

Article

Sustainable Ventilation in the Buildings of Public and Semi-Public Organizations: A Case Study in Lithuania

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Abstract: This study examines the challenges and opportunities in implementing smart ventilation systems in public and semi-public organizations' buildings, framing them as transformative for achieving sustainability goals. Public organizations in Lithuania face significant hurdles in maintaining hygiene standards and ensuring suitable indoor environmental conditions. Aging infrastructure further complicates these efforts, requiring substantial investments for adopting smart ventilation solutions. This research aims to investigate the factors influencing the adoption of solutions, which may lead to sustainability goal implementation in Lithuania. A theoretical framework was constructed, using systemic and comparative literature analysis methods; a quantitative analysis (telephone-based survey with 203 respondents) provided insights into the current state of ventilation systems and the demand for smart solutions. The survey addressed four areas: current ventilation system use, ventilation challenges, awareness of automated systems, and plans for future improvements. The findings reveal widespread dissatisfaction with existing systems, with respondents citing poor air quality, inconsistent temperatures, and inefficiencies as critical challenges. Larger buildings and high-occupancy spaces exhibit the greatest demand for smart solutions, but financial barriers, particularly high initial costs, remain a significant obstacle. This research highlights the potential of automated ventilation systems to address these issues, improve energy efficiency, and support sustainability goals. Tailored financial incentives, educational initiatives, and scalable solutions are essential for enabling the effective implementation of smart ventilation systems in Lithuania's public organizations.



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1. Introduction

The need for smart ventilation systems in buildings has become increasingly evident, with more organizations seeking to follow sustainable and health-centric goals. Smart ventilation emerges as a transformative solution, integrating advanced technologies such as sensors, artificial intelligence, and IoT systems to optimize airflow. With the rise in building management systems (BMSs), motorized windows have become a common feature in smart buildings [1]. By responding adaptively to variables such as occupancy levels, indoor air quality, and energy consumption, smart ventilation systems can provide sustainable and health-centric environments.

Practitioners and researchers recognize that optimizing building opening configurations can greatly enhance indoor conditions when using natural ventilation. Occupants who can control their indoor environment tend to report higher satisfaction levels and experience fewer building-related health issues compared to those in environments where they lack such control [2]. Refs. [3,4] stated that poor indoor air quality (IAQ) has a negative impact on the health of children and the elderly.

Ref. [5] emphasized that there is a clear link between ventilation and health; Ref. [6] demonstrated that there is a need to ensure adequate indoor temperature, fresh air inflow, and appropriate indoor temperature ventilation, especially during the cold season. Despite the mentioned facts, it is extremely worrying that the “energy efficiency first” principle advocated in the Energy Performance of Buildings Directive (EPBD) has led to decreasing air condition requirements in European Union legislations [7]. Public organizations’ inactivity can cause damage to the lives of members of society. An estimated two million disability-adjusted lifetime years (DALYs) are lost each year as a result of adverse health impacts brought on by exposure to indoor air pollution, based on the populations of 26 European countries [5].

IAQ assurance remains of major importance in aging buildings. Only over 1% of the building stock in Europe is currently undergoing renovations annually, despite recent proposals for greater rates—up to 3% [8]. An objective for the upcoming decades, according to the European Commission, is upgrading existing buildings with energy-efficient technology. Efforts to optimize ventilation systems are focused more on new buildings, which meet sustainable goals [9], instead of on solving the ventilation problems of aging buildings.

This research aims to investigate the factors influencing the adoption of solutions which may lead to sustainability goal implementation in Lithuania. Natural ventilation with the integration of automated solutions in aging buildings could be such a solution as it can ensure energy savings.

This study was implemented in two stages. First, the theoretical framework was determined, justifying five hypotheses. During the second stage, the quantitative analysis (telephone-based survey with 203 respondents), the hypotheses were tested, revealing the current ventilation system use situation, ventilation challenges, the awareness of natural ventilation with the integration of automated systems, and plans for future improvements in Lithuania.

2. Methodology

2.1. Theoretical Framework

In big buildings with high occupancy, it is quite complicated to ensure IAQ without automated ventilation systems; therefore, public and semi-public organizations in Lithuania face significant challenges in maintaining hygiene standards in aging big buildings and in assuring IAQ. According to [6], many public facilities rely on natural ventilation without automated solutions, but this solution is not appropriate, especially during colder months. This leads to high levels of carbon dioxide and indoor discomfort.

Automated ventilation systems can effectively help to solve these issues by providing real-time monitoring and smart ventilation accordingly, ensuring compliance with health standards [10] and energy-efficient consumption. The authors of [11] proved that hybrid ventilation (HV) enables energy savings of 20–25% compared with natural ventilation (NM) and 60–70% compared with mechanical ventilation (MV). Refs. [8,12] emphasized that NV lowers energy consumption and CO₂ emission in comparison to MV.

Efforts to ensure energy savings and IAQ, especially during cold seasons, in Lithuania include the search for sustainable solutions in public and semi-public organizations. Natu-

ral ventilation with automated solution implementation could be the first step, keeping in mind that public and semi-public organizations face financial barriers.

The existing literature provides a foundation for several key hypotheses that explore the relationship between the challenges of ventilation in aging buildings and sustainable goal implementation.

Hypothesis 1: *organizations dissatisfied with their current ventilation systems experience higher levels of ventilation issues.*

Studies have demonstrated that dissatisfaction with air quality, inconsistent temperature regulation, and poor ventilation control frequently drive the demand for advanced technologies. For example, Refs. [13,14] emphasize that smart ventilation systems equipped with real-time monitoring and adaptive features can significantly enhance occupant comfort and well-being while addressing the inadequacies of conventional systems. Similarly, [15] highlights the role of automated systems in addressing critical indoor environmental challenges through ventilation systems with environmental air monitoring.

Hypothesis 2: *larger building sizes and higher occupant densities are associated with an increased perceived relevance of automated ventilation systems, due to the complex challenges of maintaining optimal indoor environmental quality in such settings.*

Traditional ventilation systems often fail to provide consistent air quality in large-scale buildings, particularly those with high occupant loads [8,16]. Automated systems offer a scalable solution by integrating with building management systems (BMSs) to provide zone-specific ventilation tailored to real-time occupancy data [17]. These systems improve not only environmental quality but also energy efficiency, making them particularly relevant for large facilities.

Hypothesis 3: *perceived financial barriers—such as high initial costs and budget constraints—are negatively associated with the willingness to adopt automated ventilation systems, whereas the perceived availability of state subsidies and financial incentives is positively associated with adoption intention.*

The authors of Ref. [18] found that organizations are often deterred by the high upfront investment required for automated heating, ventilation, and air conditioning (HVAC) technologies but are more likely to adopt these systems when supported by financial incentives or subsidies. Moreover, the long-term cost savings resulting from energy efficiency further enhance the feasibility of such investments, as was demonstrated in [19] through an analysis of the economic benefits of automated ventilation systems.

Hypothesis 4: *the perceived relevance of automated ventilation systems is positively associated with the expectation that these systems can deliver energy savings, thereby contributing to sustainable building management.*

Numerous studies highlight the role of demand-controlled ventilation strategies in reducing energy consumption without compromising air quality. For instance, Wu et al. (2023) demonstrate that automated systems equipped with CO₂ and temperature sensors optimize airflow, significantly lowering energy use in both residential and commercial buildings [20]. This aligns with the International Energy Agency's (2021) findings, which emphasize the importance of integrating automated ventilation technologies to achieve global sustainability targets [21].

Hypothesis 5: *lower awareness of regulatory benefits and overall system advantages is associated with a reduced perceived relevance of automated ventilation systems.*

A lack of awareness about the benefits and operational mechanisms of automated HVAC systems often limits their perceived value and usability. Researchers emphasize that targeted training programs and informational campaigns are critical to bridging this gap, enabling building managers to make informed decisions and effectively utilize these technologies [20,22–25]. Similarly, Ref. [26] highlights that user-friendly system interfaces and comprehensive support can significantly enhance adoption rates by reducing perceived complexity.

These hypotheses address the interplay between technological innovation, sustainability, and organizational decision-making, highlighting the potential of automated solutions to overcome existing ventilation challenges while contributing to broader environmental and health objectives.

2.2. Telephone Survey on Market Situation and Sustainability Needs Regarding Ventilation Systems in Public Organizations

The questionnaire aimed to gather insights into the current market situation and consumer needs related to the adoption of advanced natural ventilation and automated window control systems in public organizations (such as hospitals, schools, and other large institutions). Additionally, the survey explored how sustainability factors into decision-making concerning ventilation system upgrades. The data collected helped identify areas for further development and in understanding the challenges and opportunities for natural ventilation with automated solutions.

The telephone-based survey, conducted over two months from October to November 2024, gathered a total of 203 responses, offering valuable insights into the state of ventilation systems in public buildings across Lithuania. The sample size was determined based on practical considerations to ensure that the survey captured a representative cross-section of facilities in Lithuania. Respondents were selected using a stratified random sampling method, targeting key categories of public buildings—such as schools, hospitals, and government offices—to ensure diverse organizational perspectives. The questionnaire comprised 15 questions, organized across multiple sections. These sections included the following: (a) general organizational and building characteristics, (b) current ventilation system use and satisfaction, (c) ventilation challenges, (d) awareness of and interest in automated ventilation systems, and (e) plans for future improvements. The full list of questions is outlined in Appendix A, along with the corresponding response modes.

The questionnaire was designed to collect comprehensive data on ventilation systems in public and semi-public organizations, aligning with methodologies used in similar studies investigating building characteristics, ventilation challenges, and the adoption of advanced systems. Questions on topics such as the building area, user roles, and type of organization were modeled after frameworks for assessing operational and structural factors influencing ventilation systems. Satisfaction levels, challenges, and needs were structured based on established approaches to evaluate the perceptions and performance of indoor environments, as seen in studies focusing on energy efficiency and indoor air quality [4,6,8,21,27,28]. By incorporating questions about financial constraints, awareness, and future plans, the survey followed best practices in exploring barriers to and enablers of adopting smart technologies [24,25]. The response modes were designed to ensure clear, actionable insights while maintaining compatibility with existing research.

Before distribution, the questionnaire was pre-tested with a sample of 25 respondents to ensure clarity and to eliminate any potential ambiguities. The involved participants are experts in building management and ventilation systems, including facility managers

and technical staff. The pilot study was instrumental in assessing the clarity, relevance, and comprehensiveness of the questionnaire, leading to refinements that improved the final version.

The survey was conducted via telephone interviews with respondents, during which a web-prepared questionnaire was filled out. This hybrid approach combined direct engagement with the structured efficiency of a digital form. The survey included several conditional questions to determine whether the respondent was qualified to proceed further (screening questions). Respondents were required to answer “Yes” to both of the following questions to continue: (1) “Do you know anything about the ventilation systems in your organization’s building(s)?” and (2) “Does your organization’s building(s) have standard plastic windows?”

To ensure that the respondents were indeed responsible for building ventilation systems, an additional question, “What is your role in the organization?”, was asked. Among the 203 respondents, 122 identified as directors, 59 identified as facility managers, and 22 provided the answer “Other” but specified leadership roles. This distribution indicates that the respondents possessed the necessary decision-making authority and competencies relevant to the topic.

The distribution of building sizes reveals that nearly half of the surveyed organizations (46.3%) operate in medium-sized buildings, measuring between 1001 and 5000 m². Smaller buildings (100–500 m²) constituted 18.7% of responses, while only a small fraction of organizations (3.9%) reported building sizes exceeding 10,000 m². These findings suggest that the sample largely represents organizations operating in mid-sized facilities, a common feature in public and semi-public buildings. In terms of organizational type, schools (including primary, secondary, and similar institutions) accounted for the largest share of respondents at 32.5%, followed by preschool education institutions (27.6%). The daily number of building users was also assessed, with the majority of organizations (64%) reporting a low number of employees (0–50) on-site daily, while visitor traffic was more varied. Nearly half (48.3%) reported an average of 101–500 visitors daily, and a smaller proportion (11.3%) accommodated between 501 and 2000 visitors. Geographically, the respondents were dispersed across various locations in Lithuania. While the majority (56.7%) were located in smaller cities or regions categorized as “Other”, a substantial number were from Vilnius (15.3%), reflecting the capital’s prominence in the sample. Other significant cities, including Kaunas (6.9%), Klaipėda (5.9%), and Šiauliai (5.9%), also contributed to the survey, ensuring geographic diversity. These findings provide a robust foundation for analyzing ventilation system use and challenges in diverse public-sector contexts.

2.3. Data Analysis and Ethical Considerations

The data for this study were collected through telephone interviews during a 2-month period (1 October–30 November, 2024), where interviewers input the respondents’ answers into an online system. Participant anonymity was ensured throughout the process. The data were analyzed using SPSS software (version 20.0 for Windows), primarily calculating percentages. Additionally, the “valid percent” method was applied to account for missing data, ensuring accurate representation of the responses.

For questions that evaluated the influence of various factors (e.g., “How much would each of the following factors encourage you to implement an automated ventilation system?”), the percentage share of each response option (e.g., “Very encouraging”, “Somewhat encouraging”, “Moderately encouraging”, “Less encouraging”, “Not encouraging at all”) was calculated based on the number of respondents who answered the question. Following the question “Would automated window and ventilation systems be relevant to your

organization?”, further analysis was conducted specifically for the 85 respondents who answered “Yes”. This subset was examined to identify motivating factors, investment potential, and future planning regarding the adoption of automated systems.

This study was conducted in strict compliance with ethical standards, with strategies implemented to reduce researcher and participant bias [29]. All participants were fully informed of the purpose of the research and voluntarily agreed to participate.

3. Results

3.1. Ventilation System Details

The analysis of ventilation systems currently in use across public buildings reveals a significant reliance on traditional methods. As shown in Figure 1, 95.1% of respondents indicated the use of natural ventilation, primarily through manual window opening (non-motorized), making it the most prevalent system. In contrast, only a small proportion (5.9%) reported the use of semi-automated systems, such as motorized window controls without automation, highlighting a limited adoption of intermediate technologies. These findings suggest that while some buildings incorporate mechanical and recuperative solutions, the majority still rely on basic ventilation methods.

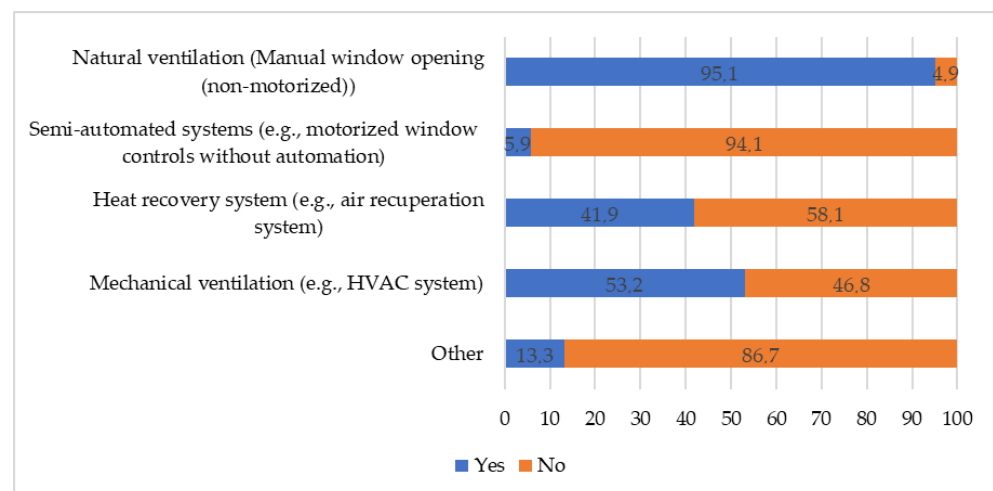


Figure 1. “What ventilation systems are currently used in your organization’s building(s)?”.

Overall, the results reveal a limited adoption of automated ventilation systems in public organizations, suggesting potential for further modernization. However, since the survey did not assess the efficiency of existing heat recovery or HVAC systems, nor did it address air quality parameters, the findings should be interpreted with caution. Future research is needed to determine whether integrating more advanced technologies could enhance sustainability and overall system performance.

3.2. Satisfaction and Perception

Figure 2 illustrates the range of satisfaction levels reported by respondents for various ventilation systems. For natural ventilation (manual window opening), 10.4% of respondents indicated that they were “Very satisfied” and 48.2% were “Satisfied”, resulting in an overall satisfaction rate of 58.6%, despite 12.4% expressing dissatisfaction. Semi-automated systems achieved the highest overall satisfaction, with 83.3% of respondents (combining “Satisfied” and “Very satisfied”) reporting positive experiences, even though none selected the “Very satisfied” category on its own.

Heat recovery systems received favorable evaluations, with 17.6% “Very satisfied” and 52.9% “Satisfied”, though 12.9% expressed dissatisfaction. In contrast, mechanical

ventilation systems (HVAC) elicited more varied responses, with only 2.8% “Very satisfied” and 18.5% “Dissatisfied”, indicating that there may be aspects of these systems that warrant further investigation. Notably, the “other systems” category recorded the highest level of dissatisfaction at 70.4%.

Overall, respondents generally expressed high satisfaction with their ventilation systems, with semi-automated systems receiving the highest approval ratings. In contrast, feedback for mechanical and other less common systems was more variable.

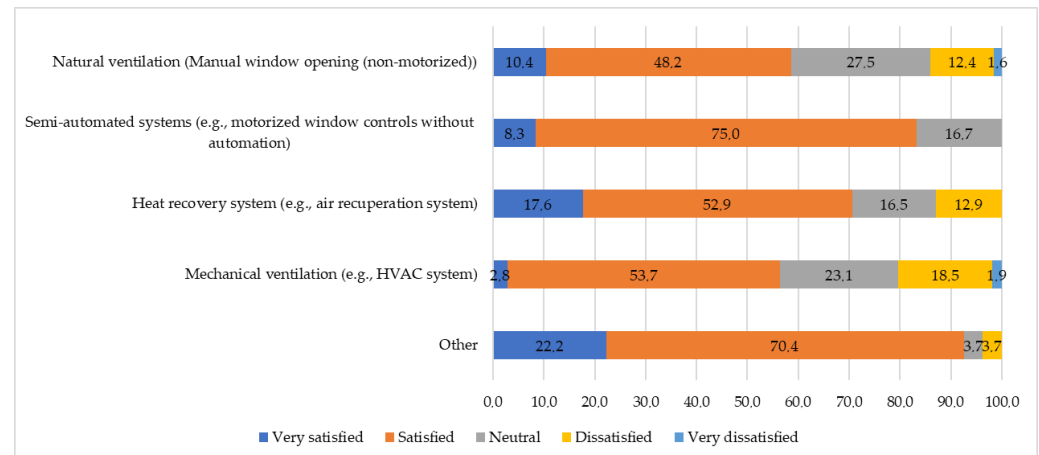


Figure 2. “How satisfied are you with your current ventilation system(s)?”.

3.3. Ventilation Challenges

The question “Are you currently experiencing ventilation issues in your building(s)?” revealed that 26.6% of respondents reported experiencing ventilation issues, while 72.9% indicated that they were not facing any such problems. These findings highlight that the majority of organizations perceive their current ventilation systems to be functioning adequately.

The question “Do building users experience drowsiness or air deficiency due to poor ventilation?” revealed that 49.8% reported that such experiences “Never” occur, 27.6% said “Rarely”, 15.3% “Sometimes”, 2.5% “Often”, and 0.5% “Always”. Additionally, 4.4% were uncertain. These results indicate that while most respondents rarely face such issues, a minority experience them occasionally or frequently.

Figure 3 presents an overview of the key ventilation challenges faced by organizations.

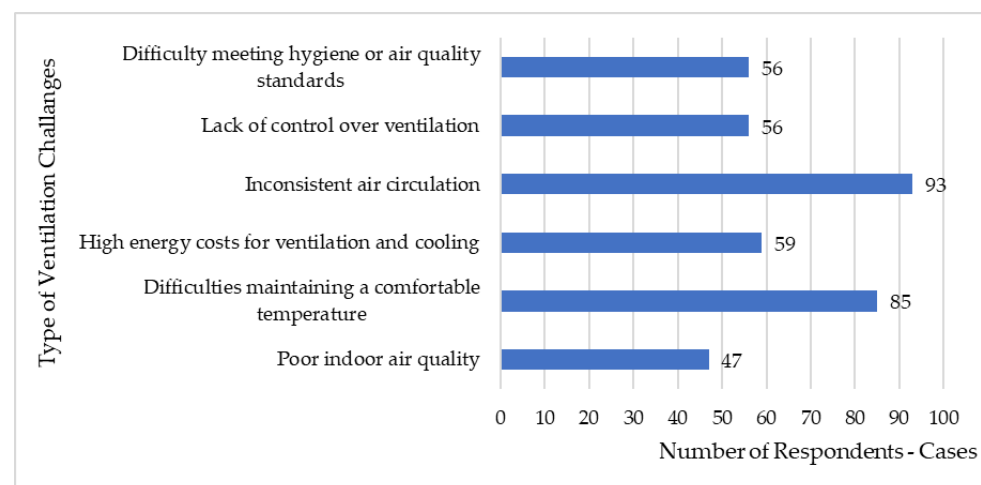


Figure 3. “What are the main ventilation challenges you face?”.

The most frequently reported issue is inconsistent air circulation, affecting 93 respondents, followed by difficulties maintaining a comfortable temperature (85 cases). High energy costs for ventilation and cooling were also noted by 59 respondents. Additionally, difficulty meeting hygiene or air quality standards and a lack of control over ventilation were each reported in 56 cases, while poor indoor air quality was identified as a challenge by 47 respondents. These findings underscore the prevalence of operational and performance issues within existing ventilation systems, particularly in maintaining comfort, energy efficiency, and air circulation.

3.4. Needs and Future Considerations

3.4.1. Need Identification

The question “Does your building require better ventilation solutions?” showed that 64.0% of respondents answered “Yes”, 33.0% said “No”, and 3.0% were uncertain. This indicates that a majority recognize the need for improved ventilation solutions in their buildings. It should be noted that these percentages represent the overall sample and are not disaggregated by building type or by the specific ventilation systems used.

3.4.2. Barrier Analysis

Figure 4 provides insight into the barriers preventing the implementation of better ventilation systems. The most prominent challenge is budget constraints for large-scale systems, reported by 92 respondents, followed closely by high cost (84 cases), highlighting financial limitations as the main deterrent. Concerns about long-term maintenance costs (51 cases) and compatibility issues with older buildings (45 cases) further underscore economic and infrastructural barriers. Additionally, a lack of technical knowledge (28 cases) and perceived installation complexity (26 cases) reflect gaps in expertise and resources. Other challenges include system compatibility issues (21 cases), doubts about benefits (15 cases), and reliance on existing systems meeting current regulations (9 cases).

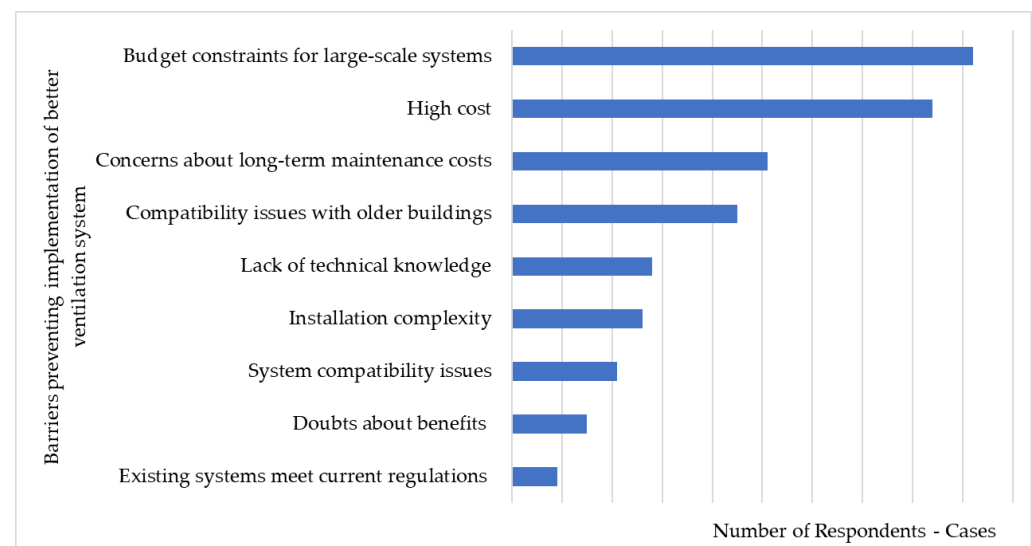


Figure 4. “Why haven’t you implemented such systems yet?”.

3.4.3. Perceived Relevance and Adoption Factors

The question “Would automated window and ventilation systems be relevant to your organization?” revealed that 63.9% of respondents answered “Yes”, 34.6% said “No”, and 1.5% responded “Maybe”. These findings suggest that a majority of organizations see relevance in adopting such systems.

Figure 5 shows the factors encouraging the adoption of automated ventilation systems. State subsidies or financial incentives for green technologies were the most influential, with 67.7% of respondents finding them “Very encouraging”, followed by cost reduction through energy efficiency (60.2%). Reliable technical support (42.1%) and easier integration with existing systems (36.1%) also emerged as key motivators.

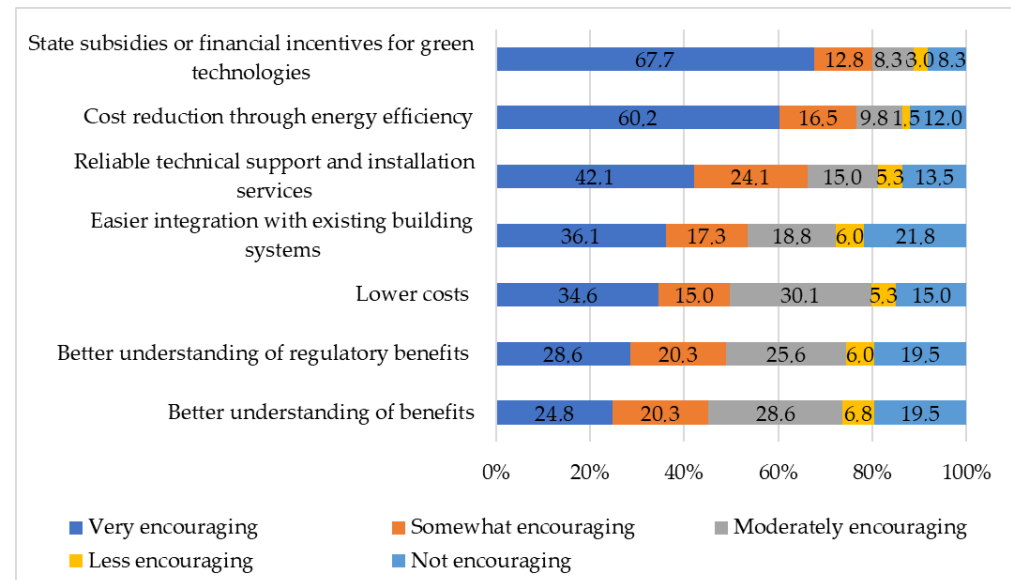


Figure 5. “How much would each of the following factors encourage you to implement an automated ventilation system?” (n = 203).

Financial concerns, such as lower costs (34.6%), remained significant, while factors like a better understanding of regulatory benefits (28.6%) and system benefits (24.8%) were less influential. These results emphasize that financial incentives, energy savings, and technical feasibility are central to promoting adoption.

Out of the total 203 respondents, 85 (41.9%) answered “Yes” to the question “Would automated window and ventilation systems be relevant to your organization?” This subset of respondents, representing those who see the relevance of such systems, will be the focus of further investigation. The next steps will involve analyzing their specific needs and future considerations, including factors that could encourage the adoption of automated systems, the potential investment their organizations could make, and their plans for improving ventilation systems, including the possibility of integrating automated solutions.

Results representing this subset show that state subsidies or financial incentives for green technologies emerged as the most significant driver, with 83.5% finding them “Very encouraging”. Cost reduction through energy efficiency followed, reported by 74.1%, reinforcing the importance of economic benefits in decision-making. Additionally, reliable technical support and installation services (52.9%) and lower costs (45.9%) were also strong motivators. Factors such as easier integration with existing building systems (43.5%) and a better understanding of regulatory benefits (36.5%) were less influential but still relevant. A better understanding of system benefits (30.6%) showed the least impact, although it remained significant for some respondents. These findings suggest that financial incentives, energy savings, and technical support are critical for encouraging organizations to adopt automated ventilation solutions, especially in buildings where relevance has already been acknowledged.

3.4.4. Investment and Upgrade Plans

The question “How much could your organization invest in an automated ventilation system?” revealed that the median investment amount was EUR 2000, indicating the typical level of financial commitment organizations are willing to make for ventilation improvements. In response to the question “Are you planning to improve or upgrade your building’s ventilation system in the next 2–3 years?”, 30.5% of respondents answered “Yes”, while 63.5% answered “No” and 5.9% were uncertain. These results suggest that while a significant proportion of organizations do not currently plan to undertake upgrades, a notable subset is preparing for improvements, representing a key target group for future development efforts.

3.4.5. Consideration of Automated Solutions in Upgrades

Regarding the question “Would you consider automated ventilation systems as part of these upgrades?”, the analysis focused on organizations planning renovations. Sustainability emerged as a key theme in the additional comments provided by respondents, with many emphasizing the need for ventilation systems to prioritize energy efficiency and minimize environmental impact. For example, when asked about including automated ventilation systems in planned upgrades, 53 respondents (71.6% of valid responses) indicated they would, citing energy efficiency and sustainability goals, while 12 respondents (16.2%) answered “No” and 9 (12.2%) were uncertain. Moreover, solutions that integrate renewable energy sources, such as solar power, and employ recuperation technologies were particularly valued, and respondents also stressed the importance of building renovations aimed at improving insulation and reducing overall energy consumption as part of a broader sustainability strategy.

3.4.6. Additional Insights on Energy Efficiency and Financial Support

Energy efficiency is a critical feature of modern ventilation systems. Automated systems equipped with sensors to monitor air quality, temperature, and oxygen levels can optimize operations, reducing unnecessary energy use. Such features not only support sustainability goals but also result in cost savings over time, making them attractive for organizations looking to balance environmental and financial considerations.

Financial support is vital to realizing these ambitions. Many respondents stressed the need for government and municipal funding to enable the transition to sustainable ventilation solutions. Increased financial assistance for public institutions, especially schools, is necessary to facilitate these changes. Investments in green technologies not only help achieve sustainability objectives but also yield long-term benefits through reduced energy costs and improved building performance.

The comments also reflected the need to address climate challenges, such as rising temperatures, through sustainable cooling solutions. Efficient air conditioning systems, particularly those powered by renewable energy, are critical during summer months. Additionally, respondents underscored the importance of balancing energy efficiency with hygiene and indoor air quality. Automated systems can ensure compliance with hygiene standards while minimizing energy use, providing clean and filtered air essential for health and well-being, especially in schools and public buildings.

Some respondents expressed uncertainty regarding certain aspects of sustainable ventilation systems, suggesting that additional information on modern, energy-efficient technologies and their benefits may be useful.

3.5. Confirmation of Hypotheses

The correlation analysis (refer to Appendix B) highlights several key relationships between the challenges in building ventilation systems and the perceived relevance and feasibility of implementing automated ventilation solutions. All five hypotheses were confirmed despite H5 showing a relatively weaker correlation of factors like understanding regulatory benefits and overall system benefits.

H1 is strongly confirmed. A significant correlation was observed between dissatisfaction with natural ventilation and the prevalence of ventilation issues (Correlation Coefficient = 0.399; sig. level < 0.001). Mechanical ventilation systems without recuperation were also significantly associated with dissatisfaction (Correlation Coefficient = 0.344; sig. level < 0.001). Furthermore, dissatisfaction with current systems was found to directly impact perceptions of overall ventilation problems (Correlation Coefficient = 0.474; sig. level = 0.012).

H2 is confirmed, with significant correlations found between building size (Correlation Coefficient = 0.221; sig. level = 0.001) and visitor numbers (Correlation Coefficient = 0.253; sig. level = 0.003) and the perceived relevance of automated ventilation systems, as measured by respondents' ratings on a survey question assessing the importance of adopting these solutions. Larger buildings with higher occupancy levels present more complex challenges in maintaining consistent air quality and temperature regulation.

H3 is confirmed. Budget constraints (Correlation Coefficient = 0.456; sig. level < 0.001) and high costs (Correlation Coefficient = 0.300; sig. level < 0.001) were identified as the primary barriers to adoption. However, the analysis also highlights the positive impact of financial incentives, which showed the highest correlation among encouraging factors (Correlation Coefficient = 0.458; sig. level < 0.001).

H4 is confirmed by the data through the strong correlation between energy savings as an encouraging factor (Correlation Coefficient = 0.408; sig. level < 0.001) and the perceived relevance of automated systems.

As for H5, while previous research highlights the potential of educational initiatives to bridge knowledge gaps, the data from this study do not directly address training or educational interventions. Instead, the relatively weak correlation between a better understanding of regulatory benefits and the perceived relevance of automated systems (Correlation Coefficient = 0.258; sig. level = 0.003) suggests that limited awareness may contribute to a lower perceived value of these technologies.

The correlation analysis confirms that dissatisfaction with current systems, larger building sizes, higher occupancy levels, and financial constraints significantly influence the adoption of automated ventilation systems. While financial barriers remain a key challenge, state subsidies and incentives can address these issues effectively. Moreover, while the supporting literature suggests that integrating automated solutions with natural ventilation systems may enhance energy efficiency and sustainability, our data do not provide direct evidence for this potential. Addressing knowledge gaps through education and training further supports adoption, emphasizing the need for a holistic approach to promoting automated ventilation solutions.

4. Discussion

The sustainability principle "energy efficiency first" should correlate with society well-being goals and IAQ assurance requirements. While the empirical findings of this research did not indicate that users experienced symptoms such as drowsiness or discomfort due to inadequate ventilation, maintaining high IAQ remains essential. Prior studies, such as [5], have highlighted the significant health implications of indoor air pollution, linking it to disability-adjusted life years (DALYs) across 26 European nations. A more accurate

understanding of IAQ's impact on health could be achieved through direct surveys of occupants rather than relying solely on perspectives from building managers.

Despite the fact that poor IAQ has impacts on health [3,4], our survey showed that 49.8% respondents have "Never" experienced discomfort due to poor ventilation. This aspect encourages us to extend the scope of our research in the future to include occupants who spend lots of time or even whole days in public or semi-public buildings. In this study, the respondents were managers at various levels, who may spend limited time in common areas.

The implementation of sustainable ventilation solutions is fundamental in the public and semi-public buildings of organizations seeking to ensure energy-efficient usage and meet the health-centric goals of occupants. The empirical analysis confirmed all five hypotheses.

H1 correlates with the existing literature, such as Lachhab et al. (2018) [13] and Luppe, Shabani, and Towards (2017) [14], which emphasize that dissatisfaction with conventional systems often drives the demand for advanced, adaptive ventilation technologies. However, while the strong correlations confirm that organizations experiencing ventilation challenges report higher dissatisfaction with current systems, our study did not provide direct evidence that this dissatisfaction leads managers to adopt automated solutions or that such systems directly address challenges in air quality, temperature regulation, and user control.

H2 is consistent with the findings in [8], which highlight the scalability of automated systems for dynamic, high-occupancy environments. The ability of these systems to optimize ventilation for different zones based on real-time data reinforces their relevance in such settings.

H3 aligns with [18], the authors of which note that subsidies and financial support significantly mitigate financial barriers and encourage the adoption of smart HVAC systems. The results validate the idea that while financial constraints remain a challenge, targeted incentives play a crucial role in overcoming these obstacles.

H4 is supported by the observed strong correlation between energy savings as an encouraging factor and the perceived relevance of automated systems [20]. Furthermore, the integration of automated systems with renewable energy sources and building management systems is highlighted in the literature as essential for achieving sustainability goals, as emphasized by the International Energy Agency (2021) [21]. These results underline the importance of automated systems in balancing energy efficiency with operational performance.

H5 aligns with [2,25], which emphasized the role of targeted training and education in overcoming informational barriers. Ref. [26] further highlights that user-friendly interfaces and accessible training materials enhance the usability and adoption rates of automated systems. The hypothesis is partially confirmed, as it identifies a gap in knowledge that can be mitigated through focused educational efforts.

To enhance the practical value of the findings, specific policy recommendations are proposed that can be implemented through targeted government initiatives. For example, government subsidies could be provided in the form of tax incentives, direct grants, or low-interest loans to support the upgrading of ventilation systems in public and semi-public buildings. Additionally, technical training programs can be facilitated via public-private partnerships, offering certified courses, workshops, and online modules for building managers and maintenance staff. Moreover, regulatory frameworks should be developed to establish standardized performance benchmarks for ventilation systems, ensuring that the benefits of automation are objectively measured. Collectively, these policy measures could accelerate the adoption of sustainable ventilation solutions, improve indoor air quality, and contribute to broader energy efficiency and climate action goals.

5. Conclusions

This study suggests that integrating automated controls, energy optimization technologies, and air quality improvements into natural ventilation systems is perceived as a promising strategy by respondents, although the survey did not directly measure improvements in ventilation issues such as poor air circulation, inconsistent temperatures, or high energy costs. This study relies solely on subjective survey data and does not include objective performance indicators.

Financial barriers, including budget constraints and high initial costs, remain the most significant obstacles, preventing the implementation of such ventilation solutions; however, state subsidies, financial incentives for green technologies, and cost savings through energy efficiency have been identified as critical enablers for adoption.

Furthermore, the findings underscore the importance of reliable technical support, easier integration with existing building systems, and enhanced awareness of the long-term benefits of automated solutions. Addressing knowledge gaps through targeted education and training initiatives will empower stakeholders to make informed decisions, improving both implementation and system management. By prioritizing sustainability through innovative, automated ventilation technologies, public and semi-public organizations can not only enhance indoor environmental quality but also achieve significant energy savings and align with modern environmental and regulatory standards. This integrated approach will enable public organizations to overcome current challenges, future-proof their infrastructure, and contribute meaningfully to broader sustainability and climate action goals.

A notable limitation of this study is that the survey did not collect data on the age of the buildings or on any recent renovations or improvements to the ventilation systems. These factors could have provided valuable context for interpreting the results, as the building age and recent upgrades may significantly influence both the current state and performance of ventilation systems. Future research should consider incorporating these variables to enable a more nuanced analysis of how such contextual factors relate to ventilation system efficiency and overall building management.

An evaluation of respondents' technical knowledge levels could be an important aspect in future research.

The effectiveness of automated ventilation systems in long-term analysis could be explored as a potential direction for future research as well.

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Appendix A. Questions Used, the Response Mode and Purpose for Each Question

Question	Response Mode	Purpose of Question
Do you know anything about the ventilation systems in your organization's building(s)?	Yes/No	Screening
Does your organization's building(s) have standard plastic windows?	Yes/No	Screening
What is the area of your organization's building(s) in square meters?	100–500 m ² / 500–1000 m ² / 1001–5000 m ² / 5001–10,000 m ² / More than 10,000 m ² / I don't know	Building Characteristics
What is your role in the organization?	Director/Facilities Manager/Other (please specify)	Liability
Type of organization:	Hospital/Other Medical or Healthcare Institution/Preschool Education Institution/School (primary or secondary, including lower secondary, gymnasium, and similar)/University or College/Informal Education Institution/Library/Municipal Building/Other	Building Characteristics
Number of building users (approximate daily average):	Employees (daily average): 0–50/51–200/201–500/501+; Visitors (daily average): 0–100/101–500/501–2000/2001+	Building Characteristics
In which city is your organization located?	Vilnius/Kaunas/Klaipėda/Šiauliai/Panevėžys/Alytus/Marijampolė/Utena/Telšiai/Tauragė/Other (please specify)	Building Characteristics
What ventilation systems are currently used in your organization's building(s)?	Natural ventilation (Manual window opening (non-motorized))/Semi-automated systems (e.g., motorized window controls without automation)/Mechanical ventilation (e.g., HVAC system)/Heat recovery system (e.g., air recuperation system)/Other (please specify).	Ventilation System Details
How satisfied are you with your current ventilation system(s)?	Very satisfied/Satisfied/Neutral/Dissatisfied/Very dissatisfied	Satisfaction and Perception
Are you currently experiencing ventilation issues in your building(s)?	Yes/No/I don't know	Ventilation Challenges

Question	Response Mode	Purpose of Question
What are the main ventilation challenges you face?	Poor indoor air quality/Difficulties maintaining a comfortable temperature/High energy costs for ventilation and cooling/Inconsistent air circulation/Lack of control over ventilation/Difficulty meeting hygiene or air quality standards/Other (please specify)/None	Ventilation Challenges
Do building users (both employees and visitors) experience drowsiness or air deficiency (due to poor ventilation)?	Rarely/Sometimes/Often/Always/I don't know	Ventilation Challenges
Does your building require better ventilation solutions?	Yes/No/Maybe	Needs and Future Considerations
Why haven't you implemented such systems yet?	High cost/Lack of technical knowledge/Doubts about benefits/Installation complexity/System compatibility issues/Budget constraints for large-scale systems/Concerns about long-term maintenance costs/Existing systems meet current regulations/Compatibility issues with older buildings/Other (please specify)	Needs and Future Considerations
Would automated window and ventilation systems be relevant to your organization?	Yes/No/Maybe	Needs and Future Considerations
How much would each of the following factors encourage you to implement an automated ventilation system?	Response scale: Very encouraging/Somewhat encouraging/Moderately encouraging/Less encouraging/Not encouraging at all Factors: Lower costs/Better understanding of benefits/State subsidies or financial incentives for green technologies/Easier integration with existing building systems/Reliable technical support and installation services/Better understanding of regulatory benefits/Cost reduction through energy efficiency	Needs and Future Considerations
How much could your organization invest in an automated ventilation system?	Text box for input in EUR/I don't know	Needs and Future Considerations
Are you planning to improve or upgrade your building's ventilation system in the next 2–3 years?	Yes/No/Maybe	Needs and Future Considerations
Would you consider automated ventilation systems as part of these upgrades?	Yes, especially for energy efficiency or sustainability goals/No/I don't know	Needs and Future Considerations

Appendix B. Spearman's Correlation

Spearman's Rho	Are You Currently Experiencing Ventilation Issues in Your Building(s)?		Would Automated Window and Ventilation Systems Be Relevant to Your Organization?		Are You Planning to Improve or Upgrade Your Building's Ventilation System in the Next 2–3 Years?	
	Correlation Coefficient	Sig. (2-Tailed)	Correlation Coefficient	Sig. (2-Tailed)	Correlation Coefficient	Sig. (2-Tailed)
What is the area of your organization's building(s) in square meters?	0.178 *	0.011	0.221 *	0.01		
Number of building users (approximate daily average): Visitors	unreliable		0.253 **	0.003		
What ventilation systems are currently used in your organization's building(s)? Natural ventilation (Manual window opening (non-motorized))	0.399 **	0	0.350 **	0		
Are you currently experiencing ventilation issues in your building(s)?	1		0.327 **	0		
What ventilation systems are currently used in your organization's building(s)? Mechanical ventilation (e.g., HVAC system)	0.344 **	0	0.271 *	0.021		
How satisfied are you with your current ventilation system(s)?	0.474 *	0.012	unreliable			
What are the main ventilation challenges you face? Poor indoor air quality	0.462 **	0	0.217 *	0.12		
What are the main ventilation challenges you face? Difficulties maintaining a comfortable temperature	0.289 **	0	0.410 **	0		
What are the main ventilation challenges you face? Inconsistent air circulation	0.284 **	0	0.332 **	0		
What are the main ventilation challenges you face? Lack of control over ventilation	0.377**	0	0.246 **	0.004		
What are the main ventilation challenges you face? Difficulty meeting hygiene or air quality standards	0.359 **	0	0.323**	0		
Do building users (both employees and visitors) experience drowsiness or air deficiency (due to poor ventilation)?	0.239 **	0.001	0.189 *	0.03		
Does your building require better ventilation solutions?	0.340 **	0	0.500 **	0		
Why haven't you implemented such systems yet? High cost	unreliable		0.300 **	0		
Why haven't you implemented such systems yet? Doubts about benefits	unreliable		0.267 **	0.002		
Why haven't you implemented such systems yet? Budget constraints for large-scale systems	unreliable		0.456 **	0		

Spearman's Rho	Are You Currently Experiencing Ventilation Issues in Your Building(s)?		Would Automated Window and Ventilation Systems Be Relevant to Your Organization?		Are You Planning to Improve or Upgrade Your Building's Ventilation System in the Next 2–3 Years?	
	Correlation Coefficient	Sig. (2-Tailed)	Correlation Coefficient	Sig. (2-Tailed)	Correlation Coefficient	Sig. (2-Tailed)
Why haven't you implemented such systems yet? Concerns about long-term maintenance costs	unreliable		0.180 *	0.039		
How much would each of the following factors encourage you to implement an automated ventilation system? Lower costs	0.179 *	0.04	0.431 **	0		
How much would each of the following factors encourage you to implement an automated ventilation system? State subsidies or financial incentives for green technologies	unreliable		0.458 **	0		
How much would each of the following factors encourage you to implement an automated ventilation system? Reliable technical support and installation services	unreliable		0.341 **	0		
How much would each of the following factors encourage you to implement an automated ventilation system? Cost reduction through energy efficiency	unreliable		0.408 **	0		
How much would each of the following factors encourage you to implement an automated ventilation system? Easier integration with existing building systems	unreliable		0.219 *	0.012		
How much would each of the following factors encourage you to implement an automated ventilation system? Better understanding of regulatory benefits	unreliable		0.258 **	0.003		
Would you consider automated ventilation systems as part of these upgrades?					0.311 **	0.007

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

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