GUIDELINES FOR OPTIMISING ENERGY CONSUMPTION OF HVAC AIR-SIDE SYSTEMS IN COMMERCIAL BUILDINGS IN SRI LANKA

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Abstract. Currently, discussions on climate change, fossil fuel depletion, and energy conservation emphasise the urgency of creating a more sustainable built environment. Reducing energy consumption and emissions in the building sector has become a priority. 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 aims to identify local and international guidelines for HVAC-airside strategy implementation. To achieve this, a literature review was conducted, and a qualitative research approach was used to pursue the research aim; an interview survey using semi-structured interviews was conducted targeting 17 experts. The collected data were then analysed using content analysis using the NVivo software. The study identified eight applicable guidelines: EEBC, IESL guidelines, CPEEB, CIBSE, ASHRAE, Singapore Green Mark standard, EPBD and SMACNA. These insights offer valuable knowledge for industry professionals seeking to improve HVAC airside energy efficiency and provide a foundation for further academic research on HVAC systems in Sri Lanka. By applying these guidelines, the commercial building sector can take a step towards a more energy-efficient and sustainable future.

Keywords. Airside Efficiency, Central Air-Conditioning System, Commercial Building

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 ensuing environmental repercussions (Zakaria et al., 2023). Especially, energy services associated 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., 2016). Within the Sri Lankan context, the building sector is the largest consumer of primary energy, constituting nearly 60% of the nation's electricity consumption (Selvakkumaran & Limmeechokchai, 2020) and within this sector, a substantial portion of energy is allocated to HVAC systems, accounting for approximately 51% (Geekiyanage & Ramachandra, 2018).

Given the complexity of HVAC systems, breaking them down into their constituent parts is essential for a thorough understanding (Ahmad et al., 2018). HVAC systems are typically divided into waterside and airside components, with both playing crucial roles in the overall performance of the HVAC system as a whole (Patel et al., 2018). A similar opinion was stated by Faulkner et al. (2023), emphasising that achieving optimal energy savings in buildings requires a broad approach that considers both the waterside and airside components simultaneously. In this context, the HVAC airside system is pivotal in enhancing energy efficiency; however, it often receives inadequate attention in commercial buildings in Sri Lanka.

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According to existing literature, energy consumption in commercial buildings accounts for approximately 20% of Sri Lanka's total electricity usage (Weerasinghe et al., 2016), with airside HVAC systems contributing to 20% of this consumption (Amjath et al., 2021). Despite the significant energy consumption and the clear need for improved efficiency, optimal energy-saving practices in airside systems are not consistently achieved in Sri Lankan commercial buildings. One key barrier is the limited awareness and adherence to established guidelines for implementing effective HVAC airside strategies. Addressing this knowledge gap is crucial for improving energy efficiency in these buildings. Therefore, this paper aims to identify key guidelines for HVAC airside strategies and provide insights to support their effective implementation in Sri Lanka.

2. Literature Review

2.1. ENERGY CONSUMPTION OF COMMERCIAL BUILDINGS

The first step to understanding where energy can be saved is to understand where it is being consumed (Frederiks et al., 2015). Running expenses of a building consume a substantial share of its total life cycle cost and range between 70% and 80% in commercial buildings (Geekiyanage & Ramachandra, 2021). As per the US researchers, the top three end uses in the commercial sector are space heating, lighting, and space cooling, which represent close to half of commercial site energy consumption (Taylor & Narel, 2012) but contradictory views were presented by Houde and Myers (2021) who stated that lighting uses more electric energy than any other system in a commercial building, which is about 38% of total energy output. Even though percentages are different among countries for different building services, the energy consumption of HVAC systems is particularly significant (González-Torres et al., 2022).

Comparable to the global context, even in the Sri Lankan context, the rising demand for electricity is a major contributory factor to the energy crisis in Sri Lanka (De Silva & Sandanayake, 2018). The commercial and industrial sector comprises a large stock of buildings that contribute to nearly 60% of the national electricity consumption (Bandara & Attalage, 2020). Further, the commercial sector alone, under which large-scale buildings fall, contributes to 24% of the consumption, where most of the buildings use energy in the form of electrical energy, and a higher percentage of it is consumed for air conditioning (Sri Lanka Sustainable Energy Authority, 2022). Geekiyanage and Ramachandra (2018) have mentioned that in Sri Lanka, more than 75% of energy consumption in commercial buildings is accounted into the HVAC system.

2.2. CENTRAL AIR CONDITIONING SYSTEM AND AIRSIDE EFFICIENCY

The central 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., 2018b). The airside system includes the zones in all of the buildings along with the associated air-handler units (AHUs) used in temperature regulation (Rawlings et al., 2018). Faulkner et al. (2023) stressed the necessity of concurrently addressing both subsystems to enhance energy efficiency in buildings. However, Sekhar (2016) asserted that the design of airside HVAC systems significantly influences achieving optimal air quality, acknowledging the inherent challenges in this design process.

Thus, airside energy efficiency is a critical aspect of overall HVAC system performance, and it serves as the key factor determining indoor air quality (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., 2022).

2.3. GUIDELINES FOR HVAC AIRSIDE STRATEGY IMPLEMENTATION

According to Khazaii (2016) guidelines refer to documents and standards that outline recommended practices for implementing specific strategies. A similar opinion was forwarded by Punt et al. (2016) emphasising that guidelines serve as structured references to ensure best practices in system design and operation. In this context, guidelines encompass not only explicit standards but also frameworks and certification systems that set benchmarks for energy performance and sustainability. The guidelines considered in this study include regulatory codes, engineering standards, and sustainability rating systems (e.g., Singapore Green Mark, EPBD), each of which provides actionable recommendations for HVAC airside design and performance (Gajaba & Dissanayake, 2024). However, globally recognised building rating systems such as LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method) were excluded from this study due to their broader sustainability focus, which covers a wide array of building systems, and their relatively limited direct technical guidance on HVAC airside systems compared to the other frameworks analysed. The successful implementation of effective HVAC airside strategies relies on adherence to these established guidelines, which aim to optimise energy efficiency, improve indoor air quality, and enhance overall system performance. These guidelines are categorised into local and international frameworks, as outlined in the following sections.

2.3.1 Local Guidelines

In Sri Lanka, HVAC airside strategies must align with national regulations and industry best practices to improve energy efficiency in commercial buildings.

Code of Practice for Energy Efficient Buildings (CPEEB) by the Sri Lanka Sustainable Energy Authority (SLSEA) provides recommendations on energy-efficient building design and operations, emphasising HVAC optimisation to reduce energy consumption (Bandara et al., 2015). Sri Lanka Sustainable Energy Authority Act, No.35 of 2007 empowers the Sri Lanka Sustainable Energy Authority (SLSEA) to specify and enforce a code of practice on efficient energy utilisation in buildings. Giving due regard to this, SLSEA has revised and finalised the CPEEB in Sri Lanka, which was first published in 2008 and has undergone revisions (SLSEA, 2020). These recommendations include airside strategies such as demand-controlled ventilation, efficient air distribution systems, proper duct insulation, air leakage minimisation, and optimised fan energy usage. Additionally, SLSEA promotes the use of energy recovery ventilation (ERV) systems and the adoption of high-efficiency air filtration methods to enhance indoor air quality while reducing unnecessary energy wastage.

The Energy Efficiency Building Code (EEBC) also outlines standards for HVAC systems, focusing on airside energy management, including airflow optimisation, duct insulation, and air filtration efficiency (Emmanuel & Rogithan, 2016).

According to Zamaan & Wickramarathna (2025), the government of Sri Lanka recognised the importance of improving the energy performance of buildings as an integral component of the national sustainable energy development strategy. The same authors 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 on a voluntary basis if they exceed any one of the criteria that is listed as follows.

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)

According to Bandara and Attalage (2020), this code failed to convince majority of stakeholders in the industry and most architects considered this code as a constraint for creativity, hence, this building energy code was never practiced in Sri Lanka and soon became obsolete. The Sri Lanka Sustainable Energy Authority (SLSEA) in 2007 established an Act of Parliament in order to drive the concept of energy efficiency on a national scale and develop a code to be followed on a voluntary basis (Sri Lanka Sustainable Energy Authority, 2008). But in this too certain concerns have been observed related to the scope of the code itself and also for its implementation; therefore, it is not widely practised.

2.3.2 International Guidelines

Several internationally recognised standards provide best practices for implementing HVAC airside strategies, ensuring high energy efficiency and environmental sustainability in commercial buildings.

The ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), is widely adopted for HVAC system efficiency (Simpeh et al., 2022). ASHRAE 90.1 establishes minimum energy performance requirements for HVAC systems, covering aspects such as ventilation rates, duct sealing, and fan energy consumption (Halverson et al., 2018). ASHRAE 62.1 focuses on indoor air quality by defining proper airflow regulation and high-efficiency filtration, while ASHRAE 189.1 provides guidance for high-performance green buildings, integrating advanced airside strategies like demand-controlled ventilation and energy recovery systems (Lorenzetti & Wray, 2016).

CIBSE (Chartered Institution of Building Services Engineers) Guidelines, offer technical recommendations on HVAC airside efficiency. CIBSE Guide B provides best practices for ventilation, ductwork design, and airflow regulation to minimise energy losses (Knight & Jones, n.d.). Additionally, CIBSE TM40 focuses on indoor air quality management, promoting the use of energy-efficient air filtration and optimised ventilation rates to enhance both energy conservation and occupant well-being (Zaniboni & Albatici, 2022).

SMACNA (Sheet Metal and Air Conditioning Contractors' National Association), established by the Sheet Metal and Air Conditioning Contractors' National Association, focuses on best practices for ductwork design and airside system performance (Zaniboni, 2021). The HVAC Duct Construction Standards outline proper duct fabrication, sealing, and insulation methods to reduce air leakage and improve energy efficiency (Breda et al., 2024). Furthermore, the same authors stated that, it has details about the HVAC Systems Commissioning manual procedures for system balancing, ensuring effective airflow distribution, and reducing unnecessary energy consumption.

Singapore Green Mark Standard, developed by the Building and Construction Authority (BCA) of Singapore, sets benchmarks for sustainable buildings, including HVAC airside strategies (Agarwal et al., 2017). It emphasises optimised ventilation rates, high-efficiency air filtration to improve indoor air quality, and energy-efficient fan operations to reduce power consumption. The certification scheme encourages the adoption of smart HVAC technologies and demand-controlled ventilation for better energy management (Zhang et al., 2024).

By integrating these international standards with local regulations, Sri Lanka's commercial building sector can enhance HVAC airside efficiency, reduce overall energy consumption, and improve indoor air quality.

3. Research Methodology

This study aims to provide guidelines for HVAC airside strategy implementation to commercial buildings in Sri Lanka. 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. Hence, a qualitative survey comprising semi-structured interviews was employed, given the significance of comprehending guidelines for the implementation of airside HVAC strategies in commercial buildings in Sri Lanka. Moreover, semi-structured interviews allow the researchers to repeat or rephrase the interviewee's responses in order to get additional clarifications and assist them in gaining a thorough understanding of the issue of interest. According to Okken et al. (2019) adapted from Bertaux (1981), a qualitative survey should 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 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 2.3.1. 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 I.

Table 1: Profile of 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	1,400,000 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	1,100,000 kWh	550,000 kWh	50%		4500kVA
E5	580,000 kWh	240,000 kWh	50%	Rs. 14 Mn	1800kVA
E6	1,500,000 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	Tower1-640kVA Tower2-800kVA
E10	1,400,000 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 drawing statistical inference (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.

4. Research Findings

The findings of the research could be presented under two headings: local guidelines and international guidelines, and each is comprehensively described below.

4.1 LOCAL GUIDELINES

One of the key regulations guiding HVAC operations in Sri Lanka is the Energy Efficiency Building Code (EEBC). Several experts emphasised its role in ensuring sustainable HVAC practices by establishing minimum energy performance criteria. The code mandates that HVAC systems be designed, installed, and commissioned in a way that enhances overall efficiency. Specifically, E12 and E14 highlighted that HVAC systems with cooling capacities exceeding 25 TR must undergo rigorous testing and commissioning in compliance with EEBC guidelines. This ensures that large-scale cooling systems in commercial buildings meet energy efficiency benchmarks before being fully operational.

Another critical guideline stressed by experts is the Code of Practice for Energy-Efficient Buildings in Sri Lanka, issued by the Sri Lanka Sustainable Energy

Authority (SLSEA). This guideline provides specific strategies for improving HVAC airside efficiency. Experts such as E4, E5, and E7 highlighted its role in promoting energy-saving measures, while E10 argued that its implementation requires greater regulatory oversight to achieve widespread effectiveness.

In addition to these standards, experts also referenced the Institution of Engineers, Sri Lanka (IESL) specifications for air-conditioning and mechanical ventilation as a key local guideline. These specifications offer detailed technical guidance on HVAC design, with a strong focus on optimising energy consumption and minimising environmental impact. Some experts noted that while these guidelines align with international best practices, particularly those set by ASHRAE, they require stronger enforcement to drive greater adoption across commercial buildings in Sri Lanka.

4.2 INTERNATIONAL GUIDELINES

ASHRAE standard was highlighted by all experts for airside efficiency strategies for HVAC systems. E1, E2, E3, and E4 confirmed that ASHRAE Standard 90.1- Energy Efficiency of Buildings is frequently integrated into the design phase of buildings to ensure compliance with best practices. However, aside from E1 and E4, the remaining experts denied the consistent application of these standards during the operation and maintenance phases of commercial buildings in Sri Lanka. According to multiple experts, this lack of adherence could be a major factor contributing to inefficiencies in HVAC systems within commercial buildings in Sri Lanka. Furthermore, E5 emphaised the importance of following this guideline as, "ASHRAE is a general worldwide standard. We have to select the country's climate zone before referring to specific data tables", and elaborated more on this by stating "if Sri Lanka falls under Climate Zone 0-A. When we use data from this category, we comply with ASHRAE 90.1 and reduce energy consumption." Similarly, E17 stated, "Being a tropical country, we cannot directly adopt ASHRAE standards but must modify them to suit our local context" mentioning the importance of customising the standard for the climate condition of Sri Lanka. Several experts also referenced ASHRAE Standard 62.1- Ventilation for Acceptable Indoor Air Quality, which provides essential ventilation requirements for different building types. E14 stressed the significance of demand-controlled ventilation (DCV), regulated by CO_2 concentration in densely occupied spaces, as well as DCV for car parks, based on CO levels. These measures are designed to optimise fresh air intake while minimising unnecessary energy use. Additionally, E15 and E17 pointed out the relevance of ASHRAE Standard 189.1-High-Performance Green Buildings, which sets more stringent sustainability criteria than ASHRAE 90.1. E17 asserted that merely achieving ASHRAE 90.1 compliance is not enough and recommended referring to the ASHRAE Green Guide and Singapore Green Mark for improved energy efficiency. E15 further emphasised that ASHRAE 189.1 aligns with global green building strategies and should be considered when aiming for high-performance, energy-efficient buildings.

SMACNA guideline was also highlighted by E14 and E17, in ensuring efficient ductwork design and installation. These standards provide detailed recommendations on ducting efficiency, leakage prevention, and airflow optimization, which are critical for maintaining HVAC performance. Experts noted that while SMACNA guidelines offer a strong foundation for HVAC efficiency, their practical implementation in Sri Lanka remains inconsistent, particularly in the operation and maintenance phases.

CIBSE guidelines, particularly CIBSE Guide B: Heating, Ventilating, Air Conditioning and Refrigeration was another that all experts mentioned. According to E1 and E4, this guide provides comprehensive best practices for the design and operation of HVAC systems, ensuring optimal energy efficiency and indoor environmental quality. Experts stated that CIBSE guidelines are widely referenced in Sri Lanka’s building sector but are less commonly enforced compared to ASHRAE standards. E5, however, pointed out a key difference between ASHRAE and CIBSE, stating, “ASHRAE is a widely accepted global standard, but CIBSE is more prescriptive and suited to specific contexts.” Despite this, experts agreed that CIBSE standards offer valuable insights into airside efficiency and system optimisation, particularly in regions with similar climatic conditions to Sri Lanka.

Singapore Green Mark was frequently cited by experts as a benchmark for achieving higher energy efficiency in HVAC airside systems. E17 suggested that ASHRAE standards alone are not sufficient and recommended supplementing them with Singapore Green Mark requirements while E15 also emphasised the importance of using this certification framework to assess energy efficiency indices in HVAC systems.

Energy Performance of Buildings Directive (EPBD), a few experts referenced as a regulatory framework that could guide future energy efficiency initiatives. According to E1 and E4, professionals involved in sustainable commercial building projects occasionally refer to EPBD principles, particularly its focus on building energy audits, performance certification, and HVAC system optimisation. Experts acknowledged that the EPBD's requirements for energy monitoring, retrofitting, and lifecycle assessment of buildings could be highly beneficial for Sri Lanka’s commercial sector. However, they also pointed out the lack of enforcement mechanisms and regulatory support needed to integrate EPBD principles into national energy efficiency policies.

5. Discussion

When considering local guidelines, the Energy Efficiency Building Code (EEBC) and the Code of Practice for Energy-Efficient Buildings (CPEEB) were identified in the literature as key regulatory frameworks specifying energy efficiency requirements for buildings, including HVAC systems. Experts agreed with this, expressing that these codes provide foundational guidance for energy-efficient practices. However, both the literature and findings highlighted that the EEBC code is outdated, raising concerns about its scope, enforcement, and implementation. Additionally, it operates on a voluntary basis, limiting its effectiveness in driving widespread adoption of HVAC airside efficiency strategies.

Regarding international guidelines, ASHRAE 90.1 (energy efficiency), ASHRAE 62.1 (ventilation and indoor air quality), and ASHRAE 189.1 (sustainability in high-performance buildings) were mentioned as key guidelines referred. These have been widely adopted in other countries, ensuring enhanced HVAC efficiency and environmental performance. However, in Sri Lanka, only ASHRAE 90.1 is commonly used, while airside strategy-related standards such as ASHRAE 62.1 and 189.1 remain largely unimplemented. Additionally, other international standards, including CIBSE guidelines, SMACNA ductwork standards, and the Singapore Green Mark Standard, were identified in both literature and expert findings. These offer structured approaches to optimising HVAC airside performance, yet their adoption in Sri Lanka remains limited.

From the findings, a newly identified local guideline was the Institution of Engineers, Sri Lanka (IESL) framework, which includes specifications relevant to HVAC airside strategy implementation. This was recognised as an important addition to local regulatory efforts. Furthermore, an international guideline, the Energy Performance of Buildings Directive (EPBD), was also identified from the research findings. EPBD provides a comprehensive framework for improving energy efficiency in buildings and can serve as a valuable reference for enhancing HVAC airside strategies in Sri Lanka.

Summarising the key findings, the following Figure 1 has been developed to illustrate the classification of relevant local and international guidelines applicable to HVAC airside strategy implementation.

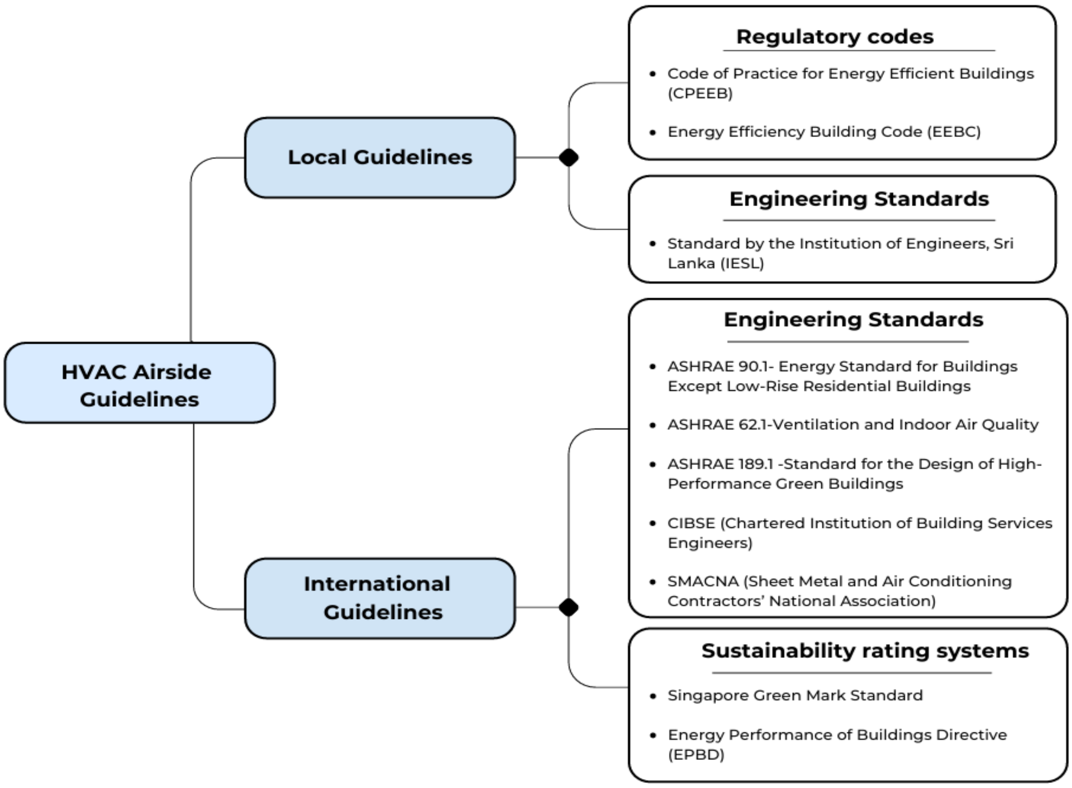

Figure 1: Local and international guidelines for HVAC airside strategy implementation

6. Conclusion

In conclusion, the research findings contribute valuable insights into HVAC airside strategies, particularly in tropical and coastal environments similar to commercial buildings in Sri Lanka. Three local guidelines were identified namely, EEBC, CPEEB, and IESL, along with five international guidelines, ASHRAE, CIBSE, SMACNA, the Singapore Green Mark Standard, and the Energy Performance of Buildings Directive (EPBD). It was found that local guidelines are not widely followed due to their voluntary nature, lack of enforcement, and outdated provisions. Additionally, international guidelines, while widely used, need to be customised to suit Sri Lanka's specific climatic conditions for optimal efficiency. Overall, the findings highlight that HVAC energy consumption in commercial buildings is significantly high, with airside systems accounting for a major portion. Implementing effective airside strategies is crucial for improving energy efficiency, and this requires the establishment of mandatory codes, clear guidelines, and increased awareness among stakeholders. Strengthening regulatory frameworks and ensuring compliance will be essential for achieving long-term sustainability in Sri Lanka's commercial building sector.

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