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Increasing Personalized Comfort in Educational Environments with Quiet Air Movement

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INTRODUCTION

When architects and engineers collaborate to design new or renovated educational spaces, occupant comfort is a critical component of the project's success. Traditionally, complex HVAC systems are designed to achieve thermal comfort in part by minimizing differences in air temperature between each space served by the system. This is done by a variable flow system that moves air from air handlers to rooms via duct work, which can result in increased background noise from HVAC blowers, motors, and air whistling through the ducts. Room-to-room noise transfer through the ducts can also be problematic in adjacent spaces. In addition, even the best systems age quickly and are often poorly maintained, creating the potential for even greater noise levels over time.

Balancing personal comfort and favorable acoustics is particularly important in educational environments, where students must clearly hear their teacher's instructions. Studies have shown that excessive background noise can have a detrimental impact on student performance[i], and have demonstrated a clear link between personal comfort, productivity, and attentiveness[ii]. Building designers of educational spaces are challenged to increase occupant thermal comfort without significantly increasing the background noise levels. This paper explores a potential solution to this challenge by increasing air movement using ceiling fans.

FIELD TEST

To explore whether air movement from fans could positively impact personal comfort without significantly increasing background noise levels, a field test was conducted in conjunction with Big Ass Solutions at the Lexington Hearing & Speech Center (LHSC) in Lexington, Kentucky. LHSC is an educational center for children six weeks to six years old with hearing, speech, and language impairments. Many LHSC students use hearing aid devices or are otherwise sensitive to even subtle audible sounds, so favorable room acoustics are critical.

LHSC is located in the former J.R. Ewan Elementary School. The school is located in an established residential neighborhood and faces a secondary artery road. The 1937 building is a two-story, masonry, load-bearing structure with insulated replacement aluminum windows.

Three first-floor classrooms, ranging in size from 504 to 638 square feet, were selected as test spaces. Each space has one exterior wall and a 9'6" dropped acoustical ceiling. The HVAC system supplies and returns air though ceiling-mounted diffusers in each room. Multiple Haiku fans (commercial, 3-airfoil, 60-inch, EC motor ceiling fans) by Big Ass Solutions were ceiling mounted in various numbers and configurations in each classroom.

Figure 1: Lexington Hearing & Speech Classroom 100

Data was collected Tuesday through Friday over a period of five weeks in September and October 2014. During weeks one, three, and five, the fans were run at speed 3 (of 7) to provide air movement without causing unnecessary drafts within the space. During weeks two and four, the fans were turned off completely. In each space, two data logging systems were placed at a minimum of 3’6” above the floor to be out of the reach of small children. Temperature and relative humidity were logged at 60-second intervals during the five-week test. Air speed was also measured at three different heights (24, 43 and 67 inches above the floor) in both horizontal and vertical directions at various points within each room. After field tests were completed, air velocity was measured with both the fans on and off while the rooms were unoccupied. The diagram below (Figure 2) shows the locations of the fans (yellow circles), data collection points (orange and green dots), and furniture and other built-in equipment (blue and grey blocks).

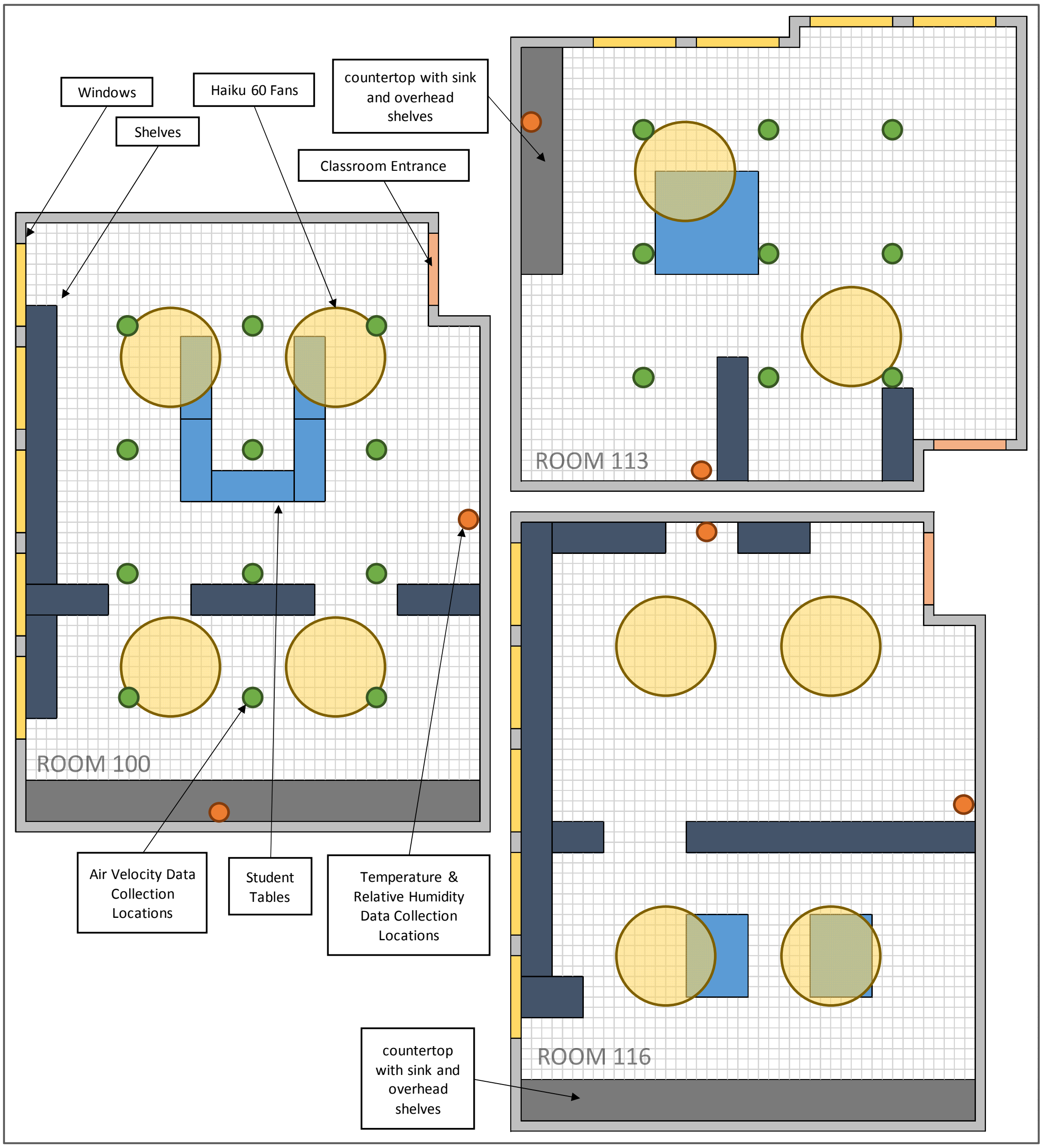

Figure 2: LHSC Room layouts with data logger placement and data collection locations

Throughout the five weeks of data collection, a teacher in each of the three classrooms completed a survey every Monday, Wednesday, and Friday between the hours of 3:30 and 4:30 p.m. The survey contained a variety of questions to gauge their perceived thermal comfort based on ANSI/ASHRAE Standard 55-2013[iii].

Each classroom was occupied by approximately eight to twelve children between the ages of one and six, and one to two teachers. The classrooms were typically occupied by the students and teachers between the hours of 8 a.m. and 5 p.m. The data collected between the hours of 7:30 a.m. and 5:30 p.m. was used in the analysis portion to represent a typical occupied day.

ACOUSTIC STUDY RESULTS

Acoustical data was collected at 7:30 p.m., after the building had been vacated by the majority of the occupants. Ambient noise levels were collected while the commercial, 3-airfoil, 60-inch, EC motor ceiling fans were on (at speed setting 3) and off. Acoustic pressure (dBA) was measured across the frequency (Hz) range (-30 to 70 dBA) and is shown in Figures 3 and 4, below. The orange line is the baseline acoustic frequency with the fans off. The green line represents the acoustic frequency with the fans on.

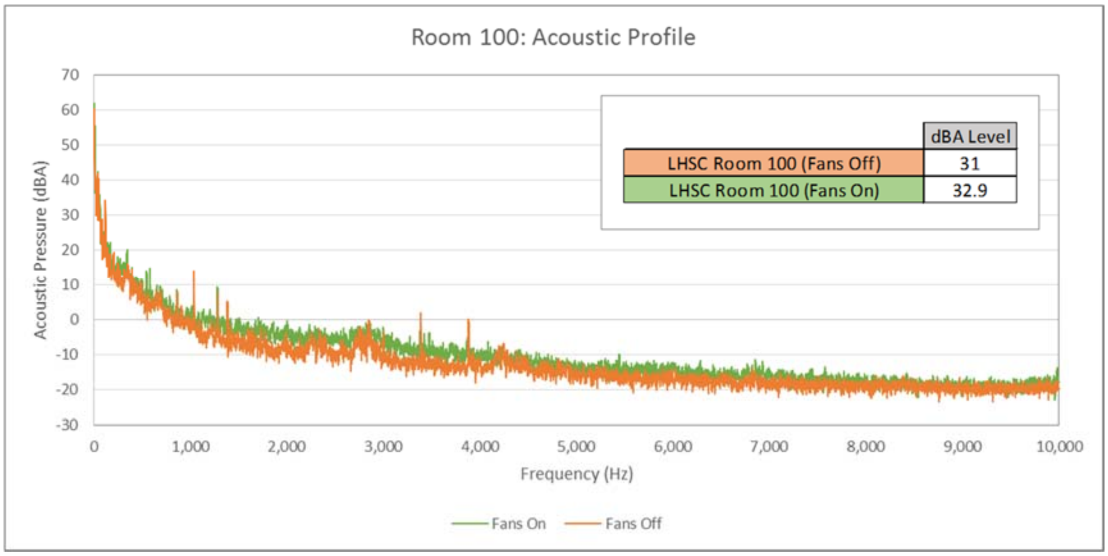

Figure 3: Acoustic Data from Room 100

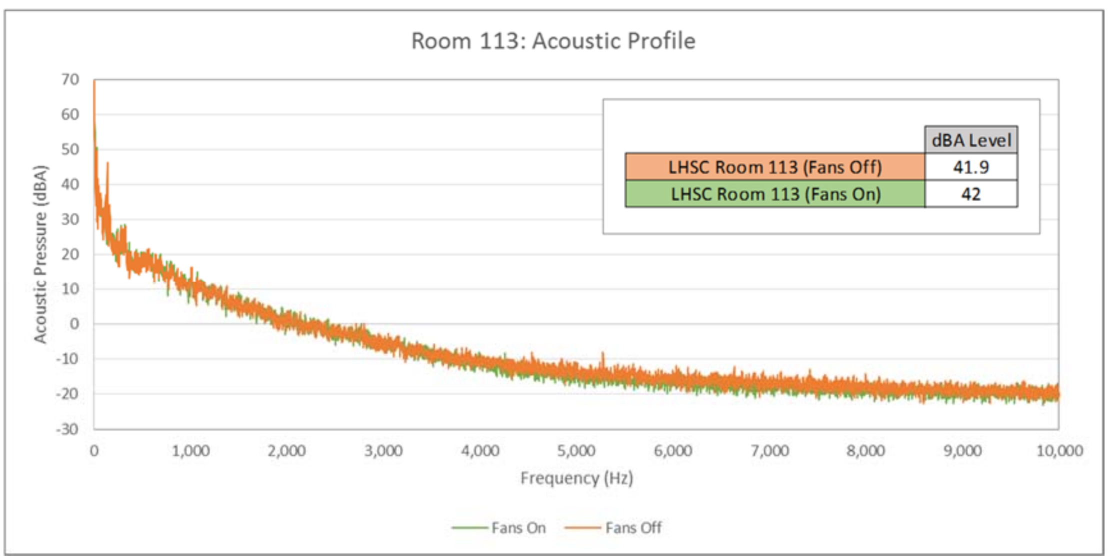

Figure 4: Acoustic Data from Room 113

In Room 100 (Figure 3), the mean background noise level with the fans off was 31 dBA. With the fans on, the noise level was 32.9 dBA—a difference of only 1.9 dBA. A difference of 1 dB is imperceptible to the human ear. When a difference of 3dB is reached a barely noticeable change in decibel level can be distinguished[iv].

In Room 113 (Figure 4), the background noise level with the fans off was 41.9 dBA. With the fans on, the noise level was 42.0 dBA—a difference of only 0.1 dBA, which is completely imperceptible to the human ear.

In both cases, the operation of commercial, 3-airfoil, 60-inch, EC motor ceiling fans in LHSC rooms had a negligible impact on the sound level to which students and teachers in each room were exposed.

PERCEIVED COMFORT TEST RESULTS

This study also considered perceived thermal comfort as a component in evaluating the fans in classroom spaces. This was measured by a survey of teachers on Monday, Wednesday, and Friday each week, measuring their perceived thermal comfort with the fans on and off. The survey was based on established questionnaires produced by ASHRAE Standard 55, and included questions about thermal sensation, type of clothing worn, daily activity level, and outdoor weather conditions.

Internal room temperatures and relative humidity levels were also recorded during the study. The recorded temperatures between the classrooms varied by an average of five degrees during occupied hours. This range in temperatures shows the differences between the microclimates of each room. The temperature variations are largely caused by the building's aging HVAC control system, which has trouble maintaining consistent temperatures across the structure. In this case, the introduction of commercial, 3-airfoil, 60-inch, EC motor ceiling fans gave each teacher greater control over his or her thermal comfort based on the temperature and relative humidity of the space.

While perceptions of thermal comfort are subjective, study findings indicated a greater level of comfort when the fans were in use. On most days, the 53-year-old teacher in Room 116 wore shorts and a polo shirt (0.5 clo), and reported high levels of daily activity. As shown in Figure 5, below, she reported feeling hot when the fans were off, reaching a point of unacceptable thermal comfort. When the fans were on, she reported feeling cooler, achieving an acceptable level of thermal comfort. The average daily temperature in room 116 was 69°F, with less than a 2°F swing.

The teacher in Room 100, age 36, typically wore a mixture of tee shirts and long-sleeved shirts with long pants (0.57-0.61 clo), and reported a relaxed to light level of average daily activity. Her thermal sensation was slightly cooler with the fans both on and off. The average daily temperature in her room was 70°F with a 3 – 4°F swing.

The teacher in Room 113, age 32, wore mostly tee shirts and long pants (0.57 clo), and reported a high level of daily activity. Her thermal sensations were also slightly cooler with the fans both on and off. Her room experienced an average daily temperature of 65°F with a 2 – 3°F swing.

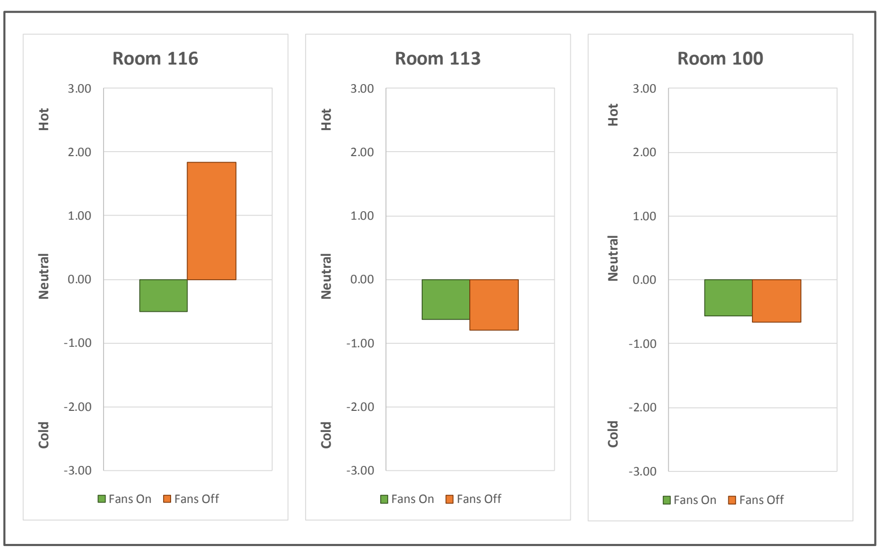

Figure 5: Thermal sensation

Air velocities in Rooms 100 and 113 were measured at three different heights, with the fans on (Figure 6, left table) and off (Figure 6, right table). This figure shows that with the Haiku fans on, there is not only greater air movement within the room, but the air movement is also more uniform.

Average Room Air Velocity at Speed 3 (fpm)		
Height & Direction	Rm. 100	Rm. 113
67" Horizontal	41.0	28.7
67" Vertical	42.9	32.3
43" Horizontal	40.8	25.0
43" Vertical	40.5	25.0
24" Horizontal	36.3	24.6
24" Vertical	33.4	16.8

Ambient Air Velocity With Fans Off (fpm)		
Height & Direction	Rm. 100	Rm. 113
67" Horizontal	0.0	10.0
67" Vertical	2.0	21.0
43" Horizontal	0.0	12.0
43" Vertical	1.0	10.0
24" Horizontal	15.0	9.0
24" Vertical	15.0	9.0

Figure 6: Air Velocity Measurements in Room 100 and Room 113

CONCLUSION

It is well documented that favorable acoustics in academic environments are critical to the development of children with normal hearing, as well as those with hearing loss or other hearing-related disabilities. Excessive noise levels can be detrimental to a student's speech perception, reading and spelling ability, behavior, attention, concentration and academic performance[v]. There is also evidence that poor acoustics can have an adverse effect on a teacher's performance, and can cause vocal pathologies and absenteeism in teachers[vi].

Two of the three key standards for appropriate acoustical levels in classrooms are set forth by the American Speech-Language-Hearing Association's (ASHA's) Working Group on Classrooms Acoustics:

1. The unoccupied classroom levels shall not exceed 35 dBA.
2. The signal-to-noise ratio ("SNR", the difference between the teacher's voice and the background noise) should be at least +15 dBA at the student's ears.
3. Unoccupied classroom reverberation must not surpass 0.6 seconds in small classrooms or 0.7 in larger rooms.

These standards have also been adopted by the American Standards Institute (ANSI) in their standard ANSI S12.60-2002 Acoustical Performance Criteria, Design Requirements and Guidelines for Schools. The third standard was not a focus of this study, since the existing materials in the room were not altered. The spaces tested already had acoustical panel ceiling and carpeted floors to minimize reverberation.

Based on the standards identified above, a difference of 1.9 dBA in Room 100 and 0.1 dBA in Room 113 shows that commercial, 3-airfoil, 60-inch, EC motor ceiling fans produce indistinguishable sound, and have little to no impact on classroom noise levels. This is particularly important when designing or renovating classrooms, since mechanical noise accounts for the highest percentages of noise complaints.

HVAC systems can generally be divided into two categories: 1) A central system with a large air handling unit that serves several classrooms, and 2) Individual units, like wall unit ventilators, that serve a single room. In both cases, the use of quiet ceiling fans can provide air movement within a room to allow for acceptable thermal comfort at higher thermostat setpoints. Higher setpoints help reduce the amount of time the HVAC units run, thereby minimizing the classrooms' largest sources of background noise.

Based on the survey results from these three teachers, it is clear how varied individual thermal preferences can be. Additionally, the recorded internal room temperatures show that each room has a drastically different microclimate. A study by D. Hawkes found that energy efficiency was improved when people were given individual control of their environment, because energy is more tailored to individual needs rather than the need for building uniformity[vii]. With the introduction of commercial, 3-airfoil, 60-inch, EC motor ceiling fans, occupants can personalize their thermal comfort level. Teachers that feel warmer can increase the speed of the fans to take advantage of the cooling effect of air movement, while others who feel cooler can decrease fan speed in their own classrooms.

The commercial, 3-airfoil, 60-inch, EC motor ceiling fans also allow building owners to increase thermostat setpoints school-wide because of the perceived cooling that fans provide. This increase in airflow provides an alternative method of cooling occupants while minimizing the use of the HVAC system and thereby reducing the noise level within each classroom. Fans can also be used to offset aging HVAC systems that struggle to maintain low temperature setpoints.

For designers of educational spaces, commercial, 3-airfoil, 60-inch, EC motor ceiling fans are a valuable tool to consider when designing a new project or renovating an existing space.

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