Laboratory for Sustainable Business Final Report: Payette and Arup

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Introduction

Payette is a 150-person architecture and design firm located in Boston specializing in both healthcare and laboratory facilities and buildings. Payette primarily completes projects within the United States. Arup is a multinational engineering firm specializing in engineering, sustainability, and structural design. Payette and Arup (P&A) are focusing on research laboratories (labs) for this project.

P&A have collaborated on lab projects that incorporate sustainability in the past and aim to do so going forward. P&A believe labs are ideal opportunities for sustainability, as often labs are the most energy-intensive buildings on campus. P&A have designed and constructed labs with the following sustainability measures, including: energy efficiency (e.g., building envelope, HVAC), renewable energy, health, safety, air quality, and water.

Problem Statement

P&A have researched and quantified the paybacks and benefits associated with energy efficiency and environmental sustainability in buildings. As such, P&A are interested in understanding the potential impacts that sustainability may have on occupant wellness, community resilience, and employee engagement, specifically in the lab environment.

Our team researched green building benefits pertaining to employee productivity, health, absenteeism, and morale (intangibles). Throughout this project, we worked to expand the business case for sustainably designed labs by bringing forward research about the benefits of green design on the ancillary benefits such as productivity, morale, and absenteeism.

Obtaining reliable quantitative data that could characterize the business case for these softer attributes was a challenge we experienced during this project. Very little research about ancillary benefits has been conducted and it remains a research opportunity.

Methodology

To complete this project, our team completed the following activities:

1. Data Collection
    a. Materials Review: Reviewed the materials provided by P&A and created a baseline for analysis and project work.
    b. Literature Review: Completed a comprehensive review of literature available on the topic, summarized the results, and extracted best practices and recommendations.
    c. Surveys: Completed targeted surveys with 38 researchers who work in labs to understand behaviors and concerns.
2. Project Stakeholder Interviews: Interviewed P&A employees familiar with green technology and ancillary occupant wellness measures. Project Stakeholder interviews included:
    a. Andrea Love - Associate Principal & Director, Payette
    b. Hilary Williams - Senior Mechanical Engineer, Arup
    c. Rishi Nandi - Associate, Project Manager for Northeastern Interdisciplinary Science & Engineering Complex (ISEC)
    d. Mark Walsh-Cooke - Principal, Arup
    e. Chris Mackey - Building Scientist, Payette
    f. Charles Klee - Principal, Payette *(declined to interview)*
3. Subject Matter Expert Interviews (SME): Interviewed SMEs who lent perspective about occupant wellness in sustainable labs. The following people were interviewed, or stated that they were not the appropriate people to comment on our project:
    a. John Sterman - Professor, MIT Sloan, Director, System Dynamics Group
    b. Leon Glicksman - Professor of Building Technology & Mechanical Engineering
    c. Les Norford - Professor of Environmental Technologies, MIT
    d. Chris Marshall, Ph.D., Scientific Associate, Ontario Cancer Institute, University Health Network
    e. Catherine Gamon, MIT Sloan, Director of Student Life
    f. John Fernandez - Professor, MIT, Director, Building Technology Group *(declined to interview)*
    g. Grey Lee, Executive Director, US Green Building Council, Massachusetts Chapter *(declined to interview)*
    h. Harvey Michaels - Lecturer, MIT, Energy Efficiency *(declined to interview)*

Findings: Literature Review

Building characteristics that impact health and wellness are often the last design considerations for new projects (Walsh-Cooke, 2016). However, there are a few building standards that seek to integrate health and wellness metrics early on in the building design process. LEED and the WELL Building Standard (WELL) are the most well known standards that place an emphasis on these design principles (USGBC, 2016 & International WELL Building Institute, 2016).

WELL Building Standard

The International Well Building Institute (IWBI) first released the WELL Building Standard in October 2014 (International WELL Building Institute, 2016). The standard itself was the result of seven years of collaboration between “leading medical scientists and building industry practitioners” and aims to promote balance between the individual systems by reducing factors that may negatively impact human performance (International WELL Building Institute, 2013). According to the IWBI 90% of our time is spent within buildings (International WELL Building Institute, 2016). As such, incremental improvements in health and wellness can significantly improve productivity and morale. The methodologies and seven dimensions depicted on the WELL scorecard are presented in **Figure 1**.

Figure 1: WELL Scorecard (International WELL Building Institute, 2016)

On a daily basis, the seven dimensions—air, water, nourishment, light, fitness, comfort, and mind—affect one another and the different physical systems in the human body. The awarded WELL score is based on the interplay of these dimensions, which translates into metrics that rate the impact the building may have on occupants. **Table 1** outlines the WELL metrics, their associated impacts, and the implementation strategies to achieve the desired results.

Table 1: WELL Building Standard Metrics, Impact, and Strategies (International WELL Building Institute, 2016)

Metric	Impact	Strategies
Air	Promotes clean air through reducing or minimizing the sources of indoor air pollution, requiring optimal indoor air quality to support the health well-being of building	Include removal of airborne contaminants, prevention and purification
Water	Promotes safe and clean water through the implementation of proper filtration techniques and regular testing in order for building occupants to receive optimal quality of water	Removal of contaminants through filtration and treatment, and strategic placement
Nourishment	Requires the availability of fresh, wholesome foods, limits unhealthy ingredients and encourages better eating habits and culture	Providing occupants with healthier food choices, behavioral cues, and knowledge about nutrient quality
Light	Provides illumination guidelines that are aimed to minimize disruption to the body's circadian system, enhance productivity, support good sleep quality and provide appropriate visual acuity where needed	Requirements for window performance and design, light output and lighting controls, and task-appropriate illumination levels, to improve energy, mood, and productivity
Fitness	Promotes the integration of physical activity into everyday life by providing the opportunities and support for an active lifestyle and discouraging sedentary behaviors.	Requirements are designed to provide numerous opportunities for activity and exertion, enabling occupants to accommodate fitness regimens
Comfort	Establishes requirements designed to create distraction-free, productive and comfortable indoor environments	Design standards and recommendations, thermal and acoustic controllability, and policy implementation covering acoustic and thermal parameters that are known sources of discomfort
Mind	Requires design, technology and treatment strategies designed to provide a physical environment that optimizes cognitive and emotional health	Providing the occupant with regular feedback and knowledge about their environment through design elements, relaxation spaces, and technology

Findings: Literature Review

Energy Efficiency

The International Energy Agency (IEA) studied how proper insulation, lighting, and refrigeration systems directly impact the health of children and adults. The research is primarily focused on issues in the home environment including subpar insulation, dampness, and mold that may lead to increased sick days. The research may also be relevant for absenteeism in labs. According to the study, "When quantified health and well-being impacts are included in assessments of energy efficiency retrofit programmes, the benefit-cost ratio can be as high as 4:1, with health benefits representing up to 75% of overall benefits" (International Energy Agency, 2014). **Figure 2** depicts energy efficiency measures and their resulting direct and indirect health outcomes.

Figure 2: Direct and Indirect Impacts of Improved Energy Efficiency on Health and Well-Being (International Energy Agency, 2014)

Table 4.1 Overview of direct and indirect impacts of improved energy efficiency on health and well-being

Energy efficiency measures	Impacts associated with energy efficiency measures		Potential health outcomes - direct		Potential health outcomes - indirect	
Insulation	Warmer, drier, indoor environment	Comfortable temperature	Reduced deaths from cold and hot spells***	Reduced excess (winter and summer) mortality***	Reduced absenteeism from school**	
Draught-proofing, pipe lagging, lighting			Reduced symptoms of respiratory disease: asthma, lung cancer, Chronic Obstructive Pulmonary Disease***		Improved academic performance*	
Extractor fans	Well ventilated/ good air quality	Reduced damp*	Reduced symptoms of cardiovascular disease (e.g. angina, atrial fibralation, risk of stroke)***	Reduced hospitalisation**	Reduced absenteeism from work**	
		Reduced mould*	Reduced depression**		Increased productivity*	
			Reduced arthritis and rheumatism**		Increased earning power**	
			Reduced injuries and death*			
Efficient, effective heating systems		Comfortable temperature	Reduced allergies**	Reduced pharmaceuticals *		
		Reduction of gas and particulates* ***	Reduced respiratory disease: asthma, lung cancer, Chronic Obstructive Pulmonary Disease***	Reduced hospitalisation***		Reduced public and private spending on health
			Reduced injuries and death**			
		Increased usable living space	Reduced stress**		Increased sociability*	
			Reduced close contact infectious diseases**		Increased space for homework*	
Efficient and effective cooking/ refrigeration systems		Reduced gas and particulates*	Reduced injuries and death*			
		Improved fitness for purpose (i.e. better refrigeration and cooking facilities)	Improved nutritional status**			
	Reduced energy bills/ reduced exposure to energy price fluctuations	Increased sense of control*	Reduced stress and despression**			
		Less fear of falling into debt*				
		More disposable income	Increased purchase of food and other essentials*		Improved nutrition**	
					Increased access to preventative health care*	

Notes: This graphic illustrates the impact pathways from energy efficiency measures to three major impacts. Colour coding established in the impacts column corresponds with the various outcomes a measure could generate for health. This simplified flow diagram does not depict all of the complex interrelationships related to energy efficiency and health and well-being outcomes.
*, **, or *** symbol indicates the strength of the evidential basis, with * being lowest and *** being highest.
* Caution: Sealing homes without adequate ventilation can cause unintended negative consequences for health.
Source: Unless otherwise noted, all material in figures and tables in this chapter derives from IEA data and analysis.

Air Quality

Health

Exposure to volatile organic compounds (VOC) can lead to sensory irritation symptoms in the absence of properly ventilated systems (Mudarri, 2010). Although research is still in its infancy, initial analysis indicates that heavy concentrations of VOCs can lead to asthma-like respiratory symptoms and other adverse conditions including headaches often described as Sick Building Syndrome (SBS) (Mudarri, 2010). "SBS consists of a group of mucosal, skin, and general symptoms that are temporally related to working in particular buildings. It is the workers who are symptomatic, but the building or its services which are the cause" (Burge, 2004).

Symptoms due to poor air quality are often associated with declines in various measures of human performance and productivity. The Environmental Protection Agency (EPA) believes that, "while productivity effects may be a direct result of changes in these indoor environmental conditions, it is also likely that some form of degradation of health or comfort acts as an intervening factor affecting productivity" (Mudarri, 2010). It is important to note the differentiation between SBS and "building related disease," which entails viruses that employees pass to one another due to the nature of their work (Burge, 2004). SBS does not include building related disease.

Proper ventilation and air conditioning appear to be the primary drivers of air quality. Studies on ventilation systems and their subsequent impact on performance show that ventilation rates below 10 liters/second (20 cubic feet per minute) per person lead to impaired health and declines in air quality (Seppanen, Fisk, & Lei, 2006). Specifically, regression analysis on multiple studies determined that there exists, "consistent improvement in performance in tasks typical of office work when ventilation rates increase" (Seppanen, Fisk & Lei, 2006). Additionally, a research effort on the organization, Polaroid, found that inadequate ventilation is responsible for 35% of short-term sick leave, or 1.2 - 1.9 days per person dependent upon gender and age. The study also concluded that Polaroid could recognize net savings (after subtracting the costs of increased ventilation) of $400 per employee per year merely by increasing ventilation (Milton, Glencross, & Walters, 2000).

The EPA expects that SBS and other illnesses associated with poor air quality cost employers between $82 billion and $104 billion annually (Mudarri, 2010). The figure is largely driven by the reduction in productivity associated with SBS. There is concern that in the future this dollar cost may increase as the volatility of our global environment increases.

Improving ventilation could also lead to significant improvements in productivity and cognitive function (Allen, et al. 2015). Researchers in the study sought to measure the impact of green buildings on the cognitive function of office employees by placing 24 participants in environmentally controlled office spaces for six full work days. Over these six days the participants were subject to various indoor environmental conditions (high VOC, low VOC) representative of the average office environment. To simulate extreme green environments, researchers increased the outdoor air ventilation rate while adjusting for carbon dioxide. Participants were subjected to a daily *Strategic Management Simulation* designed to test their decision-making processes. Each test was 1.5 hours, with participants exposed to real-world equivalent challenges. These challenges entailed tasks such as serving as mayor for a township or as an emergency coordinator. The simulation allowed the participants to strategize and act in their own respective cognitive styles. Participants were then graded according to the nine cognitive domains listed in Table 2 (Allen, et al., 2015).

Table 2: Cognitive Domains (Allen, et al., 2015)

Cognitive Function Domain[a]	**Description**
Basic Activity Level	Overall ability to make decisions at all times
Applied Activity Level	Capacity to make decisions that are geared toward overall goals
Focused Activity Level	Capacity to pay attention to situations at hand
Task Orientation	Capacity to make specific decisions that are geared toward completion of tasks at hand
Crisis Response	Ability to plan, stay prepared and strategize under emergency conditions
Information Seeking	Capacity to gather information as required from different available sources
Information Usage	Capacity to use both provided information and information that has been gathered toward attaining overall goals
Breadth of Approach	Capacity to make decisions along multiple dimensions and use a variety of options and opportunities to attain goals
Strategy	Complex thinking parameter which reflects the ability to use well integrated solutions with the help of optimal use of information and planning

[a] See Streufert et al. 1986 for detailed descriptions

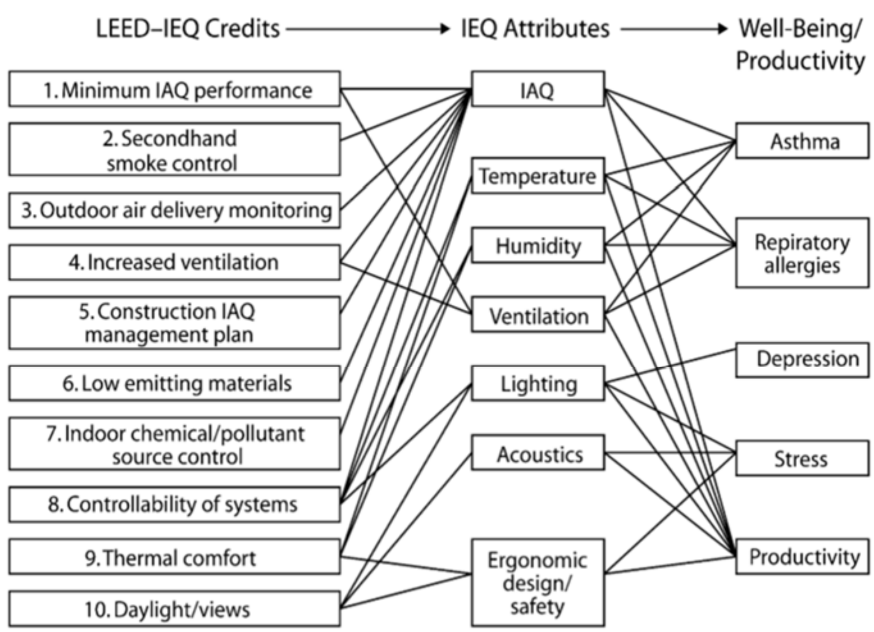
Cognitive function scores were 61% higher for participants in the well-ventilated buildings (low VOC environments) relative to the conventional building conditions (high VOC environments). Additionally, participants in the extreme green building condition scored over two times better, with scores 101% higher relative to the conventional building. The researchers discovered "statistically significant declines in cognitive function scores when CO_2 concentrations were increased to levels that are common in indoor spaces (approximately 950 ppm)" (Allen, et al., 2015).

Productivity

A separate series of studies for the American Journal of Public Health measures Indoor Environmental Quality (IEQ) and the potential effects that sustainable design elements may have on health and productivity (Singh, Sayal, Grady, & Korkmaz, 2010). Researchers contrasted IEQ between green (LEED-certified) buildings and traditional buildings. While hard to quantify, studies suggest that LEED-certified buildings improve IEQ. There are numerous qualitative studies, but few quantitative studies pertaining to IEQ[1] (Singh, Sayal, Grady, & Korkmaz, 2010).

The following criteria can exacerbate respiratory issues, like asthma, pertaining to IEQ: poor air quality, insufficient ventilation, excess humidity, and extreme temperatures. Furthermore, failures in ergonomics, acoustics, and lighting design, can significantly contribute to absenteeism in the workplace, resulting in less productivity relative to that of peers who do not face these issues (Singh, Sayal, Grady, & Korkmaz, 2010). **Figure 3** depicts the interrelationships between components associated with IEQ.

Figure 3: LEED and IEQ Structure (Singh, Sayal, Grady, & Korkmaz, 2010)



Note. IAQ = indoor air quality. The LEED credits listed here represent typical IEQ-related concerns covered in LEED rating systems; however, different rating systems may use minor variations of these credits. Case study project 1 pursed all credits 1-10, and case study project 2 pursued all credits except credit 9.

[1] The studies referenced here used self-reported surveys as the primary means of data collection

Absenteeism increased amongst employees when the IEQ attributes were below LEED criteria, thereby leading to adverse effects on health and productivity. The reverse was true when IEQ attributes were aligned with LEED criteria, as perceived by the employees. **Table 3** depicts correlation of IEQ and productivity.

Furthermore, a case study conducted at Plantronics supports green building design's ability to reduce absenteeism from 12.7% to 3.5% (World Green Building Council, 2014). The rightmost column in **Table 3** outlines the total benefits per year from a reduction in absenteeism, as specified by the *minimum average gains,* for a number of outcomes.

Table 3: Well-Being and Productivity Benefits Among Employees Who Moved from Conventional to Green Office Buildings (Singh, Syal, Grady, & Korkmaz, 2010)

Outcome	Mean Difference	P	Minimum Average Gains	Total Benefits per Year
Absenteeism attributable to asthma and respiratory allergies, d (n=25)	0.034	0.047	Reduced by 0.034 h/mo for each occupant reporting asthma or allergies	Additional 0.41 work hours/occupant
Work hours affected by asthma and respiratory allergies (n=27)	2.35	0.02	Reduced by 2.35 h/mo for each occupant reporting asthma or allergies	Additional 1.34 work hours/occupant reporting asthma or allergies
Work hours affected by depression and stress (n=34)	2.86	0.02	Reduced by 2.86 h/mo for each occupant reporting depression or stress	Additional 2.02 work hours/occupant reporting depression or stress
Direct effect of IEQ on productivity, hours (n=86)	2.59	<0.001	Productivity improved by 2.6% for all occupants	Additional 38.98 work hours/occupant

Thirty-nine hours of additional hours of work—a productivity improvement of 2.6% per occupant—is directly attributed to improving IEQ in the workplace. These statistics support green buildings' effects on health and productivity. On average, the benefits are 44 additional hours of productivity per employee per year (Singh, Syal, Grady, & Korkmaz, 2010), which translates into real cost savings.

Natural Daylight Exposure

Exposure to natural daylight over an extended period of time can improve human performance. There is ample anecdotal evidence to support this fact and a 1999 study by the Heschong Mahone Group (HMG) demonstrated that natural light improved students' test scores by an average of 7% to 18%. In this study, experts looked at over 21,000 students from three districts within California, Washington, and Colorado (Heschong Mahone Group, 1999).

HMG analyzed each classroom and assigned rooms a value of zero through five based upon the size and tint of windows and other factors including the overall amount of expected daylight. Focusing on the most diverse school district, as determined by daylighting conditions, HMG used multivariate linear regression analysis to predict student performance from historical district educational data.

The study results revealed that, "students with the most daylighting in their classrooms progressed 20% faster on math tests and 26% on reading tests in one year than those with the least … students in classrooms with the largest window areas were found to progress 15% faster in math and 23% faster in reading than those with the least" (Heschong Mahone Group, 1999).[2]

WGBC studies regarding health, well-being and office productivity reference similar metrics, including IEQ and ventilation, thermal comfort, daylighting and lighting, noise and acoustics, interior layout and active design, views and biophilia, look and feel, and location and access to amenities (World Green Building Council, 2014). These metrics are aligned with studies already referenced herein, thus painting a more comprehensive picture regarding what is important, from the perspective of building designers and occupants, to promote better productivity in the workplace.

Thermal Comfort

Thermal comfort is a critical part of building maintenance and design simultaneously effecting building occupants. **Figure 4** depicts the relationship between the external temperature and the amount of clothing that people wear indoors. The cooler the temperature outside, the larger the spread of "clothing + chair (clo)" values of occupants (Morgan & de Dear, 2003).

[2] It is important to note that there are many factors that may impact student performance, including curricula and teaching styles.

Figure 4: Thermal Insulation Worn Inside Buildings Compared to External Temperature (Morgan & de Dear, 2003)

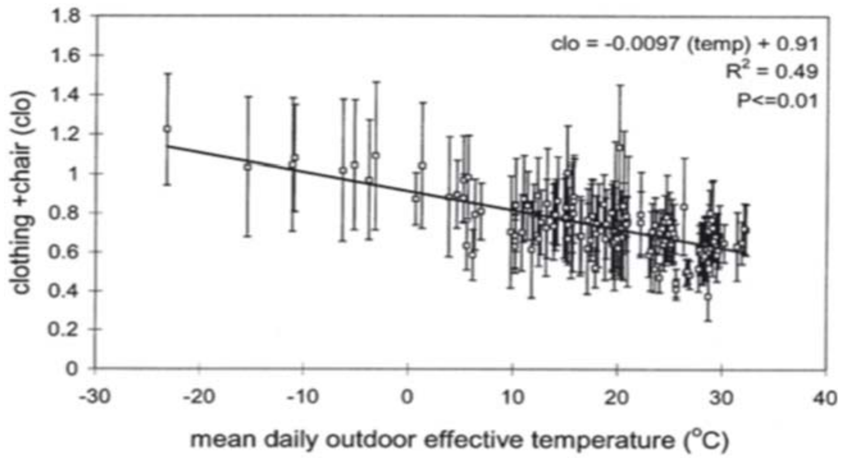


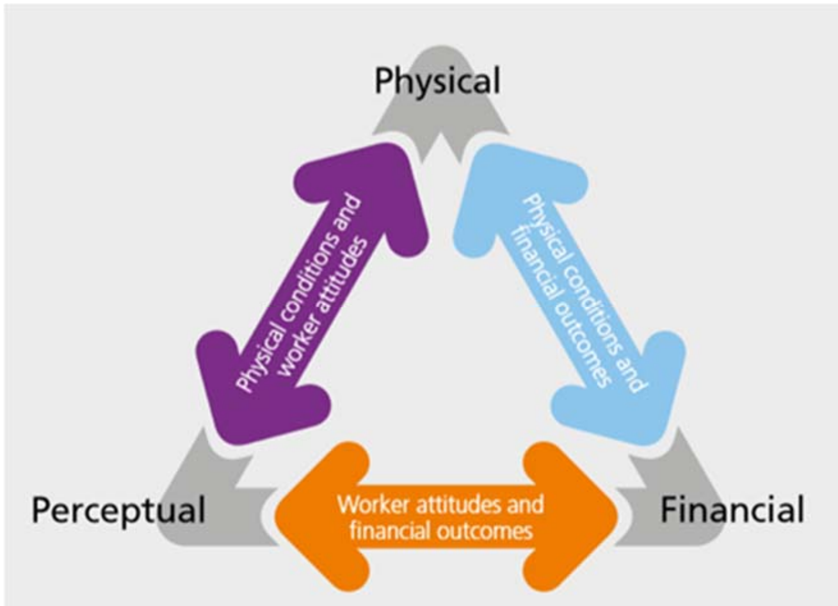
Fig. 2. Relationship between the mean thermal insulation worn *inside* buildings in the de Dear & Brager (1998; 2001) study and the mean *outdoor* effective temperature (*ET**) at the time of the study. The latter was calculated as the average of daily minimum *ET** (air temperature, relative humidity and clo values as input) and daily maximum *ET**

"Energy consumption of residential buildings and offices adds up to about 30% of total carbon dioxide emissions; and occupant behaviour contributes to 80% of the variation in energy consumption. Indoor climate regulations are based on an empirical thermal comfort model that was developed in the 1960s. Standard values for one of its primary variables—metabolic rate—are based on an average male, and may overestimate female metabolic rate by up to 35%" (Kingma & van Marken Lichtenbelt, 2015). Thermal comfort is an ongoing behavioral metric that can influence both energy savings and the intangibles.

Financial Impacts

The WGBC studies are the basis of a framework developed to help multiple stakeholders (e.g., building owners, occupants, and advisors) integrate data regarding building design impacts on employee health, well-being and productivity into financial decision-making (World Green Building Council, 2014). This framework alleviates ambiguity in metrics that measure health and social benefits of green buildings, and its impact on improving financial performance. A significant part of the framework rests on the relationship between three key elements: physical features of the work space, worker attitudes or perceptions, and financial outcomes, as depicted in **Figure 5**.

Figure 5: Interdependencies of Three Key Elements for the Health, Wellbeing & Productivity Framework (World Green Building Council, 2014)



Pertinent factors that feed into the framework include: control of the environment by building occupants (e.g. adjustable thermostats, reconfigurable spaces, natural light glares), complementary strategies to maximize occupant benefits and reduce energy/resource use, consistency in measuring metrics for relevant data, advancements in technology, and a growing implicational awareness of green design on health and wellbeing (World Green Business Council, 2014). Also, the framework suggests that "measurable" productivity factors directly affecting organizational or financial outcomes include: absenteeism, staff turnover/retention, revenue, medical costs, medical complaints, physical complaints, and task efficiency and deadlines met (World Green Business Council, 2014). In the United States, annual rates of absenteeism come at an average cost to employers, ranging between $2,074 and $2,502 per employee (World Green Building Council, 2014).

It is important to note that, while productivity can ultimately be influenced by greener designs, there are varying cost deltas associated with possible solutions. For example, retrofitting existing occupied spaces to improve daylighting is costly, while incorporating active design principles in new buildings has a lower cost. Good design, construction, behavior, and location are the main drivers to developing green buildings that create easier pathways to better health, economic gains, and productivity (World Green Business Council, 2014).

Findings - Stakeholder and Subject Matter Expert Interviews

Our team completed a site visit with Payette staff member Rishi Nandi to Northeastern University's ISEC, which has finalized building designs but remains under construction. Northeastern has stringent expectations regarding the energy usage at the site. To comply with energy usage expectations, the building includes a highly efficient HVAC system utilizing chilled beams (as seen in **Figure 6**). Although individuals cannot control the exact temperature within their workspace, the technology ensures a narrow range of temperatures throughout the building (Nandi 2016). Some of the centrally located workstations at the ISEC do not have access to natural light because of the configuration and orientation of the individual labs within the building.

Figure 6: Chilled beams at ISEC site visit, Northeastern University[3]

Similar to what was discovered in the literature review, MIT academics and SME's believe that the intangible benefits of green labs are much less quantifiable than metrics from an energy efficiency retrofit's return on investment. Regardless, health and wellness are generally regarded to be as important as the tangibles (Glicksman, 2016; Norford, 2016).

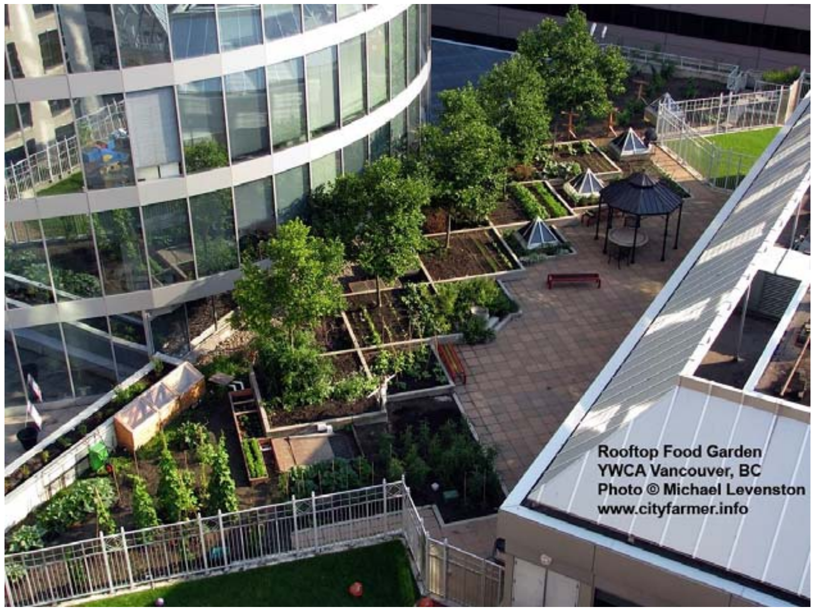
Employee Morale

Professor Les Norford stated that at MIT, architecture students are taught to pay attention to energy and carbon budgets, spending the time to discuss them during design phase (Norford, 2016). According to Norford, energy conservation can coexist with employee morale. This can be accomplished by doing things such as creating open air areas or building sky gardens. **Figure 7** depicts one such food garden at the YWCA in Vancouver, British Columbia, Canada that is both

[3] Photograph taken by Chidi Anozie, 2016

therapeutic and productive as it yields more than 600 kilograms of produce each year (YWCA Metro Vancouver, 2016).

Figure 7: YWCA Rooftop Food Garden in Vancouver, British Columbia, Canada (Levenston, n.d.)



Yang, Yu, & Gong focused on the ancillary benefits of reducing pollutants in the environment at research labs in Chicago. “One way to reach that goal [of removing existing air pollutants] is the use of urban vegetation which can reduce air pollutants through a dry deposition process and microclimate effects. The high surface area and roughness provided by the branches, twigs, and foliage make vegetation an effective sink for air pollutants” (Yang, Yu, & Gong, 2008).

Natural Light

Catherine Gamon, Director of Student Life at the MIT Sloan School of Management, highlighted natural lighting challenges in MIT Sloan’s Technology Services (STS) workspace (Gamon, 2016). STS is located in the basement of building E52. Despite the full-sized windows, part of STS remains obscured as the work space is partially below ground. When the building was renovated, the department specifically requested that the offices and cubicles be re-arranged. To maximize daylight access, cubicle staff were placed along the perimeter and offices were situated, with glass panes surrounding doorways, in the central portion of the space, as seen in the **Figure 8** below. The “atypical” configuration maximized the lighting access to all employees. On the left are the offices and conference spaces, and on the right, natural lighted cubicles.

Figure 8: STS Workspace Image[4]

Air Quality

Fume hoods consume a substantial amount of energy in labs but are required to ensure appropriate and safe ventilation. The Scientific Equipment Furniture Association (SEFA) generally requires a building's total volume changes of air to be four to twelve times per hour, unless specific configurations require additional air changes (TSI Incorporated, 2013). Although specific guidelines exist, institutions often exceed the values as an internally created safety precaution. MIT Professor Leon Glicksman stated that often labs over-utilize air by approximately 20% (Glicksman, 2016). During the Northeastern University ISEC site visit, Nandi explained that six air changes per hour are required by code, but the administration was pushing for ten air changes per hour because it would provide greater peace of mind for lab occupants (Nandi, 2016).

Multiple SMEs mentioned that changes in law and policy could be very helpful. For example, Cambridge is moving towards becoming a net zero city. As such, compliance with legislation is now becoming the driving factor for sustainable initiatives rather than cost (Nandi, 2016 & Walsh-Cooke, 2016).

[4] Photograph taken by Kate Sullivan, 2016

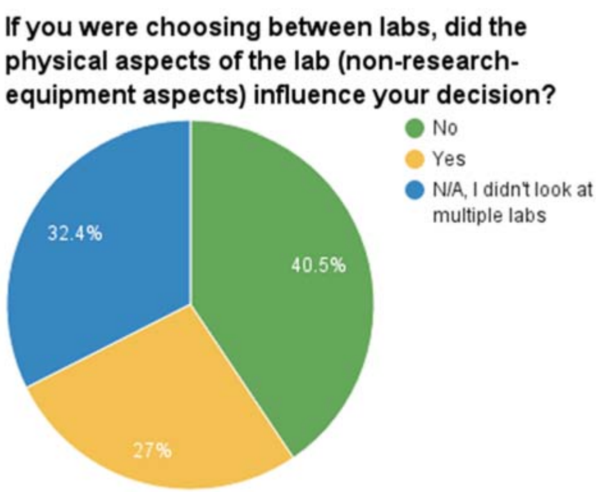
Findings: Lab Survey

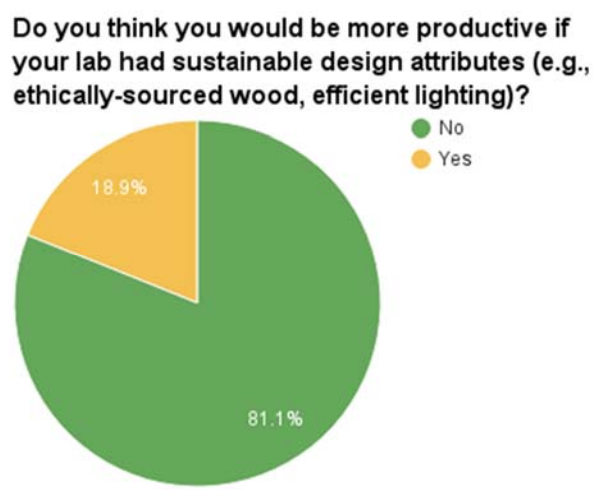
Our team conducted a survey of graduate and PhD students, postdoctoral students, and lab managers who work in or utilize labs regularly. This survey, administered through Google Forms, sought to understand behavior preferences, current lab conditions, and desired lab conditions for respondents in buildings with labs. We reviewed 38 responses obtained from 20 disciplines. The variety of disciplines is highlighted in **Table 4**. Respondents represent 13 states and two countries, resulting in a robust data set. Respondents' experience in labs ranged from less than one year to 24 years with an average of 7.5 years.

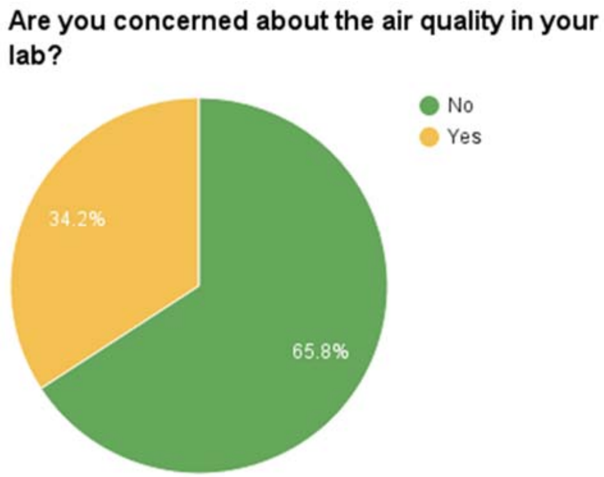
Table 4: Survey Respondent Lab Experience

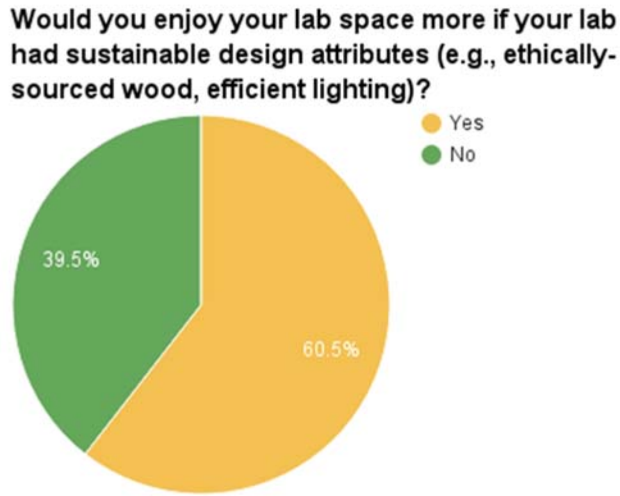
Biochemistry	Biomedical Engineering	Chemical Engineering	Chemistry	Earth & Environmental Sciences
Ecology	Electrical Engineering	Evolutionary Biology & Ornithology	Geochemistry	Geology
Kinesiology	Microbiology	Modeling Batteries	Multiphase Computational Fluid Dynamics	Neurology
Neuroscience	Organic Chemistry	Paleontology	Physics	Plasma Physics

The following graphs represent respondents' answers to the bolded questions above them. It is interesting to note that lab researchers did not link enjoyment with productivity.









Key insights include:

- Twenty-five respondents stated that there are no lighting restrictions in their labs, but only 18 have natural lighting available.
- Thirty-four respondents answered yes when asked if natural lighting was preferred. Some enthusiastic quotes submitted include:
    - "Just being able to look outside makes you feel better."
    - "It's easier on the eyes."
    - "It sometimes feels like you are trapped [without natural light] and it's difficult to notice the passage of time."
    - "[I] Would prefer natural shadows, could stay in lab longer without losing mind."
    - "Better for me, my soul, my students, and the bills!"
    - It makes for a much happier work environment
    - "Huge windows … make life so good. Plus, we sometimes write equations on them to feel smart when we experiment."
- When asked if labs promote healthy lifestyles responses varied. Highlights include:
    - "Healthy choices and lifestyles are offered by the institution."
    - "I don't spend a lot of time sitting"
    - "It's an enclosed basement space (i.e. a little depressing)."
    - "All of the lab mates utilize Fitbits and have friendly competition."
    - "Standing desks."

Conclusions and Recommendations

Based on our research, our team concludes that the benefits to green labs are similar to those seen in other settings including homes, offices, and schools. For example, lab environments include spaces where academics work, which are quite similar to office environments. Additionally, we are confident that proper daylighting, thermal comfort, and fresh air can increase employee productivity and morale and we recommend additional research be conducted to further establish the benefits of these intangibles.

Access to natural lighting: We recommend workspace configurations include natural light wherever possible, and utilize pass-through light, such as the Atrium at Northeastern University's ISEC, if necessary. "German law requires each person be no more than 23 feet from a window; windows must be operable, and there is a strong commitment to natural lighting and ventilation. These buildings are healthier, and a well-built structure in Germany uses less than 10 kWh of energy per square foot" (Vermeulen, 2012).

Taking the lead from the MIT STS, whenever possible, open seating office space, such as open desks or cubicles, should frame the exterior of a building allowing natural light to permeate to interior spaces. Common spaces utilized with less frequency or more susceptible to light issues, such as labs or conference rooms, should be the spaces placed most inboard of a building, reserving the natural lighting for employee health.

Thermal comfort: Behavioral evidence indicates that people change set points because of thermal comfort complaints. Practically, thermal comfort can be obtained in "less" comfortable temperatures by layering clothes. Currently, Payette measures thermal comfort utilizing models that include the Daylight Glare Probability, Daylight Autonomy, and Thermal Comfort Percentage.

People are physically and mentally affected by the temperature of their workspace. Starting to address employee behavior by ensuring that employees dress accordingly can enhance well-being and productivity while maintaining energy savings. Employees could also be given more control of the temperature settings or to provide feedback about how they "feel" in their area by using technology like CrowdComfort, a local Cambridge startup (CrowdComfort, n.d.). Additionally, it is important to educate building maintenance and facilities staff about thermal comfort and ranges of acceptable temperatures.

To research further, P&A could introduce a system to measure satisfaction with a built environment. Clear success metrics can help labs could determine whether they are designed correctly and have the appropriate feedback loop in place. P&A currently have models to map thermal comfort and daylight autonomy. However, P&A are the first to admit that the models are nowhere near as valuable as the information provided by the building occupants. It is not realistic for P&A to hypothesize every potential environmental condition prior to the design and building phase of projects (Love, Williams, & Mackey, 2016).

Fresh air: Open areas and green spaces are very important for employee morale. Studies demonstrate that fresh air and daylight have a significant impact on productivity. Employees must be afforded the opportunity to take breaks during the day and lunch periods, to get fresh air and light exposure, and to recharge and reinvigorate.

Further surveys should consider the factors that are most important to those utilizing lab buildings. It appears that better air and lighting results in more productive employees with less absenteeism.

Financial impacts: Finally, the financial costs (including salaries and benefits) associated with staffing an organization account for roughly 90% of business operating costs, making a compelling case for maintaining high productivity levels for employees and other occupants (World Green Building Council, 2014). Reducing absenteeism and sick days has a direct effect on the financial stability of an organization. The European Concerted Action developed a Sick Building Syndrome Practical Guide in 1989 citing that “An investigation carried out by Woods et al. on 600 office workers in the USA showed that 20% of the employees experience symptoms of SBS and most of them were convinced that this reduces their working efficiency. Other estimates report that up to 30% of new and refurbished buildings throughout the world may be affected by this syndrome” (Molina, Pickering, Valbjorn, & de Bortoli, 1989). On average, the benefits of reducing absenteeism and sick days equates to 44 additional hours per employee per year (Singh, Sayal, Grady, & Korkmaz, 2010).

Ultimately, tying all these pieces together when designing a building is essential. Further research is needed to quantify benefits from the aforementioned recommendations. P&A could leverage the existing research studies to convince a university, or large biomedical pharmaceutical company to partner and study this issue further. Depending on the partnership, P&A could find comparable labs to compare against each other, with one lab serving as a base case and the other lab fully measuring the impacts of potential green building upgrades. Also, the Boston/Cambridge area is filled with researchers working in labs so the location is ripe for research.

Also, the regulatory environment of the physical locations of labs in consideration will be an influential piece of green building design and acceptance. Quantification of these impacts is a challenge, but it will be essential to introduce the intangibles into return on investment calculations for sustainable design strategies.

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Appendix

Full Lab Utilization Survey Questions

1. In what area of study is your research?
2. Where is your lab located? (City / State, if outside US, country too)
3. If you were choosing between labs, did the physical aspects of the lab (non-research-equipment aspects) influence your decision?
4. How many years have you worked in research labs?
5. How would you describe your lab?
6. Does your lab have natural lighting / windows?
7. Are there lighting restrictions due to the research in your lab? If so, what are they?
8. If there are no lighting restrictions in your lab, given the option, would you prefer natural light in your lab? Why or why not?
9. Do you notice fresh or ventilated air (from an AC or heating system) coming into your lab?
10. Are you concerned about the air quality in your lab?
11. Do you think certain physical features of your lab or work space would increase your productivity? If so, what are those features?
12. Do you feel you would enjoy your lab space more if your lab had sustainable design attributes (e.g., ethically-sourced wood, energy-efficient lighting)?
13. Do you feel you would be more productive if your lab had sustainable design attributes (e.g., ethically-sourced wood, energy-efficient lighting)?
14. Are you afforded the opportunity to spend time outside during the work day -- taking a break for air, eating lunch outside the building, etc?
15. Does your lab promote a healthy lifestyle? If yes, how? If no, how not?
16. Would you be interested in providing more information directly to S-Lab team? (If yes, please provide your name and email address)

Additional Survey Responses

Figure 1. Location of Labs (*size of word indicates popularity of answer*)

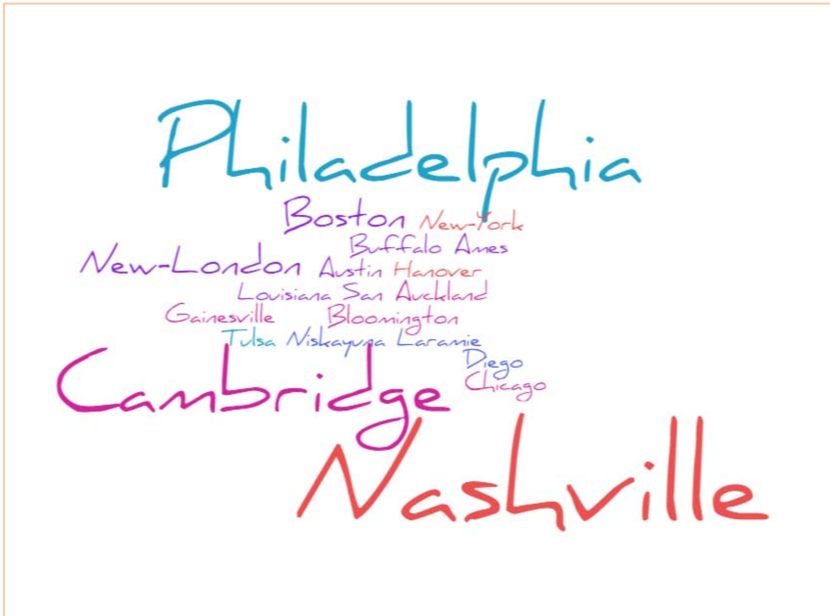

Figure 2. How many years have you worked in research labs?

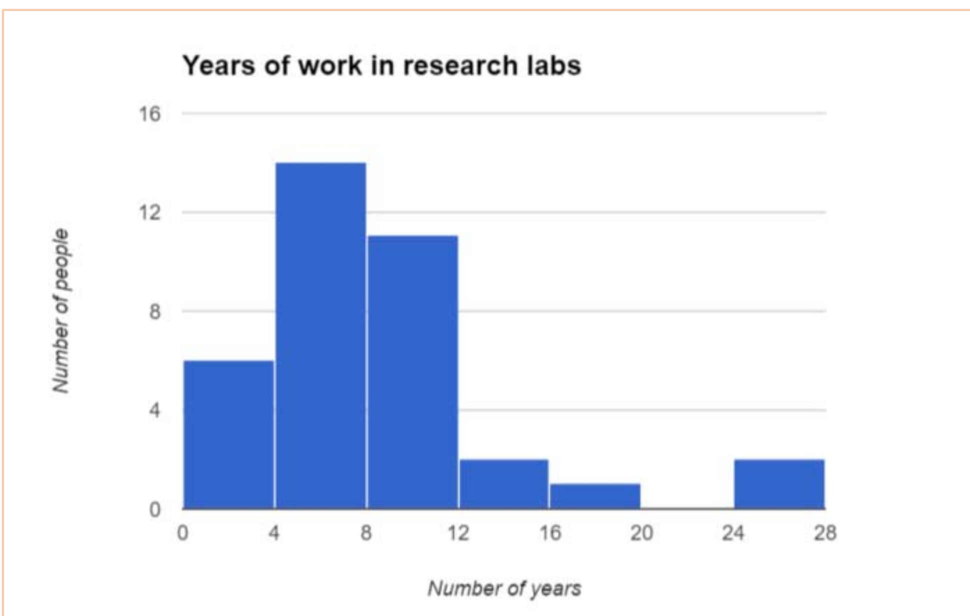

Figure 3. When was your lab built?

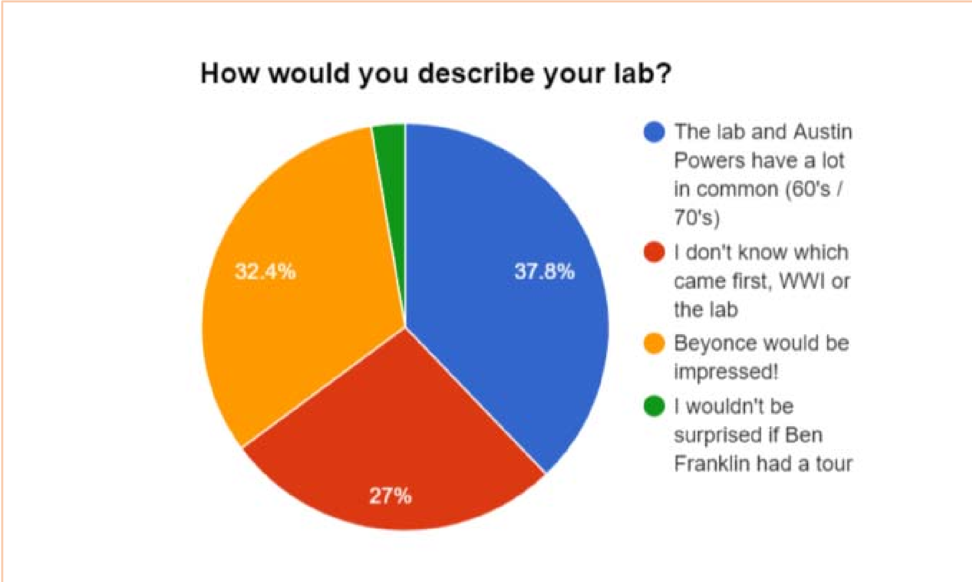

Figure 4. Does your lab have noticeable ventilation?