DLR Group

All the Design Elements We Cannot See

Pulling back the curtain on holistic building performance reveals how one school district used data-driven research to improve air quality and maximize taxpayer dollars.

A Case Study: Barrington School District 220

Within the physical environment, there is an entire world of things we cannot see that influences the human experience of a space and their ability to perform. Like pulling back the curtain on the Wizard of Oz, we design the unseen elements that make all the difference in how our built world works.

A unique aspect of our process includes advanced sensory technology to provide indoor indoor environmental quality (IEQ) testing as part of the conditions assessment procedure. A recent report from the World Green Building Council outlines the benefits of optimizing the IEQ in schools, which concludes that IEQ can have a profound impact on students' cognitive function and performance. But optimizing the environmental quality of schools involves much more than air sensors. A holistic master planning process enables clients to think beyond a bare-bones conditions assessment approach to think comprehensively about building performance. This was exactly what occurred at the Barrington School District 220 in Barrington, Ill.

The following case study gives a full overview of the survey, study, and results of this process documenting 12 schools and an administrative building to qualify and quantify the holistic building performance. Our client's "report card" measured energy performance, thermal comfort, indoor air quality, visual comfort, and acoustical satisfaction.

"DLR Group has done an outstanding job reviewing all aspects of our facilities with special attention related to sustainability and creating the ideal learning environment for our staff and students."

> Dr. Brian Harris, superintendent of schools, Barrington School District 220

Innovative Process for Holistic Master Planning

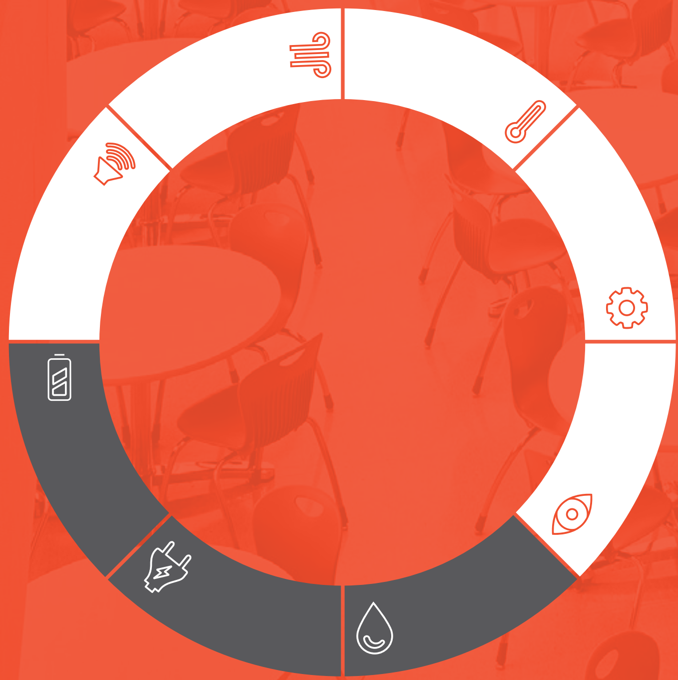
We began the process by documenting 12 schools and an administrative building with a grading system for the following elements:

- Building structure
- Electrical
- Exterior appearance
- Fire/safety/ADA Roofing
- HVAC
- HVAC controls
- Interior finishes
- Interior structure
- Pumping
- Roofing
- Site
- Technology

We also engaged teachers and students in the process by encouraging their interaction with the on-site data-logging equipment, making this a true learning opportunity.

Next, we further qualified and quantified the holistic building performance through similar grading system for:

- Acoustical satisfaction
- Energy performance
- Indoor air quality
- Thermal comfort
- Visual comfort



High-Performance Design Indicators

SUBJECTIVE
- Acoustical Comfort
- Indoor Air Quality
- Thermal Comfort
- User Functionality
- Visual Comfort

OBJECTIVE
- Energy Consumption
- Energy Demand
- Water Usage

Energy and Water

For energy performance and water consumption, we analyzed utility bills to establish a resource-consumption-per-square-foot baseline as an apples-to-apples comparison between buildings. This allowed district representatives to understand their unique energy performance, and to distinguish which buildings would benefit most from energy efficiency upgrades, or a more extensive retro-commissioning program.

Indoor Environmental Quality

According to ENERGY STAR® reports, the median energy use intensity (EUI) level for a K-12 school in the U.S. is 114 kBtu/SF. Facility managers focus on reducing this level of energy consumption but a low-energy building does not necessarily mean that the building is habitable. Buildings in this district have varying mechanical cooling capacities, which could favorably skew energy performance metrics. By establishing the indoor environmental quality grades, we took a two-pronged approach to gather qualitative and quantitative information on the school IEQ. Specifically, we looked at buildings as a whole, but we accomplish this by focusing on IEQ within the main areas of a building. And for schools, the classroom is integral to functionality of this building type, and the space where we focused our study.

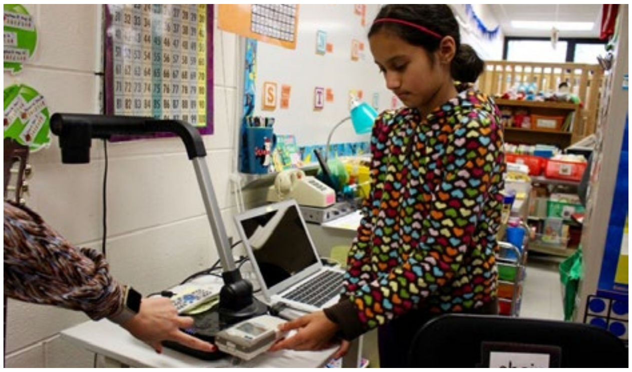
Qualitative: A district-wide IEQ satisfaction survey issued to all employees (including teachers, administration, support, and maintenance), gave everyone an equal voice to share their perceptions of the space in which they spend the majority of their working life. Using a little friendly competition between schools with the most responses, we gamified survey participation to boost survey response rates significantly.

The survey was open for two weeks and we received 566 responses which were categorized into four key comfort factors: acoustic, air, thermal, and visual. This survey, coupled with the IEQ quantitative data, resulted in a holistic understanding of the district's capital assets.

Quantitative: Using our Building Walkthrough Workbook that builds on the U.S. Department of Energy's Advanced Energy Retrofit Guide for K-12 Schools, we identified representative classrooms from each building in which to place IEQ equipment. We observed "point-in-time" spot measurements via monitors tracking temperature, relative humidity, CO_2, PM2.5, and TVOC over a data collection period of 72 hours per room. Additional qualitative observations were recorded in the workbook, such as:

- Do walls reach all the way up to the roof deck?
- What is the fraction of windows on the external walls?
- Are there any window dressings?
- Is the flooring material hard surface or soft surface?

Over the years, we have intentionally simplified our process so that students could follow it as part of their science classes, and tested this idea at Barrington. Students at each facility, selected by teachers, assisted with the walk through procedure and took advantage of this unique STEM-crossover, project-based learning opportunity.



We chose representative classrooms from each building in which to do our testing, taking a sample as a representation of the entire building. Separate classrooms were chosen if there were different HVAC systems, or an addition to the building.

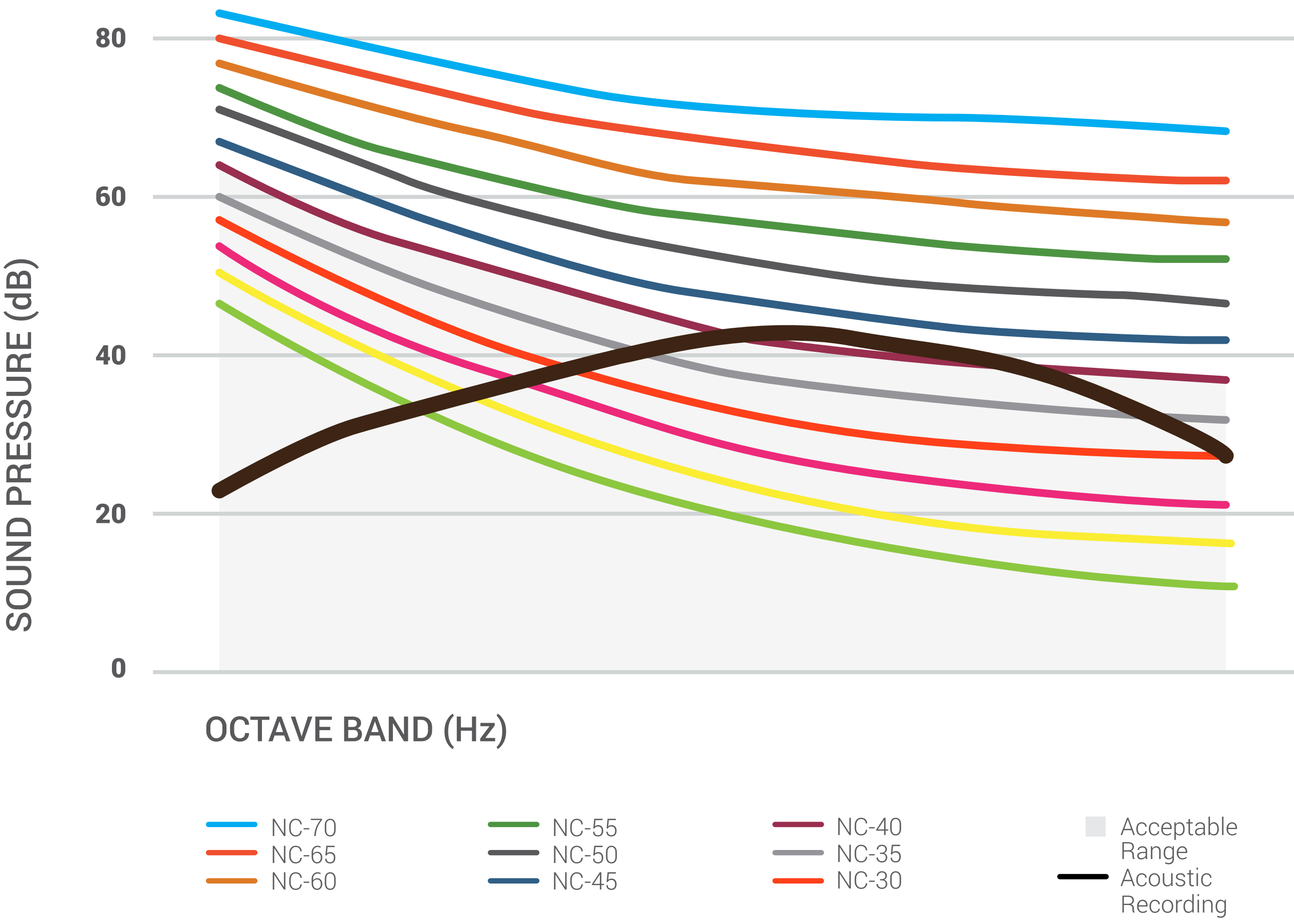
Students moved data loggers to each focus classroom, following a schedule provided by our engineering team. In each classroom, they recorded additional observations in their workbooks. Spot measurements also recorded light levels, VOCs, and background decibel levels in each focus classroom.

Once the survey, workbooks, spot measurements, and logging were complete, we compiled all data into a master grading tool, along with the basic site measurements and resource consumption results. The grading tool algorithms, written for industry standard requirements, generate IEQ grades for acoustical satisfaction, indoor air quality, thermal comfort, and visual comfort.

We quickly identified trends in survey responses and found a corollary relationship between physical complaints and the indoor environment, which identified unexpected causes of discomfort. For example, low satisfaction in visual comfort occurred most frequently when responders also noted a lack of access to daylight, and/or a lack of artificial light switch options.

Images: An example of a library with distant access to daylight (L) and a study lounge with immediate access to natural light (R).

Noise Criteria Graph



**NC = noise criteria*

Key Findings

The district-wide IEQ survey results fell into the four key findings categories: Acoustics, Air Quality, Daylighting, and Thermal.

> The most popular causes of distraction included noise from fans, or other air conditioning equipment, and noise from adjacent spaces.

Acoustics

Our IEQ survey results found a number of factors impacting acoustics. Most notably, noise from adjacent space, outside noise, mechanical equipment noise, and a series of acoustical characteristics in each room affect how sound travels throughout the district's buildings.

- Survey Findings: There were no trends indicating acoustical dissatisfaction in the multiple-choice questions, but many comments from high school occupants indicated that teachers were not conducting classes as they desired due to concern that moving furniture would disrupt classes in adjacent spaces.

- Data Collection Findings: A building walk-through with a decibel meter quantified the noise criteria of all classrooms to be around 35 NC, which is the industry standard recommendation.

Furniture was extremely heavy and moving it caused the noise criteria to almost triple.

During our time shadowing student learning, we observed teachers limiting movement in the high school classrooms so as not to disrupt adjacent spaces. As a result, further testing at the high school found that furniture was extremely heavy, and moving it caused the noise criteria inside that classroom and adjacent classrooms to almost triple with the movement of only one chair. We also measured the quantitative impact of putting tennis balls on chair legs, as some teachers had done, which significantly reduced the acoustic disruption.

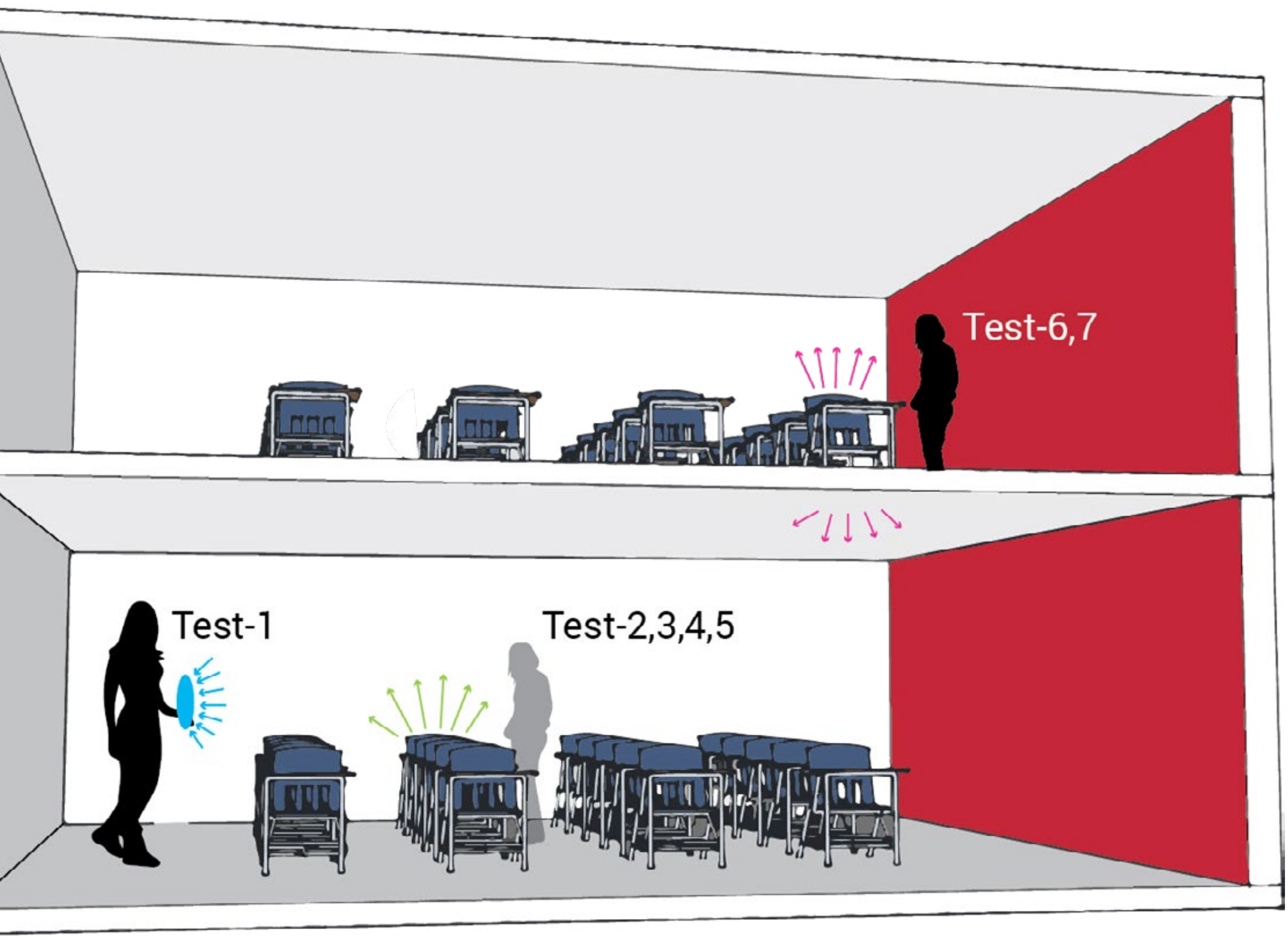


Image: Chair Tests 1-7.

- Outcome: The district was able to demonstrate a need for new furniture in the high school that facilitates flexible teaching and learning spaces.

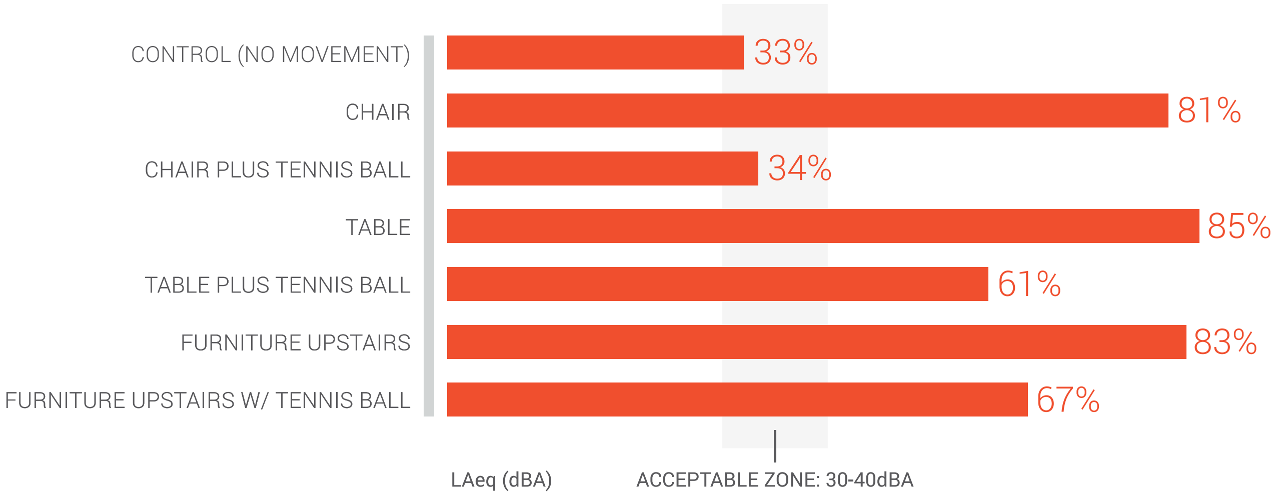
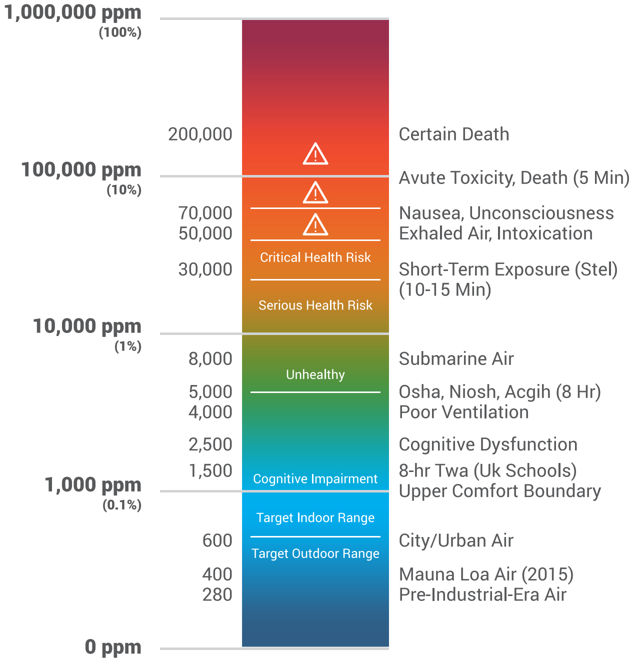


Image: Example of a student space with up to date furniture.

CO2 Hazard Scale



Air Quality

Carbon dioxide concentration often acts as a proxy for ventilation adequacy. The concentration of carbon dioxide in outside air is approximately 400 PPM and industry standard internal thresholds recommend a maximum of 1200 PPM. Beyond these levels, the brain begins to go into sleep mode, which can have a profound impact on cognitive function. Recent studies have quantified this based on decision-making ability, summarized in the graphics below.

- Survey Findings: Most occupants did not record strong satisfaction or dissatisfaction with their air quality. Of all complaints, stuffiness was the most popular – especially in summer. Common health complaints were headaches, dry hands/itchy skin, and respiratory irritations.
- Quantitative: The air quality in this district received better-than-average results. All buildings tested for volatile organic compoundswere at negligible levels throughout. One building received an initially high reading but, on further analysis, we determined the readings were conducted during an art fair where the art supplies produced VOCs from off-gassing.

Impact of CO2 on Human Decision-Making Performance

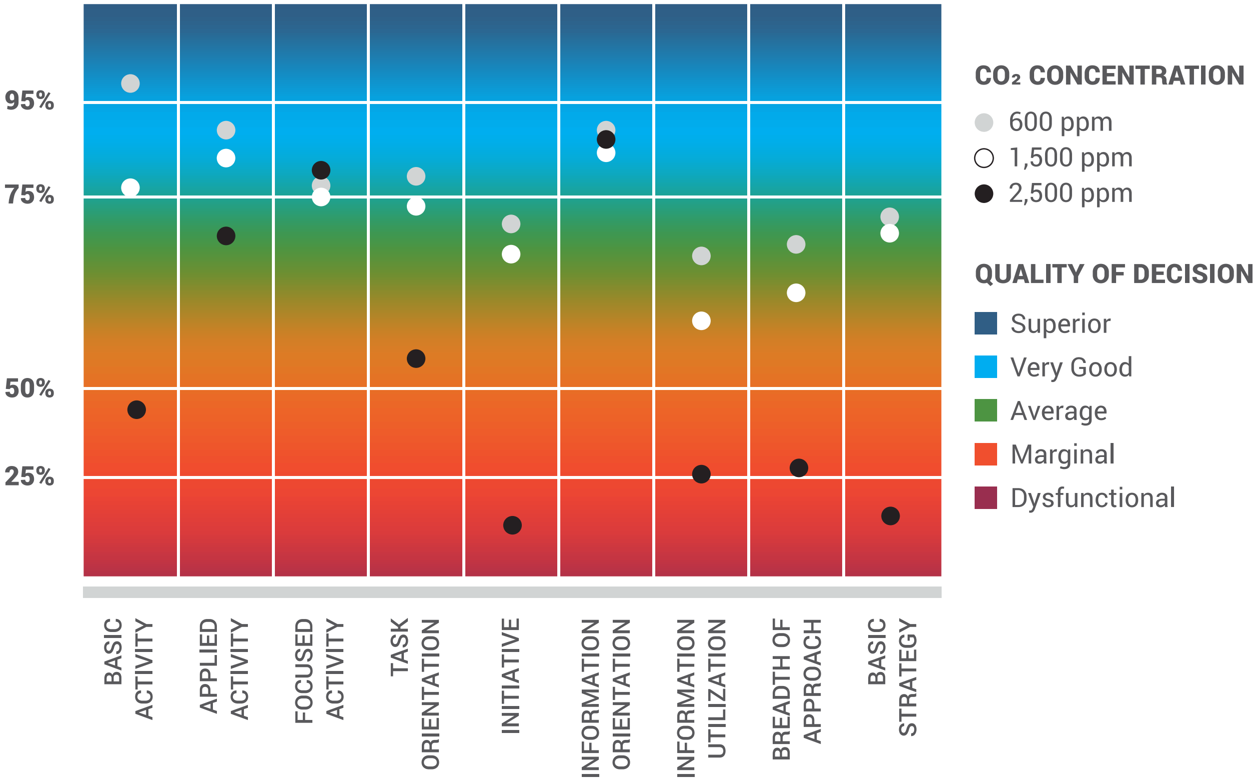
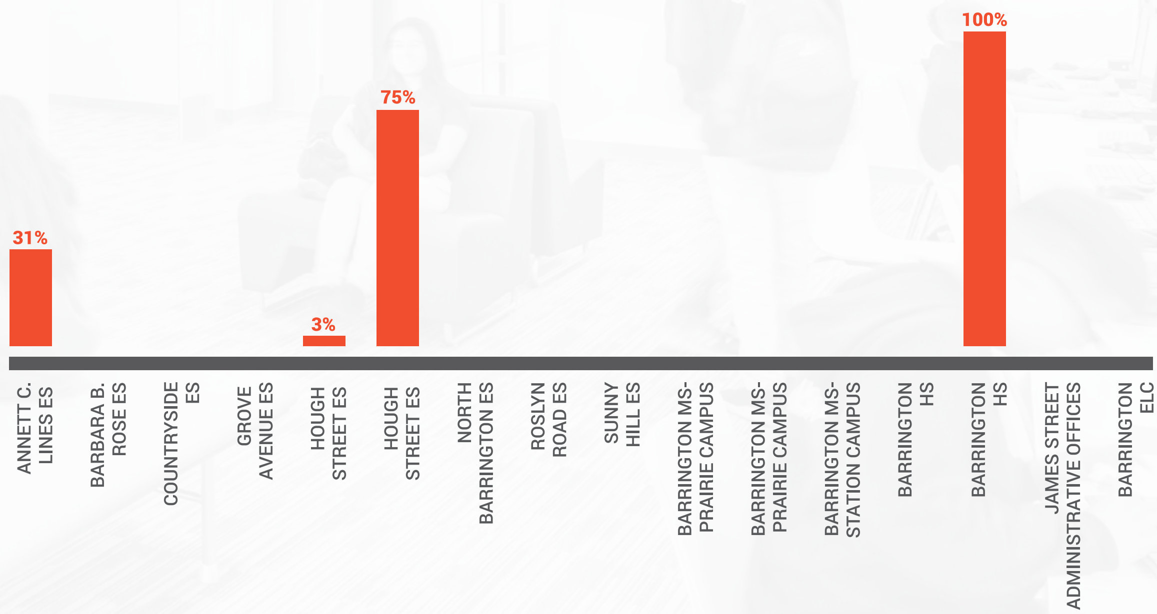


Image credit: Buildera

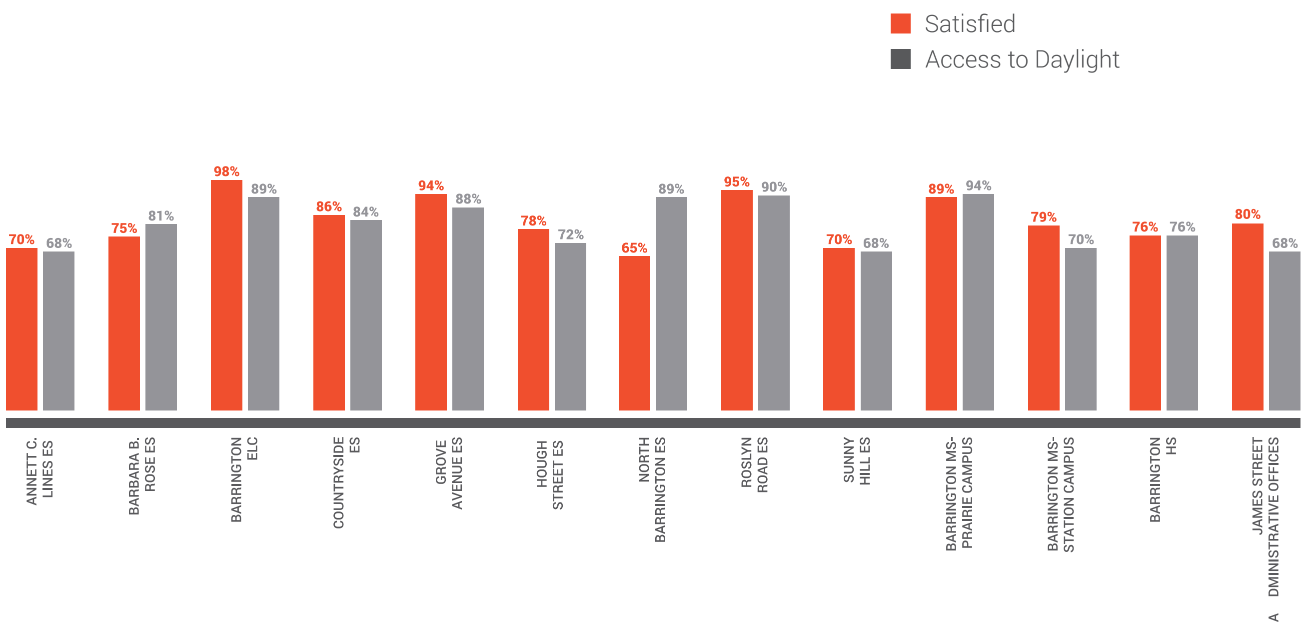
Percentage of Occupied Time When Carbon Levels Exceed 1200 PPM



Three buildings at approximately 3000 PPM exceeded ASHRAE 62.1 Ventilation for Acceptable Indoor Air Quality Standards, which specifies 800 PPM plus ambient. The district immediately revised damper positions to ensure a CO_2 level of no more than 1200 PPM at all buildings. This amendment is typically a low-cost or no-cost solution.

- Outcome: The necessary mechanical systems were in place to ventilate classrooms adequately. However, the district simply needed to revise its outdoor air damper position. Modifying this to meet ventilation needs was completed immediately, and classroom CO2 levels were brought down to below ASHRAE thresholds.

Percentage of Satisfied Occupants with Access to Daylight



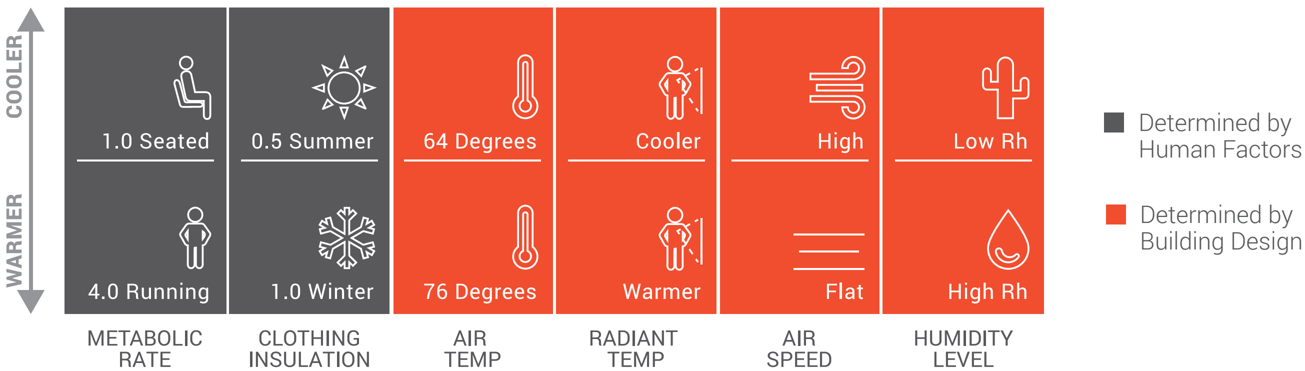
Of the 80 percent of respondents who have access to daylight, 80 percent are satisfied with their visual environment.

Daylighting

According to a recent report by the World Green Building Council, 27 percent of U.S. schools have inadequate lighting. Beyond artificial light, access to daylight counteracts disruption to circadian rhythms by the amount of time spent indoors. Misaligned circadian rhythms can cause serious health issues, including sleep disruption. Our study of the school district's light found the following:

- Qualitative: Of the 80 percent of respondents who have access to daylight, 80 percent are satisfied with their visual environment.
- Quantitative: Light levels were satisfactory. Some spaces generated higher light levels than required due to replacement of fluorescents with efficient LED bulbs.
- Outcome: Areas with too much light are scheduled for de-lamping, which will involve removing some of the LED bulbs from light fixtures to return light levels to the illumination necessary for the task conducted in the space. This will also save the district energy dollars.

Thermal Comfort Factors



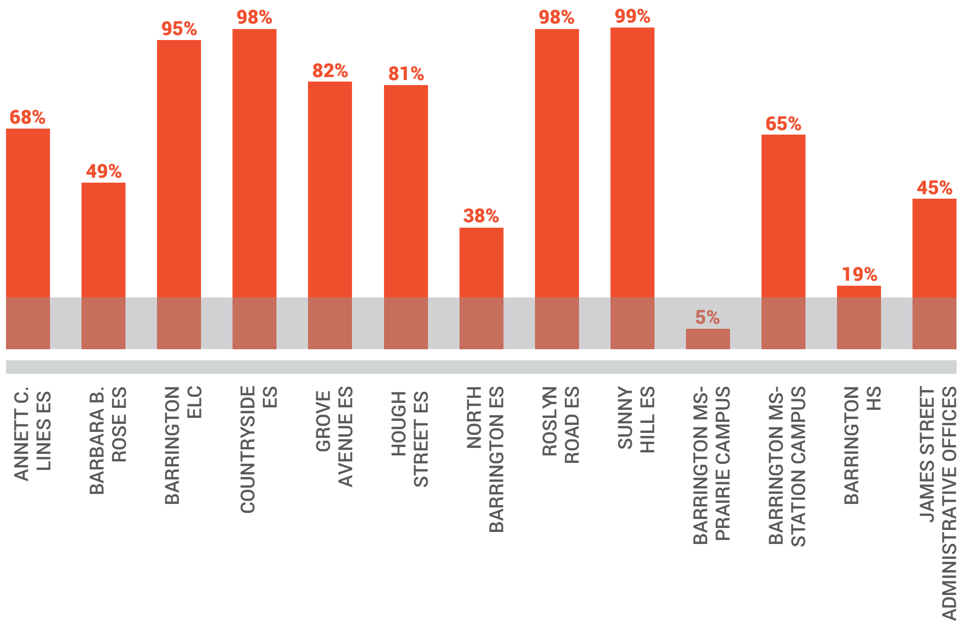
Thermal

Six factors influencing thermal comfort were determined by occupant variables such as clothing level, activity level, or metabolic rate. Other factors are determined by building design such as air temperature, radiant temperature of all surfaces, air speed, and humidity. Factors assigned by occupancy are typically out of our control, while the four factors determined by building design change due to seasonal fluctuations in temperature and humidity, as well as building condition and age.

Occupants generally have varying ranges of comfort preference. ASHRAE did extensive survey on workplace environments finding 10 percent dissatisfied which is considered acceptable. Anything beyond that level is cause for concern. Thermal dissatisfaction is subjective and studies have shown that a temperature change as small as 1 degree Fahrenheit can have an impact on student performance.

The concept of thermal comfort has received a significant amount of media attention over recent years as clothing varies between men and women, leading some to believe that the 70- 75 °F-typical air temperature set point focuses unfairly on the male suit-and-tie dress code. To account for this, clothing insulation levels of occupants were recorded in occupant surveys to calculate the ideal temperature set point based on actual clothing levels.

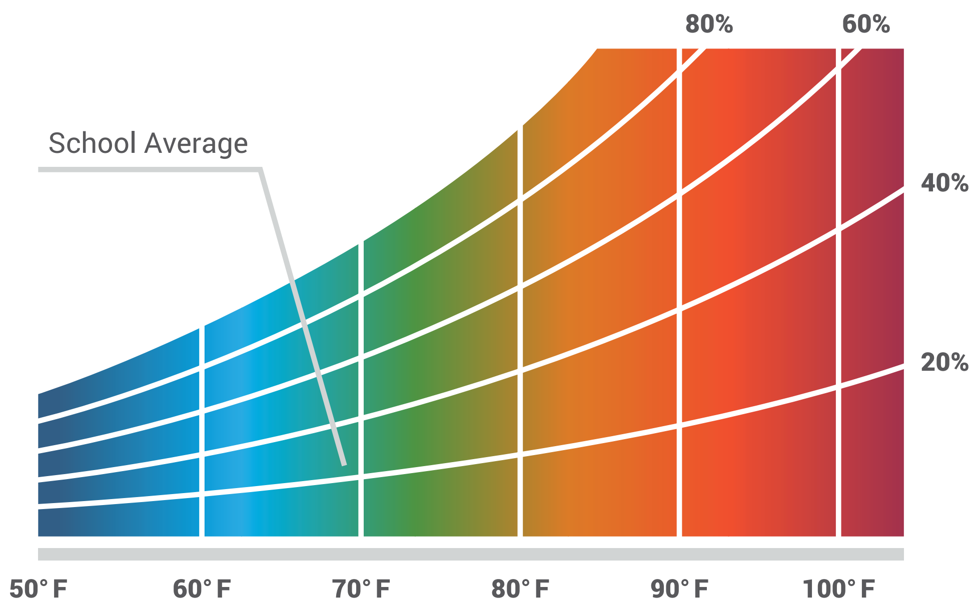
Percentage of People Dissatisfied with Thermal Comfort



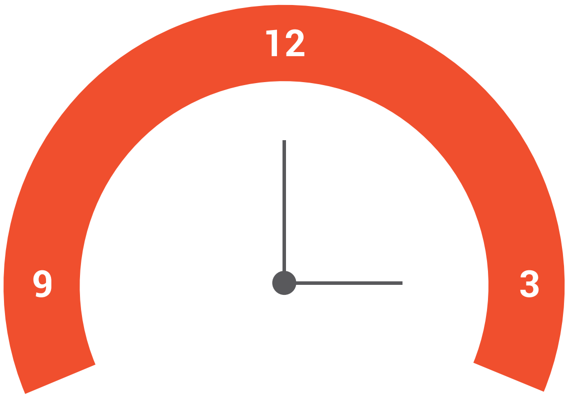
Barrington Survey Findings: On average, 65 percent of occupants are dissatisfied with their thermal environments, with more complaints in winter due to drafts and uneven temperatures.

- Data Collection Findings: Dry bulb temperatures measured across the District were lower than typical set points of 70- 75°F, averaging at 68°F, which was a conscious decision made by the district to save energy. ASHRAE Standard 55 Thermal Environmental Conditions for Human Occupancy recommends operative temperatures range between 60- 80°F depending on occupants' activity and clothing levels. Based on industry standards, this was not seen as a cause for concern.

Psychrometric Chart



Recorded Temperature



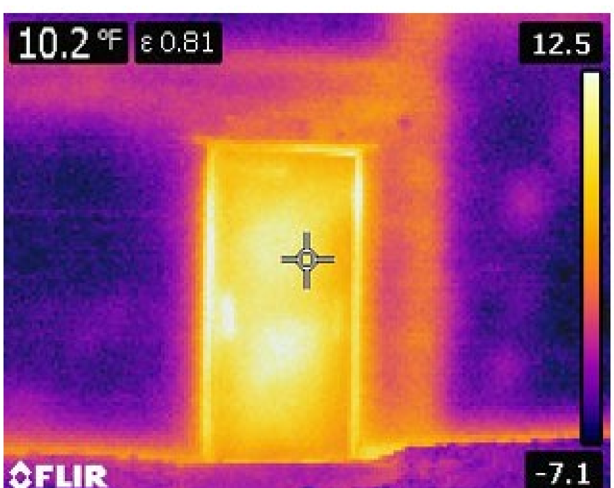
TIME & TEMPERATURE

9:00	-	61.0°F, 25.2 RH
10:00	-	62.1°F, 24.9 RH
11:00	-	61.6°F, 25.7 RH
12:00	-	63.8°F, 26.8 RH
1:00	-	66.4°F, 26.5 RH
2:00	-	67.5°F, 26.6 RH
3:00	-	68.1°F, 26.2 RH

The high school, specifically, recorded a large range of variation in temperatures, initially attributed to a number of additions to this building, and ranging ages of HVAC systems. On further analysis, the HVAC systems were able to meet an optimal set point, but required an earlier morning warmup, as buildings reached set point when students were heading home for the day.

In other schools with a high number of thermal comfort complaints, temperature readings hit the recommended set points. However, numerous elements in addition to temperature affect thermal comfort, including humidity, air speed, and mean radiant temperature of surfaces. Thermal imaging identified areas of missing or damaged insulation causing temperature asymmetry; cold spots where moisture may have penetrated a wall; thermal bridging issues at doorframes; or insufficient seals causing air drafts.

Outcome: Where dry bulb temperature set points were less than 68°F, the facilities team revised the HVAC sequence of operation to ensure the system met this set point. This was a low- to no-cost measure driven solely by the data collection process. More long-term solutions for temperature asymmetry will be incorporated into the District's future capital planning.



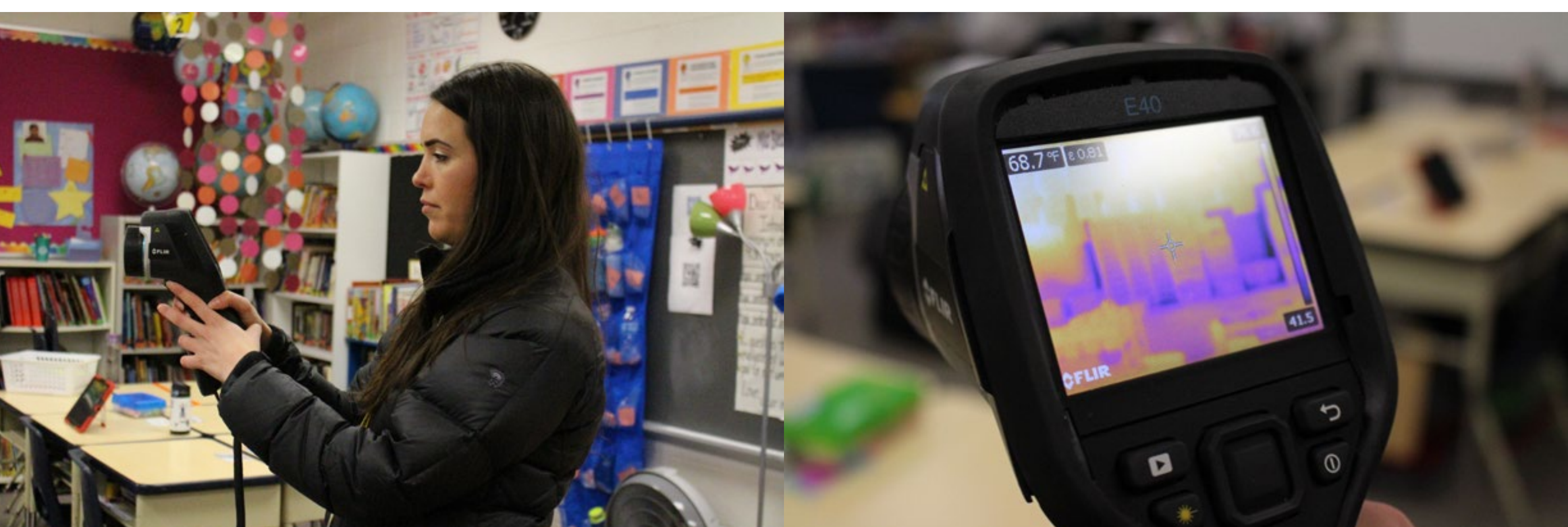
Images: Thermal imaging determined sources of drafts and/or discrepancies in envelope thermal resistance, which informed future maintence plans.

Towards Transparency

This comprehensive process helped the district make data-driven decisions on how to best use its maintenance budgets, and plan for future capital investments. These decisions are not up to the district leaders alone; it is determined by each member of the local community who votes on how to allocate local tax dollars. With that in mind, regularly hosting scheduled meetings to share findings with the community went a long way toward transparency between the district and its constituents. The district and its design team conducted one meeting per building, per phase, where we shared findings and potential solutions with attendees – a majority of which were parents, grandparents, and student guardians.

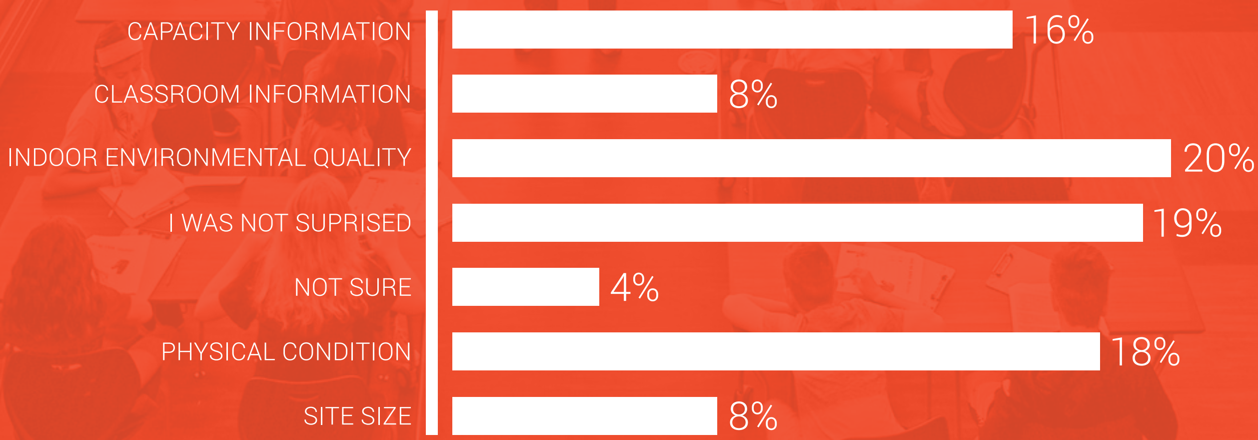
During each three-hour meeting, our IEQ results proved an important piece of the conversation – but not the only piece. Architects and engineers presented the story of each structure; teams shared their reflections from shadowing teachers and students in day-in-the-life activities; master planning experts shared how the building compares to industry standard space requirements; and evaluated how the building supported the district's learning model.

Sharing our findings in a digestible "scorecard" format helped meeting attendees think holistically about the future of their district to elevate the student experience through design. Judging by their survey responses, they found this extremely enlightening.



DLR Group conducted on-site thermal readings. Image by Shona O'Dea.

Survey Results: Most Enlightening Information of the IEQ Study



Pulling back the curtain on all things we cannot see equips everyone to better understand – and embrace – a more holistic approach to district planning.

The Value of Looking Behind the Curtain

Ultimately, while data, analysis, and recommendations play an important role in any holistic master plan to help clients make informed decisions affecting facility budgets, the greater value may lay in the deeper conversations that occur between agency and individual users. This kind of transparency and communication goes a long way in improving services for a community. Pulling back the curtain on all the things we cannot see equips everyone to better understand – and embrace – a more holistic approach to district planning.