An Investigation Comparing the Chiller-based VAV system with it's VRF Counterpart

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Abstract
This paper presents a comprehensive analysis of Chiller-based Variable Air Volume (VAV) and Variable Refrigerant Flow (VRF) HVAC systems in university settings. The study utilizes a combination of literature review, detailed survey data, and technical evaluations to assess the performance, energy efficiency, maintenance requirements, and adaptability of these systems within academic environments. The primary objective is to identify which HVAC system—VAV or VRF—offers superior performance in terms of operational cost, energy consumption, and environmental impact. The findings from a survey conducted among HVAC professionals, including system installers and maintenance personnel, provide empirical data supporting the analysis. Results indicate that while VAV systems are compatible with existing infrastructure and offer reliable performance, VRF systems exhibit higher energy efficiency and greater flexibility, particularly in applications requiring fine-tuned climate control across diverse building zones. The study concludes with recommendations for selecting HVAC systems in educational facilities, aimed at optimizing operational efficiency and occupant comfort, thus contributing valuable insights for facility managers and system designers. The research underscores a significant shift towards adopting more sustainable and adaptable HVAC solutions in academic settings.

Keywords
HVAC, VAV, VRF, Energy Efficiency, University Buildings

1. Introduction

Heating, Ventilation, and Air Conditioning (HVAC) systems are essential in maintaining a conducive learning and working environment in university buildings, affecting comfort, health, energy consumption, and operational costs. As universities expand, efficient, reliable, and adaptable HVAC solutions become increasingly critical.

Traditionally, HVAC systems in universities relied on Chiller-based VAV systems, but now there's a shift towards VRF technology. Recent studies highlight the benefits of optimizing HVAC systems using occupant thermal feedback, which enhances both energy efficiency and comfort (Pritoni et al., 2017).

Advanced control strategies and predictive models further optimize HVAC operations, reducing energy consumption while maintaining comfort (Espejel-Blanco et al., 2022). Implementing energy-efficient HVAC systems in educational buildings can lead to substantial energy savings and improved air quality (Jindal et al., 2018). Integration of smart technologies and advanced controls shows significant potential in reducing energy usage by adjusting HVAC operations dynamically (Petrie et al., 2018).

HVAC systems maintain indoor environmental quality by regulating temperature, humidity, and air purity to ensure occupant comfort and health. The VAV systems have been the standard in large buildings due to their efficiency in handling variable occupancy levels. However, VRF systems are gaining traction for their superior energy efficiency and flexibility, crucial traits as buildings move towards more sustainable practices (Kreider et al., 2009), (ASHRAE, 2020).

1.1 Problem Statement
Selecting the most appropriate HVAC system for university buildings poses significant challenges due to the diverse and complex nature of these environments. Decision-makers must balance multiple factors, including system selection, cost effectiveness, energy consumption, maintenance requirements, and the system's ability to provide

consistent comfort in various building zones. Traditional systems such as VAV have been widely used; however, emerging technologies like VRF systems offer potential advantages in energy efficiency and operational flexibility that may be better suited for the dynamic needs of modern educational facilities.

1.2 Research Objectives

The primary aim of this research is to systematically compare the performance, and suitability of VAV and VRF HVAC systems in university settings. This comparison seeks to:

1. Evaluate the energy efficiency of each system and its impact on the overall energy consumption of university buildings.
2. Analyze the suitability of each system to meet the diverse and variable climate control needs across different university building types.

1.3 Emergence of VRF Technology

VRF technology offers a significant advancement in energy efficiency. By allowing the volume of refrigerant flowing to multiple evaporators to be precisely controlled, VRF systems provide simultaneous heating and cooling across different zones, optimizing energy use and reducing overall operational costs. These systems are particularly advantageous in settings with diverse and dynamic space utilization, such as educational institutions (Enteria et al., 2020), (Radchenko et al., 2023).

1.4 Scope of the Research

This paper evaluates the Chiller-based VAV system at the M. Miller Gorrie Center and contrasts it with a hypothetical application of a VRF system. Through a methodical analysis involving literature reviews, system descriptions, and performance evaluations, this study aims to delineate the comparative advantages in terms of energy consumption, occupant comfort, and adaptability to educational settings.

2. Literature Review

VAV and VRF systems are prominent HVAC solutions used in university buildings. Recent studies indicate that VRF systems generally outperform VAV systems in terms of energy efficiency, cost-effectiveness, and occupant comfort. For instance, simulation studies have demonstrated that VRF systems can achieve energy savings of 27.1% to 57.9% compared to VAV systems, depending on system configuration and environmental conditions (Aynur et al., 2009). Additionally, VRF systems have shown up to 70% lower energy consumption for cooling due to more efficient operation modes (Yu et al., 2016).

In terms of cost-effectiveness, VRF systems tend to offer long-term financial benefits. Research has indicated that VRF systems can save 15-42% in HVAC site energy compared to VAV systems, leading to significant cost savings (D. Kim et al., 2017). A case study on a university campus recommended upgrading outdated HVAC systems to VRF systems for better energy efficiency and cost savings, highlighting their economic advantages (Ligade & Razban, 2019).

When it comes to occupant comfort, VRF systems provide enhanced thermal regulation, maintaining indoor temperatures within a narrower range. This precise adjustment improves overall thermal comfort, as demonstrated by studies comparing VRF and VAV systems in various settings (Sakali et al., 2023). The capability of VRF systems to operate in part-time-part-space modes allows individual control over different zones, significantly contributing to comfort and energy efficiency (Yu et al., 2016).

Technological advancements in control strategies for VRF systems, such as PMV-based control, further enhance their energy-saving potential while maintaining comfort. For example, adjusting temperature set-points in VRF systems can reduce energy consumption by up to 27% while ensuring comfortable indoor conditions (J. Kim et al., 2020). Environmentally, VRF systems have a lower impact due to their higher efficiency and reduced greenhouse gas emissions. Comparisons between VRF and conventional HVAC systems in university settings show that VRF systems significantly lower CO2 emissions (Alsalem et al., 2023).

Overall, VRF systems offer superior energy efficiency, cost savings, and occupant comfort compared to VAV systems, making them a favorable choice for modernizing HVAC systems in university buildings.

3. Methodology

This section outlines the methodological approach taken in the comparative analysis of VAV and VRF systems within university buildings, focusing on survey design, participant selection, data collection, and analysis techniques.

2.1 Data Collection

2.1.1 Survey Method and Participant Selection:

The study employed purposive and snowball sampling methods to ensure that the survey reached a diverse pool of HVAC professionals. This approach targeted individuals with direct experience in both VAV and VRF systems, including designers, researchers, project managers, facility managers, engineers, and HVAC equipment distributors. Participants were selected based on their relevance to the topic and their professional involvement in the HVAC field.

The survey was distributed via Qualtrics to approximately 50 people through email and via a survey QR code handed out at the Mechanical Contractors Association of America (MCAA) 2024 annual conference held in Orlando in March 2024. This strategic distribution aimed to capture a broad spectrum of insights from industry experts. The pre-estimated number of participants was 100, considering the technical nature of the survey and the specialized knowledge required to respond accurately. This number was determined based on similar studies and the expected response rate for technical surveys in professional settings.

3.1.2 Data Collection Process:

The data collection occurred from January 2024 to the end of March 2024. The Qualtrics platform provided detailed statistics and data for each response, ensuring the accuracy and completeness of the survey data. Out of 50 people contacted via email and an additional 45 through the MCAA conference, we received a total of 36 responses, of which 31 were complete.

3.1.3 Ensuring Targeted Responses

To ensure that the targeted professionals completed the survey, the Qualtrics platform was used to track and monitor response rates. Participants were prompted with reminders, and their progress was monitored to ensure the completion of the survey. This method ensured that responses were collected from individuals with relevant expertise and experience in HVAC systems.

3.1.4 Geographical and Demographic Considerations

Given that many participants completed the survey at the MCAA conference, the sample was not restricted to specific geographical locations. Instead, it reflected a diverse range of professionals present at the conference, primarily from the United States but also including international attendees, thus providing a wide-ranging perspective on HVAC systems in university buildings.

3.2 Data Analysis Techniques

3.2.1 Quantitative Data Analysis

Each survey question was individually analyzed to extract detailed insights into the professionals' evaluations of system efficiency and preferences. Cross-tabulation of responses was performed to examine relationships between different variables, providing a nuanced understanding of the professional perspectives on VAV and VRF systems.

3.2.2 Qualitative Data Analysis

Although the open-ended questions yielded limited responses, the qualitative data analysis focused on extracting meaningful insights from the feedback provided. This qualitative feedback was crucial in understanding the subtleties of professional recommendations for enhancing both VAV and VRF systems, particularly in university settings.

3.3 Theoretical Support and References

The methodologies in this study are grounded in established theoretical frameworks. Purposive and snowball sampling methods are effective for reaching specialized populations (Naderifar et al., 2017).

4. Results

The survey, structured into seven sections, begins with demographics and professional experiences of 31 HVAC industry respondents. Engineers make up 48%, Salespeople 26%, and Managers 19%, including roles like Construction Project Managers and Facility Managers. The workforce is highly experienced, with 35% having 11-20 years of experience and 32% over 20 years. All participants have experience with both VAV and VRF systems and high engagement with Air-cooled Chillers (97%) and Water-cooled Chillers (87%). Their experience spans various building types, including commercial, educational, and healthcare facilities. Additionally, 87% are very aware of recent HVAC technologies and trends. This background sets the stage for sections focused on system evaluations, energy efficiency, and other critical areas in university HVAC solutions.

In Section 2, professionals assess the energy efficiency of VRF and VAV systems, highlighting VRF systems' superior efficiency, with over 67% rating them much more efficient than typical systems. VAV systems received moderate efficiency assessments. Key factors include advanced inverter technology and zoning capabilities for VRF systems and air distribution efficiency for VAV systems. Common challenges include system design issues and inadequate maintenance.

Section 3 covers thermal comfort performance, with VRF systems perceived to offer better comfort levels. About 51.6% rate VRF systems as significantly better in providing thermal comfort, while VAV systems are seen as comparable to typical systems. Factors include zoning capabilities and consistent temperature control. Issues like poor humidity control and inadequate air distribution affect thermal comfort.

In Section 4, maintenance and operational considerations show VRF systems require less maintenance than VAV systems, though both face challenges like technical complexity and system updates. Specific challenges include ductwork maintenance for VAV systems and technical complexity for VRF systems.

Section 5 addresses implementation and adaptability challenges, noting technical complexity and high initial costs for VRF systems, and space requirements for air handling units and ductwork installation for VAV systems. Integration into existing infrastructure also presents challenges, with VRF systems reportedly facing fewer difficulties.

Section 6 examines environmental and sustainability factors, with VRF systems generally seen as having a lower environmental impact due to higher energy efficiency and positive impact on indoor air quality. VAV systems are considered to have a neutral environmental impact.

Section 7 concludes with overall preferences and future trends in HVAC technology. While no strong preference between VRF and VAV systems is evident, there is significant interest in integrating smart technology into HVAC systems. Suggestions for improving both systems in university settings emphasize adaptive controls and enhanced indoor environmental quality, indicating a forward-thinking approach to HVAC solutions that optimize energy consumption and maintain a comfortable, healthy indoor environment.

4.1 Cross-tabulation Analysis of HVAC Professionals' Perspectives

4.1.1 Cross-tabulation Analysis Role Wise

The survey data was meticulously examined to derive a comprehensive understanding based on professional roles, as shown in Table 1. In this role-wise analysis, the opinions and trends were parsed from 31 industry professionals, revealing a detailed look into their collective thinking.

Professionals across the board—Engineers, Managers, and Salespeople—resoundingly indicate that the choice of HVAC systems (VRF vs. VAV) in university buildings must pivot on the unique requirements of each project (Q11). This trend was most pronounced among Salespeople (87.5%) and Managers (83.3%), signifying a keen awareness of the need for tailored solutions. Engineers, making up nearly half of the respondents, also significantly support this view (66.7%).

Table 1: Cross-Tabulation Analysis of Professional Role with System Suitability, Overall preference and Future Trends in HVAC Technology

		Q1: Current professional role in the HVAC industry.					
Question	**Most Favorable choice**	**Total** (out of 31)	**Engineer**	**Consultant**	**Manager**	**Salesperson**	**Academic / Researcher**
Q11: Most suitable system in terms of energy efficiency	Depends on specific building requirements	22	10	0	5	7	0
		71.0%	66.7%	0.0%	83.3%	87.5%	0.0%
Q24: Overall preference between VRF and VAV systems	No preference	19	9	1	3	6	0
		61.3%	60.0%	100.0%	50.0%	75.0%	0.0%
Q25: Perceive as the future trends in HVAC technology	Integration of smart technology in HVAC systems	20	8	1	4	6	1
		64.5%	53.3%	100.0%	66.7%	75.0%	100.0%

When it comes to overall system preference (Q24), a majority of Engineers (60%) and a unanimous consensus from Consultants showcase neutrality, suggesting that decisions are likely influenced by factors other than personal preference, such as cost, functionality, or client specifications. This lack of preference was similarly high among Salespeople (75%), reflecting a versatile and client-oriented approach in their recommendations.

Anticipating the future of HVAC technology (Q25), an overwhelming number of respondents from all professional roles predict that the integration of smart technology is the next frontier. Engineers (53.3%), Managers (66.7%), Salespeople (75%), and even the sole Academic/Researcher respondent concur that this trend is pivotal, pointing to a shared vision of a technologically advanced and interconnected future for HVAC systems.

The HVAC community's collective vision for the industry is one of progressive adaptation, emphasizing the embrace of intelligent technology as the cornerstone of future HVAC advancements, as this cross-tabulation analysis elucidates.

4.1.2 Analysis Based on Participants' Years of Experience

The cross-tabulation analysis based on participants years of experience, as shown in Table 2, reveals a compelling narrative on how experience levels within the HVAC industry shape opinions and forecasts. The collected responses from 31 participants suggest that experience does not uniformly dictate preferences or expectations but does offer nuanced variations in perspective.

Table 2: Cross-Tabulation Analysis of Participants years of experience with System Suitability, Overall preference and Future Trends in HVAC Technology

		Q2: Years of experience in the HVAC industry.				
Question	**Most Favorable choice**	**Total** (out of 31)	**Less than 5 years**	**5-10 years**	**11-20 years**	**Over 20 years**
Q11: Most suitable system in terms of energy efficiency	Depends on specific building requirements	22	2	7	9	4
		71.0%	100.0%	87.5%	81.8%	40.0%
Q24: Overall preference between VRF and VAV systems	No preference	19	2	6	8	3
		61.3%	100.0%	75.0%	72.7%	30.0%
Q25: Perceive as the future trends in HVAC technology	Integration of smart technology in HVAC systems	20	1	5	9	5
		64.5%	50.0%	62.5%	81.8%	50.0%

With Q11 probing the most suitable system in terms of energy efficiency, the consensus leans heavily towards adapting to specific building requirements, a view consistently held across different experience levels. However, as experience increases, unanimity wanes; while all professionals with less than 5 years of experience find suitability dependent on the building, only 40% of those with over 20 years feel the same. This could suggest that more experienced professionals may also consider other factors, like long-term performance and operational familiarity.

In Q24, examining the overall preference between VRF and VAV systems, those newer to the field (less than 5 years) unanimously reported no preference, highlighting an openness possibly due to less ingrained experience with either system. This trend diminishes slightly as experience grows, yet a majority across all categories maintains no strong preference, indicating a broad industry acknowledgment that system selection should be dictated by the specificities of each project rather than a rigid allegiance to one technology.

Q25 invites predictions on future trends, and smart technology integration emerges as a prevalent theme. Interestingly, it is among professionals with 11–20 years of experience that the strongest conviction is found (81.8%), hinting at a generational intersection where seasoned knowledge meets contemporary tech. All experience levels, to varying degrees, mirror this enthusiasm, suggesting a shared anticipation for smarter, more connected HVAC solutions.

The analysis highlights an industry in which experience informs, but does not strictly determine, perspectives on system suitability, preferences, and future trends. It paints a picture of a field progressively embracing technological advancement, with an eye for customized solutions tailored to each building's unique demands. The insights gained from this experience-based cross-tabulation affirm the importance of flexibility and innovation in the evolving landscape of HVAC technology.

5. Discussion

The survey results offer valuable insights into the comparative performance of VAV and VRF systems among HVAC professionals. This section compares these findings with previous studies and includes a cross-tabulation analysis of HVAC professionals' perspectives, providing a comprehensive understanding of the current state and future direction of HVAC systems in university settings.

67% of respondents view VRF systems as more energy-efficient than typical HVAC systems. Studies support this, showing VRF systems' superior energy performance with potential savings of up to 30% compared to conventional systems (Yu et al., 2016). 51.6% of respondents rated VRF systems higher in thermal comfort due to precise temperature control and zoning capabilities, consistent with research findings (Sakali et al., 2023).

Existing studies align with the perception that VRF systems require less maintenance, but they require specialized knowledge for troubleshooting (Chinde et al., 2022). VRF systems face high initial costs and technical complexity (D. Kim et al., 2017). Studies (Alsalem et al., 2023) support the view that VRF systems have a lower environmental impact due to their higher energy efficiency.

5.1 Cross-tabulation Analysis of HVAC Professionals' Perspectives

The analysis reveals that the suitability of HVAC systems depends on specific building requirements. This view is particularly strong among Salespeople (87.5%) and Managers (83.3%), indicating a nuanced approach considering energy efficiency, cost, and environmental factors.

Regarding system preference, the lack of a unanimous tilt toward either VRF or VAV systems suggests a trend towards pragmatism and flexibility. Most Engineers (60%) exhibit no strong bias, highlighting the importance of context-specific solutions over market trends or brand preferences.

Looking ahead, the integration of smart technology in HVAC systems is anticipated across all professional categories, with professionals with 11-20 years of experience (81.8%) showing the most enthusiasm. This aligns with the industry's broader trajectory towards optimizing energy consumption, enhancing indoor environmental quality, and improving system responsiveness.

The survey results align with existing literature, showing that VRF systems generally offer superior energy efficiency and thermal comfort but come with higher initial costs and technical complexities. VAV systems provide reliable performance and easier maintenance. The findings indicate an industry ready to adopt emerging technologies and sustainability practices, making HVAC system choices in university buildings increasingly strategic, balancing efficiency, comfort, and sustainability.

6. Conclusions

The survey data paints a clear picture: HVAC professionals endorse a custom approach to system selection, emphasizing building-specific needs over blanket preferences. This highlights an industry shift towards targeted and flexible HVAC solutions.

Across various roles, there's a consistent lack of strong preference for either VRF or VAV systems, suggesting practical considerations take precedence over brand loyalty or technology type. The focus is on the functionality and specific requirements of each building.

Experts identify the integration of smart technology in HVAC systems as the definitive future trend. Professionals across all levels of experience recognize the transformative potential of these advancements for improving system efficiency and operational control.

The findings align with existing literature, showing VRF systems generally offer superior energy efficiency and thermal comfort but come with higher initial costs and technical complexities. VAV systems provide reliable performance and easier maintenance. The study underscores a readiness to adopt innovative solutions that promise to redefine comfort and efficiency in university buildings and beyond.

6.1 Limitations

This study is limited by its reliance on survey responses, which may not fully capture all perspectives within the HVAC industry. Additionally, the sample size, while diverse, may not represent the entire range of industry professionals. Future research should include larger, more varied samples and empirical performance data to validate these findings.

6.2 Future Research Directions

Future studies should investigate the long-term cost implications and performance metrics of VRF and VAV systems in different climatic and operational contexts. Additionally, exploring the impact of integrating smart technologies on system performance and user satisfaction in various educational settings could provide further valuable insights.

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