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# Retrofitting Building Automation System in Cold Climate Elementary Schools: Pathways towards Net-Zero Energy

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***Abstract*— One of the biggest contributors to energy problems in cold regions in the United States is old elementary school buildings; these buildings tend to spend a longer time heating, have to be well ventilated, and are old. The performance of these facilities in terms of net-zero energy is critical in terms of the minimization of operational expenses, emission of greenhouse gases, and the promotion of the quality of the indoor environment (IEQ). The budget barrier of the system of public schools, however, restricts the haste of capital-intensive retrofit measures such as the complete replacement of HVAC or deep envelope retrofit. The purpose of this research is to explore cost-effective Building Automation System retrofit routes, to enhance energy performance in elementary schools. It is a qualitative and comparative approach with a lot of flexibility, entailing a comprehensive literature overview, evaluation of cold-climate case studies, and analysis of in-stage retrofit cases. HVAC scheduling, occupancy-based controls, demand-controlled ventilation (DCV), and centralized system integration are some of the major BAS strategies considered. The findings indicated that operational gains (in terms of energy savings) of 15-60% can be achieved through the deployment of these operational improvement measures based on BAS, which is notably exhibited in heating-dominated systems. The research paper offers a staged retrofit solution in line with ASHRAE rules and LEED certification models, which offer some plausible advice on how school districts with limited funding can save to go green.***

***Index Terms:* ASHRAE, BAS, Demand-Controlled Ventilation, HVAC Optimization, LEED, Net-Zero Energy.**

## I. INTRODUCTION

Elementary schools in cold regions of the United States, such as the Northeast and the Upper Midwest, have more time of heating, lasting five to seven months a year. Boswell, Minneapolis, Harrisburg and Boston experience high heating degree days, and therefore energy consumption trends in such cities are highly geared towards space heating and ventilation demand. The majority of these school structures were constructed in the pre-modern policies of energy conservation, such as ASHRAE 90.1. Consequently, they operate outdated HVAC systems, manually and inefficient modes of operation [3]. These inefficiencies result in high energy consumption, high operation costs, and low indoor environmental quality. The latest policy initiatives, both on a national scale and on a state level, have made it clear that people need to switch to net-zero energy buildings (NZEBs) to reduce carbon emissions and ensure that the public infrastructure is sizable and more sustainable. Still, various fiscal limitations, conflicting fiscal priorities, and logistical issues tend to inhibit deep energy retrofits in schools. The other option is Building Automation Systems (BAS), which is economical and can be scaled [4]. Real-time monitoring, intelligent control, and system integration that enables the addition of new functionality to a building, BAS can significantly improve the performance of the latter, without undergoing such drastic changes in a building. Better plans such as optimization of schedules and ventilation on demand, are fruitful considering the predictability of such occupancy in elementary schools.

## II. LITERATURE REVIEW

### A. Existing Work Review

Broadly speaking, the experimental material on energy use in cold-climate buildings indicates that the regulatory Framework as well as operational performance are important variables that characterize the energy efficiency of buildings over the long-term. Taki and Zakharanka (2023) emphasize that component degradation is a significant issue in terms of heating demand, and this factor gradually creates a large gap in the lifecycle energy issues [5]. Meanwhile, the study of Huynh et al. (2021) demonstrates the fact that the development of energy regulations is disintegrated in the localities of cold climates, and therefore, standardisation of thermal performance is missing [6]. All these papers lead to the suggestion that the implementation of successful energy consumption reduction should encompass robust regulatory design and long-run performance management in such a way that buildings can be efficient throughout their lifecycle and help to achieve decarbonisation targets on the whole. Educational buildings, in particular elementary ones, have their own characteristic type of energy consummation due to the non-alternating regularity, high data concentration, and compulsory indoor ventilation. In classroom settings, HVAC

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also tends to operate on a certain length of time during classroom hours when the classroom is usually empty without need of the HVAC operating constantly which ends in unnecessary energy usage [7]. In addition, other functional areas such as classrooms, gymnasiums, and administration areas among others consume less energy and has made it a challenge to manage energy. The importance of quality indoor environment is to sustain because thermal comfort, and air quality have a direct impact on the health, and academic achievement of students [8]. Schools are regarded as very appropriate with the properties to be optimized in terms of operational controls and energy manage systems.

Building monitor/controllability is done through the use of Automation Systems (BAS) to enhance the aspects of energy efficiency. These systems are also able to optimize the performance of the HVAC system and manage the setpoints by scheduling, occupancy-based control, and adjusting setpoints to eliminate the energy wastage during non-occupancy [9]. BAS also has the demand-controlled ventilation, adjusting the air flow based on actual occupancy, that can be useful in climates where heating predominantly occurs. Additional capabilities such as the fault detection and diagnostics are created to improve the system functionality of the system since the inefficiencies can be discovered at a young age [10]. BAS is also a cost-effective solution as it leads to enhanced consistency of operations, less manual interference, and informed data, which are achieved by uniting several subsystems of buildings into a centralized platform.

Mechanical systems, envelopes and operational improvements are typically the main components of energy retrofit strategies of existing buildings. Upgrades of envelopes and replacement of HVAC can be excellent energy-saving options, but they can be very expensive and also require much time to be executed. Conversely, operational enhancements during operation optimization and automation upgrades are the more cost-efficient and less disruptive way to go [11]. Their strategies target the improved performance of a system with no important structural changes and hence they can be used by an institution with a small budget. Rather than disposing all a building and building anew, a stepwise approach of retrofitting can allow the building owner to implement shoebox-based improvements to the building, optimizing a cost/performance balance and keeping the buildings running until all buildings have been retrofitted [12].

Net-zero energy buildings are planned to equalize the yearly energy use and the on-site renewable energy creation. This can be achieved with a combination of energy saving, total efficiency system and renewable technologies. It is of utmost importance to reduce the heating requirement to the crucial minimum during long winters especially in cold weather [13]. The net-zero plans typically suggest the improvements of the building envelopes, the optimization of the HVAC functionality, and the integration of renewable energy resources such as solar panels. However, conversion of buildings into net-zero is not easy as the initial investment is expensive and the technology that can lead to net-zero is also complicated [14]. Hence, incremental and scalable strategies are necessary to allow viable and economical avenues to net-zero performance of current infrastructure.

### B. Research Gap & Contribution of This Study

Although much research has been conducted on building energy efficiency, not much has been focused on elementary schools that are unique in their occupancy and operation features. It could also be identified that a lack of studies specifically dedicated to studying cold-climate conditions, where heating dominates as the energy usage policy, is also unmet. Existing literature will indicate a focus on costly or novel solutions without paying attention to cost-effective and scalable applications. It also is deficient in the development of staged retrofit models that can make it implemented in a gradual manner. Combination of operational strategies and appropriately laid standards and real-world constraints are poorly studied.

The study is practical since it exclusively focuses on the cold climate elementary schools and offers solutions to their functional challenges. It is dedicated to cost-effective Building Automation System measures that may be implemented without any substantial structural changes. The proposed study suggests a gradual retrofit model, according to which the gradual transition to the higher energy performance is possible. Staffing of the optimization of heating and control of ventilation is also highlighted, which is essential in cold weather. Additionally, the work aligns the proposed plans with the existing industry guidelines, making them more viable to use in reality.

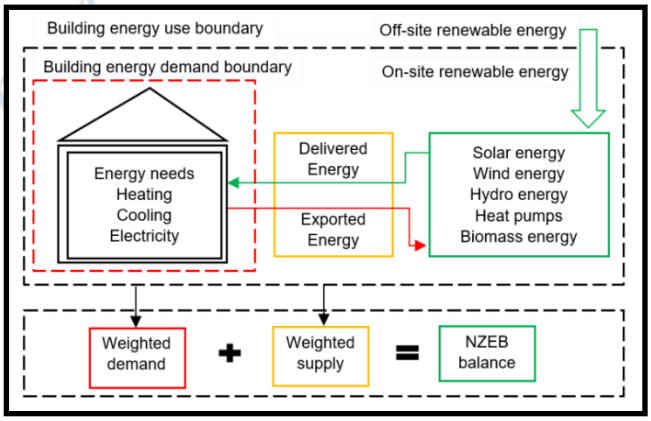



**Figure 1.** The NZEB (Source: Ahmed et al. 2022)

## III. SCHOOL INFRASTRUCTURE AND CLIMATE CONDITIONS

The climate of the United States is a country with cold climates and where winters are long and harsh with low ambient temperatures and huge heating degree days which contribute to heating-dominant profiles of the energy demand [15]. These locations have maintained five to seven months

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of heating and saved potentials of passive solar benefits. This makes the building energy consumption to be dominated by space heating and ventilation. These climate school buildings at elementary school level have steady occupancy patterns with maximum occupancy during the day and a minimum occupancy in the afternoons and during evenings and weekends [16]. However, the predominant percentage of the existing schools operate their HVAC systems during the day consequently, inefficient utilization of energy. Moreover, high ventilation needs to sustain the quality of the interior air contribute to higher heating loads, since outdoor air has to be brought to the level of indoor temperature. Such a set of climatic and operational features open up huge optimization opportunities with enhanced control measures, positioning these buildings as prime candidates to receive some energy-conservation retrofit interventions.

## IV. METHODOLOGY

This research design is considered qualitative and comparative to measure cost-effective retrofit techniques on enhancing energy performance of elementary schools [17]. The approaches that will be used are a literature review, analysis of the representative building conditions and analysis of the different retrofit scenarios. The systematic framework makes comparative analysis of the various levels of intervention to address the operation and system optimization enhancements. This design allows determining practical and scalable solutions that can be applied in practical situations in schools in cold climate areas. The research takes into account a representative elementary school structure (pre-2000) in cold climatic zones that are ASHRAE Climatic Zone 5-7 [18]. Characteristic of these buildings include old fashioned HVAC systems, little automation and average insulation. The archetype mimics generic design and functionality of infrastructures of government schools, which include fixed time-calendars, high-ventilation requirements, and space mix. The consistent nature of this standardized model allows the assessment of the retrofit strategies in different performance situations. Retrofitting is typically far more cost-effective than demolition and rebuild, and supports LEED performance goals.

### A. Baseline Conditions

The poor operational inefficiencies that have been achieved in the existing school buildings are referred to as the Baseline states. These include continuous HVAC growth with or without occupancy, constant ventilation rates and lack of control system automation [19]. The lack of good schedules and the use of old equipment imply that heating systems are not well efficient. As a result, this results into overutilization of energy particularly in cases where no one is present in the occupation. These are the pre-conditions according to which the effectiveness of the proposed retrofit interventions may be assessed.

### B. Retrofit Strategies

The three retrofit pathways are analysed to understand their complexity and levels of investment which are recommended as components of their retrofit [20]. Pathway A is also interested in operation improvement such as optimization of a schedule that is cost-effective. Pathway B presents intermediate solutions, such as replacement of legacy system. Pathway C implies a high degree of system integration, a centralized automation and diagnostics. It is a gradual process of introducing changes to the school, which allows them to be introduced in steps, but where there is an improvement in performance, which can be made over time toward a long-term target of energy efficiency.

### C. Evaluation Criteria

The performance of every retrofit pathway is determined on basis of a group of main evaluation criteria. These may be possible energy saving, cost-effective and impact on indoor environmental quality. Other ones include the fact that implementation is not an easy task, and in compliance with sustainability indicators. The criteria are aimed to make sure that suggested solutions are technically valid, practical and viable within the budget-constrained school settings, in order to make sound decisions in the way of retrofit planning.

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## V. BAS RETROFIT STRATEGIES AND IMPLIMENTATION

### A. Reasonable Solutions

It is a low-cost solution, and it engrosses the efficient utilization of the existing HVAC systems without significant investment in them. The first step in these strategies is to conduct a survey of the existing heating, ventilation and air conditioning system. During the survey, check the existing systems operation schedule, indoor air conditions by monitoring temperature and any defects in the sensors or unit itself. Once the survey is done, they then create the implementation plan that involves optimization of HVAC schedules, night setbacks and utilization of programmable thermostats. The HVAC schedule optimization encompasses the modification of the programming of heating, ventilation, and air conditioning systems to cycles to operate based on the occupancy. During the high occupancy period, it means that during school hours there is a high demand for heating or cooling. To meet this demand, the HVAC systems will operate at high capacity whereas it will operate at part load or minimum capacity during overnight, off-peak, and weekend periods. The installation of a programmable thermostat in the classrooms or occupied spaces facilitates temperature monitoring and to establish time-based temperature patterns. Which enables us to configure heating and cooling setpoints within the multiple spaces based upon the seasonal weather

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conditions and time periods without manual intervention. A night setback strategy can be implemented based on the occupancy and outdoor conditions. This is achieved by automatic zone temperature setpoint reset programming. HVAC systems automatically change the heating setpoints or cooling setpoints during unoccupied periods and use natural ventilation as required to maintain the zone setpoints. These strategies will reduce unnecessary heating and cooling of the buildings can lead to short-term energy savings. Generally, in this strategy, most of the systems are standalone and not integrated with the central system. Lacking in complexity and costs, they are an easy and cost-effective solution to meet schools that have a low budget and require a quick and effective jump in performance.

### B. Retrofitting into Automated Control

In-between solutions bring in better control measures that enhance the responsiveness and efficiency of the system. These include the retrofitting of the existing building automation system. It involves a detailed site survey before implementing these measures. During the survey, it is important to record the current conditions of the controllers, field devices like temperature sensors, pressure sensors, zone thermostats, actuators etc. Also, it is important to identify the opportunities for material reuse. In building automation projects, check whether the existing power supplies, panel enclosures and wiring can be used for the new systems. It will reduce the cost of materials and save the environment. In LEED certification, utilizing the existing material falls under the Material and Resources (MR) category. This category emphasizes on retaining onsite structure/finishes or incorporating salvaged products to divert waste and extend material life cycles. Under this category, a building can earn a maximum of 5 points towards the LEED certification. Upon completion of the survey, the control engineer designs the systems. It includes the replacement of the old legacy controllers with new energy-efficient controllers. The brain of the BMS system is the BMS software/ front end that can be replaced with the new software. It will allow for fast processing and communication between the systems within the building. It improves the HVAC, lighting and ventilation control due to faster processing and more accurate monitoring. The newer BMS and user interfaces are more intelligent. Some features are better performance tracking, enhanced data logging, making easier operation and maintenance. Newer BMS platforms are also more trustworthy, expandable and simpler to renovate with upgraded cybersecurity characteristics and standardized communication protocols, resulting in more efficient and dependable building operations. These newer systems minimize air conditioning and heating peaks and still guarantee the indoor air quality. They require moderate investment and upgrades of the system, but promise significant savings in energy and better comfort, with a balanced approach towards cost and performance.

### C. Retrofitting into Smart building Control

Retrofitting an existing school building involves upgrading the existing building system into a smart building system with intelligent devices. It is an integrated system through the centralized Building Automation System, smart sensors, and the use of artificial intelligent technology. Like retrofitting automated control, it involves a detailed site survey to count the existing system device and check the performance compatibility with the smart BMS system. During retrofitting, the key challenges include network infrastructure deficiencies, old wiring compatibility with the new systems, and cybersecurity. The process includes installation of the new DDC (direct digital control) controllers, IoT devices such as occupancy sensors, temperature sensors, energy meters, CO2 sensors, lighting control switches, and centralized building management systems (BMS). In this system, the data collected in real time enables quick response from the controllers to take necessary action to maintain the comfort conditions. Which avoids the unnecessary operation of the HVAC systems. It also helps with fault detection and diagnostics, predictive maintenance, and optimized energy use. These are fault detection and diagnostics, real-time monitoring and the incorporation of high efficiency HVAC systems and renewable energy technologies. This form of system enables proactive control and relent building performance optimization. They will be more expensive to install and the obligation to ensure their operation requires technical skills, although they will offer huge savings of energy in the long-term, which is needed as far as the net-zero energy goal in education buildings is concerned.

## VI. CASE STUDY ANALYSIS

Cold climate case studies, where retrofit measures in elementary schools have been practically used using BAS, demonstrate the effect of the retrofit. Some of the setback issues faced commonly are 24 hours of nonstop HVAC operation, poor scheduling, and over-ventilation, among others, which have led to high heating costs. The installation of retrofit measures that were phased resulted in high turnaround of the energy performance of schools. Optimal ventilation timing and control and increase of comfort levels in the cab were used to achieve a decrease in the heating energy use. Staged approach would lead to the implementation being progressive without disrupting the school operations. These case studies can demonstrate that the integrative approach of low level and middle level practices can serve as the foundation of higher level of system integration as a realistic approach in attaining better energy efficiency.

### A. Energy Performance

The retrofit pathways analysis reveals that the amount of energy saved through different retrofit interventions is different. The air conditioning reduced to a cost-effective

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level through low-cost interventions that eliminated the operational inefficiencies would lead to a saving of energy of approximately 10-20% (Opoku et al. 2019). By more effectively controlling and managing ventilation, intermediate measures increased savings as high as 20-35%. The most robust actions were the developed ones, and the potential savings of energy were between 35 and 60, which was driven by the internalisation of the systems and real-time optimisation. The results confirm that heating energy savings cannot be determined as the biggest source of total savings in cold climates, indicating that certain control measures play a pivotal role in the achievement of considerable performance variations.

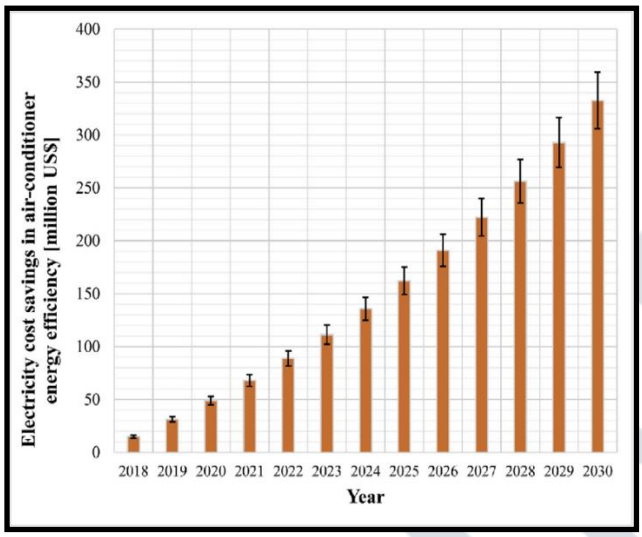



**Figure 2.** Electricity cost savings with air-conditioner energy efficiency (Source: Opoku et al. 2019)

### B. Key Findings

Results show that operational improvement in energy efficiency of structures, particularly in the existing school systems, is critical. The most influential variable that aided in reducing energy consumption in cold climates was found to be the optimisation of heating systems (Zero energy project, 2023). The study also illustrates that automation produces much consistency and reliability of system performance compared to manual control. Also, a staged retrofit strategy will enable schools to make improvements one step at a time to minimise spending and realise a noticeable benefit. All in all, the findings can reveal that cost-efficient ways of BAS can provide significant energy reductions without needing profound structural changes.

### C. IEQ Improvements

Enhancement of the quality of the indoor environment is one of the key results of BAS retrofit strategies. The ventilation systems will be better managed, a sufficient amount of fresh air will be supplied, and unnecessary loads of heating will be minimised. Zonal control and scheduling promote more efficient control of temperatures and increase thermal comfort to the occupants. Also, demand-controlled ventilation is useful in maintaining the optimum air quality by regulating the flow of air depending on occupancy rates [21]. These enhancements have led to easier and healthier learning, which is paramount in the well-being and performance of students. Overall, integration of BAs can allow achieving a compromise between energy efficiency and indoor quality.

## VII. CHALLENGES AND LIMITATIONS

All these are good, but there are numerous challenges that are associated with implementing BAS retrofit strategies. In the public school, advanced technologies are not possible due to budget reductions. This may come with complexities of integration with the existing legacy systems, and additional upgrades may be necessary [23]. The inefficiency of the system can be caused by low technical knowledge and training. Furthermore, performance evaluation could be restricted by the presence of the information and its surveillance, which could reduce the efficiency of the applied solutions.

Retrofit Building Automation systems help to achieve sustainability frameworks by improving energy performance and indoor environmental quality. Enhanced control of the system will help in earning energy efficiency credits, whereas optimised ventilation needs to help meet the indoor air quality requirements. The automation can also be used to easily monitor and report the performance of the building. Regular retrofit plans that come with set standards will offer uniformity, improve building certification opportunities, and offer sustainability in the education context in the long run.

Heating systems and demand-controlled ventilation should be optimised. The balanced price and performance will be achieved in stages by a gradual implementation process. Schools should institute scalable automation systems and take good care of the systems. Aligning retrofit strategies with laid standards is bound to increase efficiency, better the interior conditions and aid long term sustainability goals.

## VIII. CONCLUSION

In conclusion, the three retrofit strategies display a noticeable succession in cost, complexity, energy savings and performance improvement. The first strategy offers a low-cost and practical starting point by optimizing existing HVAC operations through scheduling, night setbacks, and programmable thermostats. It gives immediate energy savings with minimal investment. The next strategy, retrofitting into automated control, provides a realistic, balanced strategy of improving system responsiveness, efficiency, reliability, and affordability. It enables the partial reuse of existing materials supporting the LEED certification goal of environmental sustainability. Finally, the smart building retrofits strategy presents the greatest degree of performance through advanced smart device monitoring,

integrated control strategies and predictive fault and diagnostics capabilities. It often comes with a higher investment and technical expert level. Combined, these strategies encourage schools to adopt the solutions based on their spending budget and forward-looking objectives. This research paper proves that a cost-effective BAS retrofit is indeed an effective route to enhance energy efficiency in elementary schools. By focusing more on operational optimization and slow transition, schools will be able to achieve a massive energy reduction and at the same time make schools comfortable, which is valuable in terms of sustainability in the long and net-zero energy goals.

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