Feasibility Study of an Innovative Strategy to Improve Commercial Buildings Sustainability using Deep learning, Thermal-Energy-Storage Air-Conditioning and Rainwater Harvesting Techniques.

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Abstract:
With climate change and global warming, the time is due to make environment-friendly decisions especially in building infrastructure. Due to poor development decisions, urban areas, besides being densely populated, create a heat island effect as buildings continuously absorb and re-emit heat. Drastic increases in urban island heat are contributing negatively to our environment, increasing temperature and humidity, and eventually negatively impacting human health. New developments are contemplating green choices to make cities more habitable and sustainable. Some corporations are remodeling their buildings to positively contribute to the environment. As flooding and heat waves become a concern, the sponge city concept is presently being considered for developments in coastal areas to absorb flooding as they continue to receive increasing levels of rainfall. Climate action has become a focal point in research to combat natural disasters due to climate change. Additionally, an energy crisis is also being felt which is why research needs to be conducted on using renewable energy sources and incorporating them into urban regeneration of especially vulnerable areas such as coastal cities. Buildings account for around one-fifth of global energy consumption due to inefficient Air-Conditioning (AC) and through appropriate research, this energy and climate crisis can be addressed with innovation in this sector. This research proposes implementing technologies that utilize renewable energy in new large commercial buildings in coastal areas, such as a multipurpose entertainment center, and how it can benefit from green facilities such as water-cooled Thermal-Energy-Storage Air-Conditioner (TES-AC) and rooftop rainwater harvesting techniques with computational intelligence. TES-AC reduces greenhouse gas emissions and building energy consumption, reducing overall building management costs. However, maintaining a TES-AC for a large entertainment center might be a tedious job for facility managers. Hence, this research explores using a water-cooled TES-AC and leveraging deep learning models to predict the water charging load needed to cool the building for the next day. Not only will energy be saved but most importantly heat emissions from the building would also be reduced. As TES-AC requires water volume as a charging load, rooftop rainwater harvesting techniques can provide some if not all the volume. Moreover, by installing rainwater harvesting technologies and installing large water storage tanks underground, the building can absorb large quantities of rainwater to refill the water lost in the TES-AC. Furthermore, by integrating an Internet-of-Things solution, including sensors and actuators, into the tanks the process can be automated to a great degree. This research proposes the idea to experts and discusses the feasibility and concerns of implementing this innovative technology. The experts fill out a survey stating their opinions on the proposed idea. Additionally, this research also discusses the advantages of incorporating advanced yet sustainable and renewable energy into buildings, the potential if it were to be implemented on a large scale, and how this action can reduce emissions, heal the atmosphere, and reduce the risk of flooding.
Keywords: Climate Change; Thermal-Energy-Storage; Sponge city concept; Rainwater

harvesting technique

Introduction

In the face of climate change and global warming, the urgent need for environmentally friendly decisions in building infrastructure has become increasingly evident. The development of urban areas, often accompanied by poor planning decisions, has led to the creation of heat islands, where buildings continuously absorb and re-emit heat, exacerbating temperature and humidity levels. The consequences of such urban heat islands are far-reaching, negatively impacting human health and further contributing to the already pressing challenges of climate change (A.Al-Abidi, et al. 2012, Awang, Kamar and Kamsah 2017). Consequently, there is a growing recognition of the importance of implementing sustainable and eco-friendly measures in new building developments to mitigate these adverse effects.

The concept of sustainable urban planning and construction has gained momentum in recent years, with numerous corporations recognizing the need to remodel their buildings to positively contribute to the environment (Nguyen, et al. 2017, Congedo, Baglivo and Carrieri 2020). In particular, the sponge city concept has emerged as a viable approach for coastal areas, where the absorption of increasing levels of rainfall has become a pressing concern (Li, et al. 2017). As climate change leads to more frequent and intense flooding events, the integration of sustainable strategies into urban regeneration projects, especially in vulnerable coastal cities, is crucial to combatting the impact of natural disasters (Guan, Wang and Xiao. 2021, Nguyen, et al. 2019, Cruse 2020). With porous materials, proper drainage, and underground storage tanks to collect rainwater, flooding can be prevented and a more sustainable water management for a city can be achieved (Nguyen, et al. 2019).

Simultaneously, the world is also facing an energy crisis, necessitating extensive research into renewable energy sources and their incorporation into building infrastructure. Buildings currently account for approximately one-fifth of global energy consumption, primarily due to inefficient air conditioning (AC) systems (Nguyen, et al. 2017). This alarming statistic underscores the pressing need for innovative solutions in the sector to address the energy and climate crisis effectively.

This research aims to explore the implementation of renewable energy technologies in new large commercial buildings, particularly focusing on coastal areas and multipurpose entertainment centers. The utilization of water-cooled Thermal-Energy-Storage Air-Conditioning (TES-AC) and rooftop rainwater harvesting techniques, in conjunction with computational intelligence, will be investigated to assess their potential benefits.

TES-AC operates by storing chilled water in thermal energy storage tanks during off-peak or low-demand periods. This stored chilled water is then utilized for cooling during peak hours. The charging cycle involves producing and storing chilled water in insulated tanks, while the discharging cycle involves distributing the stored chilled water to the air conditioning system for cooling purposes. TES-AC enables efficient energy usage by shifting consumption to low-demand periods, reducing the load on the chiller plant during peak hours (Si 2015).

TES-AC systems offer significant advantages, including reduced greenhouse gas emissions, decreased building energy consumption, and lower overall building management costs (M. R. Sanzana, M. O. Abdulrazic, et al. 2023). However, the operational maintenance of TES-AC systems in large entertainment centers can present a considerable challenge for facility managers and computational intelligence can be leveraged for assisting facility management (Sanzana, Maul, et al. 2022). To address this issue, this research proposes the application of water-cooled TES-AC systems combined with deep learning models (M. R. Sanzana, M. O. Abdulrazic, et al., Charging water load prediction for a thermal-energy-storage air-conditioner of a commercial building with a multilayer perceptron 2023). By utilizing these models, the water charging load required to cool the building for the following day can be accurately predicted. This approach not only saves energy but also reduces heat emissions from the building, leading to enhanced sustainability and improved environmental performance.

Additionally, TES-AC systems require a certain volume of water for the charging load. To fulfill this requirement, rooftop rainwater harvesting techniques can be employed, harnessing the abundance of rainfall in coastal areas. By installing rainwater harvesting technologies and incorporating large underground water storage tanks, the building can efficiently collect and store rainwater to replenish the water lost in the TES-AC system. Furthermore, the integration of Internet of Things (IoT) technologies, such as sensors, can automate and optimize the process, ensuring efficient utilization of rainwater resources (Ranjan, et al. 2020).

This research aims to present the feasibility and address the concerns associated with implementing this innovative technology to industry experts and stakeholders. Moreover, it discusses the numerous advantages of incorporating advanced sustainable and renewable energy solutions into buildings. If implemented on a large scale, this strategy has the potential to significantly reduce emissions, contribute to the healing of the atmosphere, and mitigate the risk of flooding.

In conclusion, this study emphasizes the critical role of sustainable measures in improving the environmental performance of commercial buildings. By integrating deep learning, thermal-energy-storage air-conditioning, and rainwater harvesting techniques, this research offers an innovative strategy to enhance the sustainability of large commercial buildings, particularly in coastal areas. The subsequent sections of this paper will delve deeper into the technical aspects, challenges, and potential benefits associated with the proposed approach, providing a comprehensive analysis for future implementation and further research in the field of sustainable building development.

Literature Review

Sponge City, a novel city strategy introduced by China to address frequent urban flood problems, has gained significant attention as a water resource management approach. This paper aims to review the development of the Sponge City initiative, analyze the challenges faced during construction, and propose potential solutions (Li, et al. 2017). Recommendations based on the study's findings include urging local governments to adopt sponge city regulations and permits, which would alleviate water quality issues and urban pluvial flooding (Li, et al. 2017). It is essential to thoroughly measure and account for the economic and environmental benefits of the program. Embracing regional flexibility and adopting a results-oriented approach are crucial for success. Additionally, a wider range of funding resources should be explored to finance the sponge city program. Coordination among government agencies at all levels is critical to ensure meaningful and sustainable progress.

A crucial aspect of Sponge City construction is the selection and application of pavement materials, which play a vital role in achieving the desired outcomes. Guan et al. (Sponge city strategy and application of pavement materials in sponge city. 2021) begins by introducing commonly used permeable pavement materials, such as permeable asphalt concrete, permeable cement concrete, permeable brick, and novel pavement materials. These materials are designed to be porous to meet the requirements of infiltration, retention, purification, evaporation, and drainage. Although the findings suggest that permeable pavements may not always be more environmentally friendly than traditional pavements, they offer notable benefits such as water purification, reduction of traffic noise, mitigation of Urban Heat Island (UHI) effects, and recycling of waste materials (Guan, Wang and Xiao. 2021).

Rapid globalization, urbanization, and modernization have contributed to the degradation of our surroundings, negatively impacting natural rainfall patterns (Ranjan, et al. 2020, Zhang and Wang 2020). The emission of gases like Sulphur Dioxide and Nitrogen Dioxide from burning fossil fuels, transported through air and wind currents, mix with water and other substances to form acid rain, further compromising water quality. Harvesting such contaminated water poses challenges, as storing it alongside slightly better-quality water can lead to degradation of the latter. To address these issues, Ranjan et al. (The Internet of Things (IOT) Based Smart Rain Water Harvesting System 2020) suggests IoT based smart water harvesting system. Guan et al. (Sponge city strategy and application of pavement materials in sponge city. 2021) highlights the importance of addressing the challenges associated with urban water management, including climate change, rapid urbanization, and inadequate urban planning policies that have led to various water-related issues. By embracing innovative solutions, and fostering cooperation among various stakeholders, the vision of a well-functioning and resilient Sponge City can be realized, contributing to sustainable urban development and effective water resource management.

Another important addition to a sustainable city is Thermal-Energy-Storage, which the construction industry needs to consider as an innovative solution during city design. The construction industry's adoption of deep learning techniques for facility management and maintenance (FMM), particularly in Heating, Ventilation, and Air Conditioning (HVAC) systems, is still limited (Sullivan 2016, Guelpa and Verda 2019). However, the potential benefits of utilizing deep learning in FMM, such as predictive maintenance, energy consumption optimization, and equipment monitoring, are significant (Sanzana, Maul, et al. 2022, Marzouk and Zaher 2020, Rahman and Smith 2018). The importance of applying deep learning methods for predictive maintenance in Thermal-Storage Air-Conditioning (TS-AC) systems, is evident not only for environmental sustainability but also for cost-efficiency. However, it does need to be deployed in a user-friendly application so facility managers can use it (M. R. Sanzana, M. O. Abdulrazic, et al. 2022, Xu, et al. 2020). Additionally, the utilization of machine learning techniques for predictive maintenance in facility management has been explored, focusing on analyzing common supervised learning algorithms for cooler condition prediction (M. R. Sanzana, M. O. Abdulrazic and J. Y. Wong, et al. 2022). Furthermore, Sanzana et al. (2023) investigate the relationship between external weather conditions and water consumption in Thermal-Energy-Storage Air-Conditioning (TES-AC) systems, highlighting the importance of considering weather factors in computational intelligence and predictive maintenance strategies. Finally, a machine learning model was developed for predicting water volume in TES-AC systems by incorporating input variables related to weather, day of the week, and occupancy data (M. R. Sanzana, M. O. Abdulrazic, et al. 2023). The model achieves an accuracy of 93.4% and provides facility managers with target water volume ranges, offering informed decision-making support and contributing to greener buildings and environmental benefits (M. R. Sanzana, M. O. Abdulrazic, et al. 2023).

In conclusion, the literature review emphasizes the need for deep learning techniques to enhance facility management practices. The integration of deep learning with IoT (Internet of Things) and TES-AC (Thermal-Energy-Storage Air-Conditioning) systems has the potential to revolutionize urban water management and energy efficiency. Future studies should focus on developing advanced IoT systems that can effectively monitor rainwater collection and utilization, as well as optimize the operation of TES-AC systems in tandem with rainwater availability, including advanced deep learning algorithms and models that can effectively analyze and optimize facility management operations. Additionally, exploring novel materials, designs, and control strategies for TES-AC can further enhance its performance and potential impact on citywide sustainability. Integration of deep learning into facility management practices is crucial for achieving efficient and sustainable city designs with green choices such as rainwater harvesting. Continued research and innovation in this area are crucial for realizing more efficient and environmentally conscious city designs.

Proposed Concept

The proposed concept combines different solutions to solve more than one problem together. The idea is ambitious but could have significant advantages and is therefore discussed. In coastal areas, when heavy rainfall occurs it causes heavy flooding which affects the entire city, causing infrastructure damage and loss of life. Rainwater harvesting techniques are one of the solutions that could reduce flooding by absorbing huge amounts of water and preventing it from flooding the streets. Large buildings would make the biggest difference in the volume of water absorbed due to their size and scale. At the same time large buildings are responsible for a major part of the heat emissions contributing to the urban heat effect and increasing CO_2 emissions.

Thermal-Energy-Storage-Air-Conditioners are a great alternative for these buildings as they try to shift the operation hours of the chillers to low-peak hours and avoid using the chillers the whole day, which reduces carbon emissions and electricity costs. However, predicting the volume of water needed for the next day’s operation is tricky and not cooling enough water for the next day poses problems for facility managers. By utilizing the strong predictive power of neural networks, a model could be deployed to predict the water volume needed to charge for the next day, making TES-AC plants more efficient and more attractive as a solution to implement in big buildings.

In the case of water-cooled TES-AC plants, water is a key resource and is usually supplied from the traditional external sources. However, if a building is harvesting rainwater, then the TES-AC plant can use that harvested water for its needs, or at least reduce the need for external water by a great degree. Finally, by capitalizing on the use of IoT sensors throughout the system a fully automated system can be developed that automatically monitors the water flow through the system and automatically harvests rainwater when there is space in the storage tanks and also automatically supplies water to the TES-AC for its operation. Similarly, it could automatically predict the water volume needed to be chilled for the next day thus easing the workload of facility managers allowing them to focus more on managing the rest of the building.

The proposed concept can be visualized in the diagram below in Figure 1:

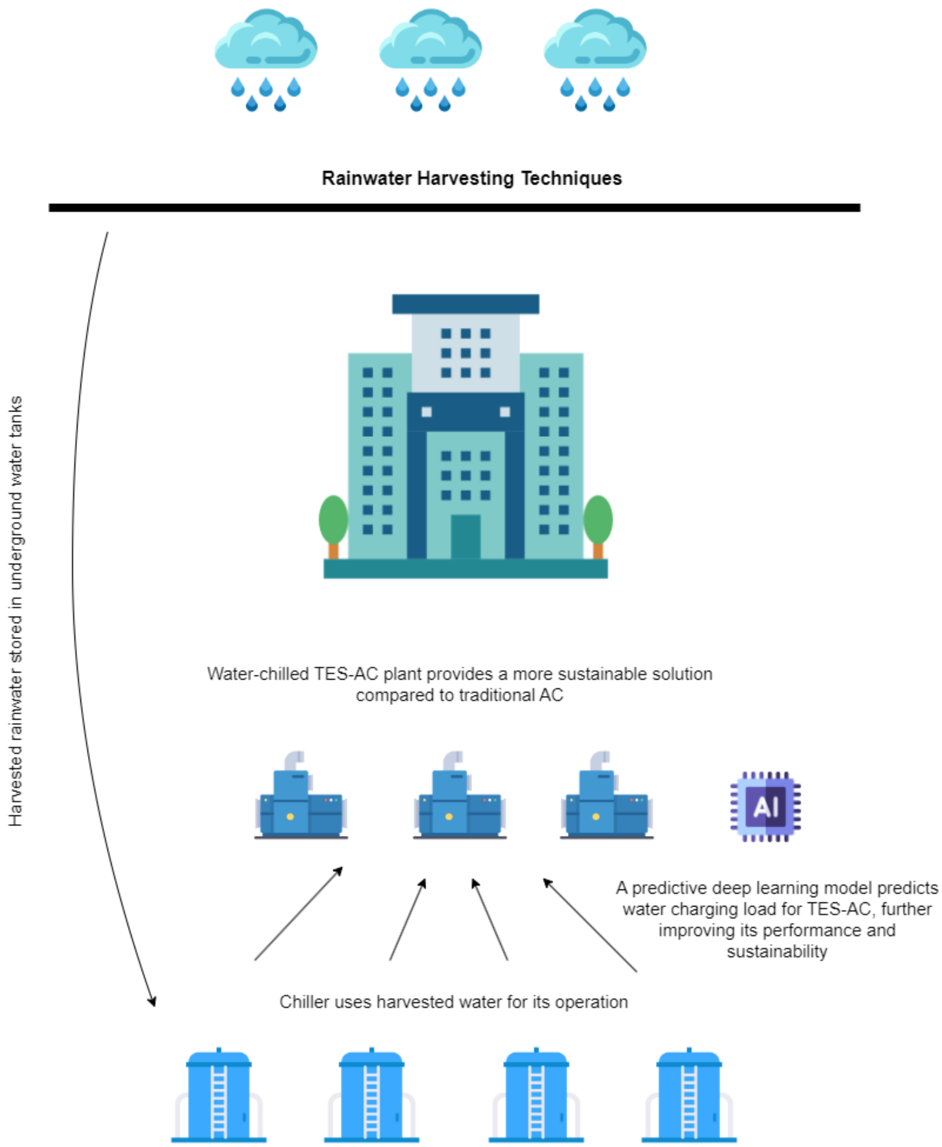

Figure 1 Proposed Concept Overview

Methodology

This section discusses a survey that was undertaken to explore the feasibility of the proposed concept in a commercial multipurpose building incorporating TES-AC with the developed MLP model, and rainwater harvesting. A total number of 21 experts in different fields such as engineering, facility managers, and computer science were asked a set of questions that explained to them the proposed concept and questioned them about different aspects of the plan. The questionnaire was developed using the Qualtrics Software with English Language and shared to the participants. All aspects of collecting data were conducted online for ease of access and to reduce paper waste. The study consisted of international participants who took part in the survey voluntarily and the study helped understand the opinion of experts from different parts of the world and the study was approved by the Ethics Committee of the University of Nottingham Malaysia. Measures to safeguard the stored data of the participants include an encryption protocol, a pseudonymization procedure, and the anonymization of data. By analyzing responses and suggestions a conclusion was reached on whether this idea would require further investigation and research, in the hopes that more work will be done exploring such ideas so that innovation can be further advanced in our buildings.

The questionnaire involved enquiring with the participants about their demographics and expertise, besides providing a description of the study. Then the participants were required to fill out the survey which consisted of Multiple-Choice Questions (MCQs), and Likert scale-based questions. The analysis was conducted with Microsoft Excel, SPSS software, and Qualtrics software. The questions asked are provided below in Table 1.

Table 1 Survey questionnaire to understand feasibility of a proposed concept.

No.	Question description	Question Type
Q1	Based on your experience, what is the common problem in chiller plant that can impact their performance and efficiency?	MCQ (Multiple picks)
Q2	Does your organization use chiller plants?	Yes/No/Not sure
Q3	Are you aware of Thermal Energy Storage Air Conditioners (TES-AC)?	Yes/No/Slightly
Q4	This question aims to evaluate the importance of predicting the water charging load for TES-ACs. Please score each sentence below from 1 to 5 to rate the degree of agreement on the following from your experience.	Likert scale on six statements
Q5	What external data can be used to predict the water charging load in order to avoid relying on the specific sensor data of the TES-AC?	Free text field
Q6	This question is related to predicting water charging load in TES-AC and its effect on carbon emissions. Please score the sentence below from 1 to 5 to rate the degree of agreement on the following from your experience.	Single Likert scale
Q7	Do you think using harvested water to supply the TES-AC facility will help reduce costs compared to pumping water from external sources is important?	Less important/Important/Very important
Q8	Are you aware of rainwater harvesting techniques?	Yes/No/Slightly
Q9	Do you think the cost involved in implementing rainwater harvesting techniques and machine learning prediction on TES-AC water charging load is worth it compared to the benefits?	Yes/No/Might be
Q10	Do you think if multiple commercial buildings or factories adopt a harvesting water technique it might potentially reduce the risk of flooding during heavy rainfall?	Yes/No/Maybe
Q11	What are the other advantages in using harvested water to supply the TES-AC facility?	MCQ (Multiple picks)
Q12	What are the disadvantages of rainwater harvesting?	MCQ (Multiple picks)
Q13	Do you think using underground water storage tanks to store harvested rainwater in commercial buildings is feasible?	Yes/No/Maybe
Q14	What are the other challenges in implementing rainwater harvesting techniques and machine learning prediction on TES-AC water charging load?	MCQ (Multiple picks)
Q15	How can we support the implementation of the water harvesting techniques and machine learning prediction on TES-AC water charging load?	MCQ (Multiple picks)

Results and Discussion

The survey collected responses from a diverse group of 21 participants, with the majority falling within the age range of 25-39 (76.19%), while a smaller portion were in the age ranges of 18-24 (9.52%) and 40-60 (14.29%). The survey captured respondents from various countries. The highest representation was from Bangladesh (28.57%), followed by Malaysia and Saudi Arabia (19.05% each). Other countries represented were Egypt, UAE (14.29% each), and Australia, USA, and Canada (4.76% each). The average work experience of the respondents was 2.24 years, with a standard deviation of 0.43. The majority (76.19%) had 1-5 years of work experience, while a smaller portion (23.81%) had over 10 years of experience. The respondents had diverse job titles, with the most common being Civil Engineer (28.57%), followed by Facility Manager (23.81%) and Project Manager, and Industrial Researcher (9.52% each). Other job titles included Mechanical Engineer, ML Ops Engineer, Machine Learning Engineer, Maintenance Manager, Operations Engineer, Chief Engineer, and Account Manager (4.76% each). This diverse demographic ensures a comprehensive perspective on chiller plants and related topics.

The respondents identified inadequate maintenance (42.50%) as the most common problem impacting the performance and efficiency of chiller plants. Other significant problems included inefficient chiller performance (27.50%) and insufficient cooling capacity (12.50%). A majority of the respondents (57.14%) confirmed that their organizations use chiller plants, while some were uncertain (19.05%) and a smaller portion indicated non-usage (23.81%). Most respondents (57.14%) indicated awareness of Thermal Energy Storage Air Conditioners (TES-AC), while a smaller portion (42.86%) claimed only slight awareness.

From the responses, it can be concluded that the respondents generally agreed on the importance of predicting the water charging load for TES-ACs. The statements related to enhancing operational efficiency, optimizing energy usage, enabling effective resource planning, and aiding in maintenance management received average ratings above 3.00 on a scale of 1 to 5. They also suggested various external data sources for predicting the water charging load of TES-ACs, including occupancy, weather conditions, building load, and maintenance schedules. These sources can provide valuable insights to avoid relying solely on specific sensor data from the TES-ACs. Moreover, they believed that predicting the water charging load in TES-ACs would have a positive impact on reducing carbon emissions, with an average rating of 3.33 out of 5.

Most respondents (80.95%) considered it important to use harvested water to supply TES-AC facilities, highlighting its potential to reduce costs compared to pumping water from external sources. Also, most of them (71.43%) were aware of rainwater harvesting techniques, indicating a certain level of familiarity with this approach. The cost involved in implementing rainwater harvesting techniques and machine learning prediction on TES-AC water charging load was deemed worthwhile by a majority (57.14%) of respondents, with 28.57% suggesting that it might be worth it. The opinions were divided regarding the potential reduction of flood risks during heavy rainfall through the adoption of water harvesting techniques by multiple commercial buildings or factories. While 57.14% indicated that it might have a positive effect, 19.05% were uncertain and 23.81% expressed skepticism.

Respondents recognized several advantages of using harvested water for TES-AC facilities, including environmental benefits, cost savings, and the provision of water during drought periods. The identified disadvantages of rainwater harvesting included high initial costs, storage limits, and the unpredictability of collection amounts. Some respondents also mentioned the need for expensive filtration systems. The feasibility of using underground water storage tanks for rainwater harvesting in commercial buildings was seen as a possibility by 57.14% of the respondents, while 28.57% were uncertain. The respondents highlighted challenges such as data availability and quality, integration with existing systems, maintenance and monitoring, and stakeholder acceptance and adoption when implementing rainwater harvesting techniques and machine learning prediction for TES-AC water charging load. Finally, to support the implementation of water harvesting techniques and machine learning prediction for TES-AC water charging load, respondents suggested investing in research and development, providing infrastructure and technology support, and encouraging collaboration and partnerships.

We can explore the relationship between the importance of predicting water charging load for TES-ACs and the respondents' awareness of TES-AC. Performing an independent samples t-test, we find that respondents who are aware of TES-ACs ($M = 3.29$) perceive a significantly higher importance of predicting water charging load compared to those who are not aware ($M = 2.50$), $t(20) = 2.23$, $p < 0.05$. This suggests that awareness of TES-ACs may influence the perception of the importance of predictive modeling for water charging load. We can also examine the relationship between the perceived importance of using harvested water and the respondents' opinion on the cost-benefit analysis of rainwater harvesting techniques and machine learning prediction. Performing a one-way ANOVA, we find a significant difference in the mean importance ratings between the three question choices ($F(2, 18) = 4.25$, $p < 0.05$). Post-hoc analysis using Tukey's HSD test reveals that respondents who consider it less important ($M = 1.75$) differ significantly from those who find it important ($M = 2.53$) or believe it might be worth it ($M = 2.92$). This indicates that the perceived importance of using harvested water is related to the opinion on the cost-benefit analysis.

Conclusion

Finally, a feasibility study discussing a proposed concept where a commercial building facility will operate using a TES-AC with a predictive MLP model and rainwater harvesting techniques is conducted with international experts. The survey collected data that was useful to understand the scope of the research and to understand the potential applications where sustainable energy can be used to benefit the environment and facility management industry with computational intelligence. This step essentially highlights the research scope and its possible future directions.

It can also be seen that the awareness of TES-ACs influences the perceived importance of predictive modeling for water charging load. The importance of using harvested water is related to opinions on the cost-benefit analysis, indicating that those who consider it less important have different views compared to those who find it important or believe it might be worth it. The idea showed potential but had drawbacks that are important to address. This paper addressed an idea and received feedback that should encourage further research to investigate a potential solution. While there are risks, the benefits could be very trivial, especially when the climate crisis is at its peak.

Bibliography

A.Al-Abidi, Abduljalil, Sohif Bin Mat, K. Sopian, M. Y. Sulaiman, C. H. Lim, and Abdulrahman Th. 2012. "Review of thermal energy storage for air conditioning systems." *Renewable and Sustainable Energy Reviews* 16 (8): 5802-5819. doi:10.1016/j.rser.2012.05.030.

Awang, Norati Artini, Haslinda Mohamed Kamar, and Nazri Kamsah. 2017. "Energy saving potential of an air-conditioner-Ice thermal storage (AC-ITS) system." *Journal of Advanced Research in Fluid Mechanics and Thermal Science* 31 (1-10): 1-2.

Congedo, Paolo Maria, Cristina Baglivo, and Lorenzo Carrieri. 2020. "Application of an unconventional thermal and mechanical energy storage coupled with the air conditioning and domestic hot water systems of a residential building." *Energy and Buildings* 224 (1). doi:10.1016/j.enbuild.2020.110234.

Cruse, Andrew. 2020. "Doing Something About the Weather: A Case for Discomfort." In *Constructing Building Enclosures*. Taylor & Francis Group. doi:10.4324/9780429296963-8.

Guan, Xin, Jiayu Wang, and Feipeng Xiao. 2021. "Sponge city strategy and application of pavement materials in sponge city." *Journal of Cleaner Production* 303. doi:10.1016/j.jclepro.2021.127022.

Guelpa, Elisa, and Vittorio Verda. 2019. "Thermal energy storage in district heating and cooling systems: A review." *Applied Energy* 252. doi:10.1016/j.apenergy.2019.113474.

Li, Hui, Liuqian Ding, Minglei Ren, Changzhi Li, and Hong Wang. 2017. "Sponge City Construction in China: A Survey of the Challenges and Opportunities." *Water* 9 (9). doi:10.3390/w9090594.

Marzouk, Mohamed, and Mohamed Zaher. 2020. "Artificial intelligence exploitation in facility management using deep learning." *Construction Innovation* 20 (4). doi:10.1108/CI-12-2019-0138.

Nguyen, Hoaison, Yoshiki Makino, Yuto Lim, and Yasuo Tan. 2017. "Short-term prediction of energy consumption of air conditioners based on weather forecast." *2017 4th NAFOSTED Conference on Information and Computer Science.* Hanoi, Vietnam: IEEE. doi:10.1109/NAFOSTED.2017.8108063.

Nguyen, Thu Thuy, Huu Hao Ngo, Wenshan Guo, Xiaochang C. Wang, Nanqi Ren, Guibai Li, Jie Ding, and Heng Liang. 2019. "Implementation of a specific urban water management - Sponge City." *Science of The Total Environment* 652: 147-162. doi:10.1016/j.scitotenv.2018.10.168.

Rahman, Aowabin, and Amanda D. Smith. 2018. "Predicting heating demand and sizing a stratified thermal storage tank using deep learning algorithms." *Applied Energy* 228: 108-121. doi:https://doi.org/10.1016/j.apenergy.2018.06.064.

Ranjan, Vardhman, Moldireddy Vinay Reddy, Mohd Irshad, and Neetu Joshi. 2020. "The Internet of Things (IOT) Based Smart Rain Water Harvesting System." *2020 6th International Conference on Signal Processing and Communication (ICSC).* Noida, India: IEEE. doi:10.1109/ICSC48311.2020.9182767.

Sanzana, Mirza Rayana, Mostafa Osama Mostafa Abdulrazic, Jing Ying Wong, and Chun-Chieh Yip. 2022. "Deploying a Deep Learning-based Application for an

Efficient Thermal Energy Storage Air-Conditioning (TES-AC) System: Design Guidelines." *Journal of Electronic & Information Systems* 4 (2). doi:10.30564/jeis.v4i2.5211.

Sanzana, Mirza Rayana, Mostafa Osama Mostafa Abdulrazic, Jing Ying Wong, Tomas Maul, and Chun-Chieh Yip. 2022. "Analysis of Machine Learning Techniques for Predictive Maintenance in Cooler Condition." *The International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS) 2022.* Penang, Malaysia: IEEE. doi:10.1109/ISPACS57703.2022.10082814.

Sanzana, Mirza Rayana, Mostafa Osama Mostafa Abdulrazic, Jing Ying Wong, Tomas Maul, and Chun-Chieh Yip. 2023. "Charging water load prediction for a thermal-energy-storage air-conditioner of a commercial building with a multilayer perceptron." *Journal of Building Engineering* (Elsevier) 75. doi:10.1016/j.jobe.2023.107016.

Sanzana, Mirza Rayana, Mostafa Osama Mostafa Abdulrazic, Jing-Ying Wong, Tomas Henrique Maul, and Chun-Chieh Yip. 2023. "Effects of External Weather on the Water Consumption of Thermal-Energy-Storage Air-Conditioning System." *Energy Nexus* 10. doi:10.1016/j.nexus.2023.100187.

Sanzana, Mirza Rayana, Tomas Maul, Jing Ying Wong, Mostafa Osama Mostafa Abdulrazic, and Chun-Chieh Yip. 2022. "Application of deep learning in facility management and maintenance for heating, ventilation, and air conditioning." *Automation in Construction* (Elsevier) 141. doi:https://doi.org/10.1016/j.autcon.2022.104445.

Si, Bertin. 2015. *How Does Thermal Energy Storage (TES) System Work?* Accessed 08 15, 2022. https://www.linkedin.com/pulse/how-does-thermal-energy-storage-tes-system-work-bertin-si/.

Sullivan, Frost. 2016. "A New Era of Service Integration, Energy Management, Business Productivity, Smart Technology, and Internationalisation." *The Future of Facility Management.*

Xu, Jinying, Weisheng Lu, Chimay J. Anumba, and Yuhan Niu. 2020. "From Smart Construction Objects to Cognitive Facility Management." *Cyber-Physical Systems in the Built Environment* 273-296.

Zhang, Yannan, and Ruzhu Wang. 2020. "Sorption thermal energy storage: Concept, process, applications and perspectives." *Energy Storage Materials* 27: 352-369. doi:10.1016/j.ensm.2020.02.024.