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Effects of School Facilities' Mechanical and Plumbing Characteristics and Conditions on Student Attendance, Academic Performance and Health

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***Abstract*—**School districts throughout the United States are constantly seeking measures to improve test scores, reduce school absenteeism and improve indoor environmental quality. It is imperative to identify key building investments which will provide the largest benefits to schools in terms of improving the aforementioned factors. This study uses Analysis of Variance (ANOVA) tests to statistically evaluate the impact of a school building's mechanical and plumbing characteristics on a child's educational performance. The educational performance is measured via three indicators, i.e. test scores, suspensions, and absenteeism. The study investigated 125 New York City school facilities to determine the potential correlations between 50 mechanical and plumbing variables and the performance indicators. Key findings from the tests revealed that elementary schools with pneumatic systems in "good" condition have 48.8% lower percentages of students scoring at the minimum English Language Arts (ELA) competency level compared with those with no pneumatic system. Additionally, elementary schools with "unit heaters/cabinet heaters" in "good to fair" conditions have 1.1% higher attendance rates compared to schools with no "unit heaters/cabinet heaters" or those in inferior condition. Furthermore, elementary schools with air conditioning have 0.6% higher attendance rates compared to schools with no air conditioning, and those with interior floor drains in "good" condition have 1.8% higher attendance rates compared to schools with interior drains in inferior condition.

***Keywords*—**Academic attendance and performance, mechanical and plumbing systems, schools, student health.

I. Introduction

SCHOOLS providing high-quality education and well-rounded opportunities to children are imperative in society. Over the last few decades, a large body of research exploring the association between physical environments and user health and wellbeing has emerged from several disciplines including design, occupational health and public policy. The active contribution of physical environments in shaping behaviors and cultural practices has been recognized in research: '…the quality […], the presence and condition of its features, the decay that it suffers, and the level at which it is maintained' [1]; together these factors influence the quality of activities taking place within the facility. There is also a growing interest and awareness regarding the influence of building facilities on teaching and learning outcomes.

Literature has suggested that there exists a multifactorial relationship between the physical environments of schools and student outcomes [2]. Schools as argued by [1] are one of the most important settings, only after home, in a child's development while [2] describes schools as one of child's 'microsystem'.

School buildings are a critical building type for children and many adults. On a typical workday, approximately 20% Americans spend their day in a school building [3]. Many of these schools are housed in aging buildings. Based on data from the US Department of Education, the average school building in the U.S. was 44 years old based on a 2012-13 survey, which was the last time the data were collected [4]. While age alone is not indicative of a problem, the condition of the building and building systems can be statistically correlated to standardized test scores [5]. Additionally, [6] offers a strong endorsement for the expansion and upgrades to public school infrastructure, arguing that the situation has been described as a "crisis". Furthermore, according to [7] school facilities would earn a low grade of D+ (up from a D in 2013 [8], and D- in 2001 [9]), and the cost to bring school facilities up to good condition is estimated at $380 billion [7].

Reference [10] found that in public schools with permanent buildings, the building systems/features were rated as being in *fair or poor* conditions in 14% to 32% schools. The fair or poor rating was earned by plumbing/lavatories in 31% schools, and for the heating, air-conditioning and ventilation/ filtration systems in 30% schools. Environmental factors were rated as unsatisfactory or very unsatisfactory in 5 to 17% of the schools. Additionally, based on survey results, 53% of public schools need to invest in repairs, renovations and modernization, requiring billions of dollars. Furthermore, [11] notes that in 2013-14, approximately 8% of the total US public school expenditure was direct capital outlays and 9% on the Operation and Maintenance (O&M) of existing facilities and equipment. Reference [12] argues that inconclusive evidence notwithstanding; policy makers resort to resource-based capital expenditure programs 'as tools to improve schools and reduce achievement gaps'. A research study by [1] found that

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school attendance mediates the relationship between school building condition and academic achievement. Their model revealed that the physical state of the buildings predicted both attendance and academic achievement, after controlling for socioeconomic status (SES), ethnicity, school size and teacher quality. They argue that student performance may be influenced in multiple ways: components in disrepair such as poorly maintained toilets and inadequate temperature control may directly impede learning; and poorly maintained systems may adversely affect environmental conditions within the buildings with higher concentrations of CO_2 and mold and other allergens.

A mediation model proposed by [2], in the research study of middle schools, hypothesized that student attendance and student perception of school's social climate mediates the relation between school building condition and academic achievement. Similar to the study by [1] set in an elementary school, the researchers in [2] also argue that attendance is an enabling condition for receiving the benefits of instruction. Additionally, [12] finds robust evidence of large, significant gains in cognitive and non-cognitive student outcomes among those attending newly constructed schools in Los Angeles Unified School Districts (LAUSD). Reference [12] estimates a 0.1 standard deviation (SD) increase in math scores and a 0.05 SD increase in ELA scores when student spends four years in a new school facility. These students also attend school for four additional days per academic year and score 0.06 SD higher on teacher-reported measure of student effort. They conclude that many of these effects are due to the better quality of school facilities.

The current research explores the relationship between the state of Mechanical and Plumbing building systems within school buildings and student academic performance. An evaluation of the electrical systems was not a part of this study.

Industry estimates suggest that Mechanical, Electrical, and Plumbing (MEP) systems account for nearly 60% of the total annual energy consumption in the US schools [13]. Mechanical heating, ventilation, and air conditioning (HVAC) systems manage and influence the indoor air quality, temperature and humidity, and ventilation. Poor Indoor Air Quality (IAQ) has been linked to sick building syndrome (SBS), which includes symptoms such as eye nose and throat irritation, upper respiratory infections, headaches and nausea among others. Studies have established association between poor IAQ and student attendance [14], [15]. Ventilation systems allow for the removal and dilution of breathing air contaminants such as CO_2 and CO that build up within enclosed spaces over time. Reference [3] refers multiple research studies to argue for good ventilation in schools because '…children breathe a greater volume of air in proportion to their body weight…schools have much less floor space per person than found in most office buildings'.

Similar to HVAC systems, plumbing systems also require continued maintenance. Public schools are often one of the largest water users in communities, and participation in water conservation programs is reported as limited due to economic challenges. It is argued by [16] that toilets are a 'central part' of many school experiences for children, as locations for 'risk, anxiety and suspicion'. Based on their research, they report that the small body of school toilet literature for elementary and middle schools settings 'almost unanimously concludes that schools toilets are inadequate' and among the cited reasons are lack of cleanliness and resources, insufficient durability and pupils' lack of ownership over the space, among others.

Additionally, exposure to lead from drinking water among children has been flagged as a serious concern as intellectual deficits have been reported in studies [17], and it is known that children and infants absorb more lead than adults. The Environmental Protection Agency (EPA) estimates that the Safe Drinking Water Act (SDWA) covers a dismal 8,000 schools and childcare facilities nationwide, while approximately 98,000 public schools are not regulated [25].

In conclusion, this research recognizes the importance of evaluating the association between mechanical and plumbing systems in schools and student academic performance. The research argues that continued research on the current state of these systems may potentially inform state and local policy decisions for future capital investment prioritization. Upfront costs for facility improvements may potentially bring back multiple benefits, including better academic performance, teacher and student retention and higher satisfaction levels among users. Therefore, a long-term perspective is recommended for such assessments. Reference [6] quotes previous research that suggests that the American public educational system is 'failing to meet the needs of all students, especially those in urban centers'; it is time we initiate a positive change.

The following sections identify the research methodology and research findings.

II. Methodology

New York State (NYS) is home to the largest school district in the United States, New York City (NYC). According to the U.S. Department of Education, there were 1,023,674 students enrolled in schools in NYC [26].

This study focused on elementary schools within four Boroughs in NYC: Manhattan, Bronx, Queens, Brooklyn (Kings County). Elementary schools were chosen under the premise that students are more likely to spend majority of their time in one to two classrooms throughout the day. This attribute may potentially reduce possible influence from multiple physical environments and provide a greater possibility to draw conclusions that link their environment to health and performance metrics. This study focuses on elementary schools within four Boroughs in NYC: Manhattan, Bronx, Queens, Brooklyn (Kings County).

The selection criteria included data access and availability from governing agencies and recognition of the urgency for educational facilities due to population trends. Confounding factors such as race and wealth were normalized by selecting schools with similar student race and wealth demographics. Only schools with a combined Black and Hispanic student

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population greater than 40% were included in the study. Additionally, only schools with similar percentages of students who receive free or reduced lunch were included in the study. The percentage of students receiving free lunch was utilized as an economic indicator of the neighborhood families. The research used the NYS Office of Temporary and Disability Assistance eligibility requirements to define free lunch [18].

The selection process led to a dataset of 125 schools with similar racial and economic demographics.

A. Data: Region, District and City Demographics

Published data available online on both the New York State and New York City public schools report cards provided rates on the following: high school graduation, college plans, absenteeism, suspension, teacher turnover, teacher experience, teacher certification, asthma, overweight and obesity proportions.

Data on school and neighborhood characteristics of the study region were obtained from the NYC Department of Education's Building Condition Assessment Survey [19], [20], the NYC Department of Parks and Recreation [5], and the City of Yonkers Parks and Facilities [5]. In addition, data on school administration procedures such as building systems conditions, operation and maintenance were also obtained from interviews with stakeholders, i.e. principals, teachers, custodians, and facility managers. Additional departmental procedures were further supported by empirical knowledge, literature review, and interviews with subject matter experts.

B. Data: Grades

Fourth grad tests scores were utilized to assess student performance. These provided the widest availability of testing options for English language (ELA), Math, and Science competency. Fourth grade is also a time in the school curriculum when room changes between classes are limited compared with middle and high school grades.

School test scores were identified as the number and the percent of students whose score meets the requirements at one of four levels. Level 3 is considered the minimum requirement for proficiency. Therefore, built environmental characteristics were evaluated based on their relationship to the percentage of students whose scores were at levels 3 or 4. Schools with grade populations not subjected to state standardized tests were removed.

C. Data: Occupant

Absenteeism and suspension were based on the 2006-07 and 2008-09 annual student attendance rate and students suspended per school based on NYS published data.

Asthma was identified based on 2005 and 2008 asthma hospitalization rates for children age 0-14. Rates were aggregated to one of NYC's 42 neighborhoods. A school's neighborhood name was identified utilizing the NYC Department of Health and Mental Hygiene webpage and based on the schools' zip code.

Overweight and obese percentages were identified based on the results of the 2007 NYC Community Health Survey [21]. The results were aggregates to one of NYC's 34 neighborhoods identified by the NYC Department of Health and Mental Hygiene's EpiQuery website.

D. Data: Building and Neighborhood

School facility characteristics were identified using images gotten remotely from Google Earth and Bing; building photographs from the NYC Department of Education's Building School Facility Reports; and the NYC Department of Education's Building Condition Assessment Survey (BCAS) from 2007-2008 [19] and 2010-2011 [20] school year.

Physical characteristics of the neighborhood were also based on remote images from Google Earth and Bing; and the NYC Department of Parks & Recreation and the City of Yonkers Parks & Facilities websites that provided park locations and sizes.

E. Data: Coding Methodology and Statistical Analysis

175 physical variables were identified based on literature reviews, interviews with educational professionals, and available data from governing agencies as potentially impacting student health and performance. 50 of these variables were for mechanical and plumbing system features.

Analysis was conducted using Microsoft Excel, Access, Minitab and SPSS. Descriptive statistics was used for primary assessments. Statistical tests included ANOVA Regression and Chi Square Tests. Significance was determined at 95% Confidence Interval (CI).

To further provide a uniform analysis of the buildings, ratings were used to distinguish between the conditions of mechanical and plumbing systems. These ratings are listed in Table I.

TABLE I
RATINGS OF MECHANICAL AND PLUMBING SYSTEMS FOUND IN THE SCHOOLS EVALUATED

Condition of Systems	Rating (scale 0-5)
Poor	5
Fair to Poor	4
Fair	3
Good to Fair	2
Good	1
No systems	0

III. FINDINGS

The following section describes the results from the investigation of 50 mechanical and plumbing system features, and their respective association with academic performance and health outcomes.

A. Heating and Cooling Systems Analysis

Pneumatic climate control systems are the most common type of climate control system found in the dataset. It is not surprising that most schools did not rely on electricity to control their HVAC systems, since the average age of the studied schools in this research study was more than 75 years and many schools had not undergone intense upgrades. Less than 6% of schools were controlled by Direct Digital Control

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(DDC) systems that allow computerized automatic control of internal climate.

Data for HVAC systems were used to investigate if schools with heating control devices in poor condition had depressed test scores and attendance rates. Detailed thermal comfort metrics were not measured.

1. Heating Systems: Types and Conditions

Six different climate control systems were found in use (Table II).

TABLE II
EVALUATED CLIMATE CONTROL SYSTEMS AT NYC SCHOOLS

Climate Control Systems	Quantity (out of 125 schools)
Direct Digital Control (DDC)	7
Pneumatic System	88
DDC & Pneumatic combined system	19
Electric system	3
Electric & Pneumatic combined system	5
Hybrid & Pneumatic combined system	2
Unknown	1

Findings (Table II) revealed that 70% of the schools investigated had a pneumatic-only climate control system, 85.6% had a combination system of DDC and pneumatic systems, and 91% had some form of pneumatic climate controls.

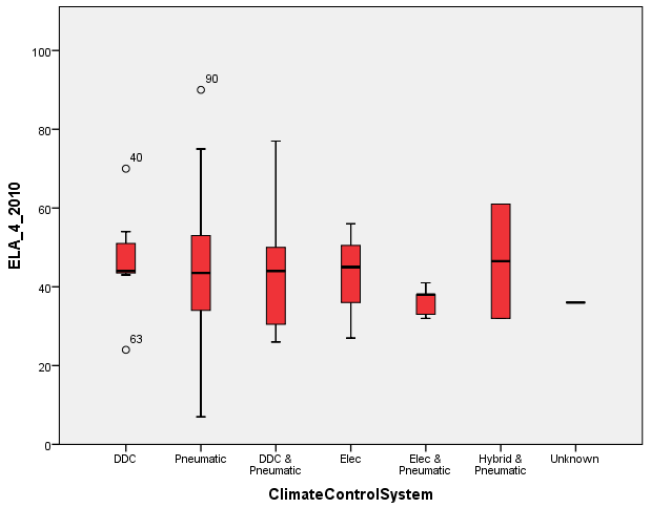


Fig. 1 Correlation between climate control systems and ELA scores

Results of the ANOVA test related to only the condition or presence of a pneumatic climate control system revealed that elementary schools with pneumatic systems in "good" condition have 48.8% lower percentages of students scoring at the minimum ELA competency level compared with those with no pneumatic system (rated as 0). Additionally, schools with pneumatic systems in "good" condition have 75.6% lower percentages of students scoring at the minimum ELA competency level compared with those in "fair to poor" condition ($p = .014$). The type of climate control system was not statistically correlated with academic performance and health outcomes. Fig. 1 illustrates the box plots of the climate control system and ELA competency test percentages analysis.

An additional ANOVA analysis of the types of climate control systems in the schools was conducted to compare the system type against academic performance and health outcomes. The results identified no statistically significant correlation to ELA competency percentages and no noticeable trend from any climate control system. The small sample sizes of systems other than pneumatic made it impossible to identify whether the type of climate control system has an impact on the student's performance or health.

2. Heating Distribution Systems: Types and Conditions

Potential correlations between heating systems and academic performance and health outcomes were investigated utilizing ANOVA tests. The schools within the dataset reported a myriad of heating distribution systems as shown in Table III.

TABLE III
EVALUATED HEATING DISTRIBUTION SYSTEMS AT NYC SCHOOLS

Heating Systems	Quantity (% out of 125 schools)
Baseboard/Fine tube heat distribution system	73.6%
Unit heaters/Cabinet heaters	73.6%
Radiators	96%
Steam Heaters	96%
Heating and Ventilating units	40%
Unit ventilator	41.6%
Coal fired boiler	0.008%



Fig. 2 Classroom with perimeter radiators at Elementary school in Bronx, NY 2012 [5]

ANOVA tests revealed that schools with "unit heaters/ cabinet heaters" in "good to fair" condition have 1.1% higher attendance rates ($p = 0.031$) compared to schools that do not have unit-or cabinet heaters (Fig. 2) or the system is in inferior condition. Additionally, while not statistically significant, schools with heating and ventilator units in "fair", "fair to poor" and "poor" condition tended to have slightly lower attendance rates. There were no significant correlations for all other heating types. Most system types did not yield significant correlation results because they included either a small sample size (represented by a small number of schools) or there was not enough variation in their conditions. It is important to note that at the time of this research, some facilities were still utilizing coal fired boilers as part of their

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HVAC system.

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3. Cooling Systems: Types and Conditions

According to the 2010-11 BCAS reports [20], about 50% of schools were identified as having Air Conditioning (AC).

ANOVA tests identified a statistically significant correlation, revealing a 0.6% higher attendance rate for schools with AC ($p = 0.037$). However, the tests did not reveal a significant correlation between AC and academic performance. Fig. 3 represents a boxplot of the results comparing attendance rates in schools based on the presence of AC.

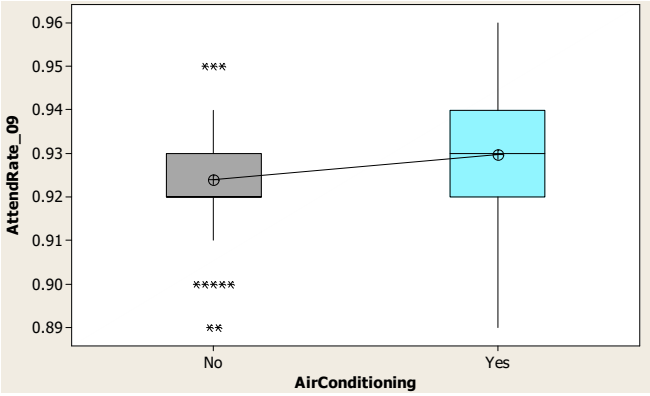


Fig. 3 Boxplot of Attendance Rates (2009) influenced by AC

B. Plumbing Systems

Many schools within the database suffered from varying levels of water infiltration issues. The section below identifies the conditions and correlations between plumbing and water related engineering systems.

1. Cold Water Supply

Over 70% of schools within the dataset did not have a Double Check Valve (DCV) as their method of backflow prevention. In the schools with DCVs, 36% were in "good" condition, 61% were in "good to fair condition," and one school is rated as "fair" condition.

ANOVA tests and regression analysis identified a statistically significant correlation: schools with water main DCV in "good" condition have 1.3% higher attendance rates compared to schools with no water main DCVs or when the DCV is in inferior condition ($p = 0.018$). A test of homogeneity of variances identified adequate variance in the attendance vs. DCV data to conduct an analysis of means test.

Results of academic performance metrics identified no statistically significant correlation between the presence of, or condition of DCVs and student test scores. However, schools with a DCV in "good" condition tended to score higher and have lower suspension rates than those without. The correlation between the water main service piping, reduced pressure zone (RPZ) devices, and academic performance and health outcomes was also investigated, and results revealed no statistically significant correlations.

It is important to note that the condition or presence of various systems provides insight into the available amenities in a school building. 73.6% of the studied schools did not have a DCV and 68% of did not have RPZ devices.

2. Hot Water

The research investigated potential correlations between student academic performance and health outcomes, and the devices that provide hot water in their schools. 76% of schools have either a gas fired water heater, or one of the other multiple types, and almost 17% of schools identify their hot water heater type as "unknown". Of the schools with a gas fired domestic water heater, 94.7% had a heater that was in "good" to "fair" condition. Table IV provides a summary of the types of domestic hot water heaters found within the dataset.

TABLE IV
DOMESTIC WATER HEATERS AT NYC SCHOOLS EVALUATED

Domestic Water Heaters	Quantity (out of 125 schools)
Electric	8
Gas Fired	79
Electric & Gas Fired	14
Electric & Oil Fired	1
Electric, Gas, & Oil Fired	1
Gas & Oil Fired	1
Unknown	21

Results of ANOVA tests identified a small correlation between the type of water heater and ELA average scores ($p < 0.05$), however the other academic performance results showed conflicting results and the health outcome metrics were not significant. Additionally, a separate ANOVA test was conducted to evaluate the potential links between schools with or without a gas fired domestic water heater, the condition of the heater when applicable, and performance and health outcomes. The results were inconclusive; ELA average scores were the highest in the one school with a gas fired water heater in "poor" condition, while the initial p value was 0.011, the small sample size of one school makes the results not significant enough to be a key factor in predicting performance and health outcomes. Based on these results, no conclusion can be drawn regarding the link between water heater types or conditions, and student performance and health

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outcomes.

Additionally, results of multiple statistical analysis methods also identified no statistically significant correlation between the domestic hot water circulating pump with student academic performance or health.

3. Interior Floor Drain and Storm Water Drain Conditions

Only 4 out of 125 schools evaluated had interior floor drains in "good" condition, the remaining were classified as "good to fair" or "fair" condition. ANOVA tests determined that elementary schools with interior floor drains in "good" condition have 1.8% higher attendance rates compared to schools with interior floor drains in inferior condition ($p = 0.023$). It was also determined that attendance rates differed with varying interior drain conditions within the schools. There were four rated with "good" condition and had 94.25%, attendance rates. 15 rated at "good to fair" had 93.33%; and 106 schools with "fair" had 92.53%. While not statically significant, there was a similar trend of improved test scores for schools with drains in better condition.

Similar to interior floor drains, condition and presence of interior storm water piping did not have a statistically significant link to academic performance but revealed a trend of decreased performance when the condition of the storm water piping changed from "good" to "fair."

ANOVA analysis identified a significant correlation to attendance rates ($p = 0.023$). Four schools with no interior storm water piping had an average attendance rate of 92.8%, Five schools rated "good" ($n = 5$) were at 94.8% attendance. Furthermore, twelve schools' drains rated as "good to fair" had an average attendance of 93.1%, and 104 schools' drains rated as "fair" had average attendance at 92.5%.

4. Plumbing Fixture Conditions



Fig. 4 Single Use Toilet Room in Kindergarten Classroom at school in Brooklyn, NY [21]

Within the dataset, most restroom and shower room plumbing fixtures were rated as "good" to "fair" condition. Two schools contained student male locker and shower rooms which were in construction at the time of the BCAS inspection. Additionally, two student female locker and shower rooms were also in construction during the BCAS inspection. Within the dataset, one school contained student urinals in "fair to poor" condition, and one school contained student drinking fountains that were in "fair to poor" condition. Figs. 4-6 provide examples of restroom plumbing fixtures and their associated conditions.



Fig. 5 Toilet Stall Doors Removed at School in Brooklyn, NY [21]



Fig. 6 Urinals in Poor Condition at Elementary School in Brooklyn, NY [5]

Results of ANOVA tests on the correlation between plumbing fixture conditions and academic performance and health outcomes yielded no statistically significant results.

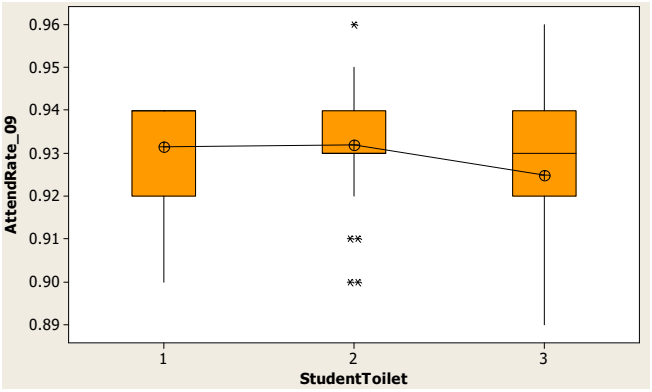


Fig. 7 Comparison between Toilet Room Conditions in Classroom (2010-11) and attendance rates (2009)

While not statistically significant, student toilet conditions showed a drop-in attendance ratings when the condition went from "good" to "fair" as shown in Fig. 7.

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IV. Discussion

Mechanical systems provide Heating, Ventilation and Air Conditioning (HVAC) to ensure thermal comfort to the building occupants. Satisfactory temperature and humidity control are crucial to maintaining student and teacher health, satisfaction, and performance. Teacher satisfaction with the indoor environment increases when they have adequate thermal and relative humidity (RH) conditions. Additionally, research studies have indicated that teachers have "higher asthma prevalence than other non-industrial worker groups" [22]. This could be attributed to schools being unable to maintain indoor RH, leading to increased allergens and irritants that are exacerbated by humidity [22]. Furthermore, changes in temperature and indoor humidity increase inflammation of respiratory system and asthma symptoms among teachers [22], thereby reducing teacher comfort and teaching efficiency.

One method to increase teacher satisfaction and control of their indoor environment is to provide operable windows in the classroom. An increase in the users' ability to control the indoor environment, not only impacts ventilation and thermal comfort, but also influences the teachers' and students' perception of the rooms appeal. Spaces with minimal control of the indoor environment may lead to teacher turnover as a result of teacher discomfort and dissatisfaction. A survey of Chicago and Washington DC teachers indicated that "30% of Chicago teachers and over 40% of teachers in Washington [DC] report[ed] that their rooms were uncomfortable" [3]. The study also identified a potential for increased teacher turnover due to undesirable indoor environmental conditions [3]. Most schools lack HVAC systems that respond to occupant behavioral patterns such as occupant density and their activities. Such systems would improve occupant comfort and reduce energy consumption [23].

Plumbing and water conveying systems are important to regulate and transport potable, gray, and black water to, from, and throughout the building. The condition of school buildings water management systems has direct implications on building integrity and IAQ. Buildings with overburdened storm and sewage systems suffer from frequent flooding which can lead to damaged finishes and furniture, rodent and insect infestation problems, and mold growth; all of which can lead to adverse health outcomes and increased asthma rates.

Findings from the evaluation of the mechanical system (pneumatic systems and cooling systems) and plumbing systems support the inference of the conditions of these systems indicating health and academic performance, as described briefly in the following subsections. Given the competitive nature of academic performance, even a 1% point in attendance or test scores can improve students' chances of getting into good school programs for high schools and higher education and could have significant changes on students' life.

A. Pneumatic System

The percentage of students scoring at the minimum competency level for Math ($p = 0.131$) and the attendance rates ($p = 0.133$) improved as the condition of the pneumatic climate control system declined from "good" to "fair to poor" (Fig. 8). However, it is difficult to determine the impact of "poor" pneumatic control systems to math scores and attendance rates owing to small sample size of two schools.

It is difficult to speculate why the condition of the pneumatic control system had the opposite effect of what was anticipated. Perhaps, as the conditions of the pneumatic control system deteriorated, the more teachers and building occupants sought measures to compensate for the thermal conditioning of their individual classrooms. Then as this individual compensation and individual control of the classroom environment increased, perhaps so did the students' thermal comfort levels which possibly lead to increased test scores and attendance rates. Another explanation is that schools with pneumatic climate control systems in "good" condition were in locations where the system was previously in "poor" condition and was recently repaired or replaced.

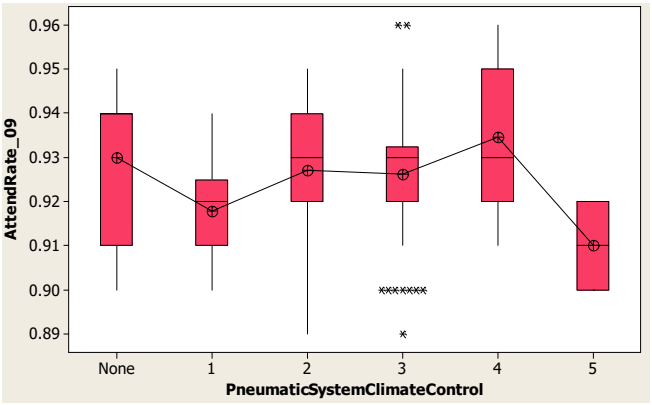


Fig. 8 Pneumatic Systems & Attendance Rates Box Plots

B. Cooling System

Potential factors for higher attendance rates in schools with ACs include improved comfort levels resulting from better air circulation; air quality changes from better control of particulate levels and comfortable interior temperatures. The results revealed a correlation between the presence of AC and student attendance. These results also support the findings obtained from the unit/cabinet heater analysis, which suggests that equipment delivering thermal comfort has an impact on student attendance rates. Students are more likely to attend schools when they are comfortable in their classrooms, which is especially important for students attending over higher temperature school sessions, such as in summer.

Since more than half the schools were constructed in or before the 1940s, it is not surprising that many do not have air-conditioned classrooms. Older buildings may rely on passive cooling techniques such as high ceilings, tall windows, and shallow floor plans. Moreover, thick masonry wall construction in these structures acts as an insulator for interior spaces. The increase in air-conditioning requirements may be a direct result of temporary and permanent alterations made to adapt to changing requirements, including blocking windows and building additions for deeper floor plates. Further, denser classrooms, use of incandescent lamps and the additional heat

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load of computer and electric equipment may all contribute to higher room temperatures.

C. Plumbing System

The trend in student toilet conditions and reduced attendance provides a sign that there might be a link and the possible cause could be attributed to student bullying. In addition to be a location for typical restroom activities, the student restrooms may also be a place where children socialize free of direct adult supervision. It is also a location where bullying from other students could occur free from the teacher's awareness. Another significant finding was on backflow prevention devices. Backflow prevention devices are critical to a city's effort to provide safe and clean drinking water to the community and a requirement in city building codes. According to a Plumbing Engineer at 2LS Consulting Engineers that was interviewed, many NYC buildings do not have DCV, Double Detector Check Valves (DDCV), and RPZ devices. The NYC building stock includes many older buildings that do not have modern backflow prevention devices that are utilized to protect domestic water from contamination [24]. In addition to the water quality concerns, private buildings without these devices face fines from the Department of Environmental Protection (DEP). The lack of DCV and RPZ devices is also a sign of the dwindling condition of the school facility infrastructure and another signal that water management upgrades are needed throughout majority of school facilities.

The interior floor drain findings further support the idea that schools with good water management systems tend to have better academic performance and health. The combination of state of existing floor drains and storm water drains, and the condition/absence of DCV and RPZ devices are signs that water management strategies are less than optimal at these schools. Inadequate systems may lead to standing water and infiltration problems which may in turn result in more illnesses such as asthma- a leading cause of absenteeism in schools. Surprisingly, it was found that asthma hospitalization rates were significantly related only to the condition of sump pumps ($p < 0.05$) and not those of the drains at schools. This corresponds with the notion that the lack of water management devices or those with diminished capacity could lead to increased standing water, mold, and asthma.

V. Conclusion

This study utilized several methods to measure outcomes on a portfolio wide scale. Google Earth was used to determine school facility characteristics. Average student grades were obtained from the New York State public schools report card, which is freely available online. This approach is more cost effective than in-person measurement given the quantity and extent of the data points involved.

The study identified that there is tremendous potential in electronic databases, statistical software, and applications that help researchers and building managers organize and analyze big data, and by establishing an electronic database for all facility data: building features and amenities, facility conditions, and energy consumption, it will be easier to help urban school districts throughout the country take steps to make necessary investments to improve the quality of student health and education. With a structured database, it was possible to support ongoing data collection and analysis for assessing the greatest challenges and benefits of school portfolio. Finally, with an integrated database, standardized statistical analysis methodologies were utilized for evaluating the multivariate links between mechanical-plumbing attributes and student academic performance and health outcomes. The restroom plumbing conditions are also a sign of other school deficiencies. New facility conditions and a wider range of features along with outcome measures can be tracked and entered into such a database, which can potentially provide a basis for city, family and school leaders to prioritize decisions for school building investments.

There are several benefits of high performance mechanical (HVAC) and plumbing systems to school administrators, teachers, and students. Some include humidity improvements, temperature control management, and financial benefits from energy efficient facilities. Based on the findings from this study, mechanical and plumbing systems are identified as critical systems to include in retrofits and upgrade building projects. They have the potential to improve occupant comfort and multiple occupant academic performance metrics.

It is important to identify the impact of the condition of the mechanical and plumbing systems on children's education, to be able to prioritize investments. Investments in our school buildings with positive health and performance outcomes are important for other reasons, such as improving children's health and well-being, community image and perception, teacher retention, the ability to secure additional funding through grants. This study shows that investment in school's mechanical and plumbing systems could lead to substantial improvement in student academic performance and health.

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