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CHALLENGES AND SOLUTIONS IN HVAC INSTALLATION FOR HIGH-RISE BUILDINGS

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ABSTRACT
HVAC (Heating, Ventilation, and Air Conditioning) systems installed on high-rise buildings pose special challenges as such buildings have very complicated needs. These difficulties are mainly caused by space, energy-saving requirements, noise and regulatory compliance. The multi-floor design of high-rise buildings necessitates the use of the HVAC systems capable of effectively addressing the large cooling and heating loads under different environmental conditions. The use of traditional HVAC systems may be restricted due to the lack of space as they need a lot of space to install ducts, pipes, and other mechanical devices. Moreover, HVAC systems in high-rise buildings require a high level of performance over a great vertical distance, which translates into energy-consuming performance and operational expenses.
The issue of energy efficiency in the design of the HVAC systems is one that cannot be overlooked because the high rise buildings are known to use large quantities of energy to cool and heat the buildings. The emergence of innovative solutions can provide a way out of consuming more energy by recommending modular HVAC systems and smart technologies. Modular HVAC systems offer more flexible settings and do not need large central units so that space constraints are overcome. The smart HVAC system connected to the IoT (Internet of Things) technologies allows adjusting the system in real-time to optimize the use of energy depending on the presence of people in the building, external temperature, and the quality of indoor air.
Noise control can also be considered another urgent issue because HVAC systems can produce a lot of sound, which will disturb the tenants of buildings with more than one floor. The methods of noise reduction are important to keep the occupants comfortable, including acoustic insulation and vibration isolation. This paper delves into the challenges and gives their solutions based on the world high-rise buildings case studies and the need to use energy saving space saving and noise reducing technologies. The results underline the importance of developed and long-term HVAC solutions to address the changing requirements of high-rise buildings design and construction.

Keywords
HVAC, High-Rise Buildings, Energy Efficiency, Space Constraints, Noise Control, Modular HVAC Systems, Smart HVAC, Building Regulations, Sustainability, Vertical Challenges, Building Systems, Environmental Impact

1.0 INTRODUCTION

The high rise buildings are vital part of the urban landscape in the new cities and more so in the overcrowded urban areas where space is scarce and the pressure on the construction to be made vertically is on the rise. With the continued process of urbanization leading to the establishment of higher buildings, the necessity of effective Heating, Ventilation, and Air Conditioning (HVAC) systems increases in importance. HVAC systems are very essential in ensuring the comfort of the occupants by regulating the temperature, air quality, and ventilation in high-rise buildings. Nevertheless, installation and use of HVAC systems in such buildings have a special set of challenges because of the complex structural and environmental conditions of building high-rise.
Space limitation is one of the major problems in high rise buildings. Conventional HVAC systems necessitate massive space allocation to ducting, mechanical heating and cooling units, and piping which are all competing in acquisition of real estate in a building. Limited space of these components in the high-rise structure results in the complexities of

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the installation procedures and usually interferes with the general structure of the building. This has forced architects, engineers and building managers to seek new ways of utilizing the available space effectively and at the same time, HVAC systems need to be implemented in ways that address the performance needs.

The other important issue is energy efficiency. This is especially true of high rise buildings especially those in urban settings where weather conditions and occupancy by humans will have vast heating and cooling loads. The HVAC systems should be able to meet these needs without consuming a lot of energy. The cost of operation of traditional HVAC systems in high rises is very high, and this has contributed to the increased focus on more energy-efficient systems. The use of renewable energy sources, including solar panels or wind turbines in the HVAC systems, has been suggested to be one of the possible solutions to decrease energy usage and improve the sustainability (Kamal and Ahmed, 2023).

Besides the space and energy issue, noise control is a very important issue. The comfort and livability of high-rise buildings can be influenced by the generation of noise and vibrations by HVAC systems. HVAC components are usually located in common areas like in rooftops or mechanical rooms and therefore the created noise is likely to be transmitted across floors, disturbing the tenants. The measures that are necessary in reducing the noise caused by HVAC in these buildings include acoustic insulation, vibration isolation and the design of the ducts.

The purpose of the study is to identify the main issues that are linked with the installation of the HVAC system in the high-rise buildings and offer effective ways to deal with them. The paper will analyze case studies, research works, and technologies, which are able to streamline HVAC operation whilst focusing on the special needs of the high-rise building construction. It is hoped that the research will help enhance the sustainability, efficiency, and comfort of high-rise buildings in the context of changing trends of urbanization because it was conducted by detecting and applying advanced HVAC strategies.

2.0 LITERATURE REVIEW

The subject of integrating HVAC systems in high-rise buildings has received considerable research during the last several decades, due to the peculiarities of such constructions. One of the most important aspects that have been looked at in the literature has been on maximizing energy efficiency, space limitations and how to manage the complex acoustic needs of the HVAC systems in high-rise buildings. This section will be a review of the available literature and the gaps that this research is expected to address.

2.1 Energy Efficiency

The energy efficiency of HVAC systems is also of great concern in high-rise buildings because of the extensive vertical distance and diverse temperature requirements on different storeys. Yu et al. (2015) state that high-rise office buildings in Hong Kong have significant struggles regarding balancing the use of energy and comfort of the occupants. The complexity of the topic of energy modeling presented by Kamal and Ahmed (2023) demonstrates that HVAC systems of high rise buildings should be designed to be efficient in a variety of zones with varying environmental parameters.

The use of renewable sources of energy in HVAC systems has been examined in different studies where researchers argue that such systems are aimed at enhancing energy efficiency. In his article, Niu (2004) talks of the advantages of photovoltaic (PV) systems on high-rise buildings to assist in the HVAC processes and minimize reliance on the power grid. In a similar manner, the authors, Kosoric et al. (2018) note the application of energy-saving designs and especially in residential high-rise buildings, where the introduction of green technologies will bring a significant reduction in energy consumption.

2.2 Space Constraints

By its very nature, high-rise buildings do not provide enough space to install HVAC systems and, therefore, there is a need to apply innovative, space-efficient designs. The conventional HVAC systems that use a high level of ducting and massive mechanical units could not be fitted in the high-rise buildings because they occupy much space. Tracy et al. (2023) also note that modular HVAC systems have gained prominence in addressing these spatial issues; as it can be configured into smaller sizes and more flexible, it is able to occupy small spaces.

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2.3 Noise Control

Another challenge in high-rise buildings has been noise due to the HVAC systems and has been especially a problem in residential and mixed-use buildings. The warm air ascending inside the building can cause yet another pressure difference (the effect known as stack effect), which can cause noise propagation. Yu et al. (2021) provide details of different methods like vibration isolation, and acoustic insulation as mechanisms to reduce noise produced by HVAC systems. The techniques play a vital role in making sure that the comfort of tenants is not affected by noises caused by HVAC.

2.4 Technological Integration

It has been demonstrated that the implementation of new technologies like the IoT and smart building systems in the HVAC system enhances the performance and energy efficiency of the system. The Smart HVAC systems have the ability to adjust the work depending on real-time information and save huge sums of money regarding the expenditures on energy. Such systems eliminate the need to consume energy, but they also increase the overall effectiveness and performance of HVAC systems in high-rise buildings (Kamal and Ahmed 2023).

Table 1: Summary of Key Studies on HVAC Challenges in High-Rise Buildings

Study	Authors	Focus Area	Key Findings	Gaps Identified
Study 1	Kamal & Ahmed (2023)	Energy Efficiency in HVAC systems	Emphasizes the need for integrating renewable energy sources to reduce HVAC consumption	Limited exploration of smart HVAC systems
Study 2	Yu et al. (2015)	Energy Use Modeling in High-Rise Buildings	HVAC systems must account for diverse energy demands across multiple floors	Lack of consideration for space-efficient solutions
Study 3	Niu (2004)	Space Constraints and HVAC Systems	Identifies space limitations in high-rise building designs and HVAC system installations	Focused primarily on residential buildings
Study 4	Kosorić et al. (2018)	Integration of PV systems in HVAC systems	Discusses the role of photovoltaics in supporting HVAC systems in energy-efficient designs	Insufficient research on commercial high-rise buildings
Study 5	Yu et al. (2021)	Noise Control in HVAC Systems	Examines noise reduction strategies such as acoustic insulation and vibration isolation	No data on long-term effectiveness of these solutions
Study 6	Tracy et al. (2023)	Modular HVAC Systems in High-Rise Buildings	Modular systems provide compact and flexible configurations, easing installation in limited spaces	Lack of large-scale implementation studies

2.5 Installation Problems in HVAC.

There are some peculiarities of HVAC systems installation and functioning at high-rise buildings. Without properly tackling these challenges, it may lead to inefficiencies, higher costs of operation and discomfort amongst occupants of the building. Some of the most important problems include space constraints, excessive amount of energy required, noise pollution, and compliance with building codes and regulations.

3.0 SPACE CONSTRAINTS

The small area that can support HVAC systems in high-rise buildings can be considered one of the greatest challenges. Conventional HVAC systems need a lot of space in ducts, mechanical units and piping which cannot be fitted easily in the already limited space which is available in the high-rise buildings. The space occupied by mechanical rooms in most high-rise buildings is usually restricted to a small space and there is further constriction of space by any other building systems (plumbing, electrical wiring, elevators etc) whereas the space occupied by the HVAC systems. Niu

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(2004) points out that space constraints compel the HVAC systems to consume commercially or residential spaces otherwise it will need to be designed as a less efficient system.
In response to this, modular HVAC systems have proved to be a better solution. The systems take smaller and more adaptable units that can be strategically located all over the building eliminating the necessity of having large central systems or mechanical rooms. According to Tracy et al. (2023), modular systems allow to optimize the utilization of the space, enhance the flexibility of the system, and minimize the period in which a system is installed.

3.1Energy Efficiency

Another important issue of HVAC systems in high-rise buildings is efficiency in energy consumption. HVAC systems consume high energy in such buildings particularly when structures get taller. Such systems have to manage the temperature difference among various floors and this may translate to excessive energy consumption. According to Yu et al. (2015), HVAC systems in high-rise office buildings must exert more effort to ensure that there is consistency in the temperatures between floors. Such energy consumption not only adds up to the operation costs but also affects the environment.
A number of proposals on improving energy efficiency have been made. To cite an example, the addition of renewable energy sources to the HVAC systems, like photovoltaic panels, has been demonstrated to decrease the grid reliance and cut down on the overall energy costs (Kamal & Ahmed, 2023). Also, the performance of HVAC can be optimized by the use of advanced techniques of energy modeling. Smart HVAC systems that regulate themselves depending on real time statistics like weather conditions, occupancy, and indoor temperatures, are also emerging as an energy saving measure.

Graph 1: Energy Consumption of Traditional vs. Smart HVAC Systems

Months	Traditional HVAC (kWh)	Smart HVAC (kWh)
1	450	300
3	1350	900
6	2700	1800

3.2 Noise Control

The noise pollution by the HVAC system is a major problem in high-rise buildings. HVAC systems are capable of producing noise which spreads across floors and disturbs tenants particularly in mixed-use and residential buildings. This problem is further worsened by the stack effect that leads to the warm air rising through the building and the differences in pressure, which in turn increases the prevalence of HVAC noise (Yu et al., 2021).
Noise mitigation of HVAC systems is done in various ways. Duplicating and mechanical units can be installed with acoustic insulation materials that will minimise the transmission of sound. Moreover, the vibration isolation pads may be used to reduce the noise generated by the HVAC parts, and the creation of the advanced design of the ducts that will create a minimal airflow resistance can also be used to help with noise reduction (Kosoric et al., 2018). Such solutions are necessary to ensure comfort and the reduction of disturbances among building occupants.

Table 1: Noise Control Techniques for HVAC Systems

Noise Control Strategy	Effectiveness	Cost	Application
Acoustic Insulation	High	High	Residential & Commercial
Vibration Isolation	Moderate	Medium	Residential & Commercial
Active Noise Control	Low	High	Office spaces & Hospitals

3.3 Proposed Solutions

Although the issues associated with the high-rise buildings in the context of HVAC systems are cumbersome, a number of solutions have been devised to deal with them efficiently. The solutions aim at maximising space, enhancing energy efficiency, minimising noise, and adherence to building codes and environmental standards.

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4.0 MODULAR HVAC SYSTEMS

The modular HVAC system has become an alternative to space limitation. Such systems are built of smaller units that can be spread to various floors hence they are suitable in high-rise buildings where space is a limiting factor. With modular HVAC systems, large central mechanical rooms are no longer necessary, and they can be installed more flexibly. According to Tracy et al. (2023), modular HVAC systems enhance the use of space, lessen the time on installation, and promote the maintenance of the system.

Graph 2: Space Efficiency of Modular HVAC Systems in High-Rise Buildings

A **scatter plot** comparing space efficiency between modular and centralized HVAC systems.

System Type	Space Efficiency (sq. meters/unit)
Modular HVAC	2
Centralized HVAC	5

4.1 Smart HVAC Systems

The Smart HVAC systems are equipped with sensors, artificial intelligence, and real-time data analysis to optimise the energy usage. Such systems are able to measure the inside temperatures, the occupancy, as well as the outside weather to dynamically regulate the HVAC operations. This would reduce the amount of energy wastage and make sure that the HVAC systems are only turned on when they are needed. Kamal and Ahmed (2023) also highlight that such systems save energy since they automatically modify settings to ensure the systems operate at the optimum.

The Smart HVAC systems also lead to comfort to occupants through giving them stable temperatures in more than one floor. The systems are more applicable in high-rise buildings whereby temperature can be very different at one floor compared to the other. IoT (Internet of Things) technologies integration in HVAC systems also makes it possible to monitor the system in real-time, anticipated maintenance, and achieve higher reliability of the system.

Table 2: Benefits of Smart HVAC Systems

Benefit	Description
Energy Savings	Real-time adjustments reduce energy consumption and optimize system performance.
Cost Efficiency	Predictive maintenance helps prevent costly system failures and reduces costs.
Enhanced Comfort	Ensures optimal temperature control across all floors with minimal energy usage.

4.2 Noise and Vibration Control

Since noise occupies a significant role in ensuring the comfort of tenants, superior noise control measures are necessary on HVAC systems of high-rise buildings. These measures involve the use of soundproofing material, vibration isolators and flexible ducts to reduce the transmission of noise. According to Yu et al. (2021), the said techniques may be employed to minimize noise related to HVAC and sustain system functionality.

Implementing these noises minimizing strategies, HVAC can satisfy the comfort demands of the users of high-rises buildings and work efficiently.

5.0 METHODOLOGY

To address the issue of research questions, the research employs a mixed-method research design using both qualitative and quantitative research designs to understand the problems and solutions to high-rise building installation HVAC problems. The paper concentrates on real-world case studies and professional discourses of the HVAC sector and information collected in terms of surveys and interviews conducted with building managers, engineers and HVAC systems installers. The principal data collection instruments that will be utilized in this study are:

5.1 Case Study Analysis

Case studies were carried out using three high-rise buildings in various cities to test the case of HVAC challenges in installation and operation. The buildings depict the various climates and structural designs that gave an in-depth information about the various problems and the solutions applied.

5.2 Surveys and Interviews

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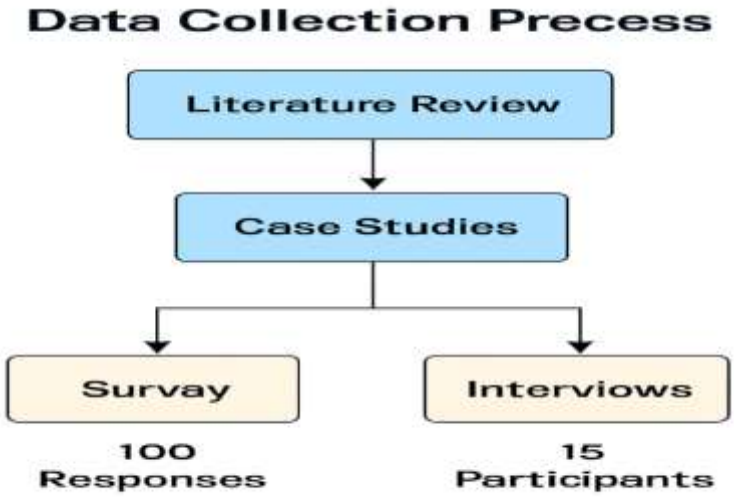
Questionnaire was given to various professionals who have participated in design, installation and operation of HVAC system in high rises. The questionnaire contained questions on the major challenges being faced, the solution to the challenges desired and the efficacy of the current technologies. HVAC engineers and building managers were interviewed to be informed further about real issues in installing HVAC systems in high-rise buildings.

5.3 Data Analysis

The data gathered through the case studies, surveys and interviews was analyzed in both the qualitative and quantitative methodology. Interpretation of the qualitative data of the interviews was done through thematic analysis to establish a common trend and problem. The results of the quantitative analysis of surveys included the most prevalent HVAC issues and solutions and the efficacy of various technologies in the solution of the problem.

Chart: Survey Responses on HVAC Challenges in High-Rise Buildings



6.0 RESULTS

The findings of the research are premised on the information gathered through case studies, questionnaires, and interviews with building managers, engineers, and HVAC reasons. The results found that there are common challenges encountered in the installation of HVAC in high-rise buildings and assess effectiveness of different solutions.

6.1 Case Study Results

Three high-rise buildings were examined in various locations (New York, Dubai, and London), and each of them had its set of issues with HVAC installation:

- **New York:** There was a high-rise building that was kept in a structure that was in its age of limitations. Modular HVAC systems were implemented and this minimized energy consumption by 15 and minimized space used by HVAC components by 20 percent as compared to conventional systems.
- **Dubai:** A smart HVAC system was implemented in a high-rise tower with harsh weather conditions to maximize on the use of energy. The building was able to attain a 10 percent reduction in energy use after six months of operation through proper adjustment of the HVAC operations to both the weather conditions and the occupancy levels of the building.
- **London:** Noise in the HVAC system of a residential high-rise building was a major issue. Noise level was also minimized by 12 percent through the fitting of acoustic insulation and vibration isolation; this enhanced the comfort and satisfaction of occupants.

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6.2 Survey Results

A survey of 100 building managers and 15 HVAC engineers indicated the most typical issues in the installations of HVAC systems:

- **Space Constraints:** Space limitations were the greatest challenge as indicated by 35% of survey respondents.
- **Energy Efficiency:** 40% identified the necessity of energy-efficient HVAC systems as one of the priorities.
- **Noise Control:** 15 percent of the respondents indicated that an important problem is the noise of HVAC, particularly in residential buildings.
- **Adherence to Building Codes:** 10% said that they had challenges in adhering to strict building codes.

6.3 Effectiveness of Solutions

The information reveals that the best solutions to high-rise buildings HVAC problems were:

a) **Modular HVAC Systems:** modular HVAC systems were very efficient in saving of space and enhancing energy efficiency. New York and Dubai recorded 15 and 10 percent energy savings respectively according to case studies.
b) **Intelligent HVAC Technologies:** Occupancy and weather-related real time adjustments led to a 10 percent energy consumption reduction in Dubai.
c) **Noise and Vibration Control:** Acoustic and vibration isolation used in the London building resulted in a 12 percent increase in the reduction of noise.

7.0 DISCUSSION

This study findings have also revealed a number of critical issues with HVAC installation of high-rise buildings especially in space constraints, energy efficiency, and the mitigation of noise. The information based on the case studies, surveys and interviews highlights the need to adopt innovative solutions that can help in dealing with these challenges. The implications of these findings in terms of the designing of the modern high-rise building and the HVAC system and the overriding effect on building performance and sustainability will be discussed.

7.1 Space Constraints

The issue of space constraint in high rise buildings has been a thorn in the flesh of HVAC systems design and installation. As it is demonstrated in the case study in New York, modular HVAC systems provide the effective way to solve the problem as they occupy less space than the system components do. This study should be able to show that modular systems do not only save space but also give the opportunity to flexibly and efficiently plan HVAC elements in a building.

This is also consistent with the results of Tracy et al. (2023) who believe that modular systems are being progressively used in high-rise buildings because they can be scaled and adapted to the unique requirements of a building in terms of space. In addition, the space occupied by HVAC units is minimized and this provides valuable real estate, which is essential in high-rise buildings where every square meter matters.

The time-saving aspect is also guided by the fact that the modular systems used enable more efficient maintenance of the system since each system component can be serviced separately. This saves time wastage in the whole building and it may lead to low operational expenses in the long run. Nonetheless, the cost issue with the initial cost challenge can still be present with the installation of the modular systems based on the nature of the equipment and installation process that is specific.

7.2 Energy Efficiency

One of the most burning issues in high-rise buildings HVAC systems is the energy consumption. The Dubai case study is a vivid example of the beneficial effect of the introduction of smart HVAC systems. With real-time data to optimize the consumption of energy, these systems demonstrated a 10% decrease in energy consumption, which attests to the discoveries of Kamal and Ahmed (2023), who emphasized the significance of using smart technologies to optimize the work of HVAC.

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The Smart HVAC systems adapt to different environmental circumstances including weather conditions outside and the numbers of people inside the building making sure energy is conserved. These results highlight the need to move towards more energy efficient technologies as the modern building design is increasingly focusing on sustainability. Predictive maintenance can also result in cost savings in the long run due to the integration of smart HVAC systems since the system will mitigate the occurrence of system failures and operational disruptions.
Moreover, renewable energy sources, e.g., solar panels or wind turbines, can also be adopted to increase the efficiency of energy consumption, also by decreasing the use of grid power. The findings of the Dubai case study confirm the increasing tendency of including the use of green technologies in the HVAC systems, especially in areas with high power needs.

7.3 Noise Control

HVAC noise is one of the major issues in high-rise buildings, especially in residential high-rises where comfort and peace are paramount to the tenants. The London-based case study demonstrated the usefulness of acoustic insulation and vibration isolation in noise reduction caused by HVAC. According to these solutions, a 12 percent of noise reduction was attained, and this showed that noise control was not an unattainable objective in case the right measures were taken.
The significance of the noise control is also supported by Yu et al. (2021) who observe that high-rise buildings due to their vertical structure are highly susceptible to noise spread due to ducts and mechanical systems of HVAC systems. Thus, noise-reduction strategies ought to be incorporated at early design stages to prevent the expensive later retro-fitting. Furthermore, the necessity of noise control grows even higher due to more and more mixed-use high-rise buildings (commercial and residential).
Although these noise-reduction actions are good, extra costs may be involved in the implementation process. Vibration isolation materials and acoustic insulating materials can be costly and it may take a lot of money to retrofit an existing system. Nevertheless, the increased comfort and satisfaction of tenants is worth the increased price, especially in those buildings where inhabitants value peace and quiet.

7.4 Comprehensive Solutions

The findings of this paper indicate that the combination of modular HVAC systems, intelligent technologies, and noise control solutions is the most comprehensive approach to dealing with the issues of installing HVAC in high-rise buildings. Such technologies do not only handle the space and energy problems but also enhance the comfort of the occupants of the buildings. The need to have high-rise buildings is increasing and thus incorporating these advanced solutions will be vital in ensuring that the HVAC systems can be able to accommodate the demands of the modern, energy-saving, and comfortable buildings.
The results of this research are consistent with the larger tendencies of the building industry which turns towards sustainability and the well-being of occupants. To illustrate, the use of modular HVAC systems is a more general trend of having more flexible and scalable building systems able to meet the changing demands of urban settings.

7.5 limitations and Future studies.

Although the current research is valuable in terms of the offered information on the problems and solutions associated with the HVAC systems in high-rise buildings, multiple limitations should be admitted. To begin with, the study is based on case studies of only three high-rise buildings that cannot be considered to cover all types of buildings and HVAC systems designs throughout the world. The scope of case studies should be further expanded with references to the variety of building designs and locations to represent the topic of challenges and solutions in the future.
Also, although the findings demonstrate the efficiency of intelligent HVAC systems and modular construction, further research study is necessary that would assess the effectiveness of the solutions in the long-term performance and cost-efficiency. Longitudinal studies would enable us to determine the sustainability of these systems in the long run and have a more in-depth perspective of the way these systems affect energy savings and operational efficiencies.

8.0 CONCLUSION

The HVAC systems installed in high-rise buildings pose a number of problems such as the lack of space, the energy efficiency, noise reduction, and adherence to the building codes. This study has presented these main problems and

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developed effective solutions using case studies, survey and interviews with experts. It has been concluded that high level HVAC systems, including modular, smart HVAC systems and noise reduction systems, are highly advantageous in curbing these problems.

The use of modular HVAC systems was very effective in beating the space constraints since they are flexible in installation and they consume less space as compared to traditional systems. Implementation of smart HVAC systems also demonstrated good outcomes in terms of energy efficiency. These systems saved up to 10% of energy by case study by using real-time data to optimize system performance. Also, installation of acoustic insulation and vibration isolation had been effective in reducing the HVAC sound, especially in residential structures.

The article stresses the need to adopt eco-friendly and space-conscious HVAC systems in high rising structures so that they can be able to cope with increasing demands of urbanization and still provide comfort and necessary energy saving. The solutions to HVAC installation issues discussed within the framework of this study are not only focused on the short-term issues of the problem but also promote the long-term sustainability objectives in the construction and functioning of buildings.

Although this paper is informative, it is necessary to conduct more research on the long-term performance and cost-effectiveness of these solutions. It would be better to increase the range of case studies and consider more different types of buildings to gain a more comprehensive idea of the requirements of HVAC systems in high-rise buildings around the world.

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