhang, Q. Falcoz, P. Neveu, C. Zhang, W. Shu, et al., Design and optimization of a high-temperature cavity receiver for a solar energy cascade utilization system, Renew. Energy 103 (2017) 478–489, https://doi.org/10.1016/j.renene.2016.11.044.

[24] Y. Cengel, A Ghajar, Heat and Mass Transfer: Fundamentals and Applications, 5th edition, McGraw Hill, New York, NY, 2014.

[25] S. Pavlovic, R. Loni, E. Bellos, D. Vasiljević, G. Najafi, A. Kasaeian, Comparative study of spiral and conical cavity receivers for a solar dish collector, Energy Convers. Manage 178 (2018) 111–122, https://doi.org/10.1016/j.enconman.2018.10.030.

[26] R.Y Ma, Wind Effects On Convective Heat Loss from a Cavity Receiver For a Parabolic Concentrating Solar Collector, Sandia National Lab. (SNL-NM), Albuquerque, NM (United States), 1993, https://doi.org/10.2172/10192244. California State Polytechnic Univ., Pomona, CA (United States). Dept. of Mechanical Engineering.

[27] M. Prakash, S.B. Kedare, J.K. Nayak, Numerical study of natural convection loss from open cavities, Int. J. Therm. Sci. 51 (2012) 23–30, https://doi.org/10.1016/j.ijthermalsci.2011.08.012.

[28] V.C. Shewale, P.R. Dongarwar, R.R. Gawande, Analysis of spherical cavity receiver of solar concentrator for heat losses, Appl. Mech. Mater. 541–542 (2014) 1011–1016, https://doi.org/10.4028/www.scientific.net/AMM.541-542.1011.

[29] S.B. Bopche, S. Kumar, Experimental investigations on thermal performance characteristics of a solar cavity receiver, Int. J. Energy Environ. Eng. 10 (2019) 463–481, https://doi.org/10.1007/s40095-019-00321-4.

[30] Y. Mazloum, H. Sayah, M. Nemer, Dynamic modeling and simulation of an Isobaric Adiabatic Compressed Air Energy Storage (IA-CAES) system, J. Energy Storage 11 (2017) 178–190, https://doi.org/10.1016/j.est.2017.03.006.

[31] S. Sun, J. Liu, R. Sang, K. Zhao, Experimental study of flow friction behavior in coiled tubing, Energy Rep. 8 (2022) 187–196, https://doi.org/10.1016/j.egyr.2022.10.291.

[32] Mazloum Y., Sayah H., Nemer M. Exergoeconomic analysis and optimization of a novel isobaric adiabatic compressed air energy storage system 2017;20:6–14. https://doi.org/10.5541/ijot.5000201781.

[33] W. Bou Nader, F. Breque, Y. Mazloum, C. Dumand, M. Nemer, Dynamic modeling and fuel consumption potential of an intercooled regenerative reheat gas turbine auxiliary power unit on series hybrid electric vehicle, J. Energy Resour. Technol. 142 (2019), https://doi.org/10.1115/1.4044366.

[34] L. Li, S. Gao, B. Wang, C. Li, Y. Wang, B. Sun, et al., Analysis of cooling and heating characteristics of thermal management system for fuel cell bus, Int. J. Hydrog. Energy 48 (2023) 11442–11454, https://doi.org/10.1016/j.ijhydene.2022.07.083.

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Innovative insights into engine performance and emissions - A numerical and experimental investigation of aliphatic hydrocarbons and renewable dimethyl ether

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ABSTRACT

This study explores the performance and emissions characteristics of renewable dimethyl ether (DME) in comparison to three commonly used aliphatic hydrocarbons: diesel, decane, and dodecane. This research addresses a notable gap in the existing literature by integrating advanced numerical modelling with experimental validation to investigate the distinct combustion behaviours and emission profiles under various operational conditions. We employ a dual approach that integrates advanced numerical modelling using GT-Suite software with experimental validation. This research presents several innovative aspects, including a comprehensive comparative analysis of multiple fuels under varied engine operating conditions, the integration of advanced numerical modelling with experimental validation, the development of detailed performance maps for optimisation, and the provision of practical insights for future engine design and environmental compliance. The work has several phases, including the variation of engine speeds (800 rpm–2400 rpm) keeping other parameters constant, secondly, the variation of fuel injection timing (20° bTDC to 20° aTDC) and thirdly, the changing of compression ratio (12–28) for all four fuels. The study also includes the energy and exergy analysis for the same fuels. Our findings indicate that DME improves brake thermal efficiency (BTE for DME is 40.71 % higher than diesel (40.03 %), decane of 40.3 %, and dodecane of 40.18 %). Compared to diesel, NO emissions were reduced by around 34 %, 30 % and 29 %, using decane, dodecane, and DME, respectively. This presents a promising avenue for developing more environmentally friendly fuel alternatives in the future.

1. Introduction

The increasing concerns about environmental degradation and the reduction of fossil fuel reserves have heightened the urgency to identify alternative, sustainable fuel solutions. Renewable dimethyl ether (DME) derived from biomass, agricultural wastes, biogas, municipal wastes, or methanol synthesis [1–3] has emerged as a promising candidate due to its advantageous combustion

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Based on the discussion above, the formation of NOx emissions depends on specific heat at constant pressure, in-cylinder gas temperature, heat release rate and excess air factors. The lower NO with DME compared to three aliphatic hydrocarbons is associated with lower specific heat at constant pressure, lower in-cylinder gas temperature, a lower heat release rate and higher excess air factors.

In this section, fuel energy and exergy for the four tested fuels are discussed. Fig. 16 (a) and (b) present the fuel energy and exergy for engine running conditions at an injection timing of 5°bTDC and CR of 22. Fuel energy and exergy for the four fuels are computed using equations (xi) and (xii) in the methodology section. As seen in the Figures, both energy and exergy increase with the increase in engine speed for all fuels. The reason for increasing fuel energy and exergy is due to the increasing amount of air utilisation at a higher speed, which causes better combustion and resulting more fuel energy and exergy. A careful look at the Figures reveals that the fuel exergy is higher than fuel energy. This is associated with the exergy factor in equation (xiii). This exergy factor is greater than unity and thus the fuel exergy is higher than fuel energy. Among the three aliphatic hydrocarbons (diesel, decane and dodecane), there are no significant variations in fuel energies and exergies. However, DME shows lower energies and exergies at all engine speeds. This is because the heating value of DME which is lower for DME than the three other aliphatic hydrocarbons.

4. Conclusions

The influence of dimethyl ether, decane, dodecane, and diesel fuel on the engine's performance, combustion, and NO emissions was investigated. Three parameters, namely, the CR, inj. timing, and speed, were investigated for the same fuels. The compression ratio varied from 12 to 28, while the inj. timing ranged from 20° bTDC to 20° aTDC, and the rpm changed from 800 rpm to 2400 rpm. The results of this investigation can be summarised as follows:

- A 1-D model was developed and built using the GT-Suite software to quantify the engine's parameters.
- The simulation results were validated with experimental results. The maximum variation of 8.7 % was observed in the experimental and simulation results.
- For the three variables of compression ratio, injection timing, and engine rotational speed, insignificant variations in BTE were observed among the four fuels, including diesel, decane, dodecane, and DME.
- DME showed lower pressure peaks than diesel, decane, and dodecane. The lower pressure peaks are associated with the lower energy content of DME.
- DME exhibits faster combustion and an earlier combustion end time than diesel, decane, and dodecane. This is because DME has higher ignitability than diesel, decane, and dodecane.
- Significantly smaller HRR rates with DME were observed for all three variables. The lower HRR results from the lower cylinder temperature.
- The excess air ratios were higher for DME than for the three paraffin fuels.
- A remarkable reduction in toxic NO emissions of 34 % was achieved with DME due to lower specific heat at constant pressure, gas temperature, rate of heat release and higher excess air factors.
- Insignificant variations in fuel energy and exergy were observed among the aliphatic hydrocarbons, but lower for DME than aliphatic hydrocarbons. This is due to the lower energy content (heating value) in DME.
- Based on the experimental and simulation results, DME is an excellent choice for internal combustion engines to achieve ultra-low emissions.

CRediT authorship contribution statement

Wisam K. Hussam: Writing – review & editing, Writing – original draft, Supervision, Software, Project administration, Funding acquisition. **Md Nurun Nabi:** Writing – review & editing, Writing – original draft, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Mohammad G. Rasul:** Writing – review & editing. **Ashfaque Ahmed Chowdhury:** Writing – review & editing, Writing – original draft. **Fazlur Rashid:** Writing – review & editing, Writing – original draft. **Nahina Islam:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

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Research article

Investigation of fiber Bragg grating sensor measurability in concrete beams under static load conditions

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ABSTRACT

Recent advances in construction materials and architecture have enhanced the safety of modern structures, which now feature higher, lighter, and more unique designs. Bridges, as critical infrastructure, face increasing load demands due to rising traffic volumes, leading to accelerated structural deterioration. This necessitates more frequent inspections and maintenance, resulting in increased costs and potential operational disruptions. Real-time built-in monitoring systems are thus essential for both new and aging structures. Fiber Optic Sensor (FOS) technology, particularly Fiber Bragg Grating (FBG) sensors, offers a reliable and stable solution for long-term Structural Health Monitoring (SHM). This study evaluates the performance and applicability of FBG sensors (FBGs) in comparison to traditional strain gauges (SGs) for capturing strains, loads, deflections, and temperature in full-scale beams under static loads. Four large-scale reinforced concrete (RC) and CFRP-strengthened beams were tested. Nonlinear finite element analysis (NLFEA) using VecTor2 was employed to simulate the behavior of these beams under static loading. Data from FBGs were compared to those from collocated electrical SGs. The results demonstrated the reliability and flexibility of FBGs in monitoring structural performance. Notably, FBGs continued to provide accurate readings even after the specimens reached their maximum load, showcasing their endurance and resilience compared to conventional SGs.

1. Introduction and background

Over the past 20 years, significant advancements in SHM have emerged, driven by new sensor technologies, monitoring systems, and non-destructive tests (NDT) methods capable of assessing structural performance [1–5]. Preserving the integrity of critical infrastructure, particularly bridges, is essential for economic stability, as neglecting inspection and maintenance can lead to severe financial repercussions.

FBGs have gained increasing attention in SHM for their lightweight design, high sensitivity, and immunity to electromagnetic interference, making them ideal for monitoring structural performance in challenging environments such as aerospace, civil engineering, and underground structures [6–8]. FBGs provide real-time data on strain, temperature, and other parameters, facilitating proactive maintenance and safety assessments that extend the service life of infrastructure [6,9,10].

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Declaration of competing interest

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References

[1] R. Soleimanpour, M. Hany Yassin, A. Mehdizadeh, D. Chronopoulos, Locating cracks in isotropic plates using nonlinear guided waves, Appl. Acoust. 211 (2023) 109522, https://doi.org/10.1016/j.apacoust.2023.109522.
[2] M.S. Islam, A. Bagchi, Statistical pattern-based assessment of structural health monitoring data, Math. Probl Eng. 2014 (2014) 926079, https://doi.org/10.1155/2014/926079.
[3] Z. Deng, M. Huang, N. Wan, J. Zhang, The current development of structural health monitoring for bridges: a review, Buildings 13 (2023) 1360, https://doi.org/10.3390/buildings13061360.
[4] Zhiguo He, Wentao Li, Hadi Salehi, Integrated structural health monitoring in bridge engineering, Autom. ConStruct. 136 (2022) 104168, https://doi.org/10.1016/j.autcon.2022.104168.
[5] Moirangthem Johnson Singh, Sourabh Choudhary, Applications of fibre Bragg grating sensors for monitoring geotechnical structures: a comprehensive review, Measurement 218 (2023) 113171, https://doi.org/10.1016/j.measurement.2023.113171.
[6] J.K. Sahota, N. Gupta, D. Dhawan, Fiber Bragg grating sensors for monitoring of physical parameters: a comprehensive review, Opt. Eng. 59 (2020) 1, https://doi.org/10.1117/1.oe.59.6.060901.
[7] Z. Liu, P. Liu, C. Zhou, Y. Huang, L. Zhang, Structural health monitoring of underground structures in reclamation area using fiber Bragg grating sensors, Sensors 19 (2019) 2849, https://doi.org/10.3390/s19132849.
[8] A. Gouws, K.R. Ford, B.H. Jones, Transverse strain measurements in polymer-embedded, polarization-maintaining Fiber Bragg Gratings, Eng. Res. Express 2 (2020) 045016, https://doi.org/10.1088/2631-8695/abc307.
[9] C.-Y. Hong, Y.-F. Zhang, M.-X. Zhang, L.M.G. Leung, L.-Q. Liu, Application of FBG sensors for geotechnical health monitoring, a review of sensor design, implementation methods and packaging techniques, Sensor Actuator Phys. 244 (2016) 184–197, https://doi.org/10.1016/j.sna.2016.04.033.
[10] Y. Hu, C. Hong, Y. Zhang, G. Li, A monitoring and warning system for expressway slopes using FBG sensing technology, Int. J. Distributed Sens. Netw. 14 (2018) 155014771877622, https://doi.org/10.1177/1550147718776228.
[11] S. Shen, S.-F. Jiang, Distributed deformation monitoring for a single-cell box girder based on distributed long-gage fiber Bragg grating sensors, Sensors 18 (2018) 2597, https://doi.org/10.3390/s18082597.
[12] A. Castaldo, M.A. Caponero, P. Clemente, C. Mazzotta, A. Polimadei, G. Terranova, M. Capasso, R. Darban, D. Lavorato, C. Nuti, S. Signorini, F. Sonzogni, C. Failla, Strain and vibration measurements by FBG sensors for engineering applications, J. Inst. Met. 18 (2023) C06030, https://doi.org/10.1088/1748-0221/18/06/C06030.
[13] National Institute for Aerospace Research "Elie Carafoli" – INCAS, Bucharest, Romania, M. Tudose, D. Enciu, I. Ursu, Towards use of fiber Bragg grating sensors for structural health monitoring of (aero)Space structures, IJMO 8 (2018) 246–249, https://doi.org/10.7763/IJMO.2018.V8.659.
[14] A.M. Mesa Yandy, R. Duchowicz, N.A. Russo, J.L. Cruz, M.V. Andrés, Development and analysis of a model based on chirped fiber Bragg gratings employed for cracks characterization in materials, Opt Commun. 426 (2018) 401–409, https://doi.org/10.1016/j.optcom.2018.05.050.
[15] S. Jinachandran, G. Rajan, Fibre Bragg grating based acoustic emission measurement system for structural health monitoring applications, Materials 14 (2021) 897, https://doi.org/10.3390/ma14040897.
[16] F. Yu, O. Saito, Y. Okabe, Laser ultrasonic visualization technique using a fiber-optic Bragg grating ultrasonic sensor with an improved adhesion configuration, Struct. Health Monit. 20 (2021) 303–320, https://doi.org/10.1177/1475921720932233.
[17] A. Krenz, J. Koch, V. Reimer, A. Doering, P. Guehlke, C. Waltermann, M. Schlag, K. Brune, M. Waris, A. Touze, Methods for FBG sensor integration for RTM process monitoring and SHM of the final CFRP component, in: 10th ECCOMAS Thematic Conference on Smart Structures and Materials, Dept. of Mechanical Engineering & Aeronautics University of Patras, Patras, Greece, 2023, pp. 1839–1850, https://doi.org/10.7712/150123.9954.444764.
[18] H. Peng, B. Chen, P. Dong, S. Chen, Y. Liao, Q. Guo, Application of FBG sensing technology to internal deformation monitoring of landslide, Adv. Civ. Eng. 2020 (2020) 1328945, https://doi.org/10.1155/2020/1328945.
[19] Z. Xiao, W. Huang, K. Wu, G. Nie, H.M.Z. Hassan, B. Hu, An experimental study on properties of pre-coated aggregates grouting asphalt concrete for bridge deck pavement, Materials 14 (2021) 5323, https://doi.org/10.3390/ma14185323.
[20] X.S. Cao, D.W. Cao, S.X. Liu, X.Q. Yang, L. Lan, Performance evaluation of a novel high durability epoxy asphalt concrete for bridge deck pavements, AMM 488–489 (2014) 550–553, https://doi.org/10.4028/www.scientific.net/AMM.488-489.550.
[21] X. Wang, J. Feng, H. Wang, Stress Analysis for Asphalt Concrete Deck Pavement with Considering Viscoelasticity of Asphalt Concrete and Interlayer Bonding Condition, Dtetr, 2017, https://doi.org/10.12783/dtetr/icaenm2017/7829.
[22] K. Kim, T.H.M. Le, Evaluation of the polymer modified tack coat on aged concrete pavement: an experimental study on adhesion properties, Polymers 15 (2023) 2830, https://doi.org/10.3390/polym15132830.
[23] America's Infrastructure Report Card 2021 | GPA: C-, (n.d.). https://infrastructurereportcard.org/(accessed October 20, 2023).
[24] S. Alampalli, M.M. Ettouney, A.K. Agrawal, Structural health monitoring for bridge maintenance, J. I. Coast Archaeol. 1 (2005) 345–354, https://doi.org/10.1080/15732480500252751.
[25] Jack Maxwell, Infrastructure Maintenance: an Economic Opportunity, 2015.
[26] R. Mason, L. Gintert, S. Sweeney, R. Lampo, K. Chandler, J. Chandler, Structural health monitoring, in: Critical Infrastructure Security, WIT Press, 2012, pp. 221–232.
[27] Charles Riley, A Portable Toolkit for Testing Bridge Structural Integrity, 2018.
[28] G. Morcous, Z. Lounis, Y. Cho, An integrated system for bridge management using probabilistic and mechanistic deterioration models: application to bridge decks, KSCE J. Civ. Eng. 14 (2010) 527–537, https://doi.org/10.1007/s12205-010-0527-4.
[29] P. Hüthwohl, I. Brilakis, A. Borrmann, R. Sacks, Integrating RC bridge defect information into BIM models, J. Comput. Civ. Eng. 32 (2018) 04018013, https://doi.org/10.1061/(ASCE)CP.1943-5487.0000744.
[30] FHWA, Bridge preservation guide. https://www.fhwa.dot.gov/bridge/preservation/guide/guide.pdf, 2018. (Accessed 21 October 2023).
[31] T.R. Board, National Academies of Sciences Engineering, Medicine, TR News March-April 2019: Renewing the National Commitment to the Interstate Highway System: A Foundation for the Future, The National Academies Press, Washington, DC, 2019, https://doi.org/10.17226/28014.
[32] GAO, Condition of Nation's Bridges Shows Limited Improvement, but Further Actions Could Enhance the Impact of Federal Investment, United States Government Accountability Office, 2010. https://www.gao.gov/assets/gao-10-930t.pdf. (Accessed 21 October 2023).
[33] V. Penadés-Plà, J.V. Martí, T. García-Segura, V. Yepes, Life-Cycle assessment: a comparison between two optimal post-tensioned concrete box-girder road bridges, Sustainability 9 (2017) 1864, https://doi.org/10.3390/su9101864.

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Optimizing food waste anaerobic digestion in Kuwait: Experimental insights and empirical modelling using artificial neural networks

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Abstract

This study investigates, for the first time, the anaerobic digestion of food waste in Kuwait to optimize methane production through a combination of artificial neural network (ANN) modelling and continuous reactor experiments. The ANN model, utilizing eight hidden neurons and a 70-20-10 split for training, validation and testing sets, yielded mean squared error values of 0.0056, 0.0048 and 0.0059 and coefficient of determination (R^2) values of 0.9942, 0.9986 and 0.9892, respectively. Methane percentages in biogas were predicted using six parameters: biomass type, pH, organic loading rate (OLR), hydraulic retention time (HRT), temperature and reactor volume. To validate the ANN results, continuous reactor experiments were conducted under an OLR of 3 kg VS m^{-3} d^{-1} and HRT of 20 days at varying temperatures (35°C, 40°C, 45°C, 50°C and 55°C). The experiments demonstrated optimal methane production in the mesophilic range, with ANN predictions closely aligning with experimental data up to 45°C. However, deviations were observed at higher temperatures, particularly under thermophilic conditions beyond 50°C. This study provides novel insights into waste-to-energy initiatives in Kuwait and highlights the potential of integrating computational models with empirical data to enhance biogas production processes.

Keywords

Anaerobic digestion, methane, food waste, continuous reactors, artificial neural network

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Introduction

With escalating global climate change concerns, many nations are shifting their focus towards reducing greenhouse gas (GHG) emissions by exploring more sustainable and cleaner energy alternatives. Compared to traditional fossil fuels, renewable energy sources offer numerous benefits, including decreased air pollution, environmental sustainability, reduced GHG emissions, and cost-effectiveness (Qi et al., 2022). Among these, biogas has emerged as a prominent solution, derived from the anaerobic degradation of organic waste and is recognized for its environmental advantages (Archana et al., 2024; Garg et al., 2024; Khawer et al., 2022).

The biogas industry has grown considerably, driven by rigorous research and governmental backing. In this context, anaerobic digestion (AD) is regarded as one of the most environmentally friendly alternatives for organic waste management due to its limited environmental footprints (Capson-Tojo et al., 2016; Jin et al., 2021), high potential for energy recovery (Kuruti et al., 2017) and biofertilizers production (Shen et al., 2013). Today, AD is regarded as a low-carbon technology that mitigates carbon emissions and effectively manages waste (Subbarao et al., 2023). It has been successfully employed to valorize several types of organic waste, including grape pomace, olive pomace, coffee waste, and dairy liquid wastes (El Achkar, 2017, 2022; El Achkar et al., 2018a, 2018c, 2020, 2022, 2023).

In addition to its environmental benefits, biogas production through AD plays a crucial role in the circular economy by transforming waste into valuable resources. The circular economy model emphasizes the continuous use of resources by minimizing waste, maintaining the value of products and materials for as

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Data availability statement

Data will be made available after reasonable request.

References

Al-Sulaimi IN, Nayak JK, Alhimali H, et al. (2022) Effect of volatile fatty acids accumulation on biogas production by sludge-feeding thermophilic anaerobic digester and predicting process parameters. *Fermentation* 8: 184.

American Public Health Association, Eaton AD, American Water Works Association, et al. (2005) *Standard Methods for the Examination of Water and Wastewater*. Washington, DC: APHA-AWWA-WEF.

Amicarelli V, Lagioia G and Bux C (2021) Global warming potential of food waste through the life cycle assessment: An analytical review. *Environmental Impact Assessment Review* 91: 106677.

Anaya Menacho W, Mazid AM and Das N (2022) Modelling and analysis for biogas production process simulation of food waste using Aspen Plus. *Fuel* 309: 122058.

Andrade Cruz I, Chuenchart W, Long F, et al. (2022) Application of machine learning in anaerobic digestion: Perspectives and challenges. *Bioresource Technology* 345: 126433.

Archana K, Visckram AS, Senthil Kumar P, et al. (2024) A review on recent technological breakthroughs in anaerobic digestion of organic biowaste for biogas generation: Challenges towards sustainable development goals. *Fuel* 358: 130298.

Braguglia CM, Gallipoli A, Gianico A, et al. (2018) Anaerobic bioconversion of food waste into energy: A critical review. *Bioresource Technology* 248: 37–56.

Callaghan FJ, Wase DAJ, Thayanithy K, et al. (2002) Continuous co-digestion of cattle slurry with fruit and vegetable wastes and chicken manure. *Biomass Bioenergy* 22: 71–77.

Capson-Tojo G, Rouez M, Crest M, et al. (2016) Food waste valorization via anaerobic processes: A review. *Reviews in Environmental Science and Biotechnology* 15: 499–547.

Chen T, Zhang L, Guo W, et al. (2024) Temperature drives microbial communities in anaerobic digestion during biogas production from food waste. *Environmental Science and Pollution Research* 31: 53823–53838.

Cheng H, Qin H, Li Y, et al. (2024) Comparative study of high-performance mesophilic and thermophilic anaerobic membrane bioreactors in the co-digestion of sewage sludge and food waste: Methanogenic performance and energy recovery potential. *Science of the Total Environment* 912: 169518.

Economou F, Chatziparaskeva G, Papamichael I, et al. (2024a) The concept of food waste and food loss prevention and measuring tools. *Waste Management & Research* 42: 651–669.

Economou F, Voukkali I, Papamichael I, et al. (2024b) Turning food loss and food waste into Watts: A review of food waste as an energy source. *Energies* 17: 3191.

El Achkar J (2017) *Méthanisation de marc de raisin. Caractérisation et optimisation du procédé et des prétraitements*. These de doctorat, Lorient.

El Achkar JH (2022) Sustainable solid waste management: Towards a complete and effective strategy. *Arab Journal of STI Policies* 3: 9–17.

El Achkar JH, Baydoun A, Salameh D, et al. (2018a) Can coffee grounds be considered as a potential for green energy production? In: *2018 4th International Conference on Renewable Energies for Developing Countries (REDEC). Presented at the 2018 4th International Conference on Renewable Energies for Developing Countries (REDEC)*, Beirut, Lebanon, pp.1–6.

El Achkar JH, El Jouahari A, Nassreddine C, et al. (2023) Anaerobic digestion of wastewater sludge for improved energy recovery: Alkaline pretreatment impact, digestate quality assessment, and reactor design. *Arabian Journal of Science and Engineeering* 48: 16109–16121.

El Achkar JH, Husain AB, Alotaibi N, et al. (2022) Could petroleum sludge be used to produce biomethane as a renewable energy source? In: *Presented at the ADIPEC*. Richardson, TX: OnePetro.

El Achkar JH, Lendormi T, Salameh D, et al. (2018b) Anaerobic digestion of grape pomace: Effect of the hydraulic retention time on process performance and fibers degradability. *Waste Management* 71: 137–146.

El Achkar JH, Rohayem C, Salameh D, et al. (2018c) Olive pomace, a source of green energy using anaerobic digestion. In: *2018 4th International Conference on Renewable Energies for Developing Countries (REDEC). Presented at the 2018 4th International Conference on Renewable Energies for Developing Countries (REDEC)*, Beirut, Lebanon, pp.1–6.

El Achkar JH, Ziade R, Louka N, et al. (2020) Treatment of dairy waste by anaerobic digestion to produce methane as green energy. In: *2020 5th International Conference on Renewable Energies for Developing Countries (REDEC). Presented at the 2020 5th International Conference on Renewable Energies for Developing Countries (REDEC)*, Marrakech, Morocco, pp.1–6.

El Bilali H and Ben Hassen T (2020) Food waste in the countries of the Gulf Cooperation Council: A systematic review. *Foods* 9: 463.

Fisgativa H, Tremier A and Dabert P (2016) Characterizing the variability of food waste quality: A need for efficient valorisation through anaerobic digestion. *Waste Management* 50: 264–274.

Gaby JC, Zamanzadeh M and Horn SJ (2017) The effect of temperature and retention time on methane production and microbial community composition in staged anaerobic digesters fed with food waste. *Biotechnology for Biofuels* 10: 302.

Garg A, Basu S, Shetti NP, et al. (2024) Biowaste to bioenergy nexus: Fostering sustainability and circular economy. *Environmental Research* 250: 118503.

Gonçalves Neto J, Vidal Ozorio L, Campos de Abreu TC, et al. (2021) Modeling of biogas production from food, fruits and vegetables wastes using artificial neural network (ANN). *Fuel* 285: 119081.

Harun N, Hassan Z, Zainol N, et al. (2019) Anaerobic digestion process of food waste for biogas production: A simulation approach. *Chemical Engineering & Technology* 42: 1834–1839.

Jacob S and Banerjee R (2016) Modeling and optimization of anaerobic codigestion of potato waste and aquatic weed by response surface methodology and artificial neural network coupled genetic algorithm. *Bioresource Technology* 214: 386–395.

Jin C, Sun S, Yang D, et al. (2021) Anaerobic digestion: An alternative resource treatment option for food waste in China. *Science of the Total Environment* 779: 146397.

Jomnonkhaow U, Uwineza C, Mahboubi A, et al. (2021) Membrane bioreactor-assisted volatile fatty acids production and *in situ* recovery from cow manure. *Bioresource Technology* 321: 124456.

Khawer MUB, Naqvi SR, Ali I, et al. (2022) Anaerobic digestion of sewage sludge for biogas & biohydrogen production: State-of-the-art trends and prospects. *Fuel* 329: 125416.

Kuruti K, Begum S, Ahuja S, et al. (2017) Exploitation of rapid acidification phenomena of food waste in reducing the hydraulic retention time (HRT) of high rate anaerobic digester without conceding on biogas yield. *Bioresource Technology* 226: 65–72.

Mahmudul HM, Akbar D, Rasul MG, et al. (2022) Estimation of the sustainable production of gaseous biofuels, generation of electricity, and reduction of greenhouse gas emissions using food waste in anaerobic digesters. *Fuel* 310: 122346.

Mougari NE, Largeau JF, Himrane N, et al. (2021) Application of artificial neural network and kinetic modeling for the prediction of biogas and methane production in anaerobic digestion of several organic wastes. *International Journal of Green Energy* 18: 1584–1596.

Obileke K, Makaka G, Tangwe S, et al. (2024) Improvement of biogas yields in an anaerobic digestion process via optimization technique.

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Designing an Effective Energy Literacy Course: A Multi-Phase Approach Tailored to Kuwaiti Students' Needs

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ABSTRACT: This study aims to develop a highly efficient energy literacy course respecting Kuwaiti cultural values and addressing the diverse needs of learners. A comprehensive approach was implemented accompanied by a range of integrated mixed-methods approach, including quantitative questionnaires, focus group discussions, and observations, was applied to assess the effectiveness of the course among 30 Kuwaiti students. The course remarkably improved the students' technical knowledge and overall energy literacy by combining various pedagogical tools and methods. Moreover, it positively influenced participants' attitudes and behaviors, fostering a greater sense of responsibility and awareness of energy conservation practices. Other universities and institutions in the Gulf region can adapt the model that is provided in this study to develop energy literacy courses that enhance students' energy knowledge and skills.

INTRODUCTION

Energy is the major challenge of our day, having consequences across ecological, economic, and academic domains. There are some studies that constantly emphasize the shortcomings of traditional methods for affecting the attitudes and behaviors of students in energy-related problems [1-3]. Adequate knowledge affects the awareness of energy-related problems, affecting students' propensity to take action for a better future even though the link between understanding and action remains ambiguous [4-5].

The significance of education as a pivotal mitigation strategy for energy-related problems such as climate change and sustainability has been emphasized by numerous studies [6-8]. Energy education must integrate diverse disciplines to serve as a mitigation driver, effectively communicate and contextualize energy science for clarity and credibility, enhance energy literacy, and empower both teachers and students, as tackling energy-related problems necessitates energy-literate public and students across all sectors of society worldwide [1, 9].

To ensure that students are equipped with responsible behaviors, such as energy consumption and renewable energy use in the era of climate change, developing an energy literacy course is a necessity [10-13]. Various factors such as socioeconomic situation, geography, and educational background affect energy literacy [14-16]. Therefore, while considering cultural and national factors, educational programs catered to increase energy literacy need to be designed [17]. With the emergence of this need, a literature gap is observed where few studies examine energy literacy in the Gulf region. Alghamdi & El-Hassan [18] assessed the energy literacy of university students in Saudi Arabia while Akinwale [19] conducted a study examining Saudi university students' energy knowledge. On the other hand, Altassan [20] created a comprehensive model for enhancing students' energy knowledge according to Saudi Arabia's 2030 vision. This shows a gap in designing an energy literacy course that exceeds the basics in the Gulf region.

As global environmental issues escalate, educational institutions play a critical role in developing environmentally aware individuals and supporting sustainable practices. Energy literacy initiatives are essential for equipping students with the knowledge and skills needed to tackle these challenges, allowing them to make informed energy use decisions and contribute to a sustainable future [10, 13]. Several factors influence the effectiveness of energy literacy initiatives, including cultural values, educational approaches, and individual characteristics. Tailoring programs to these factors ensures their success in different contexts [21].

However, there is a lack of research assessing energy or sustainability literacy levels among students despite a growing interest in sustainability in the Gulf region. While recent studies highlight the benefits of incorporating environmental themes into university curricula [22], research also reveals limitations. For instance, a study in Saudi Arabia found a lack of knowledge about environmentally friendly practices although they have improved climate change knowledge among final-year students [18]. Similarly, another study in Saudi Arabia reveals that although students were indifference due to limited understanding and awareness, they have moderate knowledge about energy conservation and

Gulf region. The favorable feedback on the teaching methods emphasizes the importance of combining technical knowledge with engaging and culturally sensitive instruction. Together, these elements provide a solid foundation for improving energy literacy and promoting sustainability education.

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REFERENCES

1. Dias, R.A., de Paula, M.R., Rizol, P.M.S.R., Matelli, J.A., de Mattos, C.R. and Balestieri, J.A.P., Energy education: Reflections over the last fifteen years. *Renew. Sustain. Energy Rev.*, 141, 110845 (2021).
2. McNeill, K.L. and Vaughn, M.H., Urban high school students critical science agency: Conceptual understandings and environmental actions around climate change. *Res. Sci. Educ.*, 42, 373-399 (2012).
3. Xie, Y., Zheng, Y. and Yang, Y., The relationship between students' awareness of environmental issues and attitudes toward science and epistemological beliefs—Moderating Effect of informal science activities. *Res. Sci. Educ.*, 53, **6**, 1185-1201 (2023).
4. García-Ferrero, J., Merchán, R.P., Roco, J.M.M., Medina, A. and Santos, M.J., Towards a sustainable future through renewable energies at secondary school: An educational proposal. *Sustainability*, 13, **22**, 12904 (2021).
5. Vainio, A., Pulkka, A., Paloniemi, R., Varho, V. and Tapio, P., Citizens' sustainable, future-oriented energy behaviours in energy transition. *J. Clean. Prod.*, 245, 118801 (2020).
6. Chodkowska-Miszczuk, J., Kola-Bezka, M., Lewandowska, A. and Martinát, S., Local communities' energy literacy as a way to rural resilience—an insight from inner peripheries. *Energies*, 14, **9**, 2575 (2021).
7. Martins, A., Madaleno, M. and Dias, M.F., Energy literacy assessment among Portuguese university members: Knowledge, attitude, and behaviour. *Energy Rep.*, 6, 243-249 (2020).
8. Šedlbauer, J., Slavík, M., Hejsková, P. and Činčera, J., Externalities are still underrated in energy education. *Renew. Energy*, 224, 120148 (2024).
9. Ilham, Z., Subramaniam, I., Jamaludin, A.A., Wan, W.A.A.Q.I., Halim-Lim, S.A., Ohgaki, H., Ishihara, K. and Mansor, M.R.A., Analysing dimensions and indicators to design energy education framework in Malaysia using the analytic hierarchy process (AHP). *Energy Rep.*, 8, 1013-1024 (2022).
10. Biasutti, M. and Frate, S., A validity and reliability study of the attitudes toward sustainable development scale. *Environ. Educ. Res.*, 23, **2**, 214-230 (2017).
11. Broberg, T. and Kažukauskas, A., Information policies and biased cost perceptions-The case of Swedish residential energy consumption. *Energy Policy*, 149, 112095 (2021).
12. Mehmood, A., Lin, R., Zhang, L., Lee, C.K. and Ren, J.Z., Qualitative mapping of barriers to the renewables' development against energy literacy dimensions: A case study of Pakistan. *Energy Rep.*, 8, 332-337 (2022).
13. Scott, W., Developing the sustainable school: Thinking the issues through. *Curric. J.*, 24, **2**, 181-205 (2013).
14. Cotton, D.R.E., Zhai, J., Miller, W., Dalla Valle, L. and Winter, J., Reducing energy demand in China and the United Kingdom: The importance of energy literacy. *J. Clean. Prod.*, 278, 123876 (2021).
15. Ji, H., Coronado, A.B., Mueller, M.A., Esposito, L.J., Tait, D. and Kim, H.J., A Learning Ecology Perspective of Energy Literacy among Youth: A Case Study from Alabama High Schools. *Sustainability*, 15, **22**, 16055 (2023).
16. Lusinga, S. and de Groot, J., Energy consumption behaviours of children in low-income communities: A case study of Khayelitsha, South Africa. *Energy Res. Soc. Sci.*, 54, 199-210 (2019).
17. Brychkov, D., Goggins, G., Doherty, E., Romero, N., Roudil, N., Di Trani, A., Singh, A., Smit, S., McLoughlin, E., de Castro Rodrigues Lima, R., Günbay, S.M., Delmonte, B.A., Hill, A., Domegan, C. and Clifford, E., A systemic framework of energy efficiency in schools: experiences from six European countries. *Energy Effic.*, 16, **4**, 21 (2023).
18. Alghamdi, A.K.H.,and El-Hassan, W.S., Saudi undergraduate students need pedagogical education for energy literacy. *J. Turk. Sci. Educ.*, 16, **4**, 521-537 (2019).
19. Akinwale, Y.O., Awareness and perceptions of university students in the business college towards energy savings and renewable energy sources in Saudi Arabia. *Int. J. Energy Econ. Policy*, 12, **3**, 470-476 (2022).
20. Altassan, A., Sustainable integration of solar energy, behaviour change, and recycling practices in educational institutions: a holistic framework for environmental conservation and quality education. *Sustainability*, 15, **20**, 15157 (2023).
21. Shutaleva, A., Ecological culture and critical thinking: building of a sustainable future. *Sustainability*, 15, **18**, 13492 (2023).
22. Freije, A.M., Hussain, T. and Salman, E.A., Global warming awareness among the University of Bahrain science students. *J. Assoc. Arab Univ. Basic Appl. Sci.*, 22, 9-16 (2017).
23. Alomari, M.M., El-Kanj, H., Topal, A. and Alshdaifat, N.I., Improving energy literacy among Kuwaiti university students with a tailored course on sustainable energy practices. *Glob. J. Eng. Educ.*, 26, **1**, 6-12 (2024).

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Performance analysis of palm tree microfibers in concrete

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This study investigates the effects of incorporating chemically treated Palm Tree Fronds (PTF) microfiber as a partial sand replacement in concrete. Concrete grades C28, C35, and C40 were evaluated with varying PTF contents ranging from 0 to 4% of sand volume. A total of 571 samples were tested using destructive and non-destructive methods to evaluate structural integrity and performance. The results revealed that PTF addition significantly enhanced workability across all grades, with higher PTF content improving slump values due to fiber-induced changes in rheological properties. Density decreased consistently, with reductions at 28 days ranging from 0.9 to 3.7% across grades, stabilizing at lower levels in higher-grade concrete. Compressive strength exhibited a linear decline with increasing PTF content, with reductions at 28 days ranging from 14.5 to 43.6% across grades, and tensile strength followed a similar trend, decreasing by 21.3% to 35.6%. Water absorption increased substantially, with an average rise from 10.6% at 1% PTF content to 51.2% at 4%, reflecting increased porosity. Thermal conductivity progressively decreased, with reductions averaging 26% to 33.6%, demonstrating enhanced insulating properties. Non-destructive tests indicated significant reductions in UPV and rebound numbers, correlating with increased fiber content and reduced matrix uniformity. SEM analysis revealed that PTF microfibers introduced porosity and microstructural discontinuities, contributing to the observed reductions in mechanical properties and increased permeability. Optimization analysis identified the optimal PTF content for balancing mechanical and thermal performance as below 1% for C28 and between 2.3% and 2.5% for higher grades. Consideration of a hybrid fiber mix, incorporating synthetic fibers such as steel, glass, or polypropylene, is recommended to compensate for the strength reduction associated with PTF addition. These findings demonstrate the potential of PTF-reinforced concrete for sustainable and energy-efficient construction, particularly in semi-structural applications.

Keywords Sustainable construction, Building insulation, Fiber reinforced concrete, Properties, Palm tree fronds

The response of the construction sector to global climate change requires an accelerated shift toward sustainable practices, underscoring the importance of eco-friendly construction materials. Fiber Reinforced Concrete (FRC) represents a significant innovation in construction materials, offering enhanced mechanical properties, durability, and sustainability. Researchers are increasingly focused on incorporating both natural and synthetic fibers, recycled fine aggregate (RFA), and industrial or agricultural waste into high-performance, sustainable concrete. These approaches are documented across recent studies[1–7], highlighting promising avenues for future material development. Recent studies highlight the potential of alternative aggregates like steel slag and fibers (e.g., steel, basalt) to enhance concrete sustainability and performance. Optimal combinations improve mechanical properties and durability, offering eco-friendly solutions for high-performance construction[8–11].

Synthetic fibers

Synthetic fibers, including nylon, polypropylene, carbon fiber, glass fiber, steel and other recycled materials, have been extensively researched for their ability to enhance concrete properties. Steel fiber-reinforced concrete (SFRC) is recognized for its high strength, crack control, toughness, post-fire performance, and cost-effectiveness[12–18]. Incorporating recycled steel fibers from waste tires (WTSF) into concrete provides environmental benefits and improved mechanical properties[6]. However, challenges related to fiber consistency necessitate further research on recycling technologies and design guidelines[16]. Tayebi et al.[15] investigated the flexural response of SFRC with recycled nylon granules (NG) and zeolite after high-temperature exposure, finding that zeolite addition

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73. ASTM (American Society for Testing and Materials). ASTM C39/C39M: Standard test method for compressive strength of cylindrical concrete specimens. https://doi.org/10.1520/C0039_C0039M-21 (2021).
74. ASTM (American Society for Testing and Materials). ASTM C666: Test method for resistance of concrete to rapid freezing and thawing. https://doi.org/10.1520/C0666-97 (2017).
75. Fibres for Concrete—Part 1: Steel Fibres—Definitions, Specifications and Conformity. (2006).
76. British Standards Institution. Fibres for Concrete—Part 2: Polymer Fibres—Definitions, Specifications and Conformity. (2006).
77. Vinutha, H. P., Poornima, B. & Sagar, B. M. Detection of outliers using interquartile range technique from intrusion dataset. In *Information and Decision Sciences* Vol. 701 (eds Satapathy, S. C. et al.) 11–518 (Springer Singapore, 2018).
78. Hashim, M. Y., Roslan, M. N., Amin, A. M., Zaidi, A. M. A. & Ariffin, S. Mercerization treatment parameter effect on natural fiber reinforced polymer matrix composite: a brief review. *World Acad. Sci. Eng. Technol. Int. J. Chem. Mol. Nucl. Mater. Metall. Eng.* **6**, 778–784 (2012).
79. Rocha, M. C. G., Acevedo, N. I. A. D., Oliveira, C. I. R. D., Sanches, M. C. & Coelho, N. N. Mercerization effect on the properties of LDPE/PHB composites reinforced with castor cake. *Polímeros* **30**, e2020037 (2020).
80. Oladele, I. O., Ibrahim, I. O., Akinwekomi, A. D. & Talabi, S. I. Effect of mercerization on the mechanical and thermal response of hybrid bagasse fiber/$CaCo_3$ reinforced polypropylene composites. *Polym. Test.* **76**, 192–198 (2019).
81. ASTM (American Society for Testing and Materials). ASTM C31/C31M: Practice for Making and Curing Concrete Test Specimens in the Field. https://doi.org/10.1520/C0031_C0031M-22 (2023).
82. ASTM (American Society for Testing and Materials). ASTM C1064/C1064M: Standard test method for temperature of freshly mixed hydraulic-cement concrete. https://doi.org/10.1520/C1064_C1064M-17 (2023).
83. ASTM (American Society for Testing and Materials). ASTM C192/C192M: Standard practice for making and curing concrete test specimens in the laboratory. https://doi.org/10.1520/C0192_C0192M-14 (2015).
84. ASTM (American Society for Testing and Materials). ASTM C143-78: Standard test method for slump of Portland cement concrete. (2017).
85. ASTM (American Society for Testing and Materials). ASTM C642: Test Method for density, absorption, and voids in hardened concrete. https://doi.org/10.1520/C0642-21 (2022).
86. ASTM (American Society for Testing and Materials). ASTM C597: Standard test method for pulse velocity through concrete. https://doi.org/10.1520/C0597-16 (2023).
87. ASTM (American Society for Testing and Materials). ASTM C805/C805M: Test Method for Rebound Number of Hardened Concrete. https://doi.org/10.1520/C0805_C0805M-18 (2019).
88. ASTM (American Society for Testing and Materials). ASTM C496/C496M: Standard test method for splitting tensile strength of cylindrical concrete specimens. https://doi.org/10.1520/C0496_C0496M-17 (2017).
89. ASTM (American Society for Testing and Materials). ASTM C469/C469M: Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression. https://doi.org/10.1520/C0469_C0469M-14 (2022).
90. ASTM (American Society for Testing and Materials). ASTM C518-21: Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus. https://doi.org/10.1520/C0518-21.
91. ASTM (American Society for Testing and Materials). ASTM C1723-16: Guide for Examination of Hardened Concrete Using Scanning Electron Microscopy. https://doi.org/10.1520/C1723-16R22.
92. Mohanta, N. R. & Murmu, M. Performance assessment of Linz-Donawitz slag as alternative coarse aggregate in concrete: a comprehensive study on mechanical and durability properties. *Innov. Infrastruct. Solut.* **8**, 281 (2023).
93. Alatshan, F., Altlomate, A., Mashiri, F. & Alamin, W. Effect of date palm fibers on the mechanical properties of concrete. *Sustain. Build. Res. Center* https://doi.org/10.12972/susb.20170007 (2017).

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Author contributions
M.H.Y: project administration, conceptualization, software, writing—original draft preparation. R.L: validation, methodology, data curation, writing—review and editing. Z.M: supervision, investigation. Jumah, A.J: data curation Farhat, M.H.F: resources, software.

Declarations

Competing interests
The authors declare no competing interests.

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Discover Civil Engineering

Review

Fiber Bragg grating (FBG)-based sensors: a review of technology and recent applications in structural health monitoring (SHM) of civil engineering structures

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Abstract
Structural health monitoring (SHM) has become increasingly common in assessing built structures and the ongoing monitoring of older ones, whether for preventive maintenance applications or for assuring the integrity of deteriorating structures. Several sensing technologies have been developed and utilized for these applications. Over the past two decades, optical fiber sensors (OFS) have been utilized in various civil engineering projects due to their inherent advantages. This includes properties such as lightweight, size, immunity to electromagnetic interference (EMI), corrosion resistance, and embedding capability. Several monitoring systems based on OFS have been developed to measure and assess real-time data of various civil infrastructures continuously. Since its inception, Fiber Bragg grating (FBG) has been an ideal candidate for OFS technology; currently, most OFS systems use FBG. Due to its inherent characteristics and potential applications, considerable efforts and advancements have been made in the FBG-based sensing field. One of the most developed FBG sensors is strain OFS. Not just because of their benefits compared to the traditional strain gauge but also because of their high sensitivity and low cost. FBG strain sensors acquire an essential share of the SHM market. This review paper aims to give a general understanding of the basic principles of FBG sensors, advances in sensing and data processing techniques, developments of novel optical fiber sensors, temperature compensation techniques, and practical applications of FBG sensing technology in SHM. Moreover, this paper aims to contribute to the existing knowledge by highlighting the evolving landscape of FBG sensors and suggesting potential research areas in the context of SHM.

Keywords Fiber Bragg grating (FBG) · Structural health monitoring (SHM) · Sensors · Optical fiber sensors (OFS)

1 Introduction

Civil infrastructures such as buildings, bridges (pedestrian and vehicular), tunnels, factories, space shuttles, large dams, and other facilities are essential for the functioning of society. Constructing and maintaining these structures demands significant economic investments and directly impacts user safety. The service life of these facilities varies, ranging from decades to centuries, depending on their significance and nature. For instance,

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The measurements captured by FBG sensors are diverse, encompassing strain, temperature, displacement, vibration, pressure, torsion, and inclination. For instance, they provide crucial insights into material deformation under loads, track movements in structures over time, and assess thermal effects on structural materials. The versatility of FBG sensors to measure multiple parameters simultaneously, combined with their capability for real-time monitoring, positions them as indispensable tools in the realm of civil engineering.

Author contributions M. H. Yassin: conceptualization, drafting, editing, and applications in civil engineering. M. H. Farhat, Conceptualization, drafting, reviewing and fiber optic related sections R. Soleimanpour: drafting, reviewing, Real-life practical applications and structural health monitoring. M. Nahas: reviewing, editing and FBG applications.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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References

1. Chun P, Yamashita H, Furukawa S. Bridge damage severity quantification using multipoint acceleration measurement and artificial neural networks. Shock Vib. 2015. https://doi.org/10.1155/2015/789384.
2. Habeeb B. Assessment of the impact of climate change and flooding on bridges and surrounding area. Front Built Environ. 2023. https://doi.org/10.3389/fbuil.2023.1268304.
3. Zinno R, Haghshenas SS, Guido G, et al. Artificial intelligence and structural health monitoring of bridges: a review of the state-of-the-art. IEEE Access. 2022. https://doi.org/10.1109/access.2022.3199443.
4. Frumkin A, Shimron AE, Rosenbaum J. Radiometric dating of the siloam tunnel. Jerus Nat. 2003. https://doi.org/10.1038/nature01875.
5. Frumkin A, Shimron AE. Tunnel engineering in the iron age: geoarchaeology of the siloam tunnel. Jerus J Archaeol Sci. 2006. https://doi.org/10.1016/j.jas.2005.07.018.
6. Τσοκασ ΓΝ, Τσούρλος Π, Kim JH, et al. Assessing the condition of the rock mass over the tunnel of eupalinus in samos (Greece) using both conventional geophysical methods and surface to tunnel electrical resistivity tomography. Archaeol Prospect. 2014. https://doi.org/10.1002/arp.1489.
7. Soleimanpour R, Hany Yassin M, Mehdizadeh A, et al. Locating cracks in isotropic plates using nonlinear guided waves. Appl Acoust. 2023;211:109522.
8. Soleimanpour R, Soleimani SM, Mohammad NK. Damage detection and localization in loose bolted joints. Proced Struct Integr. 2022;37:956–63.
9. Reza S, Mohamad SS, Sulaiman SMN. A baseline free method for locating imperfect bolted joints. Struct Monit Maint. 2022;9(3):237–58.
10. Aseem A, Ng CT. Debonding detection in rebar-reinforced concrete structures using second harmonic generation of longitudinal guided wave. NDT E Int. 2021;122:102496.
11. Linderman LE, Mechitov KA, Spencer BF. TinyOS-based real-time wireless data acquisition framework for structural health monitoring and control. Struct Control Health Monit. 2013;20(6):1007–20.
12. Diamanti K, Soutis C. Structural health monitoring techniques for aircraft composite structures. Prog Aerosp Sci. 2010;46(8):342–52.
13. Di Sante R. Fibre optic sensors for structural health monitoring of aircraft composite structures: recent advances and applications. Sensors. 2015;15(8):18666–713.
14. Goyal D, Pabla BS. The vibration monitoring methods and signal processing techniques for structural health monitoring: a review. Arch Comput Methods Eng. 2016;23(4):585–94.
15. Soleimanpour R, Ng C-T, Wang CH. Higher harmonic generation of guided waves at delaminations in laminated composite beams. Struct Health Monit. 2017;16(4):400–17.
16. Ostachowicz W, Soman R, Malinowski P. Optimization of sensor placement for structural health monitoring: a review. Struct Health Monit. 2019;18:963–88.
17. Mustapha S, Ng CT, Lu Y, et al. Sensor networks for structural health monitoring. J Sens. 2020. https://doi.org/10.1155/2020/3060672.

Case Study

Influence of Palm Tree Fiber Addition on the Physical, Mechanical, and Thermal Properties of High-Strength Concrete

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Abstract: The utilization of natural fibers as reinforcement in concrete mixtures continues to gain interest due to their environmentally friendly nature, biodegradability, economic benefits, and high strength-to-weight ratio. In this study, high-strength concrete was mixed with ground palm tree frond (PTF) short fibers at different portions of fiber 1%, 2%, 3%, and 4% of concrete weight, as replacement of fine aggregate. This paper provides an in-depth experimental investigation on the effect of adding short PTF to high-strength concrete on the physical, mechanical, and thermal characteristics of concrete. The findings indicated that the strength of the concrete deteriorated progressively with the increased addition of PTF. For instance, the compressive strength of 4% PTF concrete was 28.18 MPa, and 43.81 MPa for plain concrete. On the other hand, the split tensile strength for 4% PTF concrete and plain concrete were 2.42 MPa and 2.99 MPa, respectively. However, it was observed that, despite the decrease in strength, the thermal resistance of the concrete notably increased with the addition of PTF. The inclusion of 4% PTF in concrete reduced heat transfer rates significantly by 51.19% and 39.87% compared to plain concrete in wet and dry conditions, respectively. The maximum surface temperature recorded for 4% PTF after 30 min of heat exposure of 275 W was 33.47°C versus 39.47°C for plain concrete in a dry condition. The thermal conductivity of 4% PTF concrete was reduced by approximately 21% compared to plain concrete. Incorporating short PTF in concrete yielded excellent thermal insulation properties, which can be an attractive choice for construction materials as a potential for energy saving and energy efficiency improvement. **DOI: 10.1061/JMCEE7.MTENG-19000.** *This work is made available under the terms of the Creative Commons Attribution 4.0 International license, https://creativecommons.org/licenses/by/4.0/.*

Author keywords: Palm tree fiber (PTF); Natural fiber reinforced concrete; Building material; High-strength concrete.

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Introduction

Addressing global climate change demands that the construction industry adopt more sustainable practices and eco-friendly construction materials. Natural fibers, such as palm, coir, and bamboo, are increasingly recognized for their minimal environmental impact, excellent insulation properties, and their ability to enhance concrete properties like crack resistance and thermal tolerance (Adamu et al. 2021; Kesikidou and Stefanidou 2019; Paul et al. 2020; Razmi and Mirsayar 2017; Talaei and Mostofinejad 2021; Wu et al. 2020). Plant-based aggregates offer substantial benefits, including improved energy efficiency and lower environmental impacts across various applications and climate zones (Charai et al. 2022a, b; El Hammouti et al. 2023a; Horma et al. 2022).

Biobased concrete and composites made from plant aggregates (e.g., rice straw, husk, agave leaves, walnut shells) exhibit improved mechanical properties and hygrothermal performance, reducing the carbon footprint by substituting conventional high-energy-consuming elements (Beskopylny et al. 2023; Moussi et al. 2023; Rosas et al. 2022). Variations in energy and carbon dioxide balances between wood and concrete building materials underline the significance of transitioning toward more sustainable and renewable materials to alleviate environmental impacts (Gustavsson and Sathre 2006). Sustainable materials like blast furnace slag (BFS) concrete mixtures, aerated autoclaved concrete (AAC) blocks, and recycled steel components have the potential to lower carbon emissions in construction projects (Jang et al. 2015; Kamal 2020; Özbay et al. 2016). Integrating biocomposites, made from renewable plant fibers, into construction represents a strategic shift toward a circular economy by significantly reducing the carbon footprint.

Studies have shown that materials like spent tea, mint stem aggregates, and other plant-based additives not only improve the thermal insulation of buildings but also offer reductions in overall

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increase of the fiber percentage. The lowest heat transfer rate was achieved with 4% PTF concrete with values of 0.24°C/min and 0.21°C/min for wet and dry conditions respectively. The heat transfer rates of 4% PTF concrete were reduced significantly by 51.19% and 39.87% compared to plain concrete. Furthermore, the maximum surface temperature of plain concrete and 4% PTF concrete after 30 min of heat exposure were 37.15°C and 28.39°C for the wet condition, and for the dry condition, 39.47°C and 33.47°C, respectively. The 4% PTF concrete manifested lower maximum surface temperature recorded compared to plain concrete by 23.60% and 15.20% for wet condition and dry condition, respectively. The reduction is attributed to the low thermal conductivity of the palm fiber (0.06 W/m °K) compared to that of concrete (2.25 W/m °K) (Ali and Alabdulkarem 2017; Yun et al. 2014). Furthermore, the number of voids in the material is responsible for lowering the heat transfer, thus reducing the thermal conductivity of the material (Benmansour et al. 2014; Raut and Gomez 2016). Additionally, the inclusion of PTF in concrete lowers the heat transfer and thermal conductivity of the concrete mix compared to plain concrete; consequently, it proves the feasibility of PTF in reducing the energy consumption in buildings during the cooling and heating.

This research highlights the value of thorough material testing in civil engineering, offering essential insights for engineers and researchers in selecting materials and designing structures. Understanding these material properties and interactions opens possibilities for innovative uses of PTF-modified concrete, potentially spurring advancements in the construction industry.

Future Work

The length and volume fraction of palm fibers are crucial in determining the structural behavior and properties of reinforced concrete. The excessive addition of natural fibers in concrete reduced the internal strength of the material, which was supported by other studies (Dawood and Ramli 2011; Dayananda et al. 2018). Thus, future studies are recommended to examine the effect of using palm fiber less than 0.5% of the concrete weight on the physical, mechanical, and thermal performance of the material. Future studies should also aim to optimize PTF content to balance compressive strength loss with other beneficial properties. Short fibers offer limited benefits and pose challenges at high percentages. Thus, the strength and the elastic modulus of PTF concrete could be enhanced by adding fibers with adequate lengths. Furthermore, enhancing the interfacial bonding of the fiber and the surrounding concrete is essential for the enhancement of the performance of the concrete.

To fully understand the characteristics and performance of these composites for practical applications, further analysis and tests are required. For instance, to evaluate the long-term performance and durability of PTF-reinforced concrete, a comprehensive series of tests shall be conducted. These include freeze-thaw resistance (ASTM 2017c) to measure dynamic modulus reduction and physical deterioration under rapid freeze-thaw cycles; water permeability (BSI 2019) to assess the depth of water penetration under pressure; chloride ion penetration (ASTM 2022c) using electrical indication to evaluate resistance; sulfate attack resistance (ASTM 2010) by immersing specimens in sodium sulfate solution to measure expansion and strength loss; and carbonation depth (RILEM CPC-18 1988) by exposing specimens to a CO_2-rich environment. Additionally, rheological tests of PTF-concrete bricks will involve plastic and drying shrinkage (ASTM 2014) to monitor dimensional changes over time, creep tests (ASTM 2024) to measure deformation under sustained load. Lastly, scanning electron microscopy (SEM) tests are required, including microstructural analysis (ASTM 2021a) to observe the morphology, size, and distribution of fibers; elemental analysis (EDS) to identify the elemental composition at the fiber-concrete interface; and fractography (ASTM 2023d) to examine fracture surfaces and understand failure mechanisms. This plan will provide detailed insights into the durability, rheological properties, and microstructural characteristics of PTF-reinforced concrete.

Conclusions

This study investigates the potential of using PTF as a sustainable and cost-effective concrete additive to achieve improved thermal performance without compromising essential mechanical properties. Concrete mixtures were prepared with varying PTF volume fractions (0%, 1%, 2%, 3%, and 4%) relative to the sand content to evaluate their physical, mechanical, and thermal characteristics.

The study found that adding PTF to concrete had several key effects. The density of the concrete decreased slightly, making it lighter. However, water absorption increased because PTF is hydrophilic. Despite this, all concrete mixes maintained excellent quality, with UPV exceeding 4.2 km/s and RN tests showing good internal integrity. While the compressive and elastic strength of the concrete were slightly reduced by PTF inclusion, the split tensile strength remained acceptable. In terms of thermal performance, PTF significantly improved insulation, reducing the heat transfer rate by up to 51% and thermal conductivity by 21%. These findings demonstrate the potential of PTF as a promising material for concrete production. By lowering heat transfer and enhancing thermal insulation, PTF contributes to energy savings in buildings, supporting the development of sustainable construction practices. However, it is important to note that this research is preliminary, focusing on the use of PTF in high-strength concrete. Further tests, such as concrete durability tests and rheological tests, including concrete creep and shrinkage, are required. Additionally, SEM tests should be conducted to consider material aging.

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments

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Author contributions: Mohammad Hany Yassin: Conceptualization, Methodology, Validation, Resources, Supervision, Project Administration, Writing–Original Draft and Review and Editing. Zainab Al Hajaj: Conceptualization, Validation, Formal Analysis, Investigation, Writing–Original Draft and Review and Editing, Visualization, Supervision. Rana Lakys: Conceptualization, Literature Review and Validation of NDT (Non-Destructive Testing). Zein-Eddine Merouani: Conceptualization, PTF Collection, PTF Preparation, Mix Design and Testing Matrix. Adel Jumaah: Formal Analysis, Investigation, Data Curation.

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Conference Publications

Impact of Phase Change Materials on Temperature Regulation in Passive Cooling Systems

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Abstract. Economic and population growth in developing countries, combined with local and global warming, are primary factors in exacerbating the cooling demands by the population. Currently, energy consumption from buildings account for 36% of global energy demand and a staggering 90% in Kuwait. Electricity demand is expected to continue to rise and becomes problematic in countries that are highly dependent on the oil and gas industry for energy production. This ongoing situation underscores the importance of implementing sustainable solutions, such as, passive cooling with phase change materials (PCMs), to improve indoor-climates and reduce energy consumption. This study aims to contribute to the field by experimentally utilizing and analyzing the impact of commercially available PCMs on indoor passive cooling. Two identical 75 mm sandwich panel cabins were constructed in Kuwait —one serving as a control and the other as an experimental cabin. Both cabins were equipped with sensors to measure the indoor temperature and a weather station to monitor outdoor temperature. PCM was added incrementally over several weeks. Results demonstrated that the use of PCM significantly reduced indoor temperature fluctuations and peak temperatures in the experimental cabin compared to the control cabin. Applying PCM to all four walls reduced the maximum temperature by 4.25 °C. The findings indicate that PCM can effectively moderate indoor temperatures, maintaining a more stable and comfortable indoor climate without the need for mechanical cooling systems. This study highlights the potential of PCM as a sustainable solution for reducing energy consumption in hot climates, particularly in regions heavily reliant on air conditioning.

Keywords: Thermal Management, Energy Efficiency, Sustainable Building Design.

4 Conclusion

The rising global temperatures and economic growth in developing countries are significantly increasing the demand for indoor cooling. Currently, energy consumption from buildings constitutes 36% of global energy demand and 90% in Kuwait. This reliance on energy-intensive air-conditioning systems is particularly problematic in regions dependent on unsustainable energy sources. Consequently, it is crucial to explore and implement sustainable solutions such as phase change materials to improve indoor climates and reduce mechanical energy consumption.

This study empirically investigated the use of PCMs in Kuwait from February to March 2024. PCM was incrementally integrated into a portable cabin, with indoor temperatures compared to those of an identical control cabin. The results were promising: PCM improved the indoor climate by dissipating heat in cooler conditions and absorbing heat during warmer periods. This effect was noticeable from the addition of the first PCM wall and became more pronounced as additional walls were covered. Specifically, with four walls of PCM, there was a notable reduction in temperature fluctuations and greater stability in the temperature profile, with more significant differences between peaks and troughs during hot and cold periods compared to the control cabin.

The study underscores the practical application of PCM for passive cooling in hot climates. The reduction in energy consumption due to decreased reliance on air conditioning has positive environmental implications, contributing to a more sustainable future.

However, several limitations should be acknowledged. The findings are specific to Kuwait and would benefit from validation in other regions. Additionally, the study was conducted over a limited period (February to March 2024). Examining the effects of PCM over a more extended period and during hotter months could provide further insights. Moreover, the impact of PCM might vary with different installation sequences, such as starting with the east wall instead of the south wall, which could yield different results.

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References

[1] Mastrucci A, van Ruijven B, Byers E, Poblete-Cazenave M, Pachauri S. Global scenarios of residential heating and cooling energy demand and CO2 emissions. Climatic Change 2021;168:14. https://doi.org/10.1007/s10584-021-03229-3.

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Thermal Comfort, Humidity, and Air Quality in Passive Cooling Systems Using Phase Change Materials

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Abstract

The global demand for energy consumption is rising at an alarming rate. This increase is driven by economic growth, population expansion, and escalating temperatures due to climate change. Cooling energy demand is projected to rise by 275% globally by 2050, with the Middle East and North Africa (MENA) region being one of the most affected. In Kuwait, buildings account for approximately 90% of electricity consumption, and air conditioning alone constitutes over 70% of this usage during peak summer months. Kuwait's electricity demand is expected to reach 30,000 MW by 2030, primarily driven by cooling needs. With a population reliant on fossil fuel-based energy, there is an urgent need to find sustainable solutions that can mitigate this rising demand. This paper investigates the use of phase change materials (PCMs) to improve thermal comfort. Two portable cabins were constructed in Kuwait, one equipped with PCMs and the other serving as a control. The study evaluates the combined impact of PCM integration on perceived indoor thermal index, humidity, and air quality during the month of March 2023. Results show that PCM application reduced indoor temperature peaks by 3.31°C on average and stabilized humidity fluctuations by 10%. Moreover, daily particulate matter (PM 2.5) concentrations were reduced by 6.12 μg/m³, indicating an improvement in air quality. These findings suggest that PCMs offer a promising passive cooling solution that can enhance thermal comfort, improve indoor air quality, and the potential to reduce energy consumption in hot climates like Kuwait.

Keywords
Thermal Comfort, Building Energy Consumption, Phase Change Materials, Passive Cooling

Biographies
Arash Mehdizadeh is an Assistant Professor in the Electrical and Electronics Engineering Department at the Australian University in Kuwait. He holds a PhD in Electrical and Electronics Engineering from The University of Adelaide, Australia, where he earned a Dean's Commendation for his doctoral thesis. He then completed his Post-Doctoral Fellowship at the University of Western Australia. He also holds an MSc in Data Science from The University of Texas at Austin and an MSc in Computer Systems Engineering from Amirkabir University of Technology, Iran. He specializes in data science, artificial intelligence, microelectronics, and biomedical engineering, with a strong focus on computational biology and embedded systems design. His research interests span various domains, including computational biology, microelectronics, and biomedical devices. He has contributed extensively to the field of energy-efficient building solutions, biomedical implants, and advanced computational modeling. Throughout his academic career, he has garnered multiple research grants, including from the Kuwait Foundation for the Advancement of Sciences (KFAS), and has published widely in prestigious journals and conferences. His work on artificial intelligence applications and computational systems has earned him several best project awards at the Australian University in Kuwait. In addition to his research contributions, Dr. Mehdizadeh is actively involved in teaching and mentoring students, with a focus on project-based learning, and has held previous academic positions in Australia and Iran. He is a professional member of IEEE, Engineers Australia, and The Chartered Institute for IT.

Ahmad Sedaghat is a professor at the Australian University in Kuwait with over 30 years of experience in the field of Mechanical Engineering. He also serves as an adjunct research professor at Central Queensland University (CQU), Australia. Prof. Sedaghat has a distinguished academic and research background, focusing on renewable energy, aerodynamics, and nanofluids. He has played a pivotal role as a course coordinator in project-based learning (PBL) and is a key member of the curriculum committee at the Australian University in Kuwait. Prof. Sedaghat has been awarded multiple international research grants, including three projects funded by the Engineering and Physical Sciences Research Council (EPSRC) in the UK, as well as several grants from the Kuwait Foundation for the Advancement of Sciences (KFAS). His research has made substantial contributions to energy efficiency, fluid mechanics, and renewable energy systems. With more than 145 refereed journal publications and over 4,700 citations, his work has earned him global recognition, including the Research Achievement Award at Australian University in 2018/2019. As a Fellow of Engineers Australia and a chartered aerospace and mechanical engineer, Prof. Sedaghat is actively involved in academia and industry. He frequently reviews for prestigious journals and serves on editorial boards, having received multiple awards for his contributions as a reviewer in the fields of Energy and Renewable Energy.

Sayed Mohamad Soleimani is currently serving as a professor of engineering practice at the Lyles School of Civil and Construction Engineering at Purdue University. He boasts over 15 years of rich industrial experience, specializing in bridge engineering, concrete and steel design and construction, and project management. His professional credentials include licensure as a professional engineer in California, British Columbia, Ontario, and Australia. Furthermore, he has been honored as a Fellow of the Institution of Engineers Australia Fellow. His research interests focus on energy management in buildings, the development of sustainable, high-quality construction materials, and the repair and retrofit of civil infrastructures. He is also interested in transferring his knowledge to the next generation of engineers and this fuels his passion for research in engineering education.

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Dynamic IoT Determination of Overall Heat Transfer Coefficient in a Portable Cabin in Kuwait

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Abstract. Two portable cabins (size 2 m width, 2 m depth, 2.8 m height) were constructed using 75 mm Polyurethane sandwich panels (insulation walls) to simulate low energy buildings in Kuwait. Experimental measurements were conducted using eight K-type thermocouple probes on interior/exterior surfaces of the cabins' walls to dynamically evaluate overall heat transfer coefficient during the hot months of August and September 2023 using IoT data storage. The collected data was further curated to ensure quality by treating negative values, handling potential division by zero issues, and filtering out large numbers. The dynamic average overall heat transfer coefficients were found to be 0.186, 0.198, 0.203, and 0.206 W/m^{2}K for the East, North, West, and South facing walls, respectively. This is far better than the static (steady state) overall heat transfer coefficient of 0.2534 W/m^{2}K, indicating that the dynamic behavior of the insulation walls is very promising, particularly by saving 21.76% cooling energy demands in summertime in Kuwait.

Keywords: Insulation Sandwich Panels · Kuwait's Hot Climate · Low-Energy Building

1 Introduction

The building sector is one of the largest energy-consuming sectors in the world. In Kuwait, space heating and cooling account for about 70% of total residential energy consumption [1]. Krarti and Hajiah [2] stated that the building sector in Kuwait consumes 90% of the electricity for cooling, a figure also reported by Saber et al. [3]. There is enormous potential to increase the energy efficiency of buildings. However, a clear long-term government commitment, combined with well-designed packages of efficiency policies reinforced by adequate implementation capacity, is needed to improve energy efficiency in Kuwait's buildings.

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0.2534 W/m^{2}K, indicating superior thermal performance under dynamic conditions, particularly, during the hot summer months of Kuwait. This indicates that for the average dynamic U-value of 0.1983 for all walls, the cooling loads can be reduced by 21.76% in summer months of Kuwait. The results improved our understanding of thermal behavior of insulation walls in hot climates. The findings will contribute to development of low-energy buildings in Kuwait and countries with similar climatic conditions. Future research should continue to explore these findings across different seasons and conditions to fully establish the benefits and applicability of advanced insulation materials in energy-efficient building design.

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References

1. 2019 Kuwait Energy Outlook, Sustaining prosperity through strategic energy management. https://www.kisr.edu.kw/media/filer_public/a7/d7/a7d7ecfa-242e-4c5f-a9bc-f971295b0a41/keo_report_english.pdf. Accessed 21 June 2024
2. Krarti, M., Hajiah, A.: Analysis of impact of daylight time savings on energy use of buildings in Kuwait. Energy Policy **39**(5), 2319–2329 (2011)
3. Saber, H.H., Maref, W.: Energy performance of cool roofs followed by development of practical design tool. Front. Energy Res. **7**, 122 (2019)
4. Canberra, A.C.T.: Energy use in the Australian residential sector 1986–2020. Department of the Environment, Water, Heritage and the Arts, Australia (2008)
5. Energy Data Homepage. https://www.energy.gov.au/energy-data/australian-energy-statistics/energy-consumption. Accessed 21 June 2024
6. Aldawi, F., et al.: A new house wall system for residential buildings. Energy Build. **67**, 403–418 (2013)
7. Howard, B., et al.: Spatial distribution of urban building energy consumption by end use. Energy Build. **45**, 141–151 (2012)
8. Zhao, H.X., Magoulès, F.: A review on the prediction of building energy consumption. Renew. Sustain. Energy Rev. **16**(6), 3586–3592 (2012)
9. Panayiotou, G., Kalogirou, S.A., Tassou, S.A.: Evaluation of the application of Phase Change Materials (PCM) on the envelope of a typical dwelling in the Mediterranean region. Renew. Energy **97**, 24–32 (2016)
10. Sedaghat, A., et al.: Effects of window films in thermo-solar properties of office buildings in hot-arid climates. Front. Energy Res. **9**, 173 (2021)
11. Sedaghat, A., et al.: Climate change and thermo-solar patterns of office buildings with/without window films in extreme hot-arid climate of Kuwait. Sol. Energy **217**, 354–374 (2021)
12. Sharma, A., et al.: Review on thermal energy storage with phase change materials and applications. Renew. Sustain. Energy Rev. **13**(2), 318–345 (2009)
13. Bruno, F., Tay, N., Belusko, M.: Minimising energy usage for domestic cooling with off-peak PCM storage. Energy Build. **76**, 347–353 (2014)

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Techno-economic and environmental evaluation of integrated microgrid systems for electrification and hydrogen production

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Abstract. The present work investigates the feasibility of electrolyzer-based hydrogen generation through a hybrid renewable energy system. Evaluations focusing on technical, economic and environmental evaluations are conducted to determine the optimized system architectures that maximize energy efficiency and environmental benefits. Three hybrid renewable energy systems were assessed, including grid-connected and grid isolated configurations of solar PV array, wind turbines (WT), hydrogen fuel cells, and backup battery bank. The lowest levelized energy cost, at 0.539 $/kWh, and the lowest cost of producing hydrogen, at 6.85 $/kg were achieved by integrating solar PV and wind turbine with the grid connectivity. Integrating Solar PV and wind turbine connected to the power supply grid resulted in the lowest levelized energy cost, at However, in the case of a grid-isolated system utilizing fuel cells or battery storage banks, the hydrogen cost rises above 8.0 $/kg due to the higher capital expenses associated with the system. With yearly carbon dioxide emissions of 240841.66 kg, the optimized system produces 111 877 kg of green hydrogen annually. Additionally, the optimized system (System 1) has the lowest Human Health Damage (HHD) and Ecosystem Damage (ESD), with its Human Development Index (HDI) slightly surpassing those of Systems 2 and 3. However, System 3 creates more jobs.

1. Introduction

Clean energy has gained popularity as a means of promoting sustainable development and lowering carbon emissions. Hydrogen is an intriguing replacement to fossil fuels, but the production process is energy-intensive and expensive. Research suggests hydrogen energy is expected to fulfil 11% of global energy requirements by 2025 and 34% by 2050 [1]. Renewable hydrogen production contains considerable ability to satisfy worldwide demands. As a result, it is critical to create economically viable and environmentally conscious techniques to produce green hydrogen, primarily using wind and solar energy sources. Several research have investigated the suitable design of hybrid PV/WT/H_2 systems [2, 3, 4, 5, 6]. Integration of

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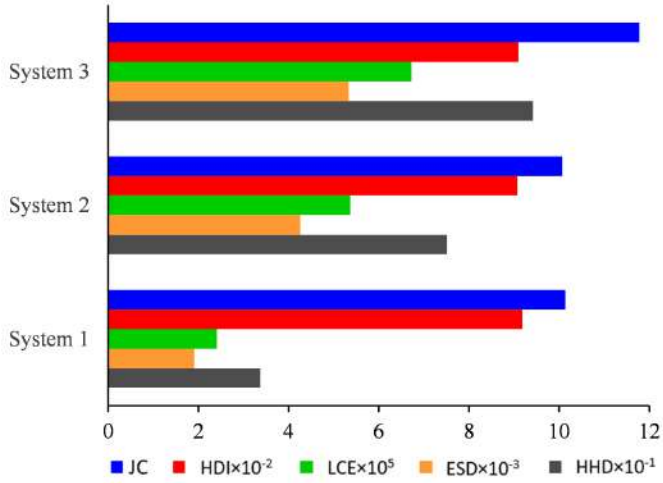

Figure 4. Socio-economic and environmental indicators for systems 1-3.

lower than reported elsewhere as in system 3 (0.941830 DALYs/year). System 1 is also extremely good for the ecosystem of the plant area, which stands out with the lowest Ecosystem Damage factor (ESD) of 0.0019099 species.yr/year, where system 2 and system C result in ESD of 0.0042566 species.yr/year 0.0053348 species.yr/year.

On the factors of the social front, all the systems score almost equally, but system 1 exhibits a slightly higher value on the Human Development Index (HDI): $1 < 2 < 3 : 0.9186 < 0.9097 < 0.9076$. System 3, however, provides the highest job creation with 11.78 jobs/year, system 1 offers the least number of 10.14 jobs/year, whereas system 2 offers 10.07 jobs/year. The results concluded that although system 1 has better environmental adaptability and social benefits, system 3 is likely also a good option for generating social benefits. Still, there is a trade-off between environmental sustainability and economic-social gain.

7. Conclusion

This research focuses on three distinct HRES configurations: grid-connected PV/WT variant, grid-isolated PV/WT variant with batteries, and grid-isolated PV/WT with hydrogen fuel cells. In that effort, several techno-economic, environmental, and social factors are considered to evaluate the three optimized systems' performance. The grid-connected configuration displays the most favorable performance, with an NPC of \$9.91 M, COE of 0.539 \$/kWh, and COH of 6.85 \$/kg. System 1 also outperforms the two off-grid systems from an environmental perspective, with the least carbon emissions at 240,841.66 kg CO_2/year and a subsequent penalty cost of \$3,612.62. A lower LCE leads to an HHD of 0.337178 DALYs/year and an ESD of 0.001909874 species. yr, which are the lowest among the three configurations. While System 3 offers higher job creation potential, System 1 remains superior in terms of economic viability, environmental sustainability, and human development, making it the most optimal choice. This work serves as a foundation for policymakers and system designers to devise an economical and sustainable approach for large-scale production of hydrogen via a grid-connected HRES.

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References

[1] Tarhan C and Çil M A 2021 *Journal of Energy Storage* **40** 102676

[2] Hasan M M and Genç G 2022 *Fuel* **324** 124564

Optimizing Solar Parabolic Concentrators with Cylindrical and Conical Receivers for Improved Thermal Performance

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Abstract. This study investigates the optical and thermal performance of solar parabolic concentrators with cylindrical-conical receivers for low-temperature heat and power generation, emphasizing the effect of receiver geometry on efficiency. It finds that maximum optical efficiency occurs when the receiver aperture aligns with the focal point, providing greater stability and less sunray leakage. The study also highlights how cone angles, receiver aspect ratio, and precise positioning significantly improve efficiency. Sealing the receiver with glass reduces convective losses, increasing thermal efficiency from 40-62% to over 80%. Future work will explore secondary reflector cones and spherical receivers to optimize configurations for decentralized solar systems, showcasing the technology's potential for efficient solar energy capture and conversion.

1 Introduction

The environmental impacts of fossil fuels have intensified the need for renewable energy adoption. Concentrated Solar Power (CSP), particularly parabolic dish collector (PDC) systems, offers a sustainable solution for thermal power generation and industrial heating [1–5]. A PDC concentrates sunlight onto a cavity receiver, converting solar energy into heat via a heat transfer fluid (HTF) for applications like power generation. System efficiency depends on two factors: the dish's ability to focus solar radiation and the receiver's capacity to minimize optical and thermal losses.

While PDC design optimization has been extensively studied, the geometry of cavity receivers critical for low-to-moderate temperature applications such as Organic Rankine Cycle (ORC) systems requires further investigation. Research highlights conflicting conclusions: cylindrical receivers exhibit variable efficiency depending on depth and baffle design [2,5], while conical configurations show marginal thermal efficiency gains in small-scale systems [1,6]. Spherical and hemispherical designs demonstrate competitive optical (71.5%) and thermal efficiencies [3,7], and cylindrical-conical hybrids achieve peak optical (85.42%) and thermal (67.95%) performance [8]. Modifications like glass covers [4] and helical baffles [2] further complicate performance comparisons. Despite these advancements, gaps persist, particularly in low-temperature applications [9] and consensus on optimal receiver geometry [7,8].

This study addresses these gaps by evaluating receiver geometry (cylindrical, spherical) and focal length effects on efficiency. It also tests secondary reflector cones and analyzes results in the context of ORC-compatible low-temperature CSP systems, aiming to resolve design conflicts and enhance scalability.

2 Receiver Design

The proposed design incorporates a cavity receiver with a secondary reflector to minimize solar spillage losses and enhance performance for an Organic Rankine Cycle (ORC) application at moderate to low temperatures. Fig. 1 illustrates the solar dish receiver with an elliptical cavity, defined by three geometric parameters: aperture diameter (Dap), vertical axis radius (R1), and horizontal axis radius (R2). Adjusting these parameters enables performance optimization.

The receiver consists of an insulated outer layer, a front aperture, and a spiral pipe fixed to the cavity's inner surface, which absorbs concentrated solar radiation. The absorbed energy is transferred to the working fluid (water) via conduction through the pipe wall and forced convection, ensuring efficient heat transfer.

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Fig. 7 Picture of the system using the cylindrical cavity

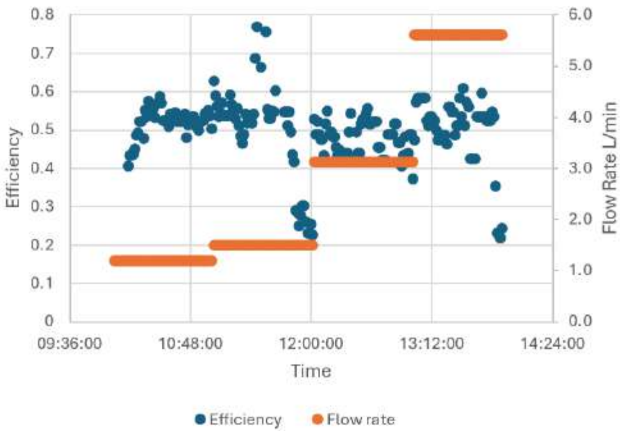

Fig. 8 Efficiency of an open cylindrical cavity under different flow rates

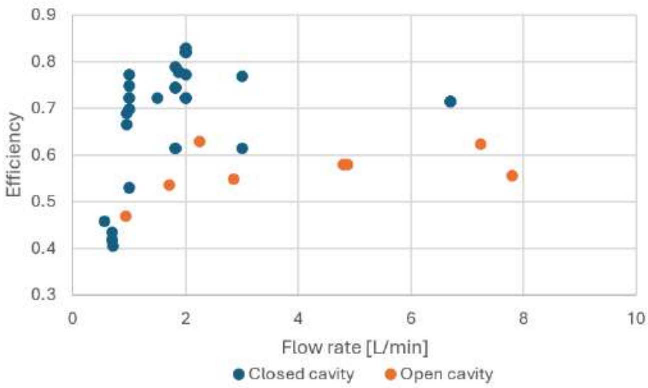

Fig. 9 comparison between the efficiency of a open and closed cylindrical cavity as a function of flow rate

6 Conclusion

This study explores the efficiency of solar parabolic concentrators with cylindrical-conical receivers and glass windows for low-temperature heat generation in decentralized applications. Key findings include optimal optical performance when the receiver aperture aligns with the focal point, with a 2.2 m focal length providing greater stability and a wider cone angle (e.g., 60°) increasing efficiency from 35% to 68%. Sealing the receiver with glass improved thermal efficiency up to 80%, reducing convective losses compared to an open cavity (40–62% efficiency). Flow rate variations had minimal impact on low inlet temperatures (30°C). Future work will test cylindrical receivers with secondary reflector cones and evaluate spherical receivers of varying diameters to optimize configurations for real-world applications, advancing the design of efficient solar thermal systems for low temperature uses.

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