MEASURING UP

Using Pre- and Post-Occupancy Evaluation to Assess High-Performance School Design

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Perkins Eastman

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EXECUTIVE SUMMARY

The term “High-Performance School” is used to describe learning environments that provide educational, health, and social benefits to building occupants (students and faculty). High-performance design aims to reduce the amount of finite resources the building draws from our planet, such as energy and water, while simultaneously providing high-quality education. Thus, to fully understand the implications of a High-Performance School, it is important to assess the application of high-performance design strategies on the school—both in terms of educational, health, and social benefits and the building’s ecological impact.

In 2015-17, Perkins Eastman conducted a design research study on the Dr. Martin Luther King, Jr. School, located in Cambridge, MA, to assess the outcomes of applying high-performance design strategies to this school. The case study focused on two main aspects of a High-Performance School: Indoor Environmental Quality (IEQ) and sense of community. For the purpose of this study, IEQ was defined as the daylighting, electric lighting, indoor air quality, thermal comfort, visual comfort, and acoustics of a space. Sense of community was evaluated on several scales, from person-to-person relationships, person-to-school, and person-to-the-community at large.

This paper provides a background on the impact of high-performance design strategies, followed by a description of the evaluated school and our qualitative and quantitative methodology. Our findings are then presented, through which we propose that high-performance design strategies can improve building performance and increase satisfaction, bringing the theoretical value-add proposition for high-performance design into reality.

BACKGROUND

In regards to sense of community, there is existing research outlining the benefits of sense of community in schools, but there is little research correlating specific features of a school environment to the sense of community. Sense of community has been shown to help support the performance, mental health, and well-being of both teachers and students. In a study of 11th grade students, those who reported having higher feelings of community within their school were likelier to have slightly higher PSAT scores [1]. Community in schools can also improve students' well-being and prepare them to become active community participants as adults [2]. Further, school connectedness can improve school attendance and encourage students to choose healthy behaviors [3].

Students in schools with a highly rated sense of community are more likely to become thoughtful and reflective, to be self-directing but also to accept the authority of others, to be concerned for and respectful of others, to avoid courses of action that are harmful to themselves or others, and to maintain higher standards of ethical conduct [4] [5]. Through our research, we aimed to identify specific design elements, strategies, and environmental conditions that help to promote community within the school and the neighborhood at large.

There have been, and continue to be, many academic studies investigating how factors of IEQ affect students and staff in schools.

Key areas of research include daylight, thermal comfort, acoustics, and air quality (see Figure 1).

Students who report higher **SENSE OF COMMUNITY** in their schools have **HIGHER TEST SCORES.**

In terms of the importance of daylight, studies have shown that students in daylit classrooms progress 20% faster on math tests and 26% faster on reading tests than students in windowless classrooms [6]. Other studies have shown that access to natural light is important to children's melatonin cycles [7] and cortisol production [8], both of which affect concentration abilities as well as general well-being.

In regards to thermal comfort, uncomfortable temperatures can cause feelings of fatigue, irritability, and depression. Studies have shown that for every decrease of 1.8°F between 77°F and 68°F, students speed performance on tests was improved from 2-4% in all tasks [9].

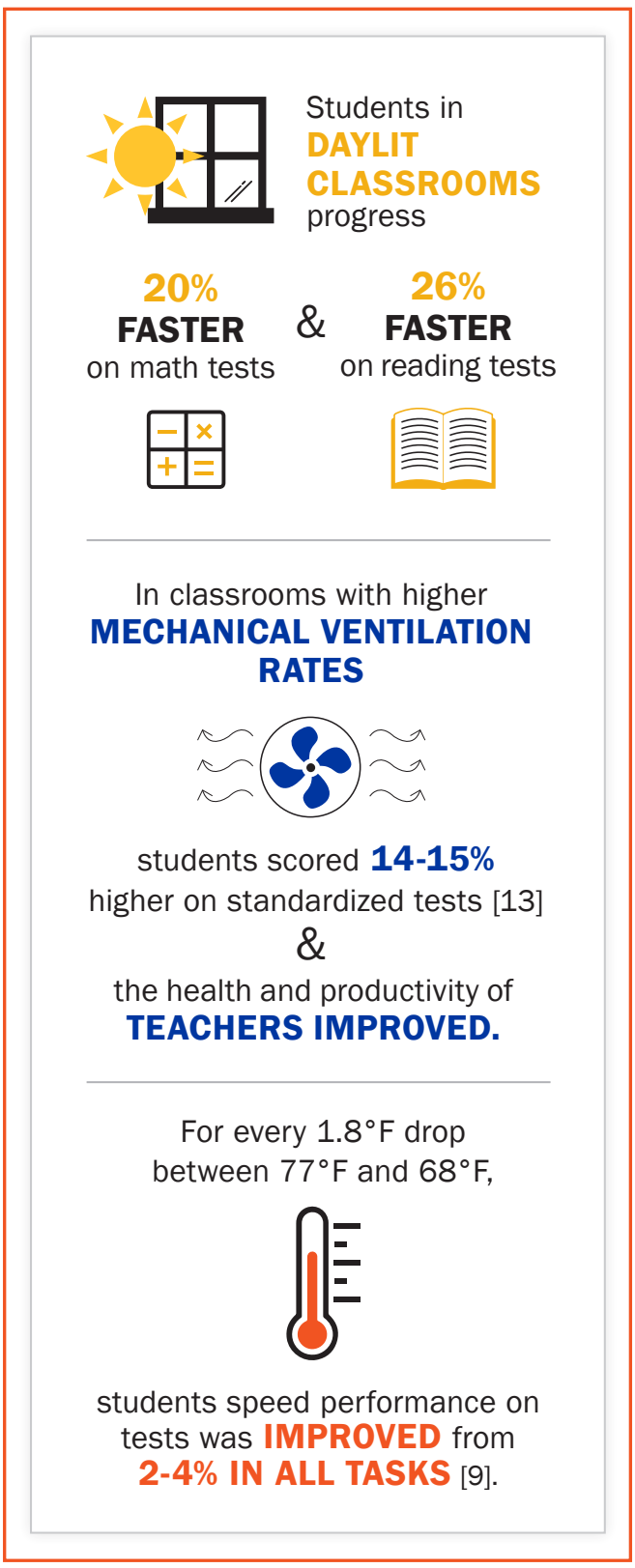
There is a **POSITIVE CORRELATION** between sense of community in schools and both **POSITIVE ATTITUDES** toward school and better academic **MOTIVATION** and **ENGAGEMENT** [14].

When looking at the effects of noise, proper acoustics can enhance a student's ability to hear their teachers, as well as reduce levels of fatigue in teachers throughout the day, whereas poor acoustics can have deleterious effects. For instance, research has shown that students at a school under the regular flight path of a nearby airport performed 20% lower on a reading test than students in a nearby school [10].

Air quality also has an impact, with improved ventilation rates and systems decreasing instances of respiratory illness [11], improving student attendance [12], increasing task completion speed [9], and improving test scores and grades. Research has shown that students in classrooms with higher air ventilation rates scored 14-15% higher on standardized tests [13].

Most of these studies, however, investigated a single IEQ factor at a time, meaning they only studied single variables, such as daylight or acoustics, independent of each other. Very few studies attempt to look at IEQ factors in tandem to assess the overall impact of high-performance design strategies on building occupants. This study, however, was designed to study multiple, concurrent factors.

Figure 1



THE DR. MARTIN LUTHER KING, JR. SCHOOL

Our case study investigation into high-performance schools focused on the Dr. Martin Luther King, Jr. School, which opened in 2015 in Cambridge, MA.

The Dr. Martin Luther King, Jr. School houses three schools on one campus: the Putnam Avenue Upper School (PAUS), Dr. Martin Luther King, Jr. School, and the Dr. Martin Luther King, Jr. Preschool. The project was complicated by its small and irregular site, the large and complex program accommodating 840 children from preschool to 8th grade, robust after-school programs, and an array of engaged stakeholders.

The overarching goal of the school's design was to synthesize the Cambridge Public Schools Superintendent's "Innovation Agenda," targeting significantly enhanced educational outcomes within this urban district, with the Mayor's desire to pursue Net Zero Energy. At first, many stakeholders involved were concerned that the two agendas would result in conflict over financial resources, which could diminish the District's educational and community goals. Instead, the process and design demonstrated a powerful synergy between the Innovation Agenda, sense of community within the school, and the pursuit of Net Zero Energy. Together, these goals inspired a sustainable, high-performance urban learning environment. See Figure 2 for an overview of the design strategies employed to promote community and IEQ at this school.

Figure 2

MASSING

To fit in its residential neighborhood, the building massing steps back, reducing shadows onto neighboring buildings. The school's two primary academic wings also provide a welcoming entry with the creation of a public entrance courtyard.

PUBLIC SPACES

King Street, an internal circulation spine, connects the different school communities, from the preschool to the Upper School, and helps create different zones and designated areas for the schools and the publicly shared spaces. King Street enables the joint-use public spaces, such as the Lower School gym, Upper School gym, Cafeteria, and Preschool by making them easily accessible and open to the public.

EXTENDED LEARNING

One aspect of the learning neighborhoods is that its circulation space was organized to provide flexible, informal, learning spaces that would allow for small group work to occur outside of classrooms, activating the "corridor" as a space for learning.

Figure 2 (continued)

LEARNING NEIGHBORHOODS

To reduce the scale of the building and encourage greater interaction between faculty and students, both the lower and upper schools were organized into “neighborhoods” comprised of classrooms, labs, administrative offices, and teacher support spaces. Each school is organized as three “neighborhoods” that were intended to encourage a sense of community among a subset of the school population.

SECURITY

To reduce bullying and create positive connections, stairs, staff areas, and primary shared spaces selectively have glazing for views to corridors, breakout spaces, and outdoor spaces.

ACCESS TO NATURE

Both the Upper School and the Lower School gyms have large doors that open up to play space. The garden provides a school-wide learning opportunity.

PUBLIC COURTYARD

The Upper and Lower Schools each have a distinct entrance within the main courtyard, promoting their individual identities and creating a welcoming front door to each community.

AIR QUALITY

A demand-controlled ventilation system senses classroom occupancy and increases fresh air as needed.

DAYLIGHT

Interior light shelves bounce daylight deep into classrooms, providing a glare-free daylit experience for students and teachers.


Today a Reader, Tomorrow a Leader
Books We've Shared
Word Vocabulary
READ

THE STUDY

An evaluation of the Dr. Martin Luther King, Jr. School not only adds to the design industry's understanding of high-performance design, but was also important since the school was a prototype: It was designed to serve as a model and testing ground for high-performance design strategies for the rest of the schools in the Cambridge Public Schools district. The lessons learned from this case study—a transition from current, dated school facilities to a new learning environment—could impact future renovations and new construction throughout the city, in addition to having a potential impact on schools nationwide.

With the hypothesis that high-performance design will improve occupant satisfaction and performance and improve sense of community among students and staff, a design research study was conducted by Perkins Eastman in 2015-17, with three main objectives:

- To become a comprehensive IEQ case study that demonstrates to the industry the value of high-performance design;
- Assess the design team's achievement of their project goals, to uncover lessons learned for the future; and
- Develop a standardized process for evaluation within the K12 education practice of our design firm.

From the outset of the study, a multi-disciplinary team was engaged. The design team enlisted the help of a practice-based design researcher to conduct a pre- and post-occupancy questionnaire to assess occupants' perceptions of performance. Sustainability specialists were brought on board to gather on-site quantitative measurements of indoor environmental quality using various measurement tools. School administrators who were involved in the design process assisted with the implementation of the evaluations, and will continue to provide on-going data regarding student and teacher performance.

While some form of post-occupancy evaluation (POE) is not uncommon in the design industry, the scope of this study intentionally expanded the typical POE process to look more holistically at the project. Our methodology included a pre-occupancy evaluation (Pre-OE) component to establish a benchmark for POE comparison, as well as comparisons of both qualitative and quantitative evaluations of IEQ.

Establishing a benchmark from which to evaluate the success and impact of the new building was an imperative step. While the new Dr. Martin Luther King, Jr. School was under construction, students from the upper and elementary school were housed for more than a year at two existing school buildings that the Cambridge school district used as swing spaces: The Kennedy Longfellow

School where PAUS occupied the 3rd floor and the Longfellow Building on Broadway. Once the new building was complete, the students were relocated. However, the Kennedy Longfellow 3rd floor and Longfellow Building locations were again filled with another group of students, awaiting the construction of another new school. This allowed the research team the unique opportunity to have access to all three buildings simultaneously. The Pre-OE study focused on the swing spaces, the most recent learning environments that the students and staff had been in, and provided the benchmark against which findings from the POE of the newly built space were compared.*

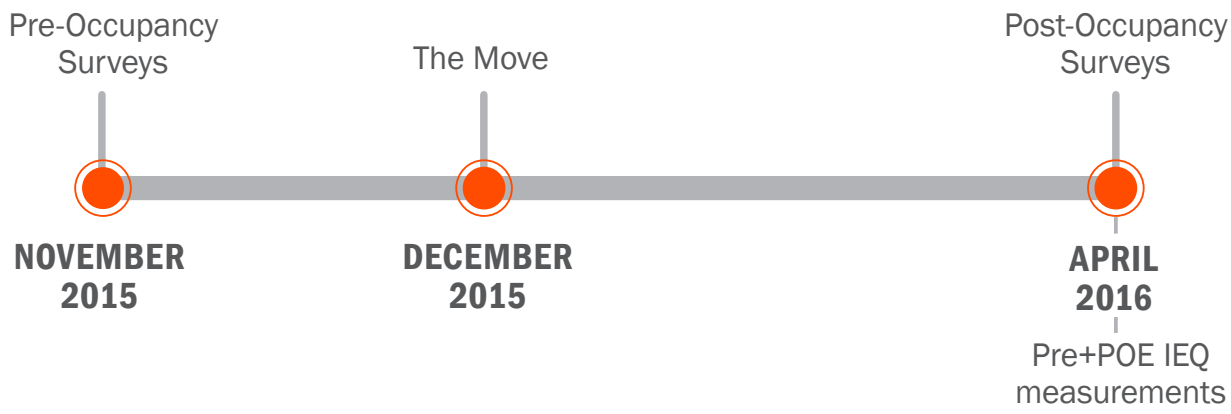
For both the Pre-OE and POE, occupant feedback was collected through an online survey distributed to the school's faculty, both before and after the move to the new school building. In the pre-occupancy survey, 61 faculty participated and 47 participated at post-occupancy (31 of which indicated they also occupied the old swing schools), equating to a response rate of about 54% to 42%, pre- and post-occupancy respectively. In order to express an accurate comparison of the old and new buildings, data presented in this report is based on the 31 participants who experienced both the swing spaces and the new building. This qualitative data collection process assessed the building occupants' perceptions about the school's design features, sense of pride, sense of community, pedagogical support, safety, and Indoor Environmental Quality (IEQ). Note perceptual data from student surveys, though part of the original design of the research study, unfortunately could not be collected due to extenuating circumstances.

Quantitative measurements of Indoor Environmental Quality (IEQ) were collected concurrently in the new building and the old (swing) spaces, then occupied by the next group of students and faculty. IEQ metrics were gathered using temperature, light, sound, and air quality metering devices at both the old and new buildings. (See Appendix A for more details about the buildings' location, floor plans, and the IEQ on-site data collection.) The perceptual survey,

QUALITATIVE	QUANTITATIVE
Design Features	Temperature
Sense of Community & Pride	Daylight
Indoor Environmental Quality	Sound
Pedagogical Support	Air Quality
Safety	

* For the purpose of this report, the swing spaces housing the PAUS and MLK school populations during the new school's construction are referred to as old MLK and old PAUS.

Study Timeline



alongside actual IEQ metrics data, allowed for a unique comparison of qualitative and quantitative data, and helped to eliminate the inherent biases that may occur when using one method or the other.

Data collection started in November of 2015 with pre-occupancy surveys, which asked building occupants about the swing spaces. After the students and teachers moved into the completed new school in December 2015, the post-occupancy surveys were distributed in April 2016, so that pre- and post-occupancy survey comparisons could be made among the same sample of building occupants.

Both the pre- and post-occupancy quantitative measurements were taken at the same time in April 2016. This allowed for outdoor conditions to be consistent across the pre- and post-occupancy measurements, allowing for direct comparison. Although this meant that the swing spaces that were studied were not occupied by the same student body, they were still occupied in the same manner and with a similar population as they had been when the Dr. Martin Luther King, Jr. School student body and PAUS student body were in them.

Two main classrooms were identified in each of the old swing space schools to conduct the pre-occupancy measurements. In the new Dr. Martin Luther King, Jr. School, four classrooms were studied to get an even broader dataset. Temperature, humidity, and CO2 levels were logged continuously throughout the week-long study using data-loggers and CO2 monitors. Additional data was collected throughout the week during occupied and unoccupied conditions. For acoustics, a Sound Level Meter was utilized to measure the ambient and occupied noise levels experienced within typical classroom environments in each of the schools. For lighting, a Light Meter was used to collect light levels in each classroom with electric lighting on and off, and a camera with different exposure settings was used to generate photos to assess the glare of these environments. For thermal comfort, in addition to the data-loggers, radiant surface temperatures of inner and outer facing walls were taken. A thermal imaging camera was also used to assess thermal bridging from the outdoors. For more information on the specific tools used in the study, see Appendix B.

FINDINGS

In general, the findings suggest that the new Dr. Martin Luther King, Jr. School is performing significantly better than the previous swing spaces in almost every parameter studied, for both perceived and measured IEQ metrics, as well as the faculty ratings of how well the building fosters a sense of community. Although the study goes into several other specific factors, some of the general feedback provides great insight into the quality of the school environment that the new design creates. For instance, of the teachers who taught in both locations, 97% said that the new building is a better place to spend their day than the old building. Additionally, 100% agree that the design of the new school is a pleasant place to work and learn.

100% AGREE

THE DESIGN OF THE SCHOOL **CREATES A PLEASANT PLACE** TO WORK AND LEARN

97% SAY THE NEW BUILDING IS A **BETTER PLACE TO SPEND THEIR DAY** THAN THE OLD BUILDING

100% PROUD

TO WORK IN THIS BUILDING

90% AGREE

THE DESIGN OF THE SCHOOL **SUPPORTS EDUCATION**


Cheetah Cubs
Life
大米是怎么来的
给我一半

COMMUNITY

The new Dr. Martin Luther King, Jr. School successfully fosters a sense of community among faculty, staff, and students. On average, a 50% improvement was seen between the new building and the old swing spaces in terms of how the space fosters a sense of community.

Part of this has to do with the creation of large group gathering spaces in the new school for both faculty and students, which 76% say are successful at supporting a sense of community in the new building.

think that the school building fosters community **among faculty and staff.**

79% think that the school building fosters community between **faculty and students.**

72% think that the school building fosters community **among students.**

76% say the large group **gathering spaces are successful** at supporting a sense of community.

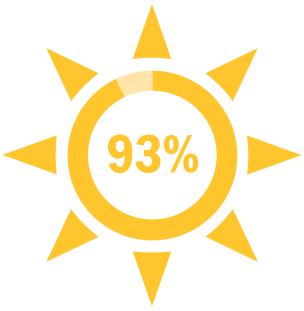
INDOOR ENVIRONMENTAL QUALITY

As described earlier, in addition to implementing high-performance design strategies to promote a sense of community, the design team focused on creating high-quality indoor environments for learning. Thus, the study also focused on the indoor environmental quality, defined as the daylight, thermal comfort, acoustics, and air quality of the school. As explained in the methodology and Appendices, survey questions and on-site IEQ measurements were used to assess each of these parameters.

Daylight

Within the classrooms, daylight was studied on two main factors: the quantity of daylight and the quality of the daylight. Although generally improving the amount of daylight in a learning environment is a good thing, if that daylight isn't properly controlled it can create glare and visual discomfort, which have adverse effects on learning [7].

In the perceptual survey, staff reported a satisfaction rate of 93% with the amount of daylight in the Dr. Martin Luther King, Jr. School building, 64% higher than their ratings from when they occupied the old swing spaces. To evaluate this on the quantitative side, daylight levels were measured across typical classrooms in both the old and new spaces and were assessed for how much of the room was under-lit, over-lit, or well-lit. Daylight in the new school building was measured to be 57-65% more well-lit than in the swing spaces.



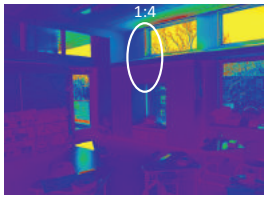
OF PEOPLE WERE SATISFIED
with the amount of daylight in the new school.

Well-Lit
NEW MLK

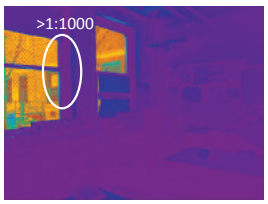
Well-Lit
OLD MLK

Well-Lit
OLD PAUS

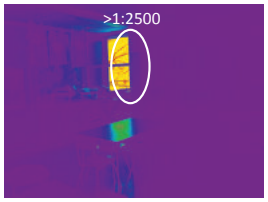
Glare Ratio Analysis



NEW MLK



OLD MLK



OLD PAUS

However, improvements in the amount of daylight do not necessarily show success in improving the quality of daylight. Glare is visual discomfort experienced as a result of excessive brightness and contrast. While 82% of staff reported satisfaction with the glare and visual comfort in the new school as compared to the old swing spaces, a 66% improvement, we also wanted to measure the actual reduction of glare in the new space.

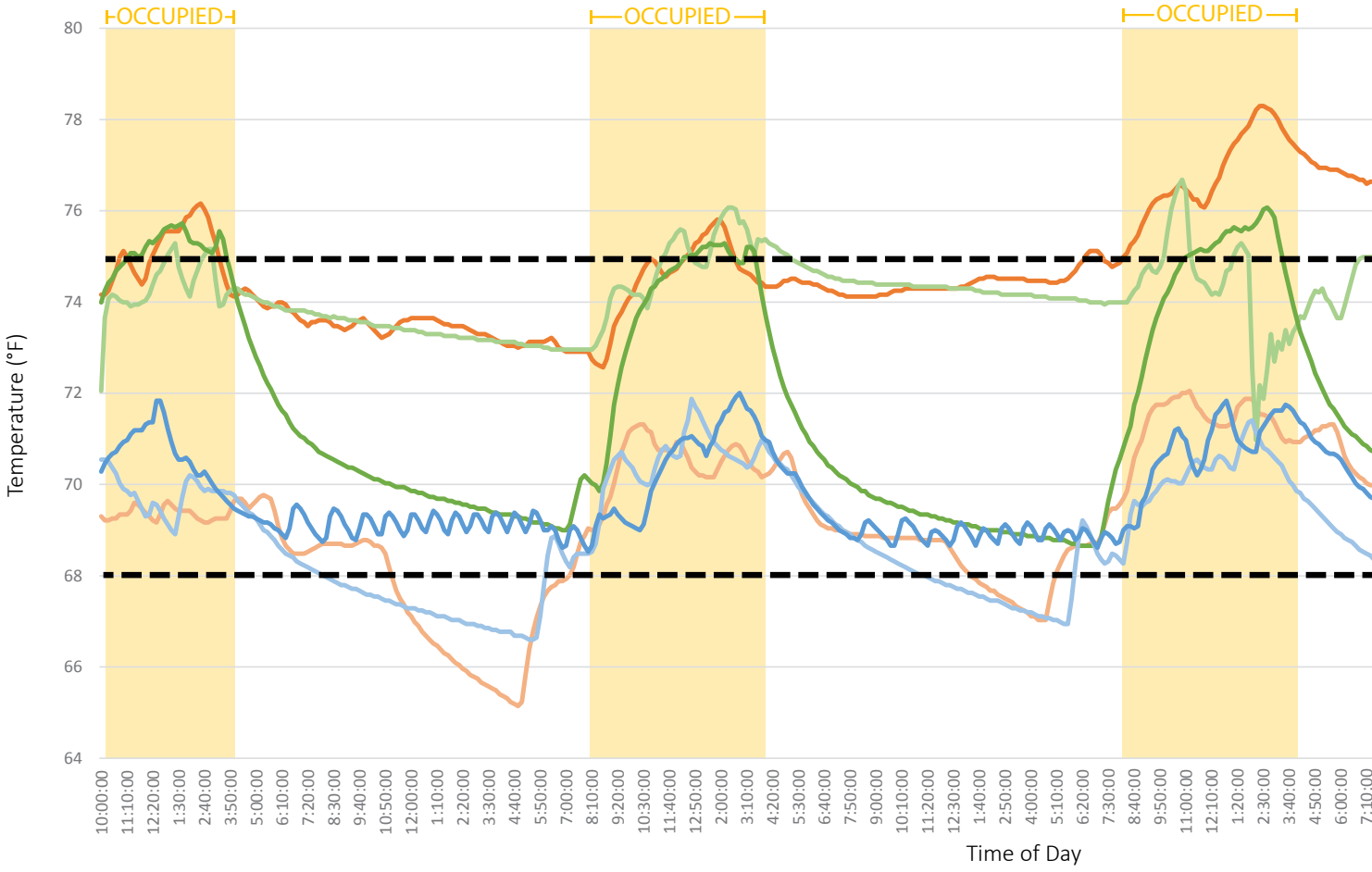
One way to analyze glare is to use a glare ratio, which calculates the contrast in luminance between nearby surfaces. Ratios in excess of 1 to 10 typically cause visual discomfort. In the classrooms that were studied, on average, we found glare ratios at the new building did not exceed 1 to 7, while the old swing spaces achieved glare ratios between 1 to 600 and 1 to 2500—falling significantly outside the comfort range. This represents a huge difference in daylight quality that ultimately results in higher satisfaction levels, as well as a reduced need for electric lighting to balance out uneven daylight levels in the classrooms at the new school.

Thermal Comfort

Being able to maintain a comfortable temperature within a classroom is an important part of creating a high-performance learning environment. Considerations regarding both the building envelope and the mechanical system come together to either support or hinder one's ability to maintain a comfortable temperature. According to the qualitative survey data, staff were 53% more satisfied with the thermal comfort of the new Dr. Martin Luther King, Jr. School building as compared to their reported thermal comfort while occupying the previous swing spaces with 61% of staff reporting positive satisfaction levels. This is further supported by quantitative data, which showed that the new school stays within a comfortable temperature range 100% of the time, while the old swing spaces would exceed comfortable temperatures by as much as 5° F and only stayed within the comfort zone 63-65% of the time.

In addition to the way air temperature affects occupants' thermal comfort, the temperature of surrounding surfaces in a classroom can also impact thermal comfort. To evaluate this factor within the schools, the radiant surface temperatures of an exterior wall (one with a window) and an interior wall (one facing the hallway or another classroom) were taken on a wintry day at both the new building and at the old swing spaces. The interior and exterior wall surface temperatures at the new school were within 4° F of each other, producing a balanced and comfortable indoor environment, whereas one of the previous swing spaces had more than double the degrees in temperature differential across the classroom.

Temperature Measurements

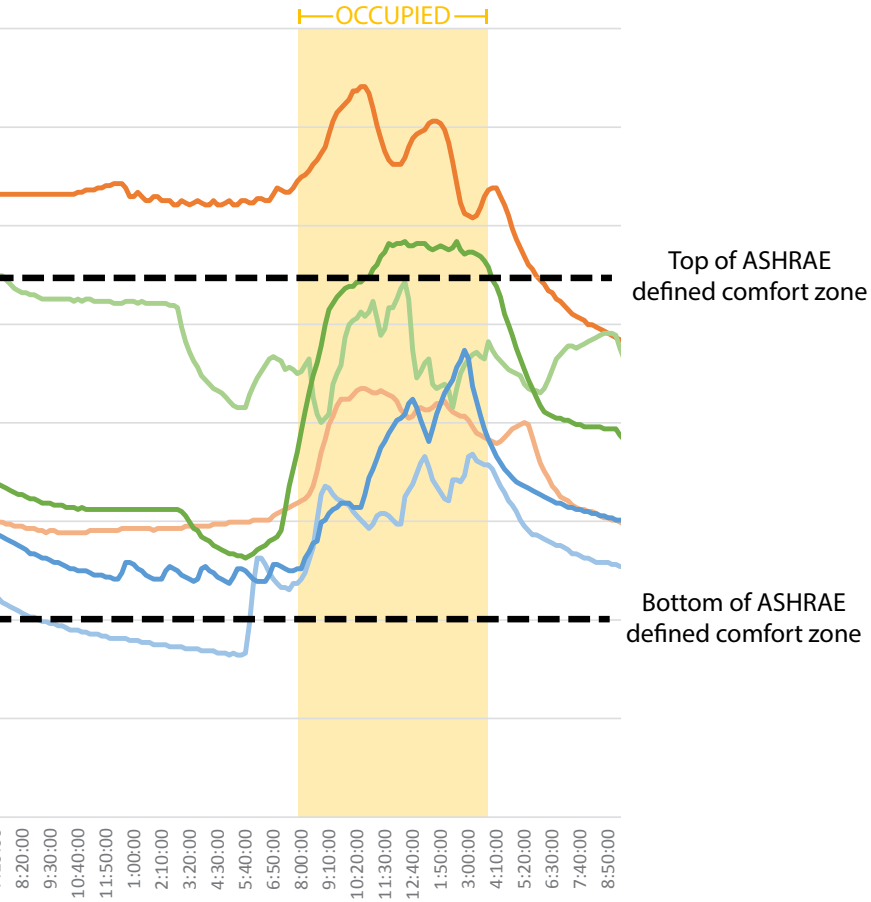


Acoustics

Noise from corridors, cars, outdoor play areas, and loud mechanical equipment can all impact the ambient noise, also known as background noise, in a space—and as evidenced earlier, high levels of background noise is detrimental to student performance. 89% of staff in the new Dr. Martin Luther King, Jr. School reported higher levels of satisfaction with the noise level in their classrooms, a 66% increase over the swing spaces, and 82% expressed satisfaction with acoustical privacy between spaces, a 57% increase over the swing spaces. The design of the new building separated louder public spaces from classroom areas to reduce interruptions. In addition, mechanical systems were selected and located to minimize disturbance. The resulting ambient noise level is 23-33% lower than that of the old swing spaces.

89%
OF PEOPLE WERE SATISFIED with the noise level in the new school.

82%
OF PEOPLE were **SATISFIED** with the acoustical privacy *(noise between adjacent spaces in the new school).*



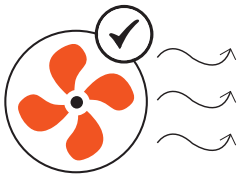
Air Quality

Measured Carbon Dioxide (CO2) levels are used to assess the ventilation of a classroom, and as demonstrated in the recent study from the Harvard School of Public Health, reduced CO2 concentrations are closely correlated with increased cognitive function [17]. CO2 is measured in parts per million (ppm), and ASHRAE standards for ventilation rates usually target levels under 1000 ppm. The Harvard study, however, showed significant improvements in cognitive function well under that level, and recommends levels below 550 ppm.

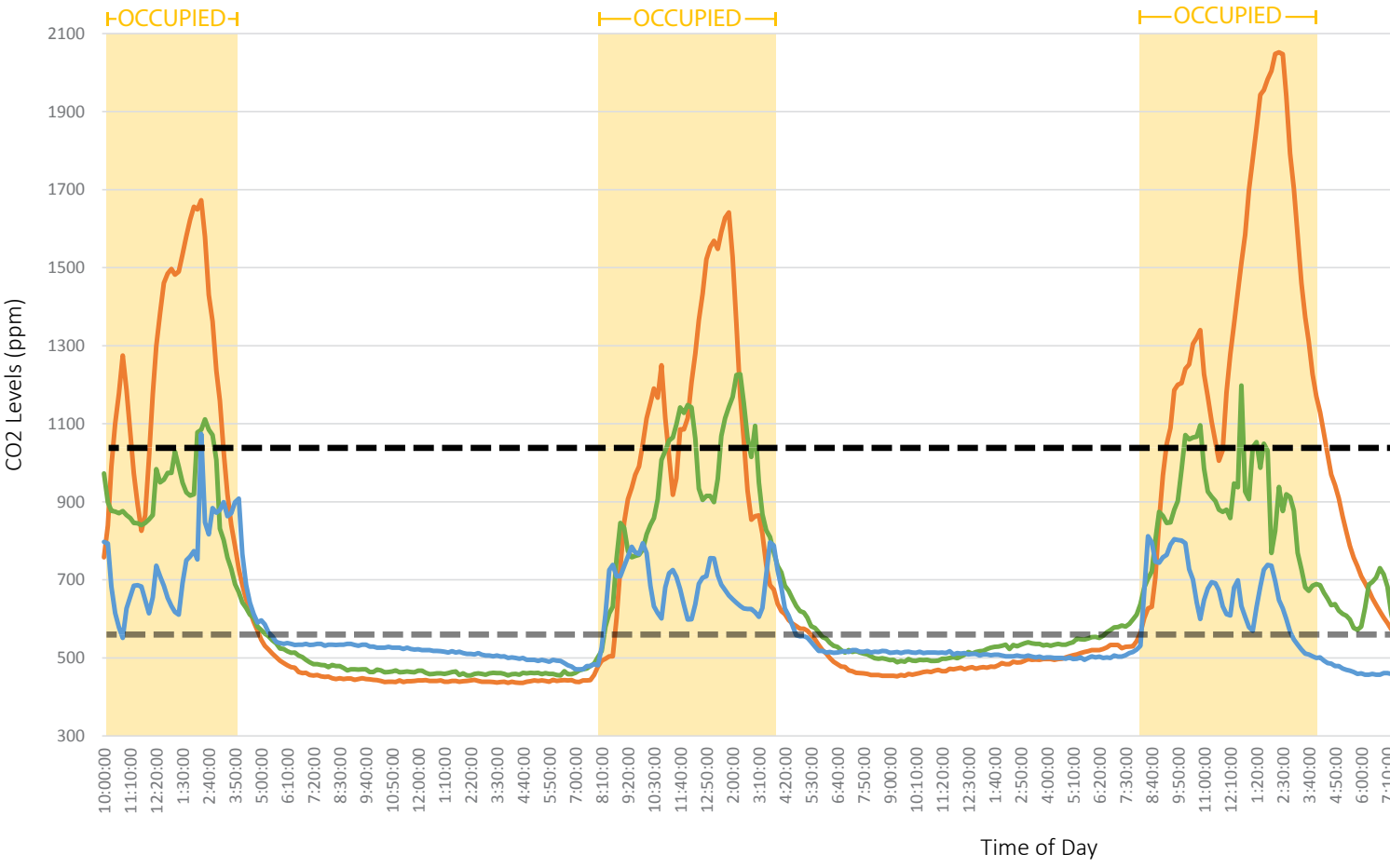
CO2 Measurements

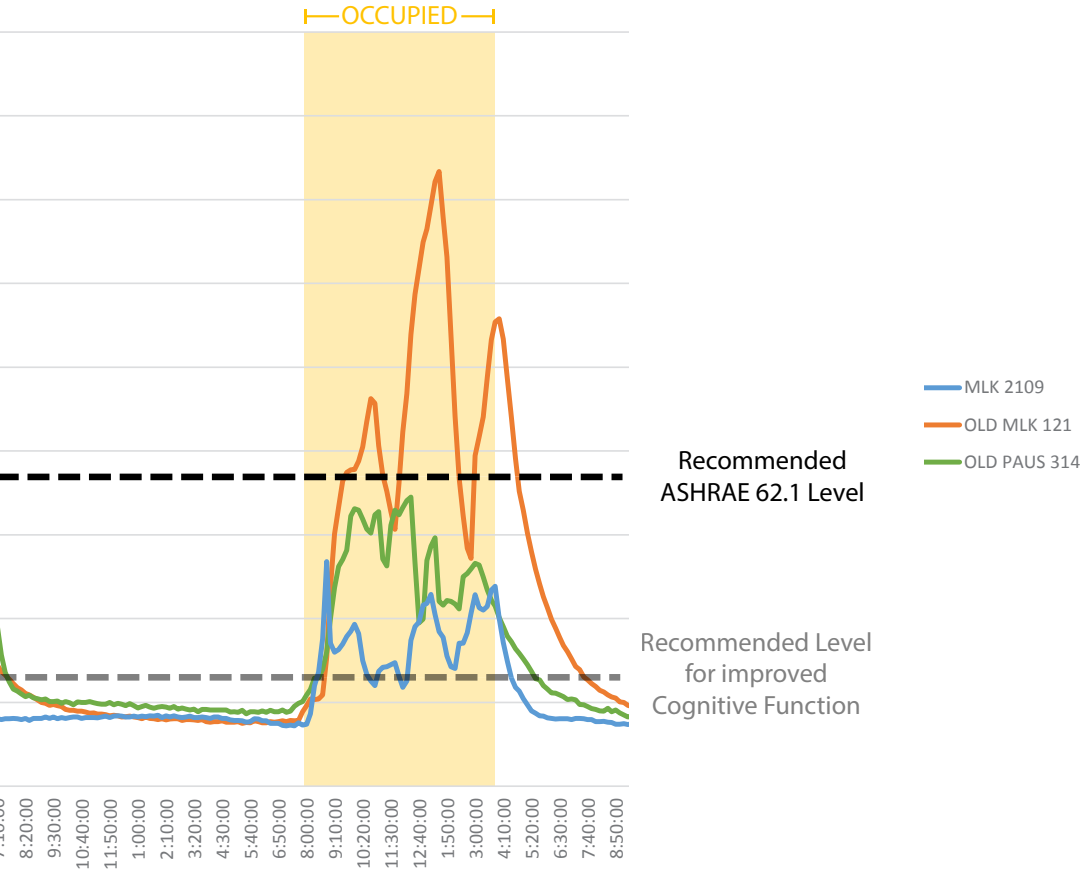
NEW MLK AVERAGE: 552 PPM
OLD MLK AVERAGE: 728 PPM
OLD PAUS AVERAGE: 629 PPM

Our research study saw that, when measured over a one-week period, the new Dr. Martin Luther King, Jr. School building's classrooms averaged CO2 concentrations of 550 ppm, 12-25% lower than those measured in the old swing spaces. In addition, 71% of staff at the new school reported being satisfied with the air quality, a 57% improvement to the ratings of the old swing spaces.



71%
OF STAFF WERE SATISFIED
with the air quality in the new school.





Recommended ASHRAE 62.1 Level

Recommended Level for improved Cognitive Function

MLK 2109

OLD MLK 121

OLD PAUS 314

Perkins Eastman

CONCLUSION

Our study of the new Dr. Martin Luther King, Jr. School found improvements in the air quality, acoustics, daylighting, and temperature of the building when compared to the swing spaces. In addition, survey data found improved occupant perception of both sense of community and all factors of indoor environmental quality. Satisfaction levels increased between 53-66% in every measure, indicating meaningful improvement.

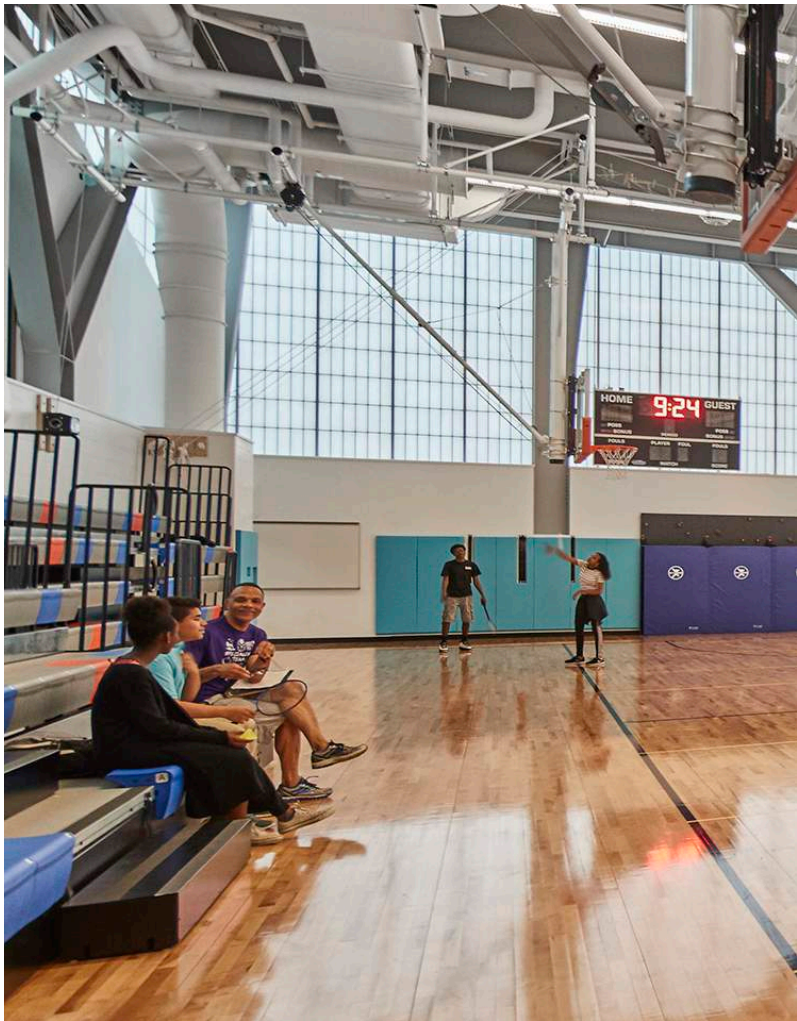
Overall, the study found that the high-performance design strategies employed by Perkins Eastman at the Dr. Martin Luther King, Jr. School in Cambridge, MA, not only had a significant impact on occupant satisfaction and sense of community, but also had a measurably positive impact on indoor environmental quality. These findings correlate high-performance design strategies to improved building performance and increased satisfaction, bringing the theoretical value-add proposition for high-performance design into reality.

By showing that even minor improvements in building performance using high-performance design strategies can significantly impact occupant satisfaction and performance, this case study becomes applicable to any industry where occupant performance is significant—especially in educational, office, and healthcare environments. Moving forward, we expect to see the implementation of high-performance design strategies increase across our firm and across the industry, as this research provides the data needed to showcase the value of high-performance design to clients.

NEXT STEPS

As the Dr. Martin Luther King, Jr. School continues to operate and evolve, we hope to carry on our investigation, sustaining the analysis of the impact of the building on the students and staff. While the occupants have not been in the school long enough at this point to see measurable impacts on occupant health (e.g., absenteeism rates, nurse visits), student achievement (e.g., standardized test scores), or staff productivity, retention, or recruitment, the study team plans to analyze indicators of success in the future. Student achievement, health, and community indicators (e.g., local property values and crime incidents) are also being tracked to see trends over time.

In addition, Perkins Eastman will continue to refine, standardize, and implement this pre- and post-occupancy evaluation process on additional school projects. The research team will continue to hone the variables in the study and consider additional metrics, such as VOCs, particulates, and other measures of sense of community. We also intend to establish a standard protocol for pre- and post-occupancy evaluations that details the desired set-up, timeline, participants (including student occupants, not just faculty/staff), and methodologies of data collection to assure greater consistency—and therefore comparability—across studies. By formalizing and evolving the process outlined in this study, design research like this can bring value to our firm as well as the industry at large, by sharing lessons learned and evidence to support high-performance design strategies and evidence-based design decisions.



APPENDICES

APPENDIX A – MAPS AND FLOORPLANS

Figure 3: Location of studied schools in Cambridge, Massachusetts

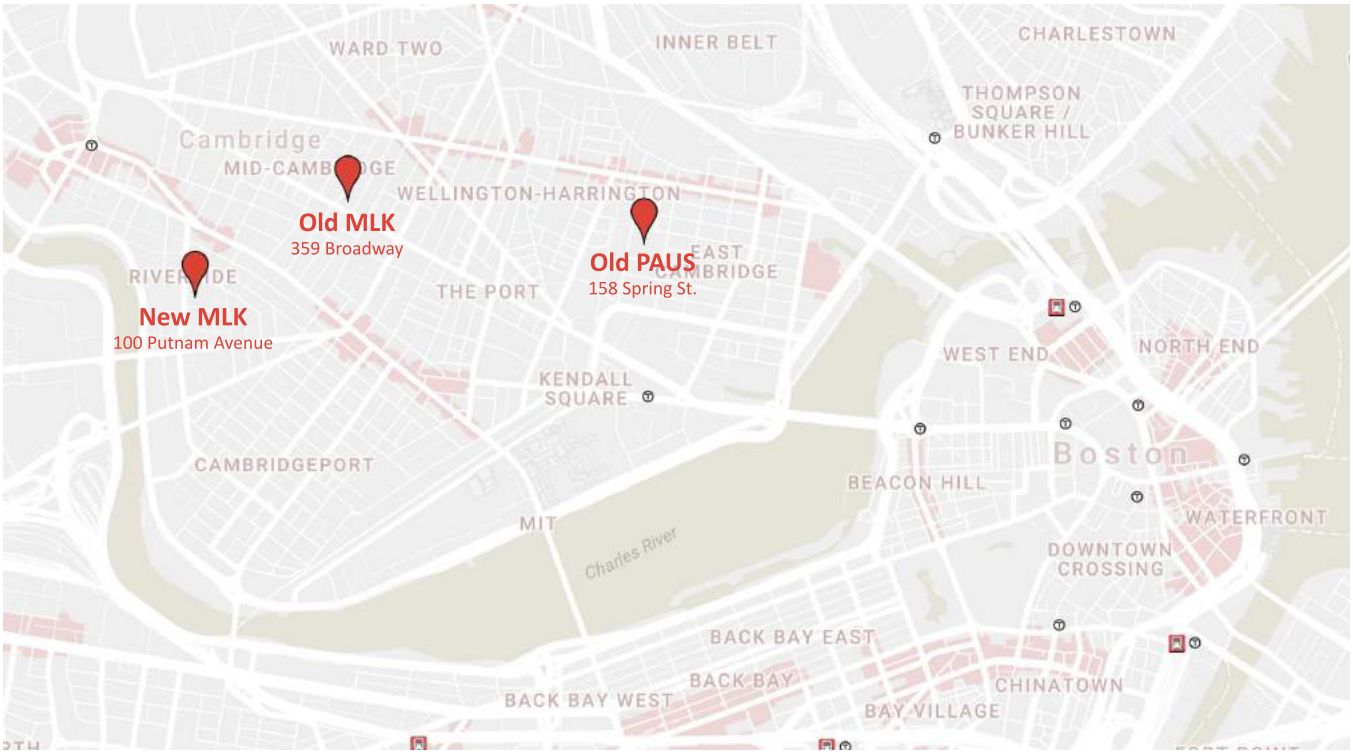


Figure 4: Floor plans identifying rooms studied in

APPENDIX B – IEQ ANALYSIS TOOLS

	Tool Used	Unit of Measure	Data-logged	Point in Time Measured	Occupied	Unoccupied
ACOUSTICS						
Noise Levels	RadioShack Sound Level Meter 	dB		●	●	●
THERMAL COMFORT						
Air Temperature	Onset HOBO Data Logger 	°F	●		●	●
Humidity	Onset HOBO Data Logger 	RH	●		●	●
Radiant Surface Temperature	Raytek MiniTemp gun 	°F		●		●
Thermal Imaging	FLIR Camera 	°F		●		●
AIR QUALITY						
CO2 Levels	Telaire CO2 Monitor + Onset HOBO Data Logger 	ppm	●		●	●
LIGHTING						
Daylight Levels	Osram Sylvania Light Meter 	footcandles		●		●
Daylight + Electric Light Levels	Osram Sylvania Light Meter 	footcandles		●		●
Glare	Camera for HDR photo generation + Honeybee/Grasshopper 	lux ratio		●		●

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