Sampling of Scientific Studies on Indoor Air

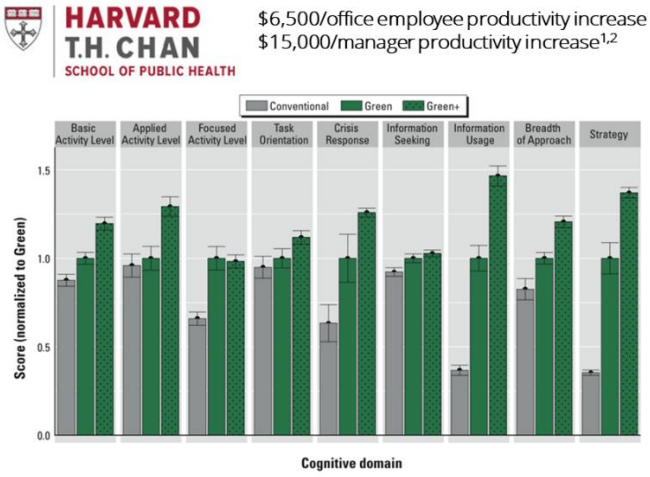
The following studies on work environments, schools, and outside air pollution represent a sample of the research on indoor air quality. The studies show the positive impact good air quality has on health, productivity, and cognitive performance. However, most of the studies focus on increasing ventilation to improve indoor air quality, which has significant economic consequences and raises energy consumption. Increased ventilation requires purchasing much higher capacity HVAC equipment, which costs more, takes up more space, and consumes much more energy. Furthermore, existing buildings often don't even have the heating or cooling capacity to increase outside ventilation.

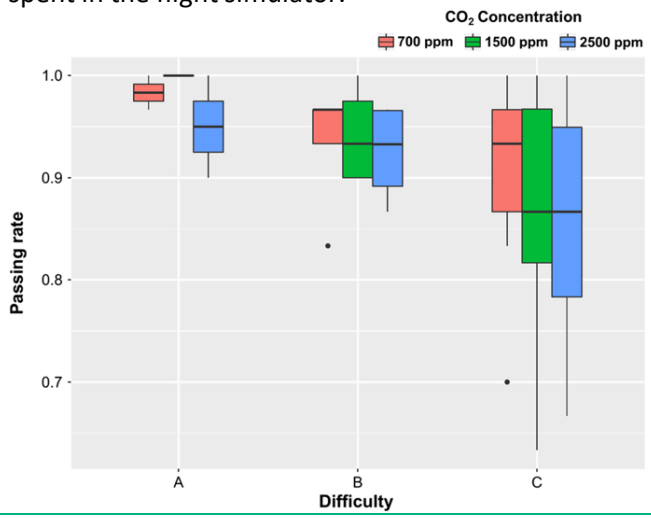
With buildings accounting for over 40% of total energy consumption and HVAC systems accounting for roughly half of that, higher ventilation rates significantly increase costs and the higher rate of energy consumption causes greenhouse gas emissions from power plants to rise. Furthermore, due to airborne pollutants, today's outside air isn't always "fresh air" and high volumes of outside air can be a problem for indoor air quality.

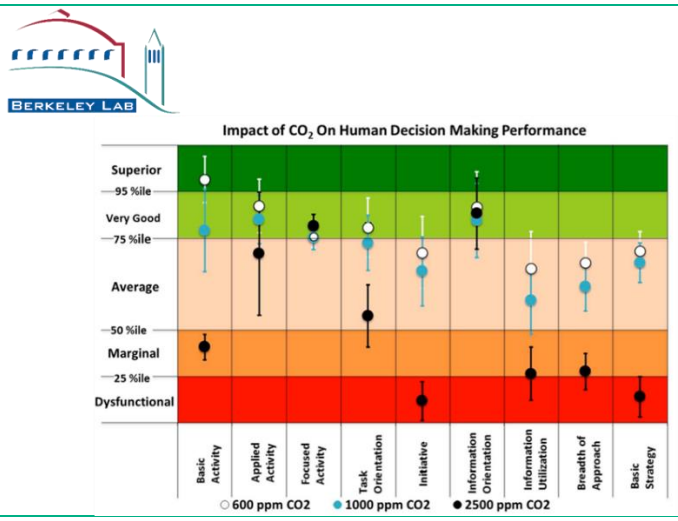
HLT technology, in contrast, saves money by reducing HVAC equipment size and cost, improves energy efficiency and thus reduces greenhouse gas emissions from power plants, and improves indoor air quality while lowering the intake of the polluted air outside. **It's a win, win, win for the building, owner, the tenants, and the earth.**

Air Quality Studies in Work Environments

The following studies show that indoor air quality has a direct effect on cognitive performance and productivity and that CO_2, once thought to be benign, negatively impacts cognitive performance and productivity.

Study	Study conclusions
"Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers" *Environmental Health Perspectives, vol. 124, 2016* Joseph G. Allen, Piers MacNaughton, Usha Satish, Suresh Santanam, Jose Vallarino, and John D. Spengler	This study by the Harvard T. H. Chan School of Public Health shows that cognitive performance can be improved 101% by reducing CO_2 and VOCs. Even reducing CO_2 alone can improve cognitive performance significantly independent of VOCs. 

"Airplane Pilot Flight Performance on 21 Maneuvers in a Flight Simulator Under Varying Carbon Dioxide Concentrations" *Journal of Exposure Science & Environmental Epidemiology, 2018* Joseph G. Allen, Piers Macnaughton, Jose Guillermo Cedeno-Laurent, Xiaodong Cao, Skye Flanigan, Jose Vallarino, Francisco Rueda, Deborah Donnelly-McLay, and John D. Spengler	This study by the Harvard T.H. Chan School of Public Health shows the detrimental affect CO2 has on the performance of airplane pilots. Pilots performed advanced maneuvers in a flight simulator with CO2 levels at 700 ppm, 1,500 ppm, and 2,500 ppm. At 700 ppm of CO2, Pilots were 69% more likely to receive a passing grade on a maneuver than they were at 2,500 ppm of CO2. They were 52% more likely to receive a passing grade on a maneuver at 1,500 ppm than at 2,500 ppm of CO2. The study also showed that the negative effects of the CO2 increased the longer the pilots spent in the flight simulator. 
"Is CO2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO2 Concentrations on Human Decision-Making Performance" *Environmental Health Perspectives, vol. 124, 2016* Usha Satish, Mark J. Mendell, Krishnamurthy Shekhar, Toshifumi Hotchi, Douglas Sullivan, Siegfried Streufert, and William J. Fisk	This study by the Lawrence Berkeley National Laboratory shows the detrimental effect CO2 has on decision making. The study measured performance across nine different areas of decision making under varied CO2 levels. Relative to their performance at 600 ppm of CO2, at 1,000 ppm statistically significant, but moderate decrements occurred in six of the nine scales of decision making performance. At 2,500 ppm, large and statistically significant reductions in decision making capability occurred in seven of the nine scales.

	
"Ventilation AND Performance in Office Work" *Indoor Air Journal, vol. 18, pp 28-36, 2006* Olli Seppänen, William J Fisk, QH Lei	This study from the Lawrence Berkeley National Laboratory and the Helsinki University of Technology analyzed a wide range of research on the subject of indoor air quality and determined that in almost all of the studies found increases in performance with higher ventilation rates.
"Perceived Air Quality, Sick Building Syndrome (SBS) Symptoms and Productivity in an Office with Two Different Pollution Loads" *Indoor Air Journal, vol. 9, pp. 165-179, 1999* Pawel Wargocki, David P. Wyon, Yong K. Baik, Geo Clausen, and P. Ole Fanger	This study from the International Center for Indoor Environment and Energy at the Technical University of Denmark demonstrated that the introduction of an air pollution source into an office environment negatively affected health, decreased attention to work, and reduced productivity. 22% of the subjects rated themselves as dissatisfied with the air quality when the pollution source was present and only 15% when it was absent. Furthermore, the prevalence of headaches increased (P=0.04) in the presence of the pollution source and subjects reported putting in lower levels of effort (P=0.02) during typing and calculation tasks. In the typing section, subjects worked significantly more slowly when the pollution source was present (P=0.003) and typed on average 6.5% less text. Reducing the pollution load on indoor air proved to be an effective means of improving comfort, health, and productivity.
"Estimates of Potential Nationwide Productivity and Health Benefits from Better Indoor Environments: An Update" William J. Fisk *Indoor Air Quality Handbook*, eds: J. D. Spengler, J.M. Samet, and J.F McCarthy, Chapter 4	This study by the Lawrence Berkeley National Laboratory reviewed a wide range of literature and research on indoor air quality and concluded that there is strong evidence to suggest that the characteristics of a building and its indoor environment significantly influence the occurrence of respiratory disease, allergy and asthma symptoms, sick building symptoms, and worker performance. Source of Productivity Gain | Potential Annual Health Benefits | Potential U.S. Annual S Gain (1996 $U.S.)

Reduced respiratory disease	16 to 37 million avoided cases of common cold or influenza	$6 - $14 billion	
Reduced allergies and asthma	10% to 30% decrease in symptoms within 53 million allergy sufferers and 16 million asthmatics	$2 - $4 billion	
Reduced sick building syndrome symptoms	20% to 50% reduction in SBS health symptoms experienced frequently at work by approximately 15 million workers	$15 - $38 billion	
Improved worker performance from changes in thermal	Not applicable	$20 - $200 billion	

Air Quality Studies in Schools

These studies found that poor IAQ results in health symptoms and lower student performance. It was also found that most schools do not have proper IAQ.

Study	Study conclusions
"Indoor environment in schools—Pupils health and performance in regard to CO2 concentrations" *Proceedings, Indoor Air '96: The 7th International Conference on Indoor Air Quality and Climate, vol. 4, pp. 369-371, 1996* Myhrvold, A.N., E. Olsen, and O. Lauridsen	This study shows that students in classrooms with higher levels of CO_2 were more likely to develop negative health symptoms. Students reported headaches, dizziness, tiredness, and difficulty concentrating at a higher rate when in classrooms with CO_2 levels between 1500 and 4000 ppm than in classrooms with CO_2 levels below 1000 ppm. Furthermore, students were able to respond more quickly to questions in classrooms with lower carbon dioxide levels. The scope of the study encompassed five school, 22 classrooms, and 500 pupils between the ages of 15 and 20.
"Indoor Air Quality at School: Ventilation Rates and It Impacts Towards Children - A Review" Naziah Muhamad Salleh, Syahrul Nizam Kamaruzzaman, Raha Sulaiman, Naziatul Syima Mahbob *2nd International Conference on Environmental Science and Technology, IPCBEE vol.6, pp. 418-422, 2011*	This study reviewed a wide variety of research in the field of indoor air quality to determine that most schools have inadequate outside air ventilation resulting in poor indoor air quality and that the poor indoor air quality is link to increased health issues and lower academic performance in students.
"Ventilation Rates in Schools and Pupils' Performance Using Computerized	This studied showed that students are likely to be less attentive and have more trouble

Assessment Tests" Zs. Bakó-Biró, N. Kochhar1, D.J. Clements-Croome, H.B. Awbi and M. Williams *11th International Conference on Indoor Air Quality and Climate 2018, vol. 6, pp. 3346-3354, 2008*	concentrating on instructions given by teachers in poorly ventilated classrooms. Changing the air exchange rate from 1.6±1.3 L/s per person to 6.8±1.4 L/s per person improved students' reaction time by 3%, picture recall memory 8%, and word recognition by 15%. The improvements were even more pronounced for tasks that require more complex skills such as spatial working memory and word recognition. The scope of the study encompassed eight schools, 16 classrooms, and over 200 students.
"Indoor Environmental Quality in Schools and Academic Performance of Students: Studies from 2004 to Present" R. Shaughnessy, PhD U. Haverinen-Shaughnessy, A. Nevalainen, PhD D. Moschandreas, PhD *IAQ 2007 Conference Proceedings*	This study demonstrates the correlation between increased ventilation and better tests scores in math and reading. The study considered one classroom in each of 50 schools.
"A Preliminary Study on the Association Between Ventilation Rates in Classrooms and Student Performance" R. J. Shaughnessy, U. Haverinen-Shaughnessy, A. Nevalainen, D. Moschandreas *Indoor Air 2006*, vol. 16, pp. 465-468, 2006	This study shows a connection the classroom-level ventilation rate and math test results. Data was gathered on CO_2 concentrations in fifth grade classrooms over a four to five-hour time span within a typical school day at 54 elementary schools. Comparing these readings to the math test scores of the students in the different classrooms resulted in a strong correlation between higher levels of ventilation and better math scores ($P < 0.1$).

How Outside Air Pollution Effects Health and Productivity Indoors

The following studies show how health and productivity is negatively affected by living or working in a building located in a metropolitan area, or near a highway, airport, or other highly-trafficked, pollutant-generating area.

Study	Study conclusions
"Association of Modeled Long-Term Personal to Ultra-Fine Particles with Inflammatory Coagulation Biomarkers" Kevin J. Lane, Jonathon I. Levy, Madeleine K. Scammell, Junenette L. Peters, Allison P. Patton, Ellin Reisner, Lydia Lowe, Wig Zamore, John L. Durant, Doug Brugge	The study by the Boston University School of Public Health, the National Institute of Environmental Health Sciences, and Tufts University indicates that those living within 1,5000 feet of a highway are at greater risk of cardiovascular disease than those living twice as far away.

Environment International, vol. 92-93, pp. 173-182, 2016	
"The Effects of Pollution on Worker Productivity: Evidence from Call Center Workers in China" Tom Chang, Joshua Graff Zivin, Tal Gross, Matthew Neidell *National Bureau of Economic Research Working Paper No. 22328, 2016*	This study by the National Bureau of Economic Research shows that higher level of pollution common to major cities has a detrimental effect on employee productivity. NBER National Bureau of Economic Research