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MISCONCEPTIONS IN HEATING, VENTILATION AND AIR CONDITIONING - AIRSIDE STRATEGY IMPLEMENTATION OF COMMERCIAL BUILDINGS IN SRI LANKA

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ABSTRACT

To lower energy consumption and emission patterns in the building sector, discussions about climate change, the depletion of fossil fuels, and energy conservation are emphasised to create a more sustainable built environment. Thus, this paper examines common misconceptions regarding the implementation of HVAC airside strategies in commercial buildings, with a primary focus on Sri Lankan commercial buildings, where Heating, Ventilation and Air Conditioning (HVAC) systems account for a significant portion of electricity consumption. For this purpose, a comprehensive literature synthesis was conducted, a qualitative research approach was used to pursue the research aim, and an interview survey using semi-structured interviews was conducted targeting 17 experts. The collected data was then analysed using content analysis using the NVivo software. The findings of the research were discussed under three topics i.e., (i) adaptation of HVAC airside strategies to a tropical country, (ii) adaptation of HVAC airside strategies to coastal and highly humid areas, and (iii) sufficiency of prioritising waterside efficiency to gain overall HVAC system efficiency. In conclusion, it was derived that a balanced approach between airside and waterside HVAC systems should be maintained for optimal energy efficiency and the HVAC system can be tailored to diverse environmental conditions buildings are situated in. The knowledge gathered through this study can be used by industry professionals to enhance HVAC energy performance, while aiding academia in researching this sub-branch of HVAC systems in the Sri Lankan context.

Keywords: *Airside Efficiency; Central Air-conditioning System; Commercial Building; Energy Efficiency; Misconceptions.*

1. INTRODUCTION

The present global energy consumption crisis has attracted widespread attention from diverse stakeholders, driven by escalating global energy demands. This surge raises concerns about potential supply constraints, resource depletion, and subsequent environmental repercussions (Zakaria et al., 2023). Notably, energy services associated

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with buildings constitute a significant share, contributing around 33% to the total global demand for final energy and the associated greenhouse gas emissions (Urge-Vorsatz et al., 2013). Within the Sri Lankan context, the building sector stands out as the predominant consumer of primary energy (Selvakkumaran & Limmeechokchai, 2013). The commercial and industrial sector, housing a substantial building inventory, significantly contributes, comprising nearly 60% of the country's electricity consumption, which is highlighted by aggregating the sub-metering data, indicating that HVAC systems constitute approximately 51% of the annual average electricity end-use breakdown in Sri Lanka's buildings (Geekiyanage & Ramachandra, 2018).

Patel et al. (2018) highlight the segmentation of HVAC systems into airside and waterside. Together, these two subsystems optimise the HVAC system's overall energy efficiency. According to Faulkner et al. (2023), to obtain the best energy savings in buildings, it is imperative to consider both waterside and airside components simultaneously. The airside system significantly influences Indoor Air Quality (IAQ), occupant health, and overall productivity (Kang et al., 2021). Similarly, Boyajieff (2017) stated that airside efficiency arguably has the most dramatic financial impact of any Energy Conservation Measure (ECM) where airside efficiency projects have a payback of 2.5 years with an average of 38% energy reduction in buildings. This is especially true for large commercial buildings that have high cooling loads and loads caused by internal heat gain (Ji et al., 2016).

Thus, according to existing literature, the energy consumption of commercial buildings makes up 20% of Sri Lanka's overall electricity consumption (Weerasinghe et al., 2016), with airside HVAC systems accounting for 20% of this total (Amjath et al., 2021). Hence, to reach better efficiency levels, it is important to implement HVAC airside system strategies so that the HVAC system as a whole can yield benefits. Despite the high percentages and the clear necessity, energy efficiency levels are not maintained in commercial buildings due to various reasons and one significant reason is the misconceptions surrounding the implementation of HVAC airside strategies. These misconceptions, observed globally, extend their influence on Sri Lanka, yet remain largely unexplored within the Sri Lankan context. Consequently, this research endeavours to address this gap, thereby paving the way for the implementation of HVAC airside strategies in Sri Lanka. Hence, this study aims to analyse the misconceptions in implementing energy efficiency strategies to the airside HVAC system of commercial buildings in Sri Lanka. Accordingly, the research question was developed as "How do the misconceptions influence the implementation of HVAC airside energy efficiency strategies in commercial buildings?"

2. LITERATURE REVIEW

2.1 ENERGY CONSUMPTION IN COMMERCIAL BUILDINGS

According to Zhan et al., (2018), buildings account for approximately 40% of global energy consumption and 33% of greenhouse gas emissions. About 60% of Sri Lanka's overall energy consumption is accounted for by the residential and commercial sectors combined (Sri Lanka Sustainable Energy Authority [SLSEA], 2020). To lower Carbon emissions and achieve sustainable development goals, the Sri Lankan government has therefore taken steps to improve energy efficiency in the built environment (Kandaudahewa & Melegoda, 2023). Thus, even though Emmanuel and Rogithan (2002) highlight the government's acknowledgement of the critical role of enhancing building energy performance in the national sustainable energy development strategy, they further stated that the scope of the Energy Efficiency Building Code (EEBC) of Sri Lanka was limited to new commercial buildings such as offices, hotels, shopping complexes, hospitals and others voluntarily if they exceed any one of the criteria that are listed as follows:

i. Building height exceeding four stories,

ii. Floor area of 2,000m^2 or greater,

iii. Building enclosed volume of 5,600m^3 or greater, and

iv. Electrical peak demand of 100 kW or greater Air-conditioning cooling capacity of 350 kW (output).

2.2 CENTRAL AIR CONDITIONING SYSTEM

The HVAC system can be categorised into two primary domains: the waterside, encompassing chillers, pumps, and cooling towers, and the airside, which includes VAV terminals, supply and return fans (Patel et al., 2018). Faulkner et al., (2023) stressed the necessity of concurrently addressing both subsystems to enhance energy efficiency in buildings. Sekhar (2016) asserted that the design of airside HVAC systems significantly influences achieving optimal air quality, acknowledging the inherent challenges in this design process. The airside system serves as the key factor determining IAQ by regulating variables such as dry-bulb temperature, indoor relative humidity, and air velocity. Furthermore, it profoundly impacts occupant health and productivity (Kang et al., 2016). Hence, the necessity to achieve airside efficiency for a commercial building is apparent.

2.3 MISCONCEPTIONS IN HVAC AIRSIDE STRATEGY IMPLEMENTATION

The energy consumption of HVAC systems in commercial buildings remains notably high, prompting significant focus on optimising their airside components (Bae et al., 2021). Existing literature underlines ongoing discussions regarding the implementation of HVAC airside strategies in commercial settings, which can be discussed under three sub-topics i.e. (i) adaptation of HVAC airside strategies to a tropical country, (ii) adaptation of HVAC airside strategies to coastal and highly humid areas, and (iii) priority of waterside HVAC system is sufficient for energy efficiency as follows.

2.3.1 Adaptation of HVAC Airside Strategies to a Tropical Country

The adaptability of HVAC airside strategies to tropical countries has been a subject of debate in the literature. Studies by Rahman et al., (2021) and Ahmed et al., (2021) suggest that conventional HVAC systems designed for temperate climates may face challenges in tropical regions due to variations in temperature and humidity. However, contrary to this misconception, successful implementations have been documented in countries such as Singapore and Malaysia, as highlighted by Shao et al. (2022) and Camargo et al. (2023). In these regions, innovative airside strategies effectively address the unique challenges posed by tropical climates, emphasizing the importance of tailoring HVAC systems to local conditions. Adaptation of HVAC airside strategies to coastal and highly humid areas

There has been discussion about research on HVAC strategies in high-humidity and coastal environments. While a study by Meng and Qu (2022) indicates challenges in maintaining efficiency in these environments, recent advancements in technology and design have showcased successful case studies. Ding et al., (2022) discuss the implementation of advanced dehumidification techniques in coastal commercial buildings, demonstrating the feasibility and efficiency of airside strategies. These findings challenge the misconception that HVAC strategies are inherently inefficient in coastal and high-humid areas.

2.3.2 Sufficiency of Prioritising Waterside Efficiency to Gain Overall HVAC System Efficiency

Contrary to the belief that waterside HVAC system strategies alone are sufficient, recent research emphasises the significance of airside strategies in achieving optimal energy efficiency. The research study of Tanriverdi and Gedik (2023) stresses the importance of considering airside factors in HVAC design, as neglecting these aspects can lead to suboptimal performance. Additionally, a study by Kang et al., (2016) provides evidence of energy savings achieved through prioritising airside efficiency over waterside systems, deflating the misconception that waterside strategies alone are satisfactory.

3. METHODOLOGY

Abutabenjeh and Jaradat (2018) suggested that research approaches encompass the plans and procedures guiding research from broad assumptions to detailed methods of data collection, analysis, and interpretation. Accordingly, for this study, a qualitative approach was selected, because it facilitates answering questions about the experiences, perceptive, and thoughts of the participants which cannot be understood in numerical or statistical data. Additionally, a qualitative survey comprising semi-structured interviews was employed, given the significance of comprehending varying viewpoints and misconceptions about the application of energy-efficient strategies to the airside HVAC system in commercial buildings in Sri Lanka. Moreover, semi-structured interviews allow the researchers to repeat or rephrase the interviewee's responses to get additional clarifications and assist them gain a thorough understanding of the issue of interest. According to Okken et al., (2019) adapted from Bertaux and Kohli, (1984), a qualitative survey sample was determined based on achieving data saturation and thorough exploration of the research questions within the specific context of the HVAC industry, hence, for this study, a sample of 17 respondents was chosen who all experts in the HVAC industry are.

The targeted 17 experts (refer to Table 1) are from two categories where one category comprises mechanical/HVAC engineers or facility managers of commercial high-rise buildings (E1-E11) whereas, the rest of the experts are consultants of HVAC, building services, or Building Management System (BMS) of commercial buildings (E12-E17). Experts belonging to Category 1 were selected based on their role, expertise, and experience of current engagement in a commercial high-rise (Building profile given in Table 2), in which the commercial buildings are on par with the Energy Efficiency Building Code (EEBC) as mentioned in Section 2.1. This will enable a comparison between the opinions of the experts as they all belong to the same category of commercial high-rises. The summary of the profile of the respondents is presented in Table 1.

Table 1: Profile of the respondents

Respondent	Designation	Area overlooked/ Area of Specialty	Work experience (years)
E1	Head of Facilities Management	HVAC	12
E2	HVAC Engineer	HVAC	7
E3	Facilities Manager	HVAC	19
E4	HVAC Engineer	HVAC	20
E5	Facilities Manager	HVAC	11
E6	Maintenance Engineer (Mechanical)	HVAC	23
E7	Mechanical Engineer	HVAC	7
E8	Mechanical Engineer	HVAC	5
E9	Head of the Engineering Department	HVAC	7
E10	Assistant Maintenance Engineer	HVAC	8
E11	MEP Manager project	Building Services	15
E12	HVAC consultant	HVAC consultant	42
E13	Assistant Director	MVAC	15
E14	ELV and BMS Consultant	ELV	10
E15	Building Service Engineer	Building Services	25
E16	HVAC System Consultant	Building Services, HVAC system designer	10
E17	Consultant MEP Engineer	HVAC	15

Table 2: Building profiles

Respondent	Total energy consumption (monthly average)	Total HVAC consumption (monthly average)	HVAC as a percentage	Total monthly bill	Peak demand
E1	1.4 Mn kWh	704,359 kWh	50%	Rs. 33 Mn	4200kVA
E2	669,310 kWh	468,517 kWh	65-70%	Rs. 16 Mn	1400 kVA
E3	190,000 kWh	95,000 kWh	50%	Rs. 2 Mn	400 kVA
E4	1.1 Mn kWh	550,000 kWh	50%		4500kVA
E5	580,000 kWh	240,000 kWh	50%	Rs. 14 Mn	1800kVA
E6	1.5 Mn kWh	705,000 kWh	50%	Rs.36 Mn	400 kVA
E7	453,246 kWh	172,694 kWh	40%	Rs. 800,000	1500-1600 kVA
E8	473,342 kWh	129,866 kWh	27.6 %	Rs.800,000	1500 kVA
E9	400,000 kWh	289000 kWh	30%	Rs. 4,700,000	Tower 1-640kVA Tower 2-800kVA
E10	1.4 Mn kWh	704,359 kWh	50%	Rs. 33 Mn	1000 kVA
E11	235,670 kWh	66,480 kWh	30%	Rs. 5,385,740	904 kVA

The analysis of data requires several closely related operations such as the establishment of categories, and the application of these categories to raw data through coding, and tabulation (Mishra et al., 2019). For this study, the content analysis method was used, and it was done using the NVivo software (2010) manufactured by Qualitative Solutions and Research (QSR) International (Pvt) Ltd.

3.1 RESEARCH FINDINGS

Every respondent offered perceptions based on their comprehension of HVAC Airside energy efficiency and the research findings are comprehensively described under three topics hereon.

3.1.1 Adaptation of HVAC Airside Strategies to a Tropical Country

E9 and E3 stated that the adaptation of the airside strategies for a tropical country, with a warm climate, is not possible, whereas E15, E8 and E16 had opposing ideas. According to experts E15 and E16, '*HVAC is a technical system. As far as the technology is concerned it doesn't matter what the country is, as long as the building manager has the knowledge. And in HVAC we don't use H, the heating part in Colombo, because it's a tropical country, but the remaining letters have enough impact*' and, E12 further expressed similar views to that as, the location of the country does not matter, whether it is a tropical or not, '*ASHRAE standard is a general worldwide standard. Not like CIBSE. Hence, we have to select the country climate zone, then you have to refer the particular data tables'* where it was further elaborated as '*. E.g.- SL in climate zone 0-A, when we use data from this category, we comply with ASHRAE 90.1 and reduce energy'*. A comparable opinion was given by E17 as '*being a tropical country we cannot exactly adopt things from ASHRAE, but we have to slightly modify it suitable to our country'*. Adding on to it, E14 stated that, 'tropical country' means Sri Lanka has different RH levels and temperature levels, compared to other countries, and these strategies are adaptable. Hence, many experts agree that this statement is theoretically illogical, and as E10 mentioned, '*people say this, because sometimes, the expected gain may not be there. Certain things may work, but expected output/ gain will be less'*, hence explaining why certain building service facilitators can have misconceptions about airside energy efficiency strategies. Adding on to that, E2 gave examples of HVAC airside strategies that could be easily implemented in the Sri Lankan context as the installation of efficient AHU filters, Variable Air Volume (VAV) system implementation, advanced controls and automation, Variable Speed Drive (VSDs) installation, a control system addressing varying loads, Pre-cooled Air Conditioning System (PAU), Demand Control Ventilation (DCV), night purging and air distribution and balancing.

3.1.2 Adaptation of HVAC Airside Strategies to Coastal and Highly Humid Areas

E7 stated that '*building is close to the sea so that fresh air is salty and equipment getting corroded, so we aren't going for many air efficiency improvements'* and E5 stated that, '*the facility is in the coastal area, so new methods cannot be practised as all the equipment can corrode, and equipment for proper installation would cost money for the organisation*'. Many experts had contradictory views to that of E7 and E5, and E14 generalised this statement by saying, '*corrosion is a problem in the coastal area, and it is applicable to every system. Not only to the HVAC system*'. Adding on to this, E16 stated that' *equipment that is outside, must anyway have the precautions to protect the equipment, it's not related to the energy efficiency of the airside, anyway if you have equipment outside, you need to have a precautionary method to protect the equipment*' hence stating precautions are needed for any equipment that is outside. Furthermore, E14 elaborated his opinion by stating that, considering the airside system, the RH level goes up when getting closer to the sea and the RH level in Colombo goes up to 80-90% whereas the comfort level that should be maintained is 50-55%. Therefore, a high heat load is undertaken by the air conditioning system, to bring down the air from 90% to 55%. That heat load should be undertaken by the air conditioning system, and that is the reason why '*buildings in the coastal area, require different strategies to improve the efficiency of the system, paying more attention to RH controlling. Airside controlling, therefore, is very much needed'* completely opposing the initial opinions by E7 and E5. Further, E15 explained that using his personal experience, '*most of the commercial high-rises are in Colombo. So, the coastal belt. And I have practically implemented these strategies, so it can be done'*, and E13 stated that, '*strategies can be adopted, but when we are designing, we have to design properly to be energy efficient. When designing. equipment selection or equipment should be suitable to the location/area*' where it was disclosed that air-cooled systems (air-cooled chillers, packaged units, split units, etc.) are not used near the sea belt, because of corrosion, hence explaining why selection should be done properly, and highlighting limitations that can exist when implementing HVAC Airside strategies to commercial buildings in the coastal area.

3.1.3 Sufficiency of Prioritising Waterside Efficiency to Gain Overall HVAC System Efficiency

It was observed from the findings that only a few commercial buildings measure the HVAC Airside energy efficiency. E2 said that '*we are always thinking of the chiller side for energy efficiency than AHU side'* and expert E3 stated, '*main part is chiller'* hence expressing that more focus is given to the waterside system explained the reason for this by stating, '*high percentage of energy-saving is with the waterside, that's why people are more focused on it. We have energy-efficient potential in airside, but not much as in the waterside*'. Therefore, his opinion is that, compared to the energy consumed by equipment on the waterside, the airside is not significant. E17 stated a similar opinion by mentioning that there is a logical reason for prioritising the waterside. It was his opinion that, considering the total HVAC energy efficiency, at least 60% is contributed by waterside equipment hence stating why experts prioritise implementing and measuring energy efficiency strategies to waterside than airside. However, the same expert further elaborated that, to gain total HVAC system efficiency, strategies should be adopted for both waterside and airside. E8 stated a different reason for prioritising waterside HVAC, 'im*provements that are to be done for airside equipment has not yet been addressed in the industry. Because we think, putting a blower and AHU that will work efficiently and there is no room to improve it. But still, there are improvements which can be done. Therefore, that analytical part or rather lack of knowledge is one reason*, hence stating why this area is neglected in the industry. This was further, agreed by the E14 and E15, where E14 stated that *'60-70% of the building electricity bill of Sri Lanka is for HVAC and we are compelled to tell it's because of the chiller. Because it's an easy answer'* and that people focus on bigger devices in HVAC (e.g.- chiller, cooling tower saying they consume more electricity).

Hence, in summary, this study has identified three prevalent misconceptions regarding the implementation of HVAC airside strategies in commercial buildings in Sri Lanka. First, there is a misconception that adapting HVAC airside strategies to tropical climates is impractical, despite evidence suggesting the adaptability of such strategies through adjustments in system design and operation. Second, there is a misconception that HVAC airside strategies cannot be effectively implemented in coastal and high-humidity areas due to equipment corrosion risks, overlooking feasible mitigation measures and the importance of RH control in energy efficiency. Lastly, there is a misconception that the waterside HVAC system holds priority over the airside system in achieving energy efficiency, despite potential gains that can be realised through improvements in airside equipment and operations. Addressing these misconceptions is crucial for enhancing energy efficiency practices in commercial buildings, emphasising the need for informed strategies tailored to local conditions and a comprehensive understanding of HVAC system dynamics.

4. DISCUSSION

The findings from the research shed light on the prevailing perceptions and misconceptions regarding the adaptation of HVAC airside strategies in specific contexts. The literature review underlines the debate surrounding the adaptability of airside strategies to tropical countries, emphasising the importance of tailoring HVAC systems to local conditions. As Shao et al. (2022) and Camargo et al. (2023) highlighted, innovative airside strategies effectively address the unique challenges posed by tropical climates, and the same was found from the findings of the research. The second misconception is related to airside strategies in coastal and highly humid areas where a recent study by Ding et al. (2022) discusses the implementation of advanced dehumidification techniques in coastal commercial buildings, demonstrating the feasibility and efficiency of airside strategies. This was also confirmed from the research findings that, it is very practical to implement these Airside HVAC strategies, as experts in Sri Lanka have already implemented them in coastal area commercial buildings and are gaining benefits from it. Furthermore, the study delves into the prioritisation of waterside HVAC systems over airside strategies. While some experts emphasise the significance of waterside systems for energy efficiency, citing higher potential savings, others, such as Tanriverdi and Gedik (2023) and Kang et al. (2016), highlight the importance of considering airside factors to achieve optimal energy efficiency. The research findings highlight the need for a holistic approach, debunking the misconception that prioritising waterside systems alone is sufficient.

5. CONCLUSIONS

In conclusion, the research findings contribute valuable insights into the prevalent perceptions and misconceptions surrounding the adaptation of HVAC airside strategies, particularly in tropical and coastal environments. The literature review establishes a foundation for understanding the ongoing debate, emphasising the necessity of customising HVAC systems to local conditions. Additionally, the research highlights the importance of a balanced approach between airside and waterside HVAC systems, refuting the misconception that prioritising waterside alone is sufficient for optimal energy efficiency. In essence, the research highlights the dynamic nature of HVAC airside strategies, emphasising the need for a nuanced understanding and a tailored approach to system design that considers the diverse environmental conditions buildings may face. Overall, the study emphasises the dynamic nature of HVAC airside strategies and the importance of bridging the gap between theoretical understanding and practical implementation in real-world scenarios.

6. REFERENCES

Abutabenjeh, S., & Jaradat, R. (2018). Clarification of research design, research methods, and research methodology: A guide for public administration researchers and practitioners. *Teaching Public Administration*, *36*(3), 237–258. https://doi.org/10.1177/0144739418775787

Ahmed, T., Kumar, P., & Mottet, L. (2021). Natural ventilation in warm climates: The challenges of thermal comfort, heatwave resilience and indoor air quality. *Renewable and Sustainable Energy Reviews, 138*, 110669. https://doi.org/10.1016/j.rser.2020.110669

Amjath, M. R., Chandanie, H., & Amarasinghe, S. D. I. A. (2021, July 10). *Energy retrofits for improving energy efficiency in buildings: A review of HVAC and lighting systems*. 9th World Construction Symposium, Sri Lanka. [Online]. https://doi.org/10.31705/WCS.2021.25

Bae, Y., Bhattacharya, S., Cui, B., Lee, S., Li, Y., Zhang, L., Im, P., Adetola, V., Vrabie, D., Leach, M., & Kuruganti, T. (2021). Sensor impacts on building and HVAC controls: A critical review for building energy performance. *Advances in Applied Energy*, *4, 100068.* https://doi.org/10.1016/j.adapen.2021.100068

Bertaux, D., & Kohli, M. (1984). The Life Story Approach: A Continental View on JSTOR. *Annual Review of Sociology*, *10*, 215-237. https://www.jstor.org/stable/2083174

Boyajieff, R. (2017, June 23). *Airside efficiency: A must have ECM.* Energy sustainability solutions. https://essmag.co.uk/airside-efficiency-a-must-have-ecm

Camargo, K. C., González, J., Solano, T., Yuil, O., Velarde, V., & Austin, M. C. (2023). *Energy-Efficiency Measures to Achieve Zero Energy Buildings in Tropical and Humid Climates*. DOI:10.5772/intechopen.1002801

Ding, Z., Yu, X., Ma, Z., Wu, W., Zhang, L., Yu, D. Y. W., & Cheng, D. H. K. (2022). On-site measurement and simulation investigation on condensation dehumidification and desiccant dehumidification in Hong Kong. *Energy and Buildings*, *254, 111560*. https://doi.org/10.1016/j.enbuild.2021.111560

Emmanuel, R., & Rogithan, R. (2018). How energy efficient is the EEBC? Evaluation based on a simulated office building. *Built-Environment: Sri Lanka*, *3*(1). https://www.researchgate.net/profile/R-Emmanuel/publication/306020738_How_energy_efficient_is_the_EEBC_evaluation_based_on_a_simulated_office_building/links/57ff5d8108aeaf819a5f4ac4/How-energy-efficient-is-the-EEBC-evaluation-based-on-a-simulated-office-building.pdf

Faulkner, C. A., Lutes, R., Huang, S., Zuo, W., & Vrabie, D. (2023). Simulation-based assessment of ASHRAE Guideline 36, considering energy performance, indoor air quality, and control stability. *Building and Environment*, *240*, 110371. https://doi.org/10.1016/J.BUILDENV.2023.110371

Geekiyanage, D., & Ramachandra, T. (2018). A model for estimating cooling energy demand at early design stage of condominiums. *Journal of Building Engineering*, *17*, 43–51. https://doi.org/10.1016/j.jobe.2018.01.011

Ji, Y., Xu, P., Duan, P., & Lu, X. (2016). Estimating hourly cooling load in commercial buildings using a thermal network model and electricity submetering data. *Applied Energy*, *169*, 309–323. https://doi.org/10.1016/j.apenergy.2016.02.036

Kandaudahewa, H., & Melegoda, N. (2023). Sustainable development goals (SDGs): Implementation, achievements and challenges faced in Sri Lanka. In *Business Sustainability through Lean and Green Practices: Manufacturing SMEs in Sri Lanka*. (pp. 1-24). Faculty of Graduate Studies, University of Colombo. https://www.researchgate.net/publication/359055559

Kang, S., Ping, T. S., Islam, M. R., & Pwint, M. (2016). *Energy measurement & audit: Reference manual*. Singapore certified Energy Manager. https://www.ies.org.sg/Tenant/C0000005/PDF%20File/Registry/SCEM/EMA(1).pdf

Meng, M., & Qu, D. (2022). Understanding the green energy efficiencies of provinces in China: A Super-SBM and GML analysis. *Energy*, *239*. https://doi.org/10.1016/j.energy.2021.121912

Mishra, P., Pandey, C., Singh, U., Keshri, A., & Sabaretnam, M. (2019). Selection of appropriate statistical methods for data analysis. *Annals of Cardiac Anaesthesia*, *22*(3), 297. https://doi.org/10.4103/ACA.ACA_248_18

Okken, G. J., Jansen, E. P. W. A., Hofman, W. H. A., & Coelen, R. J. (2019). Beyond the 'welcome-back party': The enriched repertoire of professional teacher behaviour as a result of study abroad. *Teaching and Teacher Education*, *86*. https://doi.org/10.1016/j.tate.2019.102927

Patel, N. R., Risbeck, M. J., Rawlings, J. B., Maravelias, C. T., Wenzel, M. J., & Turney, R. D. (2018, July 12). *A case study of economic optimization of HVAC systems based on the Stanford University campus airside and waterside systems.* 5th International High Performance Buildings Conference, Purdue. https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1252&context=ihpbc

Rahman, N. M. A., Haw, L. C., & Fazlizan, A. (2021). A literature review of naturally ventilated public hospital wards in tropical climate countries for thermal comfort and energy saving improvements. *Energies 4*(2). https://doi.org/10.3390/en14020435

Sekhar, S. C. (2016). Thermal comfort in air-conditioned buildings in hot and humid climates - why are we not getting it right? *Indoor Air*, *26*(1), 138–152. https://doi.org/10.1111/ina.12184

Selvakkumaran, S., & Limmeechokchai, B. (2013). Energy security and co-benefits of energy efficiency improvement in three Asian countries. *Renewable and Sustainable Energy Reviews*, *20*, 491-503. https://doi.org/10.1016/j.rser.2012.12.004

Shao, X., Zhang, Z., Song, P., Feng, Y., & Wang, X. (2022). A review of energy efficiency evaluation metrics for data centers. *Energy and Buildings*, *271*, 112308. https://doi.org/10.1016/j.enbuild.2022.112308

Sri Lanka Sustainable Energy Authority. (2020). *Sri Lanka Sustainable Energy Authority*.

Tanriverdi, B., & Gedik, G. Z. (2023). Importance of HVAC system selection in reducing the energy consumption of building retrofits–case study: Office building in London. *Civil Engineering and Architecture*, *11*(1), 217–227. https://doi.org/10.13189/cea.2023.110118

Urge-Vorsatz, D., Petrichenko, K., Staniec, M., & Eom, J. (2013). Energy use in buildings in a long-term perspective. *Current Opinion in Environmental Sustainability*, *5*(2), 141–151. https://doi.org/10.1016/j.cosust.2013.05.004

Weerasinghe, A., Ramachandra, T., & B Rotimi, J. O. (2016). A simplified model for predicting running cost of office buildings in Sri Lanka. In P. W. Chan and C. J. Neilson (Eds.), *Proceedings of the 32nd Annual ARCOM Conference*, *Manchester.* https://www.researchgate.net/publication/337992269_A_Simplified_Model_for_Predicting_Running_Cost_of_Office_Buildings_in_Sri_Lanka

Zakaria, Z., Kamarudin, S. K., Salehmin, M. N. I., Ahmad, N. N. R., Aminuddin, M. A., Hanapi, I. H., Osman, S. H., & Mohamad, A. A. (2023). Energy scenario in Malaysia: Embarking on the potential use of hydrogen energy. *International Journal of Hydrogen Energy*. https://doi.org/10.1016/j.ijhydene.2023.05.358

Zhan, J., Liu, W., Wu, F., Li, Z., & Wang, C. (2018). Life cycle energy consumption and greenhouse gas emissions of urban residential buildings in Guangzhou city. *Journal of Cleaner Production*, *194*, 318–326. https://doi.org/10.1016/j.jclepro.2018.05.124