AU-KFAS Research Grants

Publications Report

Academic Year

2022/2023

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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 2022/2023.

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 2022/2023, AU faculty members have published a total of 15 research works funded by KFAS (8 journal papers and 7 conference papers). Many peer-reviewed papers were published in Q journals: 6 publications in Q1 journals, 1 in Q2 journals, 0 in Q3 journals and 1 in Q4 journals.

This report outlines 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 the 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 follow:

- 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 2022/2023, AU faculty members have published a total of 15 research work related to the funded KFAS grants (8 Journal papers and 7 Conference papers) 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, 6 publications in Q1 Journals (research paper published in top 25% of the international journals), 1 publication in Q2 Journals (research paper published in the middle-high position – between top 50% and top 25%), 0 publications in Q3 Journals (middle-low position), and 1 publication in Q4 journals.

Type	Total
Journal Paper	8
Conference Paper	7
Grand Total	15

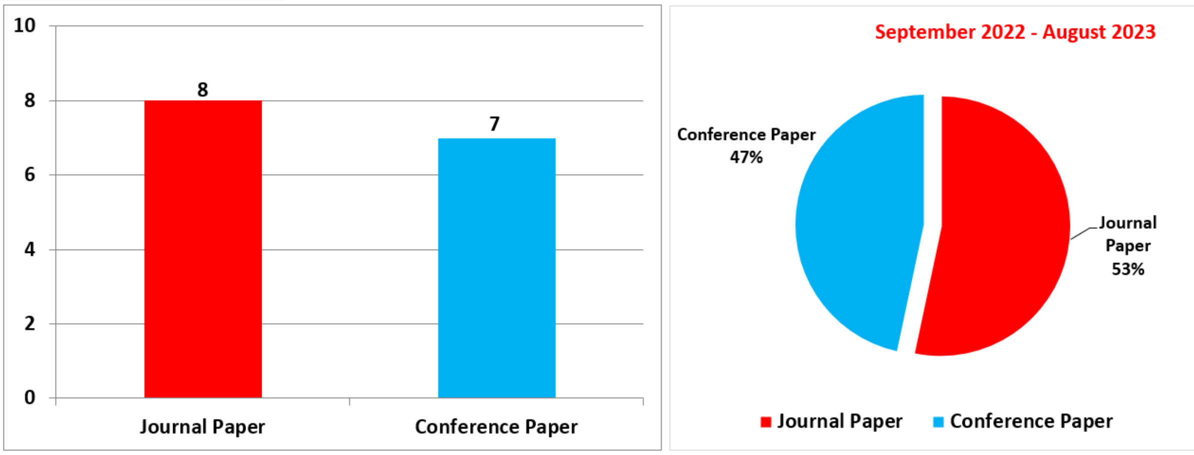

Figure 1. Summary of published research by AU faculty members as related to KFAS grants for the academic year 2022/2023

Quartile (From Scopus)	Number of Published Jounal Paper
Q1	6
Q2	1
Q3	0
Q4	1
No Quartile	0
Grand Total	8

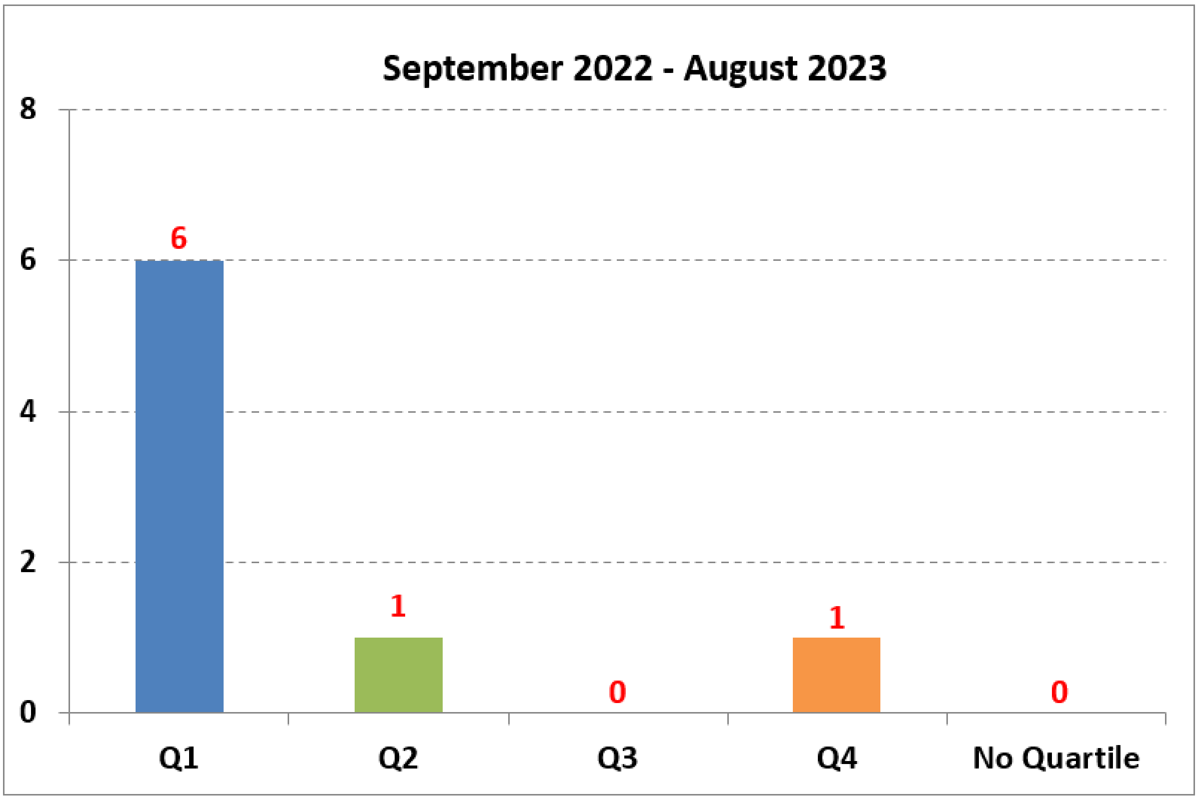

Figure 2. AU Research Faculty Output in Q-Journals for academic year 2022/2023

Full Details of Publications

AU Faculty Research Output, KFAS Grant (September 1st, 2022 – August 31st, 2023)

Department : Scientific Research Centre

Academic Year : 2022-2023

AU Faculty Research Output

Publications – KFAS Grants (Academic Year 09/2022-08/2023)						
Sr.	**Authors المؤلف**	**Publication Title عنوان النشر**	**Name of Journal/ Conference اسم المجلة/المؤتمر**	**Category / Impact Factor عامل التأثير / الفئة**	**Date التاريخ**	**KFAS Grant #**
Mechanical Engineering Department						
1.	Solomon Huluka, A. Abdul-Latif, R. Baleh, A. Larbi, I. Deiab, **K. Khanafer**	Biaxial characterization of open-cell aluminum foams from macro to micro responses	Materials Science & Engineering A: Structural Materials: Properties, Microstructure and Processing	Journal (Q1: Impact Factor: 6.96) **H index: 267**	9/2/23	CR20-15EM-02
2.	**Ahmad Sedaghat**, Hayder Salem, Wisam K Hussam, et al.	Exploring energy-efficient building solutions in hot regions: A study on bio-phase change materials and cool roof coatings	Journal of Building Engineering	Journal (Q1: Impact Factor: 7.21)	1/7/23	CN19-35 EM-06
3.	**Ahmad Sedaghat**, Sayed Mohamad Soleimani, Mohamad Iyad Al-Khiami, Mohammad Sabati, Mohammad Rasul, et al.	Development of a Novel Low-Energy Building: Effects of Room Orientation and Wall Materials	Key Engineering Materials	Journal (Q4: Impact Factor: 0.48)	19/5/23	CN19-35 EM-06

Publications – KFAS Grants (Academic Year 09/2022-08/2023)						
Sr.	**Authors المؤلف**	**Publication Title عنوان النشر**	**Name of Journal/ Conference اسم المجلة/المؤتمر**	**Category / Impact Factor عامل التأثير / الفئة**	**Date التاريخ**	**KFAS Grant #**
4.	Alireza Zabihihesari, Arezoo Khalili, Mohammad-Javad Farshchi-Heydari, **Armin Eilaghi**, and Pouya Rezai	Simple microfluidic device for simultaneous extraction and detection of microplastics in water using DC electrical signal	New Journal of Chemistry	Journal (Q2: Impact Factor: 3.48)	4/4/23	CN20-45EM-01
5.	Z, Al Hajaj, & M.Z. Saghir	Numerical Study on the Influence of Embedded PCM Tubes on the Energy Storage Properties of the Geothermal Energy Pile.	International Journal of Thermofluids	Journal (Q1: Impact Factor: 10.4)	7/7/23	CN20–35-EM-04
Civil Engineering Department						
6.	Reza Soleimanpour, Mohammad Hany Yassin, Arash Mehdizadeh, Dimitrios Chronopoulos	Locating cracks in isotropic plates using nonlinear guided waves	Applied Acoustics	Journal (Q1: Impact Factor: 4.23)	10/7/23	PR19-15EC-09, and CR20-13EV-01
7.	Sayed Mohamad Soleimani, Martin Jaeger, Alanoud Faheiman, and Abdel Rahman Alaqqad	Success factors of recently implemented e-learning methods at higher education institutions in Kuwait	Quality in Higher Education	Journal (Q1: Impact Factor : 1.87)	11/11/22	CORONA PROP 118
8.	Rana Lakys, Ahmad Saad, Taha Ahmed and Mohammad Hany Yassin	Awareness, drivers, and acceptance of sustainable construction in Kuwait with a special focus on CEBs as	Case Studies in Construction Materials	Journal (Q1: Impact Factor: 5.06)	19/7/22	CR19-15EV-01

Publications – KFAS Grants (Academic Year 09/2022-08/2023)						
Sr.	**Authors المؤلف**	**Publication Title عنوان النشر**	**Name of Journal/ Conference اسم المجلة/المؤتمر**	**Category / Impact Factor عامل التأثير / الفئة**	**Date التاريخ**	**KFAS Grant #**
		sustainable alternative construction material				
Conference Publications						
9.	**Ahmad Sedaghat**, Hayder Salem, Wisam K. Hussam, Arash Mahdizadeh, Mohamad Iyad Al-Khiami, Mahdi Ashtian Malayer	Experimental Study on Cool Roof Methods for Two Identical Portable Cabins in the State of Kuwait	Proc. International Conference on Mechanical, Automotive and Mechatronics Engineering (ICMAME 2023), 29-30 April 2023, Dubai, UAE	Conference	29-30/4/23	CN19-35 EM-06
10	**Ahmad Sedaghat,** Hayder Salem, Wisam K. Hussam, Arash Mahdizadeh, Mohamad Iyad Al-Khiami, Sayed Mohamad Soleimani, Mohammad Sabati**,** Mohammad Rasul, Ramadas Narayanan, Masud M. K. Khan, Mahdi Ashtian Malayer	Development of a Novel Low-Energy Building: Effects of Climates and PCM Materials	11th International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings May 20-23, 2023, Tokyo, Japan	Conference	20-23/5/23	CN19-35 EM-06
11	A Sedaghat, S.M. Soleimani, M. Al-Khiami, M.	Development of a Novel Low-Energy	2022 9th International Conference on Power and	**Conference**	9-11/9/22	CN19-35EM-06

Publications – KFAS Grants (Academic Year 09/2022-08/2023)						
Sr.	**Authors المؤلف**	**Publication Title عنوان النشر**	**Name of Journal/ Conference اسم المجلة/المؤتمر**	**Category / Impact Factor عامل التأثير / الفئة**	**Date التاريخ**	**KFAS Grant #**
	Sabati, M. Rasul Khan, and R. Narayanan	Building: Effects of Room Orientation and Wall Materials	Energy Systems Engineering (CPESE 2022)			
12	**Taha Ahmed**, Aditya Singh, Elie Hajj, and Ahmad Saad	Modification of Mix Design Characteristics to Improve Performance of In-service Raveled Pavements in Arid Climatic Regions: Case of Kuwait	Proceeding of the ASCE International Airfield and Highway Pavements Conference (Pavements 2023), Austin, Texas.	**Conference**	14-17/6/23	CR20-15EV-01
13	**Taha Ahmed**, Aditya Singh, Elie Hajj, and Ahmad Saad	Performance Life using Mechanistic-empirical Analysis of Asphalt Mixtures in Arid Climatic Conditions-Case of Kuwait	Proceedings of the Second International Conference on Maintenance and Rehabilitation of Constructed Infrastructure Facilities (MAIREINFRA 2023). Honolulu, Hawaii	**Conference**	16-19/8/23	CR20-15EV-01
14	**Hayder Salem**, Ahmad Sedaghat, and Mahdi Ashtian Malayer	Passive Cooling with Finned Roof Tiles	7th International Conference on Green Energy and Applications conference (ICGEA 2023)	**Conference**	10-12/3/23	CN19-35EM-06
15	**Michel Nahas**, Mohamad Farhat, Sami	Assessment of a Hybrid Renewable	2022 International Conference	**Conference**	23-24/11/22	

Publications – KFAS Grants (Academic Year 09/2022-08/2023)						
Sr.	**Authors المؤلف**	**Publication Title عنوان النشر**	**Name of Journal/ Conference اسم المجلة/المؤتمر**	**Category / Impact Factor عامل التأثير / الفئة**	**Date التاريخ**	**KFAS Grant #**
	Asaad, Marc Anthony Mannah	Energy System: The Case of Kuwait	on Electrical and Computing Technologies and Applications (ICECTA)			PN20-35EE-04

Journal Publications

Applied Acoustics 211 (2023) 109522

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Applied Acoustics

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

Locating cracks in isotropic plates using nonlinear guided waves

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ABSTRACT

Guided waves are gaining popularity in the NDT (Nondestructive Testing) industry due to their potential for cost and time savings when inspecting structures and their high sensitivity in detecting micro-defects over large areas. Cracks caused by various issues are one of the most common causes of material failure, severely affecting the structure's durability and serviceability. The significance of small cracks may vary across different applications. As a result, detecting and classifying damages is a challenging process limited by the current detection techniques. This makes the damage detection process challenging and sets the limit on the range of damage detection techniques that can be used. This study uses experimental and numerical approaches for detecting and locating cracks in isotropic plates using the second harmonic of the symmetric guided wave (S_0) induced by cracks. This article analyzes a range of numerical models with varying orientations and dimensions. The second harmonic of the (S_0) guided wave is used for detecting and locating the crack. The results show that the second harmonic of the (S_0) guided wave induced by crack can detect and locate cracks in plates. The proposed technique is accurate, reliable, and does not require baseline data, providing an advantage over conventional ultrasonic testing techniques.

1. Introduction

Plate Structures offer outstanding benefits due to their unique qualities, including both exceptional levels of robustness and lightness. Consequently, they represent a highly favored solution across many engineering segments such as those related to aerospace, civil engineering, and electronics among others. In particular, they are vital in constructing airplane fuselages; wings and tail sections; or even satellites within the aerospace industry given their superior strengths per unit weight ratios. This is paramount when it comes down to meeting critical weight specifications [1]. Civil engineers also utilize plate structures for various applications, such as bridges, buildings, and storage tanks. These structures provide the necessary stiffness and stability, making them suitable for construction projects where the structure must withstand the forces of nature including wind and earthquakes [2]. In the electronics industry, plate structures are used in the manufacturing of printed circuit boards and other components. Their versatility, low cost, and high stiffness make them an ideal solution for electronic applications where precision and stability are essential [3].

The optimal performance of plate structures is majorly impacted by diverse factors interwoven in both the loading system and material properties. Therefore, it becomes requisite for engineers to factor in these relevant details pivotal to sound construction practices over time. In spite of their benefits, plate structures still experience varying degrees of damage due to a gamut of reasons like overloading or corrosion; fractures that may result from fatigue, or other natural phenomena such as earthquakes or impact forces upon them. The cracks, excessive deformation, or buckling are commonly observed modes affecting the plates' stiffness. These changes in stiffness can alter the behavior and stability of the structure, posing a threat to its safety and integrity and potentially leading to catastrophic failure. Thus, it is essential to detect and address plate structure damage promptly and effectively. For enhanced safety measures in plate structures, it is imperative that regular inspections are carried out. Regular inspection protocols and continuous monitoring are essential in determining any early signs of structural impairment promptly. Swiftly attending to these concerns with necessary repairing measures prevents prolonged exposure that could jeopardize overall structural safety considerably. Advanced developments such as NDT technology allow for the precise detection of structural damages while also pinpointing a clear outline of how plate structures will perform under certain loads.

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0003-682X/

Since the proposed technique works based on the captured second harmonic amplitude at receivers, the reliability and accuracy of the proposed method may be affected by crack orientation. To investigate this effect, the influence of crack orientation on the amplitude of the second harmonic captured at monitoring points T_2 and T_3 for all damage scenarios was investigated which has been summarized in Fig. 18a & b for transducer T_2 and T_3 respectively. The SPDs' of all crack orientations indicate that the second harmonic of the S_0 guided wave has the smallest amplitude at a crack orientation of 0°, and the largest amplitude at a crack orientation of 90°. As these figures indicate, the data from both transducers display a rising trend in SHG when the crack orientation approaches 90°, where the crack is perpendicular to the direction of propagation. Again, this can be attributed to the fact that the normal force and resultant contact energy reach their highest levels in this scenario. Therefore, the optimal damage localization results can be achieved when the crack is perpendicular to the propagation direction. Accordingly, the accuracy of the proposed damage localization decreases as the crack becomes more aligned with the propagation direction.

9. Conclusion

This study presents a framework for detecting and locating cracks in aluminum plates. The technique uses a transducer network of three sensors for damage detection and localization. Unlike linear guided wave techniques, this approach does not depend on baseline data but rather relies on SHG induced by CAN. Through numerical case studies evaluating a wide range of damage scenarios with varying crack sizes and orientations, the efficiency and reliability of the proposed method were assessed, with experimental case studies that further validated its effectiveness. Both experimental and numerical results confirm the success of the proposed technique in detecting and locating cracks in aluminum plates. Moreover, it was identified that crack orientation and monitoring point location may affect the accuracy of the technique. In turn, scattering analysis was performed to gain deeper insight into these parameters' effect on SHG. The results highlighted that optimal results are achieved when the wave propagation direction is perpendicular to crack orientation while accuracy decreases when the crack aligns with the propagation direction. Overall, this study's findings may advance damage detection and localization in isotropic plates by deepening the understanding of SHG. The findings of this study have the potential to advance damage detection and localization in isotropic plates. For engineers, this work showcases a useful methodology that surpasses the shortcomings of regular linear wave parameters in detecting and locating cracks in plate structures. With its advanced capabilities, this technique offers accuracy and increased dependability to aid in inspections.

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CRediT authorship contribution statement

Reza Soleimanpour: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition. **Mohammad Hany Yassin:** Software, Validation, Investigation, Resources, Writing – original draft, Writing – review & editing, Funding acquisition. **Arash Mehdizadeh:** Methodology, Software, Validation, Writing – original draft. **Dimitrios Chronopoulos:** Writing – original draft, Supervision, Project administration.

Data availability

Data will be made available on request.

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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Exploring energy-efficient building solutions in hot regions: A study on bio-phase change materials and cool roof coatings

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A R T I C L E I N F O

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Cool roof
Energy saving

A B S T R A C T

Creating low-energy buildings in arid, hot desert climates like Kuwait poses significant challenges. This research examines the potential of Bio-PCMs and cool roof coatings as energy-saving methods in three hot climate locations, using both experimental and computational approaches. Two identical portable cabins were meticulously constructed, and their thermal properties were analysed under two different cooling conditions. These cabins offer a unique testing ground for various energy-saving techniques, as their thermal similarity has been experimentally confirmed. A six-zone model was developed in TRNSYS software to study Bio-PCM integrated walls. The findings for the desert climate of Kuwait and subtropical climate of Rockhampton, Australia, demonstrated the best performance with autoclaved aerated concrete block walls, achieving energy performance indices of 761.7 and 496.3 kWh/m^2/year, respectively. Bio-PCMs integration in three positions within walls and roof were examined, which were yielded energy savings of 22%, 23%, and 53% in Kuwait, Australia, and India, respectively, while experimental results on two cool roof methods, cool roof paint and aluminium foil roof, indicated that energy savings proved to be negligible. Incorporating insulation materials via sandwich panels in buildings can substantially enhance energy efficiency in Kuwait and Australia, with observed reductions of 35.7% and 43.8% compared to autoclaved aerated concrete blocks from simulation results. However, in tropical climate of Kodaikanal, India, energy consumption were increased dramatically by 126.2% when sandwich panels were used. This study offers valuable insights into optimal wall materials and energy-saving strategies, such as cool roof methods, insulation and Bio-PCM, for use in various hot climates.

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Data availability

Data will be made available on request.

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Numerical study on the influence of embedded PCM tubes on the energy storage properties of the geothermal energy pile

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ABSTRACT

Geothermal energy pile is a remarkable alternative energy source that can provide heating and cooling energy to meet the energy demands in buildings. This study aims to quantify and expand the knowledge on the thermal storage performance of the geothermal pile system embedded with phase change material containers as compared to the one without, as a goal to expand the wide application of the system. In this study, numerical predictions were conducted on lab-scale energy pile systems, namely Design A (i.e., no PCM) and Design B (i.e., with PCM). The work aimed to investigate and quantify the energy storage properties of geothermal energy piles, and the influence of the incorporation of paraffin wax PCM tubes in the pile, at different flow rates. Incorporating PCM in a geothermal energy pile demonstrated considerable improvement in the amount of energy stored and extracted compared to the one with no PCM. For 735, 1470 and 2100 mL/min, Design B exhibited an increase in the energy stored by 42.21%, 44.71% and 46.23%, respectively compared to Design A. On the other hand, for the flow rate 735, 1470 and 2100 mL/min Design B illustrated an increase in the energy extracted by 45.87%, 53.09% and 59.55%, respectively compared to Design A. The use of PCM in the energy pile has a promising solution to enhance the storage capacity and improve the heat exchange capacity.

1. Introduction

The impact of climate change is the main environmental challenge that is facing the world. The majority of the energy used is from non-renewable energy resources, and the main example is fossil fuels. These non-renewable fuels release carbon dioxide and other greenhouse emissions, which contribute to climate change. Thus, researchers and scientists have been seeking to provide a way to reduce global carbon emissions, and one such option is to utilize clean energy that comes from natural source or replenished sources.

Indoor climate control accounts for the highest energy consumption of residential buildings [1,2,3]. Due to the peak demand to find clean energy resources for heating and cooling in residential buildings, a geothermal energy pile (GEP) has been introduced. GEP acts as energy extraction and storage in the ground that is used as an effective method of cooling and heating in buildings. The system transfers the geothermal energy to buildings by fluid in heat exchanger (HEX) pipes embedded in the concrete pile. The fluid used in heat exchanger pipes is usually water [4,5]. In summer, the thermal energy will be injected and extracted in winter, which can be used for seasonal energy storage.

Several research investigated the thermal response and heat exchange performance of geothermal energy piles (GEP) and the factors that affect their performance. Gashti et al. [6] found that the double U-tube systems steel piles perform better with higher heat transfer efficiency than the single U-tube systems at a certain fluid flow rate. Sani et al. [7] observed that the performance of the GEP is influenced by the temperature change in the soil surrounding the pile, which is affected by the soil saturation, the period of heating process and the rate of heat injection. Suryatriyastuti et al. [8] confirmed that the amount of heat energy produced in the GEP notably depends on the type and level of saturation of the soil, the type of the heat pump and the existence of the ground water flow. Mousa et al. [9] performed a study on the thermal response of a 3D numerical model energy pile, which has been validated by an experimental study of a small-scale in situ model. The study reported that the flow rate magnitude influences heat rejection and extraction [9].

Yan et al. [10] observed that the utilization of phase change material (PCM) in the GEP decreases the temperature variation and enhances the energy storage efficiency [10]. Jouhara et al. [11] reported that the

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storage capacity of the GEP rises with increasing the PCM content. Mousa et al. [26] revealed that the implementation of PCM in the GEP increases the amount of energy stored and extracted by more than 200% compared to no PCM GEP. Similarly, Yang et al. [27] found that the total amounts of heat exchange for the traditional energy pile and the PCM energy pile were 2900.5 kJ and 3162.7 kJ, respectively at the same interval time. The study noticed that the PCM energy pile enhances energy storage properties and heat capacity transfer [27]. Bao et al. [28] demonstrated that the PCM in energy pile has a significant effect on thermal energy absorbing and releasing during the heat exchange process. The heat storage efficiency of 735, 1471 and 2100 mL/min of Design B with PCM incorporated were significantly improved by 11.85%, 10.32% and 2.90%, respectively, in comparison with the one reported in the literature [24].

The study found that with increasing the flow rate, the thermal storage capacity and thermal extraction capacity increase. Batini et al. [29] found that increasing the fluid flow rate resulted in increasing the heat transfer rate by 11%. Miyara et al. [30] observed that the heat exchange rate of the ground heat exchanger escalates remarkably when the flow rate increases from 2000 mL/min to 4000 mL/min. Studies [8,9,29,30,31] confirmed that the water flow rate affects the thermal response of the heat exchanger, the higher the flow rate, the higher the heat rejection rate.

4.2. Practical implications

The outlet temperature of the water of the present GEPs manifested a similar profile response with respect to time, at each of the flow rates during the charging and discharging process. A significant increase in the temperature was observed in all cases, in which the temperature raised from 8.7 °C up to approximately 35 °C (i.e., during the 0.4 – 0.45 h.). The initial dramatic increase in the temperature of the water during the charging process (i.e., from 0 h. to ~ 0.45 h.) was attributed to the heat transfer between the water in the steel tubes and the surrounding layer.

In Design A, at the beginning of discharging process ($t = 1.5$ h), the heat exchanger was at approximately 35 °C, indicating that the heat exchanger tubes act as a heater, however the concrete layer act as an energy storage medium. On the other hand, the role was inverted after completion of discharging process ($t = 3$ h), in which the tubes of the heat exchanger began extracting the energy stored in the concrete. Yet, the temperature of PCM tubes in Design B was in a range of ~ 22 °C – 24 °C, which indicates the complete melting of PCM tubes regarding to ref. [24].

At a higher flow rate, the difference between the energy stored and extracted is minimal, as a result, the storage efficiency was high. With increasing the flow rate, the amounts of energy extracted and stored were increasing, resulting in high storage efficiency.

The profile of the heat exchange pipe plays an essential role in the thermal GEP performance. The U-loop has been extended to multiple tubes to enhance the thermal storage properties of the system. The thermal efficiency of the energy pile improves remarkably with increasing the number of heat exchange pipes [32,33]. Wu et al. [34] confirmed that the thermal injection rate of the pile decreases with decreasing the number of U-loops. The study also found that increasing the total length of the heat exchange pipes, increases the total thermal energy stored in the GEP [34].

PCM tubes embedded in the energy pile system offer a remarkable opportunity to enhance the overall thermal storage properties, which was evident in the present work. The study confirmed that the thermal energy stored and extracted of the PCM pile (i.e., Design B) was greater than the traditional pile (i.e., Design A), attributed to the ability of the PCM to absorb, store and extract heat.

5. Limitations

Due to the limitation of the scale size of the model, the temperature difference was limited. The present numerical model is unable to examine the influence of soil type, rock, and other types of geological conditions on the thermal performance of the system. The thermal performance of the pile could be improved with the incorporation of nanofluid. Th number of loops embedded within the GEP has a great influence on the energy generated in the system [35]. However, due to the construction design of the system the number of loops was limited.

6. Conclusion

A geothermal energy pile system is a reliable source of energy as compared to traditional energy resources. It not only provides cooling and heating in the building, but also provides structural support. The use of GEP can reduce energy consumption considerably for space heating and cooling. The work and the findings are summarized as the following:

- The numerical thermal investigation was carried out on two lab-scale energy pile systems, namely Design A (i.e., no PCM) and Design B (i.e., with PCM) at different volume flow rates.
- Qualitative and quantitative studies on the GEP performance were conducted, and the influence of PCM containers on the GEP system was performed.
- The thermal performance of GEP was significantly improved by incorporating PCM enclosed tube containers.
- For 735, 1470 and 2100 mL/min, the total heat stored was 15.04, 15.10 and 15.11 kJ/kg for Design A, and 21.40, 21.84 and 22.10 kJ/kg for Design B, respectively. On the other hand, for 735, 1470 and 2100 mL/min, the total heat extracted was 13.12, 13.22 and 13.25 kJ/kg for Design A, and 19.14, 20.24, and 21.14 kJ/kg for Design B, respectively.
- Incorporating PCM enclosed tube containers in GEP is a promising approach to enhance its thermal performance and storage efficiency.

Future work

Several aspects of the current study could be addressed in the future. The present numerical study has been performed on a small-scale model, in order to avoid time-consuming prediction. A multiscale model of the GPE system close to the real borehole depth could be considered in future. The influence of ambient temperature and storage duration on the energy stored and extracted could be investigated. Furthermore, the influence of different types of melting temperatures and latent heat values of phase change materials on the overall thermal performance of the pile can be examined. Additionally, investigation should be performed on the effect of different flow regimes of the fluid inside the pipe on the energy stored and extracted. Heat transfer enhancement can be achieved by using nanofluid. Experimental examination of the thermal response of the GEP performance on-site buried in the ground is vital, considering parameters such as various soils and different climate conditions.

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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.

Data availability

No data was used for the research described in the article.

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Development of a Novel Low-Energy Building: Effects of Room Orientation and Wall Materials

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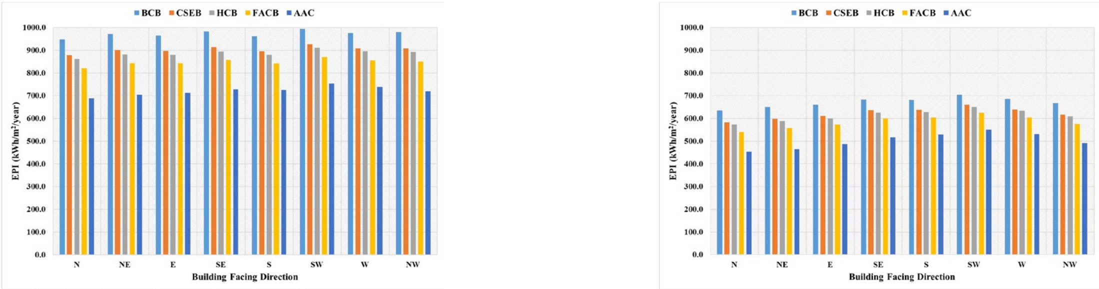
Keywords: Building, Climate, Energy-performance index (EPI), TRNSYS, Solar energy

Abstract. The development of low energy buildings in hot subtropical and desert like climates such as Australia and Kuwait, requires strategies that are rather challenging. Five (5) experimental rooms are going to be built to assess these energy saving techniques for a research program jointly between Kuwait and Australia. Before the construction phase, these rooms are simulated in TRNSYS18 for the two sites based on available weather data collected from Kuwait International Airport and Rockhampton Airport. The objectives are to investigate room orientation and walling materials on energy performance of the rooms. It was found that all rooms return identical temperature profiles in each of the eight (8) dominant directions, i.e., N, NE, E, SE, S, SE, E, and NW. Five (5) different commercially available wall materials were employed for the five (5) simulated rooms in Kuwait and Australia. It was found that autoclaved aerated concrete (AAC) wall materials and north (N) building face orientation are the preferred construction material and orientation in both sites. The energy performance index (EPI) showed that AAC wall materials for the room faced towards north (N) provides the lowest cooling EPI of 646 and 448.4 kW/m^2/year in Kuwait and Rockhampton, Australia, respectively.

Introduction

The building sector is one of the largest energy-consuming sectors in the world [1]. In Kuwait, space heating and cooling accounts for about 70% of the total residential energy consumption, reported in Kuwait Energy Outlook 2019 [2]. Krarti and Hajiah [3] reported that the building sector represents 90% of the electricity consumption in Kuwait, also appeared in Saber et al. [4]. There is enormous potential to increase the energy efficiency of the buildings, however, a clear long-term government commitment, combined with well-designed packages of efficiency policies reinforced by adequate capacity for implementation is needed for improving energy efficiency in buildings in Kuwait. On the other hand, space conditioning, or heating and cooling, accounts for an average of 40 to 50% of household energy use in Australia [5, 6]. It generates about 30% of the total CO_2 emissions [5]. The problem related to energy consumption and CO_2 emission in Australia will be more acute as the residential energy consumption was 467 PJ (Petajoules) in 2020 compared to 402 PJ in 2008 which indicates an average increase of 15% [7]. With high projected space cooling requirements in buildings in both Kuwait and Australia, there is a critical need for researchers to develop a thermally efficient building for mainstream use, however, it is extremely difficult to overcome this challenge as further improvement of currently used conventional building envelopes, construction materials and



(a) Kuwait (b) Rockhampton, Australia

Fig. 7 Annual energy performance index (EPI) for total cooling/heating for each room with 5 different wall materials in the 8 dominant directions in (a) Kuwait, (b) Rockhampton, Australia

Summary

In this paper, the design of 5 experimental rooms is modelled in Sketchup and transferred to TRNSYS18 to allow selecting desirable materials for each zone, independently. Simulations are conducted for two weather conditions of Kuwait and Rockhampton, Australia, to investigate room orientation and walling materials on energy performances. The findings of the present study are as follows:

- Thermal performance from one room to another is identical if all rooms are oriented in a fixed optional direction using identical materials.
- Thermal performance will vary from one room to another if each room is oriented differently. The most desirable orientation is North (N) facing direction for both sites in Kuwait and Australia that provides the lowest EPI.
- Autoclaved aerated concrete (AAC) walling material provides the lowest cooling EPI for both sites in Kuwait and Australia in all directions.
- Cooling EPI values for rooms facing North (N) are 646.0 and 448.4 kW/m^2/year in Kuwait and Rockhampton, Australia, respectively.
- A benchmark standard EPI value reported for residential buildings in warm and humid and hot and dry climate of India which is merely 70 kW/m^2/year [1].
- EPI can be improved by 9.8 times in Kuwaiti buildings and 6.8 times in Rockhampton of Australia buildings compared with the benchmark EPI. This can be achieved by using smart low energy building materials instead of the current type of building materials.

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Success factors of recently implemented eLearning methods at higher education institutions in Kuwait

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ABSTRACT
This study determines the critical success factors for students and academic staff when applying and evaluating online delivery methods in colleges and universities in Kuwait. The recently implemented eLearning systems and methods in the country, due to the COVID-19 pandemic, are evaluated and the perception of the eLearning system is gauged. Targeted surveys are distributed to a representative sample of undergraduate engineering students and academic staff. The following critical success factors are considered: benefits of the eLearning system, educational system quality, information quality, instructor quality, learner quality, service quality and technical system quality. Results show that there is a correlation between the perceptions of students and academic staff, particularly regarding instructor quality, information quality and benefits of the eLearning system. Both groups of respondents agreed on the high importance of instructor quality and the low importance of benefits.

KEYWORDS
eLearning; COVID-19 pandemic; undergraduate engineering education; academic staff; critical success factors; Kuwait

Introduction

The COVID-19 pandemic wrought havoc on many aspects of day-to-day life. Countries around the world ordered the closure of schools and universities for an indefinite period to contain the spread of the COVID-19 virus. A prolonged closure of academic institutions affects the progression and matriculation of students at all levels. Over the course of the outbreak, many institutions around the world have transitioned to online education to make sure that students continue their education while maintaining physical distancing as recommended by the World Health Organisation. Kuwait's Ministry of Education has begun exploring the possibility of allowing

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between success factors and experience. However, knowledge and maturity of academic staff reflect stronger relationships between perceived success factors and experience. For students, virtually no relationship was identified because of students' limited experience.

Confirming the previous interpretation of descriptive results, the Mann–Whitney *U* test shows only a significant difference between academic staff and students (research question 3) regarding the two success factors, Instructor Quality (IQ) and Service Quality (SQ). This may show the importance of professional development for IT staff and academic staff.

The rankings of the success factors (research questions 4 and 5) indicate that both cohorts, academic staff and students, perceive Instructor Quality (IQ) as an important success factor and Benefits (B) and Information Quality (InfoQ) as less important success factors. The perceived low importance of Benefits (B) can be explained due to several factors, most notably the outbreak of COVID-19, which forced higher education institutions in the country to embrace eLearning, when not many academic staff or students were ready for such a sudden implementation.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The datasets generated during or analysed during the current study are not publicly available due to restrictions set by the funding agency but are available from the corresponding author on reasonable request.

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Conference Publications

Modification of Mix Design Characteristics to Improve Performance of In-Service Raveled Pavements in Arid Climatic Regions: Case of Kuwait

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ABSTRACT

Arid climate conditions of Kuwait, along with the poor asphalt mix design characteristics, have further accelerated the rate of raveling of in-service pavements. Therefore, this study evaluated and modified Kuwait's current mix design characteristics. To carry out this study, two mix designs, that is, the traditional Marshall mix design used in Kuwait and the new Superpave mix design, were prepared as per specifications. Several key changes were implemented to the mix designs to improve their resistance to moisture damage and raveling. The mechanical properties of the two asphalt mixtures were evaluated through tensile strength ratio (TSR), Hamburg wheel track (HWT), and dynamic modulus (E*) tests. E* test was performed for both unconditioned (UC) and moisture-conditioned samples for one (1C) and three (3C) freeze-thaw cycles to capture the effect of moisture conditioning on the performance of the asphalt mixtures. Results showed that the recommended modifications to the current Kuwaiti mix design procedure were successful and proven to improve the moisture damage resistance of the mixture, which is a leading cause of the raveling of in-service asphalt pavements.

Keywords: Superpave, Raveling, Arid Climate, Moisture Damage, Hamburg Wheel Track (HWT), Dynamic Modulus, Kuwait

1. INTRODUCTION

Raveling is defined as the continuous disintegration of the asphalt mixture's surface layer because of the dislodgement of the aggregate particles. It is one of the failure modes in flexible pavements observed in highway and airport pavement surfaces. Raveling results in loose debris on the pavement surface, high surface roughness, and collected water on the raveled surface that can result in vehicle hydroplaning and loss of skid resistance (ASTM 2018). Several factors, such as insufficient asphalt binder, poor asphalt mixture quality especially poor resistance to moisture damage, insufficient compaction, segregation, or stripping, can cause raveling.

The state of Kuwait has what is known as an arid climate. According to the Köppen climate classification, arid or desert climate is known to have extreme dry heating conditions all year long with moderate winters which have concentrated medium to heavy rainfall that last only for a short time (Peel et al, 2007). In the summer months, the country regularly experiences temperatures exceeding 50º-C (122º-F) and was named the hottest place on Earth in 2016, with evaluating and modifying the current mix design properties to address the raveling problem in the arid climatic region of Kuwait. To complete this study, two mix designs, i.e., the traditional modified Marshall mix design used in Kuwait (M1) and the new modified Superpave mix design (M2), were prepared as per the newly adopted Qatari specifications. The selected OBCs at the design air voids for M1 and M2 asphalt mixture was 3.7% and 4.1%, respectively. Several key changes were implemented to the mix designs, including adding 1.5% of hydrated lime to the mixtures to improve their resistance to moisture damage and blending the used Pen 60/70 asphalt binder with 3% tetra ethylene polymer to achieve a performance grade of PG 76-XX as required by the new Qatari specifications. The mechanical properties of the two asphalt mixtures were evaluated through a series of tests, including Tensile Strength Ratio (TSR), Hamburg Wheel Track (HWT), and Dynamic Modulus (E*). Furthermore, the E* test was performed at both unconditioned and moisture-conditioned states for one and three freeze-thaw cycles to capture the effect of moisture conditioning on the performance of the asphalt mixtures.

HWT test results showed that both asphalt mixtures had good rutting resistance. However, M2 asphalt mixture exhibited a slightly higher rut depth due to its higher OBC. TSR and E* test results showed that M2 asphalt mixture exhibited a better moisture damage resistance than M1, indicating better performance than M1.

In conclusion, TSR, HWT, and E* tests results showed that the recommended modifications by this study to the current Kuwaiti mix design procedure were successful and proven to significantly enhance the moisture damage resistance of the asphalt mixture, which is a leading cause of raveling in the in-service asphalt pavements.

5.1. Ongoing and Future Work

Currently, the research team is evaluating the performance of M2 mix at UC and 3C-conditioned states. The evaluation includes Cyclic Fatigue testing as per AASHTO TP 133 and Stress Sweep Rutting (SSR) testing as per AASHTO TP 134. Once these tests are complete, a full mechanistic-empirical pavement (MEP) analysis will be conducted to determine the impact of moisture damage on the performance life of the modified asphalt mixture, M2. The results from this comprehensive study will help to understand moisture's influence on pavement performance over time and to recommend the appropriate changes to the current mix design practice in the arid climatic region of Kuwait.

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Passive Cooling with Finned Roof Tiles

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***Abstract*— Cooling load demands have increased rapidly over the recent years. In extreme hot climates, the building sector consumes more than 90% of the total electricity of the country. Thermal comfort can however be improved by using passive cooling techniques. One of these methods is the cool roof approach. Two identical cabins were designed and constructed in Kuwait to test different cool roof techniques. In this study, a new system was proposed by using aluminum sheet tiles equipped with tilted fins to minimize direct sun light in the roof and reduce its temperature. Hourly temperatures and humidity were monitored for both units along with the power consumption of air conditioning, if required. The initial data shows nearly identical thermal properties of both units. The results were shown for two months of winter in Kuwait and the study will continue for other months of the year with more improvements, like using reflective paint or spacers between the tiles and the roof.**

Keywords—Cool roof, passive cooling, power consumption, air-conditioning, solar heat gain

I. Introduction

In extreme hot climates, such as Kuwait, electricity consumption can be as high as 10 times the consumption in tropical climate [1]. The building sector in Kuwait consumes 90% of its generated electricity [2,3]. With high projected space cooling requirements for buildings in Kuwait, there is a critical need for researchers to develop thermally efficient buildings for mainstream use; however, it appears extremely difficult to overcome this challenge as further improvement of currently used conventional building envelopes, construction materials and methods have already been exhausted [4,5]. The application of mechanical air conditioning systems has increased in the last few decades and therefore a passive cooling design is now more important to reduce the cooling energy consumption and increase thermal comfort [6,7]. These passive cooling systems improve the thermal comfort in these hot regions by utilizing a fraction of the energy used by conventional mechanical systems [8].

There are huge potentials in developing effective cool roof methods for hot-arid climate. Rawat and Singh [9] made an extensive review on energy savings of different cool roof methods in different climates. They reported that the average energy-saving of cool roofs varies from 15% to 35.7% in different climates including hot-arid climates according to literature. Cool roofs are the passive energy efficiency options that are aimed to lower roof temperature during the day when the sun is shining [10]. Sunlight is the main factor that heats up a roof during sunny hours. Cool roofs are desirable techniques for a building for several reasons:

- Cool roofs decrease roof operating temperature and extend roof service life.
- Cool roofs decrease indoor air conditioning demands,
- Cool roofs increase indoor thermal comfort, and
- Cool roofs protect environment while saving money on electricity bills

Cool roofs use solar reflective materials to reduce roof surface temperature. A traditional dark roof can heat up to 74.6 ℃ in summer while a cool roof under same condition can only heat up to 40.5 ℃, i.e., 34.1 ℃ cooler. Cool roofs may be feasible options because in many cases they cost the same amount as alternatives traditional non-cool roofs. Energy savings of cool roofs depends on several factors, including local weather condition, whether the roof is insulated or not, and residents' habits on energy use, cost of electrical energy, and the type and efficiency of heating and cooling systems in the building.

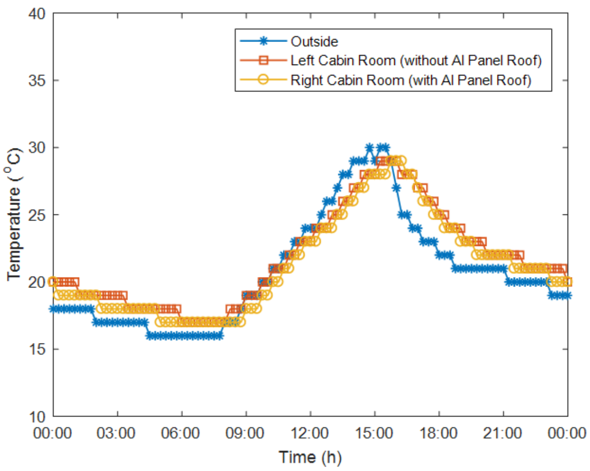
In this context, the purpose of this paper is to investigate the performance of the proposed passive cooling system and its potentials in practice for a hot and dry environment. In this study, a passive cooling system was developed by using aluminum finned tiles that were designed and installed on the roof of one of two identical buildings in a field application. The effect of using such passive system was investigated over the period of two months in Kuwait. The temperature, humidity and cooling load were monitored and presented in this study. The aim of the project is to further study different types of cool roof for the climate of Kuwait.

II. Experimental Setup

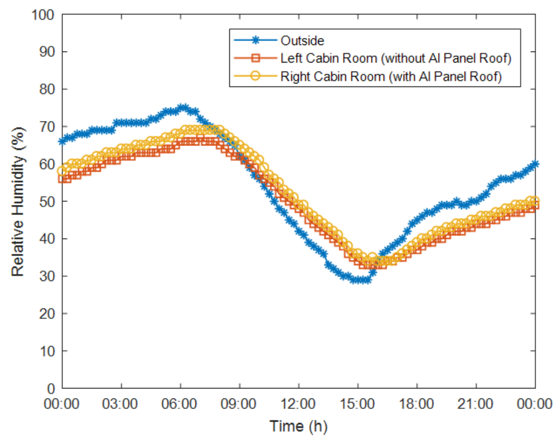
A. Cabins Construction

Two portable cabins are designed with 2.2m × 2.2m ×3m external dimensions. Inside height up to the false ceiling is 2.8m. Hence, the interior space of each room is exactly 2m width, 2m depth, and 2.8m height. The rooms are fabricated of steel frame by using 120mm I-beam at bottom and 40mm × 40mm square hollow section for frame support at the bottom. Columns are made from 50mm × 50mm × 2mm (thickness) hollow sections with angles (See Figure 1). Leg height is 300mm from the ground. Lifting lugs are used for lifting and handling. Purlins are used in the roof from 50mm × 50mm ×

between the roof and the tiles during hotter times of the year. Ceiling temperature will also be monitored in the future as well.



(a)



(b)

Fig. 7. Cabins Indoor thermal properties in comparison to outdoor ones for November 21st 2022 (a) Temperature (b) Humidity.

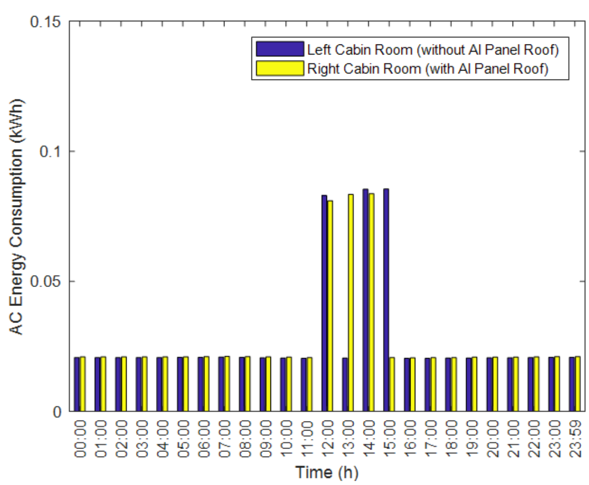


Fig. 8. An example of hourly AC power consumption for both units (December 7th, 2022).

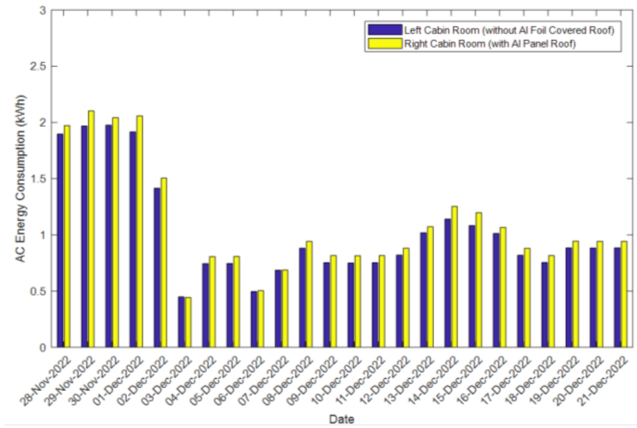


Fig. 9. Daily power consumption for the period between November 28th – December 21st, 2022.

IV. Conclusion

Aluminum finned tiles were suggested as a passive cooling technique for single story building in very hot climates. The initial results collected from a small, insulated cabins for the months of November and December were not promising. More thorough investigation is needed for the rest of the year, especially in summer with reflective paints and spacings as future improvement for this technique. The proposed roof may be improved by creating an air gap between the roof and the tiles and later by applying reflective paints during hotter times of the year. Ceiling temperature will also be monitored in the future study.

Acknowledgmen

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engineering proceedings

Proceeding Paper

Performance Life Using Mechanistic–Empirical Analysis of Asphalt Mixtures in Arid Climatic Conditions—Case of Kuwait †

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† Presented at the Second International Conference on Maintenance and Rehabilitation of Constructed Infrastructure Facilities, Honolulu, HI, USA, 16–19 August 2023.

Abstract: The extreme arid climatic conditions and poor asphalt mix design characteristics have further accelerated the rate of deterioration of in-service asphalt pavements in Kuwait. Pavement distresses, such as raveling, rutting, and fatigue cracks, worsen in severe climatic and loading conditions, such as high temperatures, elevated humidity levels, and high traffic loads on the pavement surfaces. In this study, a life performance evaluation using mechanistic–empirical analysis of a new modified Superpave mix design was undertaken. The performance life of the modified Superpave asphalt mixture was evaluated, and the results showed that the new modifications to the mix improved the rutting and fatigue cracking resistances of the asphalt mixture for the unconditioned state. However, fatigue cracking resistance under the moisture-conditioned state still needs further improvement for the newly modified Superpave asphalt mixture.

Keywords: arid climate; asphalt mixture; pavement distresses; Superpave; mechanistic empirical

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1. Introduction

The proper design and maintenance of asphalt pavement will extend its service life and help it to maintain a satisfactory level of service. However, due to in-service conditions, asphalt pavements can be damaged by certain types of distresses. Pavement distresses, such as raveling, rutting, and fatigue cracking, worsen in severe climatic and loading conditions, such as high temperatures, elevated humidity levels, and high traffic loads on the pavement. The extreme arid climatic conditions of Kuwait and poor asphalt mix design characteristics have further accelerated the rate of deterioration of in-service asphalt pavements [1]. To combat this issue, Kuwait's Ministry of Public Works (MPW) adopted the Superpave asphalt mix design from the Qatari Construction Specifications, which considers both climate and traffic, unlike the Marshall mix design approach. However, the long-term performance of this newly adopted Superpave asphalt mix design must be evaluated to determine its long-term resistance to common pavement distresses [2].

Mechanistic–empirical (ME) analysis is based on the theory of mechanics and predicts the responses of the pavement to the application of loads. The empirically derived models employ these pavement responses to forecast distress in terms of cracking and rutting. ME analysis can forecast asphalt pavement's long-term performance over its design period. As a result, the objective of this study was to use a ME analysis to assess the resistance of the Superpave asphalt mixture against prevalent pavement distresses, including rutting and fatigue cracking. This ME study assisted in comprehending how the modified material properties impact pavement performance over time and if further modifications are required to the newly approved mix design procedure.

using Method B had a longer fatigue and rutting life, but it still required improvement to withstand the 20-year design traffic of 30 MESALS. Method C increased the asphalt pavement thickness until the pavement met the performance parameters for the Superpave asphalt mixture at the UC state. However, the pavement could only endure 5.5 years after the 3-C state indicating a durability issue in the mix design.

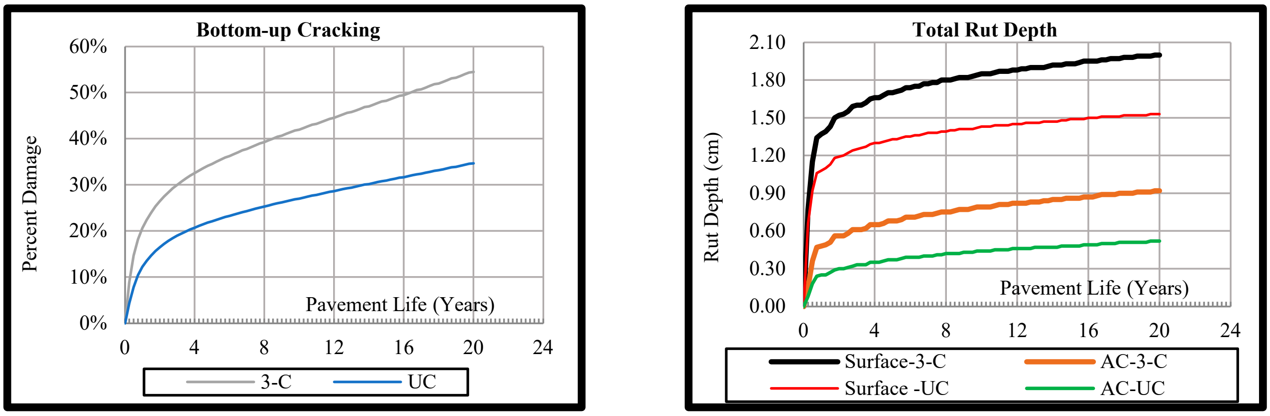

Figure 3. Example of FlexPave^{TM} results for design method A.

Table 4. Pavement Design Life of the Superpave Asphalt Mixture for 30 MESALS Traffic.

Design Method	Fatigue Life (UC)	Rutting Life (UC)	Fatigue Life (3-C)	Rutting Life (3-C)
Typical sections (A)	3.75 years	20 years	1 year	12.75 years
AASHTO 93 (B)	18.25 years	20 years	4.25 years	20 years
FlexPave^{TM} (C)	20 years	20 years	5.5 years	20 years

4. Conclusions and Recommendations

This study focused on the process and importance of conducting mechanistic–empirical analysis for the newly adopted Superpave asphalt mixture. Results showed that the newly adopted Superpave asphalt mixture enhanced the rutting and fatigue cracking resistances at the unconditioned state. However, fatigue cracking resistance under the moisture-conditioned state still needs further improvement for the newly modified Superpave asphalt mixture.

Author Contributions: T.A. and A.S. (Aditya Singh): Conceptualization, data curation, supervision, writing—original draft, software, and data analysis. E.H. and A.S. (Ahmad Saad): Conceptualization, investigation, methodology, data curation, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Assessment of a Hybrid Renewable Energy System: The Case of Kuwait

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***Abstract*— The energy needs in Kuwait are increasing rapidly and more power sources are required to cover this demand especially in peak time in summer. Renewable energy has a good potential of use in Kuwait due to Kuwait's weather and environment with lot of sunny days and wind. The purpose of this paper is to study and develop a cost-effective solution based on hybrid system that allows obtaining green energy in Kuwaiti's residences. The proposed off-grid system includes solar panel, wind turbine, battery bank and fuel cell system to form a standalone power system. Furthermore, the load demand of a typical Kuwaiti residence along with available meteorological data are measured and considered. The overall performance of the hybrid system is analyzed to form an optimum and dynamic system with high performance all year round that fits the load of the residence.**

Keywords—Renewable energy, solar, wind, fuel cells, optimization.

I. Introduction

Renewable energy sources have now huge attention and acceptance within the past few years as governments, organizations and people everywhere on the planet are accepting their environmental responsibilities [1]. Renewable energy technologies have an enormous potential and are currently leading growing fields in the electrical industry. With an installed capacity of 98 GW by the end of 2017, solar Photovoltaic (PV) additions went up a record 29% per year [2]. In addition, according to preliminary statistics published by WWEA (World Wind Energy Association) the overall capacity of all wind turbines installed worldwide by the end of 2017 reached 540 MW slightly more than in 2016 accounting alone for 51,4 MW [3]. Recently, PV and wind energy technologies grew the fastest according to IRENA (International Renewable Energy Agency).

Kuwait's electricity consumption relies almost entirely on oil products and natural gas for power generation. Currently, the country is facing important grid and capacity issues as well as rapidly growing energy demand. As a response to these shortages, the Kuwaiti government is planning to increase generation capacity in the next decades. Most of newly planned capacity will come from natural gas or oil, but the government also aims to generate 15% of its electricity from renewable sources by 2030. Currently, only 0.13 per cent of electricity in Kuwait comes from renewable energy sources [4]. To reach the target of supplying 15% of peak electricity demand from renewable energy sources by 2030 set by HH Sheikh Sabah Al-Ahmad Al-Jaber Al-Sabah, the Amir of the State of Kuwait, the country can capitalize on its wind and solar energy potential. Solar resources are abundant in Kuwait and there is also a significant potential for wind power. The Global Horizontal Irradiance is 1,900 kWh/m^2/year and the full load hours for wind is 1605 hours/year [5]. Kuwait has also set energy efficiency targets to reduce energy consumption by 10% in the residential and industrial sector, as well as to improve power generation efficiency by 5% in the utility sector [6].

The main objective of this paper is to design a stand-alone off-grid hybrid power system based on renewable energy sources such as solar, wind and fuel cell. Moreover, this paper will investigate the best configuration of the different renewable energy sources (solar, wind and full cell) based on the meteorological data specific to Kuwait's environment and weather conditions. The perfect sizing of the solar array and the number of wind turbines used along with the needed fuel cell is very important in the design as it helps in decreasing the initial cost and allows working at maximum efficiency. In this paper, an investigated hybrid system situated in Kuwait desert (latitude of 29.08̊, longitude of 47.6̊) - designated as remote location, will be optimized. The perfect sizing and the minimum cost are estimated while providing the highest possible efficiency. The below steps will be implemented in this paper:

- Load specification: A typical small residential unit consumption is determined.
- Environment characteristics: Meteorological data (irradiance and wind speed) are defined for the current location.
- System validation: The functionality of the complete system (including PV system, Wind turbine, Fuel cell) is validated, and the optimization process is presented.
- Optimization study: Different sizing for PV / Wind are evaluated to define the most efficient and optimized size.

II. Load Specification

Sizing the PV array alongside with the number of turbines used in generating electricity from wind is directly related to the load demand. Also, the size of the Fuel cell with its electrolyzer in order to manage the load demand during intermittency of renewable sources will be determined. The sizing of the system will be hugely related to the load demand. The power being consumed by electrical components is analyzed. Each equipment has its own specific power rating. Table I below shows the consumption distribution to define the total energy consumed during a year. Numbers are

V. Overall Outcome

The results below depict the different simulations outcomes in terms of energy storage and basic cost. Figure 4 underlines the amount of energy stored in the tank throughout the year. A mandatory criteria is to have a positive average value of stored energy. The line in the middle separated the positive and negative areas. The amounts of energy stored depends on the sizes of the PV and wind systems, and thus it reflects also the cost of the system. The selected system should be somewhere above the line but close to it (2 selected values given as example).

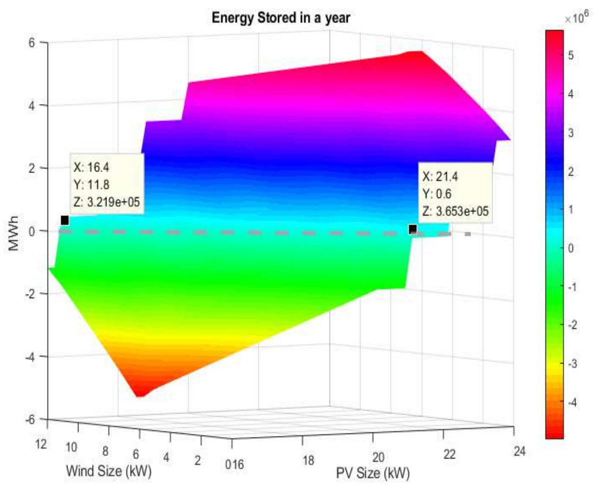

Fig. 4. Energy Stored in One Year

Figure 5 shows the basic PV and Wind costs function of the selected sizes. Only valid simulation with positive energy stored values are considered. We note that the suitable solution corresponds to a higher size of PV with a lower size of wind. Thus, the optimized solution will be somewhere around the selected values shown on the figure: 21.4 kW PV and 0.6 kW Wind. Of course, these sizes may change depending on the market's products availability.

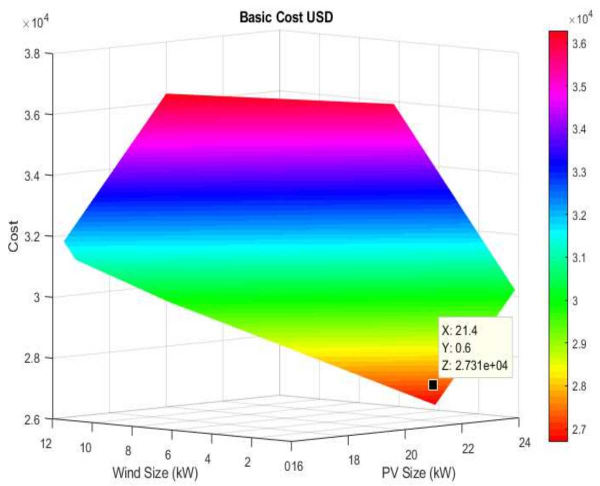

Fig. 5. Basic Cost of the Hybrid System in USD

All the different combinations have resulted in the same result. Increasing the PV size was more effective than increasing the size of the wind system. This is suitable especially that PV panels have a lower cost compared to large wind turbines that require a complex installation and maintenance compared to PV panels. The selected system has approximately a 21.4 kW PV and 0.6 kW Wind sizes. As a result, we need to use 107 PV panels and 1 single wind turbine. Each PV panel is rated 200 W and costs 250 USD, whereas the Wind turbine is rated 2 kW and costs 1882 USD. Of course, the system needs to be implemented in April or May to charge enough the hydrogen tanks, or these latter need to be filled (capital investment cost) if the system is to be implemented in October or November.

VI. Conclusion

In conclusion, multiple scenarios were used to evaluate the economic impact of introducing small scale standalone hybrid systems for residential units in Kuwait desert. Results show that such solutions are ineffective and not of interest unless, the application is for areas with no access to the grid (e.g. no alternative solutions). Though wind turbines are much less effective than solar systems, their use is mandatory to account for any deficiency at long cloudy periods. Fuel Cells initial cost could be attenuated by using traditional batteries, however at the expense of an increased maintenance cost. This work will be continued by validating the above results with a small scale prototype by considering their legitimacy since far located villas in the desert (with no access to the grid) may not have an alternative solution.

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