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Strategies to Enhance Energy Efficiency of HVAC Airside System of Commercial Buildings in Sri Lanka

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Abstract

At present, debates addressing climate change, fossil fuel depletion, and energy saving highlight the need for a more sustainable built environment to reduce energy consumption and emission trends in the building sector. With a primary focus on commercial buildings in Sri Lanka, where Heating Ventilation and Air Conditioning (HVAC) systems account for a significant portion of electricity usage, this research investigates into the underexplored area of airside efficiency strategies. For this purpose, a comprehensive literature synthesis was conducted, and a qualitative research approach using a semi-structured interview survey was conducted targeting 17 experts. The collected data was then analysed using content analysis. The findings of the research revealed 17 strategies under 3 categories namely, Air Handling Unit (AHU) optimisation, system design and layout optimisation, and cooling system optimisation. Key strategies identified are, the installation of efficient AHU filters, Variable Air Volume (VAV) system implementation, advanced controls and automation, reduction of coil losses, Variable Speed Drive (VSDs) installation, a control system addressing varying loads, night purging and air distribution and balancing. The knowledge gathered through this study can be used by respective industry professionals to enhance HVAC energy performance, while it will also help the academia to research more on this sub-branch of HVAC system in the Sri Lankan context.

Keywords
Airside Efficiency, Central Air-conditioning System, Commercial Building, Energy Efficiency, and Strategies

1. Introduction
The global landscape is witnessing a surge in energy consumption, triggering concerns about resource depletion and environmental repercussions (Song et al. 2015). Within this context, the building sector stands out as a significant contributor, accounting for approximately 33% of the world's final energy demand and greenhouse gas emissions (Urge-Vorsatz et al. 2019). At the forefront of energy consumption in buildings is the Heating, Ventilation, and Air Conditioning (HVAC) system, a vital component that plays a pivotal role in providing thermal comfort and indoor air quality. When it comes to the Sri Lankan context, a similar situation can be seen. For example, in the context of Sri Lanka, the building sector has become the dominant consumer of primary energy, constituting nearly 60% of the nation's electricity consumption (Ministry of Power & Energy 2019). Within this sector, a substantial portion of energy is allocated to HVAC systems, reflecting the operational and functional characteristics of commercial buildings. Analysis of aggregated sub-metering data reveals that HVAC systems account for approximately 51% of electricity end-use breakdown in Sri Lanka (Geekiyanage & Ramachandra 2018).

Recognising the complexity of HVAC systems, it is imperative to dissect their components for a comprehensive understanding (Ahmad et al. 2018). Patel et al. (2018) emphasise the division of HVAC systems into waterside (chillers, pumps, and cooling towers) and airside (VAV terminals, supply and return fans). Both these subsystems contribute synergistically to the overall energy efficiency of the HVAC system. Faulkner et al. (2023) stress the need to consider both waterside and airside components simultaneously to achieve optimal energy savings in buildings. Hence, the HVAC airside system plays a critical role in the broader context of energy efficiency. The airside system significantly influences indoor air quality (IAQ), occupant health, and overall productivity (Kang et al. 2021).

Boyajieff (2017) highlights the financial impact of airside efficiency, highlighting its potential for substantial energy reduction in buildings with a relatively short payback period.

Thus, according to existing literature, the energy consumption of commercial buildings makes up 20% of Sri Lanka's overall electricity consumption (Weerasinghe et al. 2020), with airside HVAC systems accounting for 20% of this total (Amjath et al. 2021). Thus, to reach better efficiency levels, it is important to identify strategies to enhance HVAC airside system so that the HVAC system as a whole can yield benefits. Accordingly, this paper is aimed at exploring strategies to enhance the energy efficiency of the HVAC airside system of commercial buildings in Sri Lanka. Thus, the research question of the study was formulated as "How could the energy efficiency of the HVAC airside system of commercial buildings in Sri Lanka be enhanced?"

1.1 Objectives

The following objectives were formulated to achieve the aim of the paper.

- Identify strategies to enhance energy efficiency of HVAC Airside system
- Evaluate the identified strategies for enhancing energy efficiency of HVAC Airside system in the context of Sri Lanka

2. Literature Review

2.1 Energy and built-environment

The relationship between energy consumption and the built environment has acquired significant attention in the literature, as buildings contribute to a significant portion of the world's energy demand. Globally, buildings are responsible for approximately 40% of total energy consumption and 33% of greenhouse gas emissions (Zhan et al. 2018). Similar to the global context, Sri Lanka, a developing country that is experiencing rapid urbanisation, its built environment plays a crucial role in energy consumption. According to the Sri Lanka Sustainable Energy Authority (SLSEA), the residential and commercial sectors collectively account for nearly 60% of the country's total energy consumption (Sri Lanka Sustainable Energy Authority 2020). Hence, the Sri Lankan government has taken initiatives for energy efficiency in the built environment to be aligned with sustainable development goals and reduce carbon emissions (Kandaudahewa 2023). Moreover, the commercial sector, encompassing significant structures like large-scale buildings, contributes to 24% of total energy consumption in Sri Lanka (Sri Lanka Sustainable Energy Authority 2020). Emmanuel and Rogithan (2018) highlight the government's acknowledgement of the critical role of enhancing building energy performance in the national sustainable energy development strategy. Thus, the scope of the Energy Efficiency Building Code (EEBC) of Sri Lanka was enforced to new commercial buildings such as offices, hotels, shopping complexes, hospitals, and others on a voluntary basis if they exceed any one of the criteria that is listed below (Ceylon Electricity Board, 2022).

i. Building height exceeding four stories
ii. Floor area of 2,000 m2 or greater
iii. Building enclosed volume of 5,600 m3 or greater
iv. Electrical peak demand of 100 kW or greater v Air-conditioning cooling capacity of 350 kW (output)

2.2 Central air conditioning system

Central air conditioning systems are integral to maintaining indoor comfort in large buildings, comprising two key components, namely, the waterside system and the airside system (Chua et al. 2016). The airside system includes the zones in all of the buildings along with the associated air handling units (AHUs) used in temperature regulation (Rawlings et al. 2018). A similar opinion was expressed by Risbeck et al. (2020), where it was stated that, an airside system compromise of the air space and thermal mass of one or more buildings. The same author elaborated that, the airside encompasses the area that supplies and distributes conditioned air throughout the buildings, with AHUs typically used for this purpose, along with controlling temperature and moisture content in centrally heated or cooled buildings.

Airside energy efficiency is a critical aspect of overall HVAC system performance. Efficient airside strategies not only contribute to energy savings but also enhance the environmental sustainability of buildings (Chua et al. 2016). Various strategies could be implemented to achieve airside efficiency and these strategies help optimise the use of energy by adjusting ventilation rates and air distribution based on actual occupancy and load conditions, ultimately reducing energy consumption and operational costs (Chenari et al. 2016). Furthermore, Baldini et al. (2018) stated airside efficiency solutions offer the adaptability needed to efficiently monitor the indoor environmental quality and subsequently notify building management systems about evolving circumstances so they can appropriately modify HVAC settings, resulting in the ideal level of ventilation for nearly all building conditions. Hence, the need to achieve airside efficiency for a commercial building is apparent.

2.3 Strategies to enhance energy efficiency of HVAC airside system

As the energy consumption of HVAC system of commercial buildings is high, considerable attention has been devoted to optimising the airside components of HVAC systems (Bae et al. 2021). Literature suggests a multifaceted approach to enhance energy efficiency, encompassing various strategies, and these could be identified under three categories, namely, Air Handling Unit Optimisation, System Design and Layout Optimisation and Cooling system Optimisation The summary of strategies identified from existing literature is presented in Table 1.

Table 1. Summary of HVAC Airside Strategies

Strategy Category	Energy efficiency strategy	Reference
Air Handling Unit Optimisation	Efficient AHU filter	[1] [9] [10] [13] [19]
	Efficient AHU fan system	[8] [13]
	Airside economizer	[5] [10] [12]
	Heat Recovery Wheel	[11] [14]
System Design and Layout Optimisation	Efficient ducting system design	[8] [15] [16]
	Installation of Variable Air Volume (VAV) system	[7] [8] [9] [17]
	Efficient AHU selection	[17] [18]
Cooling system Optimisation	Pre-cooled Air Conditioning System (PAU)	[6] [7] [15]
	Demand Control Ventilation (DCV)	[3] [7] [14] [18]
	Optimal start-stop mechanism	[2] [20]
	Advanced Controls and Automation	[2] [4] [6] [8] [10] [18] [20]
[1] (Ruan and Rim 2019); [2] (Chua et al. 2013); [3] (Kong et al. 2022); [4] (Cho & Kim 2016); [5] (Tang et al. 2018); [6] (Yildiz et al. 2022); [7] (Yu et al. 2014); [8] (McQuiston et al. 2023); [9] (Chen et al. 2009); [10] (Ni and Bai 2017); [11] (Badiei et al. 2023); [12] (Zhao et al. 2017); [13] (Okochi & Yao 2016); [14] (Liu et al. 2020); [15] (Ahmed-Dahmane et al. 2018); [16] (Lee and Cheng 2016); [17] (Parhizkar et al. 2020); [18] (Ruan and Rim, 2019); [19] (Ozturk et al., 2013); [20] (Mathews et al., 2021)		

As shown in Table 1, an efficient AHU filter in a main strategy highlighted in the existing literature under AHU Optimisation category. Considering the System Design and Layout Optimisation category, the installation of Variable Air Volume (VAV) system is the most important strategy as it can facilitate conditioned air for a varying load (Chen et al. 2019). Advanced Controls and Automation is the strategy under the Cooling system Optimisation category that has been highlighted by many authors. The categorisation helps to organise the strategies based on their functional focus within the HVAC airside system. It's important to note that some strategies may overlap and complement each other. For instance, the use of VAV systems and VSDs in the AHU work together to optimise air distribution and reduce energy consumption. Similarly, a control system can integrate with various components to achieve overall efficiency.

However, strategies identified from the literature (refer Table 1) are general in context. Strategies to enhance the energy efficiency of the HVAC airside system of commercial buildings in Sri Lanka are yet to be discovered. This is because strategies to enhance airside efficiency in the context of Sri Lanka have not been discussed yet in existing literature. Thus, in bridging this knowledge gap, this paper intends to explore the energy efficiency strategies for airside HVAC systems, specifically in the Sri Lankan context. The next section discusses the research process adopted in bridging this knowledge gap.

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. A qualitative approach is chosen for its effectiveness in evaluating opinions and behaviours indicative of biases (Hennink and Kaiser 2022). The main reasons for selecting the qualitative research approach for this study are, that it gives the freedom to question participants' experiences, perceptions, and thoughts, aspects which are not easily captured in numerical or statistical data and also, it allows a deeper understanding of contextual factors and emergent strategies which may not be fully captured through quantitative measures alone. Moreover, a qualitative survey employing semi-structured interviews was used to gain insights into diverse perceptions regarding the current usage of energy efficiency strategies and identify existing gaps and recommendations of strategies that can be used in the context of Sri Lanka to enhance energy efficiency of airside HVAC systems of commercial buildings. The reason for selecting semi-structured interviews is that it facilitate a broad understanding of this research topic and provides the flexibility to seek clarifications through re-questioning or repeating responses.

Given the nature of this study, probability sampling, typically employed in statistical surveys, was deemed unsuitable. Therefore, judgmental/purposive sampling under non-probability sampling was reasoned more appropriate. As Etikan (2017) stated, this sampling method relies on the researcher's judgment to select individuals who can provide the most relevant information for the study objectives. The main reason for choosing judgmental sampling for this study is that it allows for the intentional selection of participants with expertise and firsthand experience in the energy efficiency of HVAC airside systems in commercial buildings in Sri Lanka, ensuring that the sample includes key stakeholders who can provide rich and insightful perspectives on the topic. This approach enabled the researcher to focus on individuals or organisations with in-depth knowledge and practical insights, facilitating a more targeted and comprehensive exploration of the research objectives.

Furthermore, adhering to the purposive sampling method, in this study, the sample consists of experienced and knowledgeable experts in building services, who are currently working in the industry. To ensure a comprehensive representation of diverse perspectives, efforts were made to include participants from various sectors and roles within the field of building services, including, mechanical/HVAC engineers, facility managers, and ELV and BMS consultants. By intentionally selecting participants with diverse backgrounds and experiences, this approach aims to capture a wide range of viewpoints and insights regarding energy efficiency strategies for HVAC airside systems in commercial buildings. This inclusive sampling strategy enhances the validity and generalisability of the research findings. Data analysis was conducted using code-based content analysis. It is vital to have an in-depth understanding of the strategies as it is essential to enhance the energy efficiency of the HVAC airside system of commercial buildings in Sri Lanka. However, so far, there has been no systematic academic analysis of this perspective. Thus, to investigate strategies in depth, this paper applies the categorisation identified through literature review (Refer to Section 2.3).

4. Data Collection

According to Okken et al. (2019) adapted from Bertaux (1981), a qualitative survey shall be more than fifteen per sample therefore, for this study, a sample of 17 respondents was chosen who are all experts in the HVAC industry. The targeted 17 experts (refer Table 2) are from two categories where one category comprises mechanical/HVAC engineer or facility manager 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 3), which the commercial buildings are on par with 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 (Table 2 and Table 3).

Table 2. 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-MCAV consultant	MVAC	15
E14	ELV and BMS Consultant	ELV	10
E15	Building Service consultant	Building Services	25
E16	HVAC system consultant	Building Services, HVAC system designer	10
E17	Consultant MEP Engineer	HVAC	15

Table 3. 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, tabulation, and then concluding (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.

5. Research analysis and findings

The findings of the research could be presented under five sub-sections: Air Handling Unit (AHU) optimisation, system design and layout optimisation, and cooling system optimisation where each is comprehensively described below.

5.1 Air Handling Unit (AHU) Optimisation

AHU is the main component in the HVAC Airside system, thus strategies to optimise it should be given priority. Table 4 shows the AHU Optimisation strategies discovered from the findings.

Table 4. Summary of AHU Optimisation Strategies

Code	Strategy
Ao/S1	Efficient AHU filter
Ao/S2	**Reducing coil losses***
Ao/S3	Efficient AHU fan system
Ao/S4	Airside economiser
Ao/S5	Heat Recovery Wheel
Ao/S6	**Installation of Variable Speed Drives (VSDs)***
Ao/S7	**Installation of a control system to meet varying loads***

Ao/S- '**A**ir Handling Unit **O**ptimisation/**S**trategy'
Note: *Findings that are identified only from the research analysis

In the pursuit of optimising HVAC Airside systems, particular attention is given to enhancing the efficiency of AHU systems. The strategy to install efficient AHU filters (Ao/S1) will enable the reduction of AHU filter losses and is a vital component impacting energy efficiency. E4 emphasises the impact of efficient filters on energy efficiency and stresses the significance of maintaining a filter pressure drop below 150 Pascal. In addition, E15 recommends a Minimum Efficiency Rating Value (MERV) of 8 for filters in typical office areas. The reduction of coil losses (Ao/S2) is identified as a crucial factor in AHU optimisation. While E14 suggests coils with a pressure loss below 40 kPa, E16 highlights the challenge, stating that high filtration, while necessary, can lead to increased pressure drop and energy consumption. E8 contributes valuable insight by describing a methodology for calculating pressure drop based on measuring air volume after running the AHU and fan at full force. Efficiency gains in the AHU fan system (Ao/S3) significantly contribute to overall energy conservation. E11 emphasises the dependence of fan energy consumption on flow rate and pressure head. Fine-tuning the ducting system to reduce pressure drop was highlighted by few experts and E17 stressed the need for proper design and blower selection. Several experts suggest the implementation of Variable Speed Drives (VSDs) and Electronically Communicated (EC) motors as effective strategies for optimising fan systems. E12 emphasizes the importance of motor selection, stating, '*when selecting motors, its efficiency class should be high, and one should at least select an 'IE3- class' fan motor'* highlighting that an efficient fan system should be selected for effective optimisation. The integration of airside economisers (Ao/S4) emerges as an additional strategy for improving system efficiency. E4 introduces the concept of an enthalpy energy recovery wheel, stating, "*we are using one type of economiser system, to regain cool energy of exhaust air, which transfers the cool energy of exhaust air to fresh air'*. E11 further emphasises ongoing efforts to implement airside economizers into Building Management Systems (BMS) for enhanced overall system efficiency. Heat Recovery wheels (Ao/S5) are important for AHU optimisation. E2 emphasizes the need for a higher temperature gradient to maximise system efficiency. It was further explained by the E14 as, *'rotating the wheel consumes some energy, as the electric motor is needed to run the heat wheel to facilitate the heat exchange. If heat gain is lower than the power consumption of the motor, you will not gain anything out of the system'*, explaining that the output gained should be more than the energy input. The adoption of Variable Speed Drives (VSDs) (Ao/S6) is driven by substantial energy-saving benefits. E15 highlights the importance of a well-designed VSD arrangement for Variable Air Volume (VAV) systems, emphasizing a feedback mechanism involving fresh air sensors, pressure sensors, and VAV adjustments accommodating the variability load of the building. E14 provides an alternative perspective, proposing increased fan speed instead of augmenting the chiller load for enhanced energy efficiency. It was elaborated by stating, that comfort being a subjective experience, can be achieved by manipulating less resource-intensive parameters, hence, '*increasing the chiller load will heighten its duty and, consequently, escalate its electricity consumption. However, opting to exert load on the VSD to elevate the speed of air circulation proves to be a more energy-efficient alternative. Occupants experience comfort through enhanced air circulation without the associated increase in chiller-related energy consumption*', which will give the same output of enhancing the occupant comfort. Addressing the need for proper control systems to accommodate varying loads (Ao/S7), E14 emphasises the challenge posed by factors such as outdoor conditions and occupancy rates. The importance of a well-tuned control system is underscored, with a specific concern highlighted for Sri Lanka regarding comprehensive control system implementation and tuning for optimal outcomes.

5.2 System Design and Layout Optimisation

Considering HVAC systems, achieving optimal energy efficiency is contingent upon a well-designed and strategically laid out system design and layout. Table 5 shows the System Design and Layout strategies discovered from the findings.

Table 5. Summary of System Design and Layout Optimisation Strategies

Code	Strategy
So/S1	Efficient ducting system design
So/S2	Installation of Variable Air Volume (VAV) system
So/S3	**Air distribution and balancing***
So/S4	Efficient AHU selection

So/S- '**S**ystem Design and Layout **O**ptimisation/**S**trategy'
Note: *Findings that are identified only from the research analysis

Efficient System Design and Layout Optimisation pivot on a well-crafted ducting system design (So/S1), as highlighted by experts. E4 stresses the need for energy-efficient strategies to reduce duct losses, maintaining an AHU W/CMH figure below 0.34 while E8 highlights the significant impact of duct parameters such as bending, radius, length, and size on overall energy efficiency. The consensus among experts, including E13, E17, and E16, advocates for minimising pressure drops through meticulous ducting system fine-tuning. E16 emphasises, '*it is important to fine-tune the ducting system to reduce the pressure drop. If there is a lesser pressure drop, then the power consumption of the fan is less. Therefore, have smooth ducts, round bends, avoid sharp bends, etc.*' System Design and Layout Optimisation extend to Variable Air Volume (VAV) systems (So/S2). While E6 acknowledges maintaining minimum floor rates through VAV, E2 highlights a common shortcoming; the underutilisation of VAV capabilities, reducing it to merely on/off functioning. E4 notes the prevalence of Constant Air Volume (CAV) systems in Sri Lanka, contributing to higher energy consumption. E15 emphasises the need for proper VAV system utilisation, stating '*installing VAV merely isn't enough; it needs proper locating of the thermostat and fine-tuning functionality of VAV dampers*', thus elaborating that finetuning is of utmost importance. Efficient air distribution and balancing systems (So/S3) are proposed strategies, with E4 suggesting periodic rebalancing during commissioning and subsequent fit-outs. E10 confirmed this statement by highlighting experiencing issues from neglecting rebalancing over time, emphasising its importance in commercial buildings. E2 reveals the adoption of manual monitoring and damper adjustments to address ongoing issues, highlighting the importance of regular rebalancing to mitigate airside problems in commercial buildings. Proper AHU selection (So/S4) is another crucial strategy, positioned at the terminal end of the HVAC system. E14 emphasises the importance of efficiency on the plant side, asserting that the system's design and component selection significantly impact overall efficiency. This underscores the priority that should be accorded to AHU selection during HVAC system design. In summary, System Design and Layout Optimisation encompasses efficient ducting, proper utilization of VAV systems, proper implementation of air distribution and balancing systems, and careful AHU selection. The integration of these strategies, as explained by experts, is pivotal for achieving energy efficiency in commercial HVAC systems.

5.3 Cooling System Optimisation

Efficient Cooling System Optimisation is paramount for achieving optimal performance and ensuring sustainable operation in commercial buildings. Table 6 shows the Cooling Optimisation strategies discovered from the findings.

Table 6. Summary of Cooling System Optimisation Strategies

Code	Strategy
Co/S1	Pre-cooled Air Conditioning System (PAU)
Co/S2	Demand Control Ventilation (DCV)
Co/S3	Advanced Controls and Automation
Co/S4	**Night Purge Ventilation***
Co/S5	Optimal start-stop mechanism
Co/S6	**Enthalpy Controlling***

Co/S- '**C**ooling System **O**ptimisation/**S**trategy'
Note: *Findings that are identified only from the research analysis

The prevalent use of Precooled Air Conditioning Units (Co/S1) in commercial buildings is confirmed by insights from both E14 and E16, emphasising the energy-saving benefits of pre-cooling fresh air. Instead of introducing fresh air directly into the Air Handling Unit (AHU), which can increase energy consumption due to its higher initial temperature, a widely adopted strategy involves pre-cooling the air using exhaust air from the room. Notably, this approach synergises with the utilisation of heat recovery wheels, demonstrating a comprehensive strategy for energy-efficient airside HVAC systems. Addressing Demand Control Ventilation (Co/S2), E15 emphasises its objective as '*controlling CO2 levels and contamination within occupied spaces'*. E15 explains the integration of CO2 sensors inside occupied spaces, noting that the ventilation rate is designed based on specific ASHRAE standards. In Colombo, Sri Lanka, with a set maximum CO2 limit of 1250 ppm, E15 suggests *'if it's near that limit, the fresh air dampers are closed.*' This dynamic adjustment of fresh air intake based on real-time CO2 levels, as supported by E12 referencing ASHRAE 90.1 standards, not only ensures indoor air quality but also optimizes energy consumption. Additionally, the implementation of Advanced Controls and Automation (Co/S3) emerges as a key focus for HVAC system optimisation. Experts highlight the significance of integrating sophisticated controls, machine learning algorithms, and real-time monitoring to dynamically adjust system parameters for optimal energy efficiency through predictive controls. Night Purge Ventilation (Co/S4) is a practised strategy in commercial buildings, utilising cool outdoor air during nighttime hours to naturally ventilate and cool indoor spaces. This nocturnal approach reduces dependency on mechanical cooling during periods of lower outdoor temperatures, aligning with sustainable energy practices. Another strategy, the Optimal start-stop mechanism (Co/S5) is used by predicting the cooling needs of space by setting early enough to reach the setpoint at the beginning of scheduled occupancy. Enthalpy controlling (Co/S6) is another strategy that could be used if the enthalpy of fresh air is lower than that of return air, fresh air can be directly used to maintain the supply air temperature. Further, E12 stated that, if fresh air has reached its maximum position, then mechanical cooling can be introduced. In summary, these research findings underscore the importance of Precooled Air Conditioning Units, Demand Control Ventilation, Advanced Controls and Automation, Night Purge Ventilation, Optimal start and stop mechanism and Enthalpy Controlling as integral components of a holistic and energy-efficient approach to HVAC airside optimisation in commercial buildings.

6. Discussion

By reviewing the existing literature, 11 strategies to enhance the energy efficiency of HVAC Airside system were found. However, these strategies were in general and not specific to the Sri Lankan commercial buildings. These strategies seem to be possible for Sri Lanka as per research findings. According to Ni & and Bai (2017), an efficient AHU filter plays a major role in the optimisation of the AHU. As the author elaborated, filters with higher filtration efficiency need to be selected and proposes to substitute for a MERV 7 or 8 filter, which is the same derived from the findings of the research. Installation of VAV system was found as the most highlighted strategy under the System Design and Layout Optimisation category. According to Bhandari et al. (2022), VAV system was approximately 17.0%-37.6% more efficient than CAV system and the same was derived from the findings. As stated by an expert, in Sri Lanka, HVAC systems are predominantly CAV, but in order to enhance energy efficiency, a VAV system should be installed. Also, it was noted that, even with the presence of a VAV system, some commercial buildings are inefficient due to the absence of proper placement of thermostats and fine-tuning of VAV damper functionality. Referencing to Cooling system Optimization category, advanced controls and automation was the strategy that was commonly cited in the literature. From the analysis of findings, it was found out that it is important to integrate sophisticated controls, machine learning algorithms, and real-time monitoring to get better efficiencies from the HVAC airside system and this will enable dynamic adjustments of system parameters, ensuring optimal energy efficiency through predictive controls.

In addition to that, three strategies for AHU optimisation (refer code Ao/S1, Ao/S6 and Ao/S7), one strategy for System Design and Layout Optimisation (refer code So/S3) and finally two strategies for Cooling system Optimisation (refer code Co/S4 and Co/S6) were found from research findings, which are specifically practised in the Sri Lankan context. When referring to AHU optimisation, experts' opinion was that AHU coils with a pressure loss below 40 to reduce energy consumption. It also highlighted the challenge of high filtration, while necessary, can lead to increased pressure drop and energy consumption. Considering the installation of VSDs, experts stated that, VSDs are used in different applications and the importance of system design to accommodate variability was highlighted. Referring to the installation of a control system to meet varying loads, experts highlighted the existing mismatch between delivering a constant output for varying loads results in discomfort and energy wastage, hence highlighting that a comprehensive control system should be implemented. Under System Design and Layout Optimisation, air distribution and balancing were emphasised. Experts suggested periodic rebalancing during commissioning and subsequent tenant fit-outs to mitigate airside HVAC problems in commercial buildings. Night purge ventilation and enthalpy controlling are strategies identified from the research findings under Cooling system optimisation which involves the utilisation of cool outdoor air during nighttime hours to naturally ventilate and to use fresh air if its enthalpy is lower than that of return air.

7. Conclusions

In Sri Lanka, the building service that uses the most energy in a commercial building is HVAC. It combines elements of both waterside and airside systems, and at the moment, energy-efficient techniques are primarily applied to waterside systems because they have larger and more numerous components. Nevertheless, implementing waterside-only energy efficiency measures will only result in approximately 60% of energy savings; the remaining 40% can be attained by implementing airside-only energy efficiency measures, as the combined effect of both systems will result in savings for the HVAC system as a whole.

Even though this is already adopted in developed countries, this is an area, in which commercial buildings in Sri Lanka are lagging in. Thus, this research was intended to explore the strategies to enhance the energy efficiency of HVAC Airside systems of commercial buildings in Sri Lanka. Altogether, 17 strategies were identified from this study to enhance energy efficiency of HVAC Airside system. Out of it, 11 are from the literature review, and they are namely, installation of an efficient AHU filter, efficient AHU fan system, airside economizer, heat recovery wheel, efficient ducting system design, installation of VAV system, efficient AHU selection, Pre-cooled Air Conditioning System, Demand Control Ventilation, advanced controls and automation and optimal start-stop mechanism. Additionally, six strategies were discovered from the research findings, and they are, reducing coil losses, installation of VSD, installation of a control system to meet varying loads, air distribution and balancing, and night purge ventilation. The conclusion of the literature analysis and expert insights underscores several key strategies pivotal for enhancing the energy efficiency of HVAC Airside systems. Among these, the installation of efficient AHU filters, implementation of VAV systems, adoption of advanced controls and automation, reduction of coil losses, installation of VSD, implementation of a control system addressing varying loads, air distribution and balancing, enthalpy controlling and embracing night purging emerge as central pillars. These strategies, consistently highlighted across diverse literature and emphasised by experts, collectively form a robust foundation for advancing energy-efficient practices in the realm of HVAC airside optimisation. Furthermore, it can be concluded from the research findings that all identified strategies are applicable to the Sri Lankan context and will facilitate commercial buildings to reach energy efficiency levels, hence mitigating the existing energy wastages of the HVAC system.

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