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Impact of Increased Ventilation Rates in Classrooms on Energy Usage and System Functionality in a US Midwest Climate

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ABSTRACT

The COVID-19 pandemic brought building ventilation into the focus of public health. Low ventilation rates increased the rate of respiratory infection. Ventilation in ASHRAE climate zone 5A directly impacts energy use due to the extremely cold winters and warm-humid summers. This paper assesses the spatial, energy, and HVAC needs of ventilation upgrades for five major school types in an Iowa school district. The schools were selected based on time and type of construction, location and orientation of classrooms, and type of HVAC system. Recent ASHRAE Standard 62.1 – 2016 for Ventilation for Acceptable Indoor Air Quality required a combined outdoor air rate of 6.7 L/s/p or 14.2 CFM/p based on the default occupant density in classrooms (age 9 plus). Based on review of post-COVID-19 literature, a revised 'Minimum Fresh Air Rate per Person' (MFApP) of at least 20 L/s/p or 42.4 CFM/p is recommended by ASHRAE 241 – 2023. To determine the necessary building operations changes for these increased MFApP rates, thermal models were developed in the energy simulation tool ClimateStudio for one classroom per school. Load calculations and assembly systems reflected construction documentation data. ClimateStudio uses a preset MFPApP rate of 4.72 L/s/p or 10 CFM/p based on ASHRAE 62.1 - 2022, which was compared to 6.7 L/s/p or 14.2 CFM/p and 20 L/s/p or 42.4 CFM/p with respect to annual and seasonal building energy consumption. Furthermore, the pressure drops across the ductwork were assessed in the current HVAC systems to understand if ducts and fan motors could handle these increased ventilation rates. The results reveal that as MFApP rates increase, site EUI increases by up to 30% for the highest CFM/p depending on the system. In most cases ductwork and fan motors would need to be replaced to continue efficiency and keep noise levels low. This paper thus assesses energy use and HVAC systems impact of improved ventilation rates to allow the school district to dedicate funds effectively and keep energy cost increases as low as possible while improving Indoor Environmental Quality (IEQ).

INTRODUCTION

For this project, Des Moines Public School District collaborated with the research team to develop best practices for retrofits. In response to the COVID-19 pandemic, awareness of the relationship between indoor air quality (IAQ) and respiratory infection rates has been increasing. IAQ in classrooms has a direct impact on the respiratory infection rates of the occupants of these classrooms, and this IAQ is directly impacted by the minimum fresh air per person rate. For classrooms and other public spaces, there are set amounts of minimum fresh air per person that must be provided by the HVAC system in

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the building. These minimum fresh air per person standards can be found in ASHRAE Standard 62.1 with the latest version issued in 2022 and are followed by engineers when designing the building's HVAC system. Yet the air change rate recommendations have not changed since 2016.

A post-COVID literature review on K-12 public schools and ventilation rates provided insight into the discussion to increase ventilation recommendations and potential issues regarding energy efficiency and indoor air quality. Recent research is placing more emphasis on the rates of viral transmissions during a pandemic, specifically COVID-19 (Pampati et al. 2022). This literature review organized its sources into the following numerous key areas: strategy applied, energy use, space type, infection rate, HVAC system alternatives, filter types used, computer tools used, monitoring, and the impact of natural ventilation on COVID-19 risk rates (Mesquita et al. 2022).

Ventilation and filtration strategies suggested by ASHRAE, REHVA, and recent literature are shown in Table 1. The Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) offers building-specific recommendations for airborne transmission control. Notably, the literature review indicates increasing fresh air supply to 20 L/s per person could reduce SARS-CoV-2 transmission.

Table 1. Ventilation and Filtration Requirements to Control SARS-CoV-2

Types	ASHRAE 62.1 – 2022 (equiv. to (62.1-2019)	ASHRAE 62.1 - 2016	ASHRAE 241 - 2023	REHVA
Air Rate	4.72 L/s/p – 10 CFM/p	6.7 L/s/p – 14.2 CFM/p	20 L/s/p – 42.4 CFM/p	3 L/s/p – 2.12 CFM/p

The review also provided practical insights from the National Renewable Energy Laboratory (NREL), that acclaims energy retrofitting in schools could obtain both energy savings and a healthier learning environment (Baltimore Banner and Quaranta. 2023). For students in Baltimore and Denver who bear a lack of proper air conditioning, it was found that they obtain lower test scores and higher rates of absenteeism, which makes an effectively working HVAC system imperative (Chalkbeat Colorado. 2022; EPA; Mendell et al. 2013). Reports and guides from EPA (Environmental Protection Agency) and CDC (Center for Disease Control) further underline the fact that it is time for a new generation of schools, built and retrofitted to protect against extreme heat, wildfire smoke, and airborne diseases through improved ventilation and filtration—including installing MERV-13 (Minimum Efficiency Reporting Value) filters (EPA. 2024; CDC. 2023). The reviewed literature highlights that effective ventilation and robust HVAC systems are important in sustaining academic performance and decreasing the potential for the spread of air-borne diseases as well as creating healthy learning environments. (Mendell et al. 2013).

The Des Moines Public School District in Iowa is considering ventilation upgrades which in turn would help combat respiratory infections in the classroom. Six Des Moines Public Schools were evaluated for ventilation system improvements and to determine an effective workflow that could be utilized in future renovation and new building work. This paper thus starts to answer the research question: what is the impact of an increased ventilation rate in a school setting on energy usage and operating cost?

METHODOLOGY

To examine the impact of increased ventilation rates on classrooms of differing attributes, six schools were chosen in Des Moines Iowa as they represent a wide range of types of HVAC systems and classroom layouts to produce a large, versatile sample of data. Information was then collected from one representative classroom in each selected school. These rooms were selected on a series of determining factors: year constructed, placement within the building (which adjusts for adiabatic surface availability), assembly used in construction, number of fenestrated facade walls and their direction, and range of HVAC utilization (see Tables 2 and 3). Thus, two classrooms were at the core of the buildings and 4 at the perimeter. To provide comparable, systematic data, poles with environmental sensor were positioned in different locations across each classroom and monitored conditions for two consecutive days in August and again in December 2022. The August dayes represented the hottest days of the year and students were not present in the classrooms, while the December days were among the coldest in the school year and students were present.

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Table 2. Classroom Specifications

School	Construction Year	Floor Level	Room Dimensions (L x W x H)	Floor Area
#1	1910	2nd Floor (With Third Floor)	28’-8” x 28’-2” x 10’-0” 8.74 m x 8.59 m x 3.05 m	813.65 ft^2 75.59 m^2
#2	1954	1st Floor (No Second Floor)	34’-3” x 25’-4” x13”-8” 10.44 m x 7.72 m x 4.17 m	880.93 ft^2 81.84 m^2
#3	1966	1st Floor (No Second Floor)	45’-9” x 19’-0” x 9’-0” 13.94 m x 5.79 m x 2.74 m	800.00 ft^2 74.32 m^2
#4	1972	1st Floor (No Second Floor)	34’-0” x 30’-0” x 9’-0” 10.36 m x 9.14 m x 3.05 m	1020.00 ft^2 94.76 m^2
#5	2003	2nd Floor (No Third Floor)	39’-4” x 34’-0” x 9’-0” 11.99 m x 10.36 m x 2.74 m	1338.00 ft^2 124.30 m^2
#6	2013	2nd Floor (No Third Floor)	30’-3” x 21’-0” x 10’-2” 9.22 m x 6.40 m x 3.10 m	653.90 ft^2 60.75 m^2

Table 3. Classroom Specifications Continued

School	Construction Type	HVAC Type	Main Orientation of Windows
#1	Gypsum Board on Metal Studs (Interior Walls Only)	VAV (hydronic) Heating and Cooling	NA (core)
#2	Gypsum Board on Plywood Framing with Stucco/Brick Exterior	Individual Heat Pump	South
#3	Gypsum Board on Steel Studs (Interior Walls Only)	Central Heat Pump	NA (core)
#4	Gypsum Board on Metal Studs with Brick Exterior	Central Heat Pump	South
#5	Gypsum Board on Metal Studs with Brick Exterior	VAV (hydronic) Heating and Cooling	North
#6	Gypsum Board on Metal Studs with Brick Exterior	VAV (hydronic) Heating and Cooling	North

Energy Use Analysis using Climate Studio (a Graphic User Interface for EnergyPlus)

The energy analysis was conducted using Climate Studio, which utilizes the EnergyPlus engine and inputs adhere to ASHRAE standards. ClimateStudio was chosen due to its ability to model the classrooms in a versatile 3D modeling program Rhinoceros and for its simulation speed. This also allowed us to compare the results of three different ventilation rates effectively. To ensure a proper energy model for each classroom, a systematic step-by-step process was carried out—beginning with model creation and progressing through careful assignments of space use definitions, operation schedules, material properties, and HVAC systems. The process started with the creation of the energy model for each classroom from the existing school documents and drawings. The "Space Use" setting was then based on ASHRAE 90.1-2019 for a Medium Office (the closest option to a classroom that was available on the list for Climate Zone 5), which provides a standard comparison baseline. Following that, operation schedules were customized to each classroom's individual usage patterns, including the times when the HVAC systems were activated and shut off. To heighten the fidelity of the thermal performance simulations, the material layers of the building envelope were carefully inputted into the model. Finally, each classroom's

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HVAC system was instantiated according to its respective system type designation to ensure the simulation was an accurate reflection of real-world conditions. Throughout the study, the heating setpoint was maintained in the model inputs at 19.09°C (66.36°F) and cooling setpoint at 24.98°C (76.96°F), which aligned with normal operation conventions in the Midwest and verified with the onsite measurements.

To explore the effect of varying rates of fresh air ventilation, three minimum rates of fresh air per person are compared: the 4.72 L/s/person (10 cfm/person) is the Climate Studio default rate per person and most closely aligns with the widely quoted 5 L/s/person (10 cfm/person) for a range of occupancy and building types based on ASHRAE 62.1-2016 (ASHRAE, 2016) and its earlier releases; the ASHRAE 62.1-2016 combined recommended rate of 6.7 L/s/person (14.2 cfm/person), incorporating both People Outdoor Air Rate and Area Outdoor Air Rate, based on the standard's default floor area per person for classrooms 9 years and older; and an elevated rate of 20 L/s/person (42.4 cfm/person) based on a recommendation from ASHRAE 241-2023 (ASHRAE, 2023) for high indoor air quality. The adjustment from the 5 L/s/person rate to 6.7 L/s/person is the adjustment from a ventilation rate that is based on the per-person fresh air requirement alone (People Outdoor Air Rate) to a rate that incorporates occupant density into the calculation (Combined Outdoor Air Rate). A review of later ASHRAE standards, for example, ASHRAE 62.1-2022 (ASHRAE, 2022), reveals that while the numerical values of outdoor air requirements remain the same, the newer standard no longer explicitly tabulates the Combined Outdoor Air Rate. However, calculated using the same process, the derived ventilation requirement is still 6.7 L/s/person.

By inputting three different ventilation rates into Climate Studio's six energy models for the six classrooms, we extracted valuable data, including Energy Use Intensity (EUI), energy consumption by specific equipment such as fans, operational carbon emissions, and estimated energy costs. The estimates of energy costs were made based on reference prices from Climate Studio, which were derived from the NYSERDA annual dataset and other local sources in New York State.

Mechanical Systems Analysis

To determine if the current mechanical equipment could still be used with increased minimum fresh air per person rates as per ASHRAE 241-2023, a mechanical systems analysis was performed to determine new flow rates and pressure drops with the new settings. New air flow volumes and pressure drops were then calculated. First, the required air volume for each classroom had to be recalculated to meet both increased minimum fresh air per person rates. This was done by dividing the current volume by the current rate and then multiplying the result by the increased rate. An example calculation of this process can be seen below in Figure 2. Next, the updated flow rates were used to calculate the pressure drop and velocity of air in each section of the ductwork. These values were then compared to the current values to determine if upgrades would need to be made to parts of the existing HVAC system (Figure 1 shows one example for school #3).

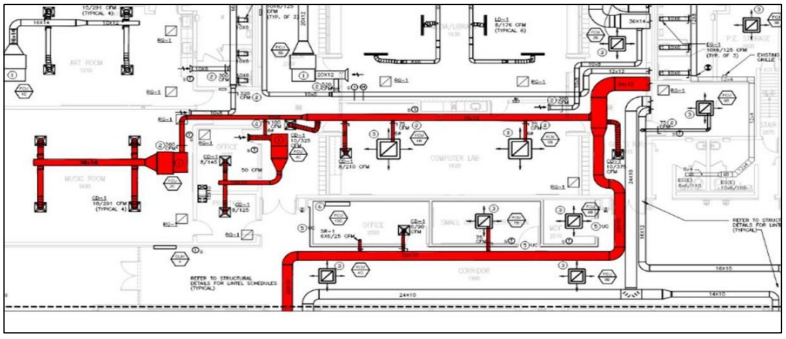

Figure 1 A Map of the Duct Run Used for Analysis at School #3, a Central Heat Pump System with Fan Coil

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$$\frac{\text{Current Volume}}{\text{Current Flow Rate per Person}} \times \text{New Flow Rate per Person} = \text{Increased Volume}$$

$$\frac{3655\ \text{CFM}}{10\ \text{CFM/person}} \times 42.4\ \frac{\text{CFM}}{\text{person}} = 15{,}500\ \text{CFM}$$

Figure 2 Formulas Used for Calculating Increased Volume and an Example Calculation for the Increased Volume

RESULTS

Table 4. Results on the Volume and Pressure Drop at Increased Ventilation Rates

	School #2	School #3	School #4	School #5
Current Volume	3655 CFM / 1724 L per second	3995 CFM / 1885 L per second	4810 CFM / 2270 L per second	5520 CFM / 2605 L per second
Increased Volume	15500 CFM / 8210 L per second	16940 CFM / 7995 L per second	20395 CFM / 9625 L per second	23405 CFM / 11050 L per second
% Difference	324.08%	324.03%	324.01%	324.00%
Current Velocity	654 FPM / 3.32 m/s	1410 FPM / 7.16 m/s	1353 FPM / 6.87 m/s	630 FPM / 3.2 m/s
Increased Velocity	2200 FPM / 11.2 m/s	4569 FPM / 23.21 m/s	4384 FPM / 22.3 m/s	2041 FPM / 10.4 m/s
% Difference	324.08%	324.03%	324.01%	324.00%
Current Pressure Drop	0.17 in/Hg / 4.32 mmHg	0.09 in/Hg / 2.36 mm/Hg	0.4 in/Hg /10.21 mm/Hg	0.41 in/Hg / 10.5 mm/Hg
Increased Pressure Drop	1.44 in/Hg/36.58 mm/Hg	0.79 in/Hg/30.73 mm/Hg	3.41 in/Hg / 86.61 mm/Hg	3.50 in/Hg / 88.9 mm/Hg
% Difference	648.16%	648.06%	648.02%	648.00%

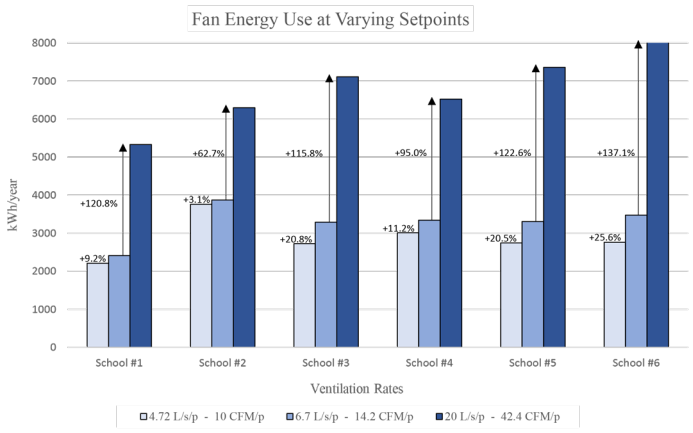

Figure 3 ClimateStudio Results of kWh Used per Square Meter per Year at Varying Ventilation Rates

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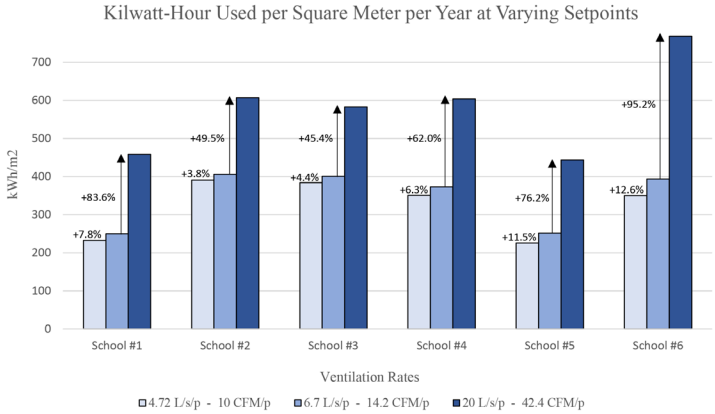

Figure 4 ClimateStudio Results of kWh Used per Square Meter per Year at Varying Ventilation Rates

This analysis reveals that there is a consistent increase in both the volume of air needed, and pressure drop across the ductwork at all schools that were studied. These increases are similar across each school, with the volume increasing around 324 percent and the pressure drop increasing around 648 percent. The higher values, especially the pressure drop, are significant and could affect the performance, efficiency, and even the functionality of the equipment in the system.

In addition to the amount of air passing through these systems, various changes in operation by the systems were also assessed through ClimateStudio simulations. Both numerical results and plotted data can be seen below in Figures 3, 4, and 5 as well as Tables 5, 6, and 7.

The data presented above in Figures 3 and 4 demonstrates a direct relationship between the increase in ventilation rates and an increase in fan and system energy usage, as they both increase across all the schools that were observed. However, this increase is not at a consistent rate across all the schools, indicating that certain types of HVAC systems and classrooms may handle an increase in ventilation rate more efficiently than others. This trend can also be observed in the numerical values displayed in Tables 5 and 6, which correspond to Figures 3 and 4.

Table 5. Change in Fan Energy Usage at Varying Ventilation Rates (kWh/m^2)

School Number	School #1	School #2	School #3	School #4	School #5	School #6
ASHRAE 62.1-2022	2211	3757	2728	3011	2746	2762
ASHRAE 62.1-2016	2415	3872	3295	3347	3308	3469
Change (%)	8.82	3.01	18.83	10.57	18.57	22.69
ASHRAE 241 - 2023	5332	6300	7110	6526	7364	8229
Change (%)	141.16	67.69	160.63	116.74	168.17	197.94

Table 6. Change in Total Energy Usage at Varying Ventilation Rates (kWh/m^2)

School Number	School #1	School #2	School #3	School #4	School #5	School #6
ASHRAE 62.1-2022	232	391	384	351	226	350
ASHRAE 62.1-2016	250	406	401	373	252	394
Change (%)	7.8	3.8	4.4	6.3	11.5	12.6
ASHRAE 241 - 2023	459	607	583	604	444	769
Change (%)	97.8	55.2	51.8	72.1	96.5	119.7

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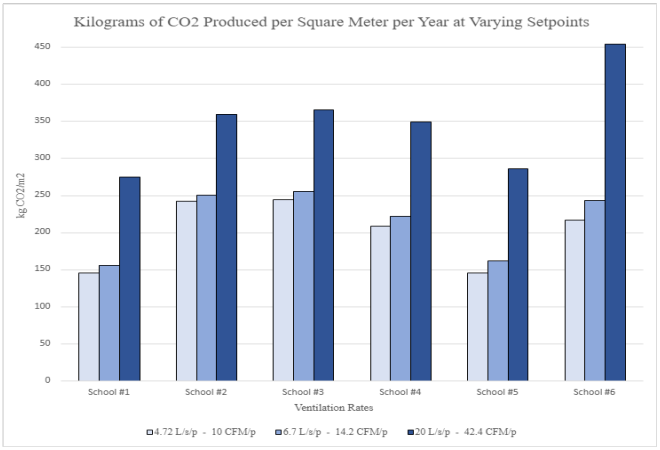

Figure 5 ClimateStudio Data of CO2 per Square Meter at Varying Ventilation Rates

Table 7. Change in CO2 Produced per Square Meter at Varying Ventilation Rates (kg CO2/m^2)

School Number	School #1	School #2	School #3	School #4	School #5	School #6
ASHRAE 62.1-2022	146	242	245	209	146	217
ASHRAE 62.1-2016	156	251	256	222	162	243
Change (%)	6.9	3.7	4.5	6.2	10.9	11.9
ASHRAE 241 - 2023	275	360	366	349	286	454
Change (%)	76.3	43.4	42.9	57.2	76.5	86.8

The average Operational Carbon increase when comparing the current ASHRAE Standard 62.1-2016 of 10 CFM/person (4.2 L/s/person) to the ASHRAE Standard 62.1-2016 of 14.2 CFM/person (6.7 L/s/person), is around 7.4%, with the average Operational Carbon comparison from the ASHRAE Standard 62.1-2016 to the ASHRAE Standard 241-2023 being much higher at around 63.9% (Table 3). These values show that the emissions associated with the operation of the building would consistently increase across considered ventilation rates but will increase at a proportionally lower rate at the ASHRAE Standard 62.1-2016 when compared to the ASHRAE Standard 241-2023.

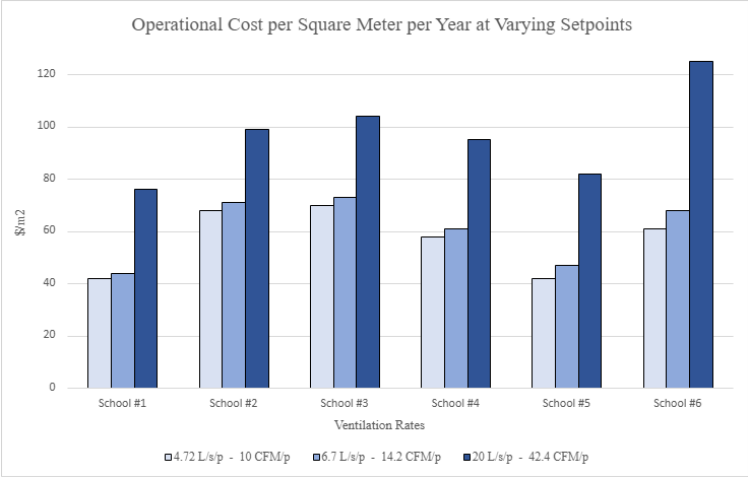

Figure 6 ClimateStudio Data for Operating Cost per Square Meter at Varying Ventilation Rates

As shown in Table 8 below, when comparing the ASHRAE Standard 62.1-2022 (4.2 L/s/p or 10 CFM/person) to the ASHRAE Standard 62.1-2016 (6.7 L/s/p or 14.2 CFM/person), the operational cost does increase across all of the schools, but it is important to recognize that operational cost increase is lower than flow rate increase.

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Table 8. Change in Operational Cost at Varying Ventilation Rates ($/m^2)

School Number	School #1	School #2	School #3	School #4	School #5	School #6
ASHRAE 62.1-2022	42	68	70	58	42	61
ASHRAE 62.1-2016	44	71	73	61	47	68
Change (%)	4.8	4.4	4.3	5.2	11.9	11.5
ASHRAE 241 - 2023	76	99	104	95	82	125
Change (%)	72.7	39.4	42.5	55.7	74.5	83.8

DISCUSSION AND CONCLUSION

Simulation results showed that with an increase in minimum fresh air per person, there were upward trends in the energy usage, carbon emissions, and energy cost of the school's HVAC systems, which was expected. Yet, while fan energy increases for ASHRAE Standard 62.1-2016 compared to 14.2 CFM/person or 6.7 L/s per person for all school class rooms averaged 7.4 percent, results for ASHRAE Standard 241-2023 of 42.4 CFM/person or 20 L/s per person resulted in a much higher average increase of around 69.2 percent for energy use. Furthermore, percentage increases in EUI, carbon emissions, and operational cost are worth noting, as they all are significantly lower than the percentage that the minimum fresh air per person was increased, indicating a non-linear relationship with the HVAC system's performance. This non-linear relationship shows that assumptions about system performance at an increased minimum fresh air per person rate would need to be assessed on a case-by-case basis and are system dependent.

The impact of the varying ventilation rates drastically changes with the type of system. From the above data, trends can be seen between the types of HVAC systems in the schools and their efficiency when outputting a higher ventilation rate than they were originally designed for. Across Figures 3-6 and Tables 5-8, School #1 has a consistently lower percentage of change across all metrics studied when compared to the other schools. This difference from all the other schools can be attributed to the type of HVAC system at School #2, which has individual heat pumps in each classroom. These individual heat pumps are separate from the main system that would see an increase in ventilation rate and would not see as much of an increase in load. This is also apparent with Schools #5 and #6, a hydronic VAV heating and cooling system, as all the values increase significantly more than any of the other schools.

A limitation to note is that estimates of energy costs are based on reference prices in New York State, computed in ClimateStudio from the NYSERDA annual energy prices dataset and other regional data sources. Since energy prices vary widely by state and region, this may not reflect the actual cost effect for Des Moines schools or any other city. Yet it shows the trend. The application of normalized cost data brings some variability into assessing the monetary impact of varying ventilation rates. Further efforts will involve adding regional energy price data to facilitate more local and accurate cost analysis. Still, this model could be used as a framework to be applied to other schools considering an increase in minimum fresh air per person to obtain an estimation of the effects on other existing systems.

To mitigate the effects of an increased ventilation rate in a cost-effective manner, several practices could be deployed to benefit the system efficiency that would be running with higher ventilation rates than it was designed for. The first of these practices to potentially increase the efficiency of a system is a fan upgrade. To allow the system to continue functioning optimally and efficiently, it would likely be beneficial to replace the fan motor in the air handling units to handle a higher pressure drop and be able to push more air through the system. An overworked fan could increase energy usage, possibly leading to inefficiencies in the system, and even cause the fan to stop working all together. Another solution to reducing the effects of an increased ventilation rate throughout the system could be widening sections of the ductwork. This could also solve other problems in the system besides the pressure drop, such as reducing the load on the fan and other equipment as well as preventing increased noise by lowering the velocity at which the air is moving. This would be especially effective in Schools #3, #4, and #5, for which large pressure drops can be seen in Table 4. Additionally, it is important to mention that for Schools #1 and #6, which have VAV heating, it could be necessary to replace some of the VAV boxes to be able to heat the increased amount of air moving through the system.

Lastly, it is important to note that a greatly increased ventilation rate could increase the noise criterion of the diffusers and duct work, which would negatively affect the occupants of those spaces. To conclude, this study shows the potential impact of improving fresh air ventilation rates on energy use, CO2 emissions and cost for selected school classrooms. Results can help decisions for HVAC system upgrade to be considered by school districts such as Des Moines Iowa.

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