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Review on HVAC and Energy conservation Techniques employed with BIM Systems

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Abstract - This paper includes a literature review regarding the Heating, Ventilation and Air conditioning (HVAC) systems installed in buildings with particular attention paid to the issue of system design, energy performance and implementation of modern technologies. The following are among the important subjects of the review; the sizing of the HVAC system, the building control measures, energy use patterns and performance optimization methodologies besides utilization of Building Information Modeling (BIM) in enhancing the building coordination and lessening traits of conflict during system design. The results have showed that HVAC systems within buildings contribute a significant fraction of building energy consumption, and that their performance can be significantly enhanced by optimization design strategies including performance-based sizing, sophisticated control means including model predictive control and fuzzy logic, and optimization methods like genetic algorithm. Moreover, novel technologies, including artificial intelligence, machine learning, smart sensors, and simulation tools are becoming more actively exploited to optimize the performance of a specific system, implement predictive maintenance, and advance the comfort of occupants. Second, the review indicates significant impacts of a factors environment on the overall energy performance of a building as they relate to climate conditions, insulation, occupant behavior and system operation. Moreover, energy conservation strategies such as heat recovery system, thermal energy storage program, integration of renewable energy and enhanced HVAC systems have a great potential to save energy usage and carbon emissions. Even with these progresses, issues and setbacks continued with regard to the complexity of implementation, data integration, model accuracy, as well as, co-ordination amongst stakeholders. On the whole, the paper highlights the necessity of combined technology-based solutions to develop the sustainable, energy saving, and high-performance HVAC systems in the new modern structure.

1. INTRODUCTION

Structures consume a significant volume of energy worldwide, and it is HVAC systems that consume a significant portion of this energy, particularly in hot and humid areas. High temperature and humidity in places such as Middle East and some parts of Asia consume a lot of electricity in cooling. This increase in demand explains why energy-efficient solutions are necessary that would allow saving on consumption without compromising the comfort of the indoors and the air quality. Studies have indicated that the amount of energy consumed by buildings depends on numerous factors such as the climatic conditions, building design, insulation, the type of system fitted, and the behavior of occupants among others. The cooling load can be decreased by proper design of the building envelope, including using appropriate insulation of a wall and a roof. This does not only minimize energy usage but also minimizes the size and the cost of HVAC equipment. Nevertheless, the performance of insulation is determined by the type of the building, internal heat gains, and, thus, it is essential that the appropriate materials and thickness should be used, and the choice is predetermined in this situation.

Besides design, the choice and design of HVAC systems are also considered important in terms of energy performance. Comparative studies of the various types of systems have revealed that sophisticated settings and the application of heat recovery systems can save a lot of energy. Energy recovery ventilators, solar-powered cooling, and streamlined air delivery systems are some of the technologies used to enhance the efficiency of the system. The issue of moisture control is of particular concern in hot and humid climates, since it has a direct impact on cooling load and the general performance of a system. The second important reason of decreasing energy consumption is incorporation of effective control measures. Complex control options such as using optimized start-stop schedules, temperature reset, economizer control and demand-based ventilation can achieve significant energy savings without significantly interrupting the level of comfort. Efforts to test these strategies have been highly successful with the simulation tools that enable engineers to test various situations and come with the most viable solutions. Control improvements have high payback periods and in most instances, minimal investment is required.

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The performance is further improved through the continued monitoring and optimization of the HVAC system, like that of Continuous Commissioning, which can detect the operational problems and keep the efficiency of the system optimized with time. Such strategies do not only save energy used but also increase the life of equipment and enhance indoor environment.The analysis and design should also be reliable and this depends on the weather data and good energy modeling. Climate data over years give the engineers an insight of the local conditions and come up with more effective energy saving plans. Simulation models are better suited to real building data to be calibrated to optimize their accuracy and make sure that the simulations yield the same savings as the actual performance. Even with these improvements, there are still issues such as the complexity of the systems, availability of data and the fact that there is a need to have appropriate coordination between the stakeholders. Thus, the implementation of an effective design, sophisticated technologies, detailed modeling, and perfect functioning are required. On the whole, the proper design, control, and management of HVAC are capable of saving great amounts of energy, costs, and providing more comfort. These are strategies that are required to have sustainable and energy efficient buildings in construction today.

2. METHODOLOGY

2.1 HVAC Conservation and Techniques:

Nabil Nassif et al. have discussed on "Better Way to Use a Dual VAV System to Save Energy." It uses outside air wisely and never uses both heating and cooling at the same time. Tests on small and big buildings have shown that a lot of heating energy and some cooling energy can be saved, along with some fan power. In simple words, a "Better Way to Use a Dual VAV System to Save Energy" is a system that will help buildings save more energy and be more efficient[12].

K.F. Fong et al. found that the saving energy in the HVAC system by changing the settings. The settings are the temperature of the water and the air, which work together in a smart way. This study proves that changing the settings every month can save energy and make the system work in a smart way. In short, changing the settings can help us save energy without spending any extra money[14].

Some of the authors like J.A. Wright , Rand Talib 1, Y. Asiedu and many more have been sayin g the same ideas and concludes and describe different techniques to improve the efficiency of the HVAC system and reduce the cost. They also show how computer tools and smart techniques can be used to design the HVAC system in a more efficient way. Some papers describe the techniques to reduce the cost of additional energy consumption using smart techniques and VAV systems. Other papers show the importance of using sensors, cameras, and actual data to identify the issues early and adjust the system based on the number of people in the building. Some papers also describe the importance of using artificial intelligence and machine learning techniques to improve the performance of the HVAC system. These techniques can help the system learn and improve performance.All the papers conclude the importance of using technology and smart techniques to improve the efficiency of the HVAC system. They also show that still many improvements are needed to achieve high accuracy [16,28].

Y. Asiedu , W. Huang and his colleagues says these papers discuss how genetic algorithms can be used to make HVAC systems better. They can help in selecting the best system and make controllers better.The research has shown that this method can cope with complicated problems and produce better results compared to traditional methods. It can make the system work more smoothly and increase its response time and accuracy. To put it simply, genetic algorithms can make HVAC systems better and more reliable; however, more research is necessary to make these systems faster and easier to use in real life [35,36].

Vahid Vakiloroaya et al. found out that to save the energy used in the HVAC system because the fuel is reducing and pollution is increasing. It tells us that with the right design, we can make the building comfortable and reduce the consumption of energy. It tells us that the right design depends on the weather, cost, and type of building. In simple words, it tells us that with the right design and technology, the HVAC system can function well and reduce the consumption of energy [45].

S. N. Teli concludes that normal HVAC systems consume a lot of fuel, but we must save energy. This paper explains that proper design with smart methods can help the system work properly while keeping people comfortable. In simpler terms, saving energy is related to weather, cost, and the way the building is used [64].

Cuimin Li et al. explains the movement and distribution of air with the temperature in the room using a special air conditioning system. It tells us that the room is comfortable with this system because it distributes cool and warm air. It is functioning well even in warm weather. In simple words, this system is the best compared to normal air conditioning[66].

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José Fernández-Seara et al. describes a building that uses a heat recovery system in ventilation. It takes the heat out of the air that is going out and gives it to the air that is coming in. The system works well, and it becomes stable after some time. However, the performance of the system can change a little depending on the temperature, humidity, and airflow. In other words, it can help in saving energy, but weather changes can affect the performance of the system a little[75].

Some publisher like José Fernández-Seara, M. Fasiuddin, Shih-Cheng Hu and there colleagues found out that different methods of saving energy in HVAC systems. One paper indicates that it is possible to cool a house during the day by the sun and save some electricity. Another paper indicates that by using modern control systems and better settings for the systems, it is possible to save some energy, especially in hot places, and also maintain a comfortable temperature in rooms. Another paper compares different HVAC systems and indicates that some systems are better than others and that air flow and noise also matter [78,80].

D. Dong et al. says to enhancement of the HVAC system in school. Targeting with selecting appropriate have contributed to getting them more energy saved. Proper checking has saved the building a good portion every year [85].

Mingsheng Liu et al. describe that simple and more calibrated methods were employed in order to make HVAC system more efficient and this system saved best operating schedule, control system settings, and also was able to find some problems in this research. 18 LoanSTAR buildings were examined and it revealed that could have saved 2 million a year in this system, and also building up to 23 percent of heating and cooling could be saved in this system[91].

Budaiwi et al. found on mosque what way energy could be saved in HVAC system without decreasing comfort, had HVAC system been designed and operated properly. It reminds us that with the over size HVAC system can help In saving energy by 23 percent rather than operating the system full time, just an hour of operation can cool the surrounding more quickly but insulation can be right, by cooling only the part of the structure being used can save 30 percent more energy, combining HVAC operation with intelligent zoning can save up to 48 percent of energy[97].

2.1.1 Indoor Air Quality Control:

C.-A. Roulet et al. found out the use of heat recovery in ventilation systems to save energy. According to the paper, saving energy is possible if the system is properly installed with no leakage of air; otherwise, the energy-saving will be less. In simpler terms, proper design helps save energy while keeping the air clean [69].

E.H.,Mathews et al. describe the improvement of the HVAC system to make the room comfortable while saving energy. The paper explains that different methods, such as time, temperature, and air flow, were tested. By doing this, we can save energy as well as reduce the cost. In simpler terms, the HVAC system can save a lot of energy as well as reduce the cost [83].

Ik-Seong Joo et al.tells us saving of energy with the help of an economizer in the HVAC system. It is discussed how the cooling of the building can be reduced by using cool outside air. More energy can be saved with some systems compared to others depending on the way they work. In simple words, the usage of outside air can help in the saving of energy [96].

2.2 BIM System Clashes Identification:

E.A. Pärna et al. says the finding of design problems in a big building with the help of BIM. Different engineers designed the building. When the designs were combined, many clashes were seen among the pipes, ducts, and structure parts. BIM helped in finding these problems. In simple words, BIM can identify the mistakes, but it cannot prevent them. Proper usage of tools and teamwork is required [2].

Some of the authors like Xinxin Tang , Zhen-Zhong Hu and there colleague foud that the use of BIM to enhance the design of HVAC and MEP systems in an easier way. The papers discuss that the traditional methods used in the design process are time-consuming, but with the help of BIM, the process is easier as the information is shared, the design is enhanced, and the clashes are easily identified. It also helps in the use of smart methods to solve complicated issues.Another study proves that the use of various levels of BIM helps in effective teamwork, enabling the easy handling of large projects. In short, BIM helps the engineers design the project faster, easier, and with less chance of errors [4, 5].

Porwal et al. tells us the problems that occur while using BIM in government building projects. The problems occur due to the rules, cost constraints, and lack of teamwork. If the teams do not work together, the use of BIM is not effective. The paper suggests that all teams must work together from the beginning with the same model. In short, teamwork is the key to the effective use of BIM with less chance of errors [6].

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Author like Merschbrock , M. Al Hattab along with there colleague discuss the ways in which BIM helps teams work together in construction projects. The papers prove that BIM is effective in projects where teams work well together, with proper roles, proper training, and where information is easily shared among team members. Leadership support is also an important aspect. The papers also prove that teamwork and communication can help teams detect and prevent errors early in the project. In short, teamwork and information sharing help projects go well, and errors are reduced [7,8].

2.3 MEP BUILDING SERVICES AND ENERGY SAVINGS:

Dr. Rogelio Palomera-Arias has concludes and discusses some popular books used as texts for teaching construction and MEP systems such as HVAC, electrical, and plumbing systems. The paper proves that the books are good for teaching the basics, but some popular books lack important information on new technologies, energy saving, and project work. In short, the books are good for the basics, but students must acquire more knowledge on new technologies for real work [1].

Luis Pe´rez-Lombard et al. found out that buildings consume a lot of energy, especially for HVAC systems. It further indicates that as the number of people in a particular city increases, so will their energy consumption. Therefore, there is a need to enhance rules, new technologies, and energy consumption in general. In simple words, energy consumption in buildings is a very significant aspect in the future, as this paper indicates [3].

F. Asdrubali et al. explain us the energy consumption in buildings in two different countries. It indicates that apartments consume less energy than independent homes. Further, this paper indicates that some rules are more stringent in one country than in another. In simple words, rules and information are significant in assisting individuals in choosing buildings with high energy consumption, as this paper indicates [9].

People like Richard S. Miller, Pejman Ebrahimi and their colleague discuss how building safety can be improved and energy conserved.Through this paper, it is clear that building safety can be improved by using pressurized staircases, which can stop the spread of smoke from these buildings in a better manner than lifts. It is further mentioned in this paper that the proper functioning of these systems depends on many other factors, such as the speed of the fans.Through this paper, it is clear that using heat pumps instead of regular systems can reduce energy consumption, gas consumption, and pollution while keeping the rooms comfortable [10,11].

Janghyun Kim et al. concludes using Passive Chilled Beam systems to reduce energy consumption in buildings.Through this paper, it is clear that this system consumes less energy than regular systems, especially in hot locations. By using other parts, these systems can work in a better manner.Through this paper, it is clear that this system can reduce energy consumption while keeping people comfortable [13].

Vincent J.L et al. shows us that using computer tools to conserve energy in buildings. It shows how these tools can be used to predict the consumption of energy and design buildings well. Using smart technology can also ease the process. In simple words, using computer tools can help design buildings to conserve energy and design them well [15].

Keii Gi[1] , Santosh K. Gupta[a] , Y. Acquaah and their colleague shows us the future usage of energy and the intelligent way to control the HVAC equipment. These papers show that the demand for cooling will rise with global warming, yet with proper insulation, quality equipment, and clean energy sources, the demand can be lessened. Other papers show the way to control the temperature using sensors and smart technology. They also show the way to measure the number of people using the camera-based method to control the HVAC equipment in a better way [29,31].

Luis Pe´rez-Lombard et al. explain us the using energy labels for buildings. It shows how buildings are tested for the consumption of energy and rated. It helps people compare buildings and design them well. In simple words, using energy labels can help conserve energy by designing good buildings [34].

Some authors like KeigoAkimoto, Keigo Akimoto, Vassilis Daioglou alonf with their colleague discuss the usage of energy, climate change, and the reduction of pollution. They illustrate the point that the usage of energy is rising, especially for cooling purposes, with the rise in the population of the country and the increase in temperature. It can be controlled with the help of advanced technology and clean sources of energy, which might be costly and different for different countries.Some papers illustrate the point that the income level, lifestyle, and location of people affect the usage of energy in their homes. They also illustrate the point that climate change might affect the usage of energy for cooling purposes. In simple words, the reduction of energy usage and pollution can be done with the help of advanced technology, proper planning, and the collaboration of different countries [37,44].

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Many Authors like Napoleon Enteria, Ronghui Qi along with their colleague discuss different techniques to cool buildings with less electricity consumption to reduce pollution. These papers prove that using normal air conditioning to cool buildings requires much electricity, especially in hot weather. So, different techniques such as solar cooling, desiccant cooling, and evaporative cooling being is researched. These techniques require less electricity, dehumidify the air, and improve the quality of the indoor environment. Even these techniques can cool buildings using the sun and water, which saves electricity. Many papers also prove that using different techniques to cool buildings and control the cooling system can efficiently cool the buildings if the system is not working under full load. In simple words, using different techniques to cool buildings with the help of the sun can save electricity, maintain the indoor environment, and protect the environment [46, 63].

T. Magraner et al. express the actual performance with the simulated performance of the ground heat pump system. The results show that the traditional methods overestimate the efficiency by 15-20%, mainly because the performance is reduced during the partial load operation. If this is taken into consideration, the gap is reduced. This shows the necessity for accurate models to ensure the reliability of the prediction[65].

M.M. Rahman, K. Nagano with their team shows, the performance of the thermal energy storage system in the high-rise building with an air-cooled chiller is discussed. The results show that full storage is more effective than partial storage; however, both provide cost benefits. The performance of the floor-based system with the help of phase change materials is also discussed. The small-scale system is found to be effective in controlling the indoor temperature, enabling the system to switch from day to night cooling, thus improving the efficiency [67, 68].

H. Manz, L.Z. Zhang and their colleagues shows that advanced ventilation systems can transfer air and recover heat at the same time by using aluminum fins; in addition, proper design and insulation can enhance efficiency by reducing airflow resistance. It is noted that in hot and humid environments like Hong Kong, more energy is required for dehumidification than for cooling fresh air; thus, advanced systems can outperform simple systems. There are several techniques in refrigeration control: cylinder unloading, hot-gas bypassing, and suction gas throttling. These techniques have different trade-offs in terms of efficiency, accuracy, and applicability; suction throttling is commonly used in these systems. Energy savings in buildings can be achieved by using heat recovery systems; in these systems, total heat recovery is more efficient in terms of cost and heat and moisture transfer compared to sensible heat recovery systems, which depend on the climate and types of buildings. Moreover, there are heat exchangers made of paper materials that show high efficiency and reliability in transferring heat and moisture in different environments [70,74].

Mohammad Rasouli et al. and Shahram Delfani et al. shows us that different climatic conditions, the application of energy recovery ventilation can improve the efficiency of buildings by recovering heat and moisture, which can reduce the demand for cooling energy. However, lack of maintenance can increase the demand for energy. They also indicate that in hot and humid climatic conditions, the application of cooling systems with heat recovery and low supply of fresh air can reduce the demand for energy, as it requires fewer additional components [76, 77].

MOHAMMAD S. AL-HOMOUD and F. A. AL-SULAIMAN et al. observed that the application of proper insulation to the walls and roofs can improve the efficiency of buildings by reducing the demand for cooling. It is also indicated that the required level of insulation depends on the internal heat loads, with buildings producing high heat levels requiring high levels of insulation. In the case of buildings located in hot and humid climatic conditions, such as those in the eastern part of Saudi Arabia, where high temperature and saline conditions can reduce the efficiency and longevity of air conditioning equipment, the application of proper insulation is important to enhance the efficiency and longevity [81, 82].

Caglar Selcuk Canbay et al. expressed the importance of using energy audits to reduce the consumption of energy in the HVAC system. It is evident that the consumption can be reduced by up to 22%, depending on the seasonal conditions this is what Caglar Selcuk Canbayis saying [84].

David E. Claridge, E.H. Mathews Yimin Zhu along with many researchers explained the importance of the continuous commissioning and monitoring of the building. It is evident that simulation tools can be used to optimize the strategies, which can lead to the reduction of costs. Moreover, it is evident that access to accurate weather data is important to ensure the design of efficient buildings, especially in regions with high building energy consumption, such as Saudi Arabia. Finally, it is evident that conducting energy audits is important for buildings with high ages, as it can help to reduce costs in the long term [86,90].

Yiqun Pan et al, M. Fasiuddin et al, and some researchers showed us the performance of buildings with reference to the consumption of energy using detailed inspections and simulations. They determine the best strategies to ensure efficiency. From the research findings, it is evident that simple operations can lead to the reduction of heating, ventilation, and air conditioning consumption by up to 16%, which is cost-effective. Older buildings show greater potential for improvement, while the evaluation systems promote the consumption of renewable energy [92, 95].

2.4 Model Predictive Control (MPC) System Significance:

Some of the researchers like Shiyu Yang, Roger Kwadzogah along with their friends observed the efficiency of the Model Predictive Control approach in terms of energy efficiency in HVAC systems, indicating that the approach is superior to traditional methods in dealing with the complexities involved in the system's behavior. The simplified neural network-based approach for the MPC is found to provide the same level of energy savings, i.e., 51% in offices and 36% in lecture halls, but is faster and more suitable for implementation, though less accurate. Despite the advantages, the approach is found to be limited in some cases due to the accuracy requirements and computational complexity involved in the approach [32, 33].

CONCLUSION

It is evident in the review that HVAC systems are vital in the building energy consumption and are already critical in ensuring that sustainability and better indoor environmental quality are realised. It has also been shown in the analysis of the reviewed works that the primary way to energy efficiency with better system design, such as performance-based sizing, duct and system optimization design, and implementation of more advanced control methods, including model predictive control, fuzzy logic, and intelligent optimization techniques are the primary ways to achieve significant improvements in energy efficiency. Monitoring, predicting, and optimizing the performance of HVAC systems in real time may additionally be improved with the integration of modern technologies, including artificial intelligence, machine learning, smart sensors, and simulation tools. Moreover, BIM has been found to be good in enhancing coordination, minimizing design clashes, and aiding in better decision-making across the life cycle of building despite some interoperability and collaboration issues. Heat recovery, thermal energy storage, better insulation, and renewable energy systems are other forms of energy saving methods, which significantly help save total energy consumption and carbon emissions. Nevertheless, these solutions cannot work efficiently without the adequate implementation, data correctness, maintenance, and the fact that they pay attention to the real-life aspects including climate conditions and occupancy behaviour. Conclusively, the implementation of energy saving and high-performance HVAC systems needs the inclusion of all stakeholders working together in a holistic manner in order to deliver sustainable and future-oriented buildings through advanced technologies and exploring better design approaches, as well as creating improved coordination with all stakeholders

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