Health in the Built Environment:
Testing Health Impacts of Green Buildings

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ABSTRACT: *This team has used the Bullitt Center, the world's greenest commercial building, as a pilot project to develop and implement methodologies for collecting data on buildings and building occupants related to health impacts at the building scale. These data include testing how the building impacts 1) physical activity 2) indoor environmental quality, and 3) the bacteria and other microorganisms present in the building. The study team measured stair and elevator use, took numerous empirical measurements of light, temperature and humidity of the building, collected and analyzed dust and air samples for microbial populations, and surveyed building occupants related to wellbeing, physical activity and their perceptions of the indoor environmental quality of the building. These data were collected both in the new building over the first nine months of occupancy as well as at two office spaces just prior to the organizations' move to the new building.*

Keywords: Health; Physical Activity; Active Design; Microbiome; Indoor Environmental Quality; Bullitt Center

INTRODUCTION

As the first office building certified as a "Living Building," the Bullitt Center serves as a paragon of sustainable building practices. The Living Building Challenge presents the most comprehensive standard of sustainability in the built environment, with considerations ranging from construction materials to social equity (Living Building Challenge n.d.). While technical performance benchmarks such as energy consumption and water usage can be easily measured in a building, other criteria—including human health and wellbeing—prove significantly more challenging to assess. This study is an effort to understand select health impacts of the Bullitt Center on its occupants using a combination of quantitative and qualitative research methodologies.

At the building scale, design features can directly influence health by guiding the way humans move through their surroundings, as well as by shaping the microbiological conditions of the surfaces and air with which people interface on a daily basis. For example, stair climbing in place of elevator usage results in increased physical activity during the workday, yielding weight management benefits and strengthened cardiovascular health (Dolan et. al. 2006). In addition, buildings with widespread access to daylight, view, and fresh air can boost positive perceptions of the work environment, provide positive physiological responses through circadian rhythm impacts, and increase occupant performance and productivity (Ries et al. 2006, Loftness et al. 2001).

Building design features impact the composition of the resident microbiome, which comprises the living microorganisms within an environment including bacteria and fungi. For example, many buildings rely solely on HVAC (heating, ventilation, and air conditioning) systems for ventilation and temperature control rather than operable windows. These systems have been shown to function as breeding sites, aggregators, and disseminators of microbial pathogens such as *Legionella pnuemophilia* that causes Legionnaires' disease (Greig et al. 2004)

This research project presents an interdisciplinary approach for measuring the impacts that a green building has on its occupants' health and wellbeing. The methodology implemented in this study provides a framework that combines an investigation of building features, empirical data collection, and occupant perceptions to create a platform for analyzing the health attributes of this and other buildings. Positive connections between sustainable design and occupant health and well being will advance the case for more green buildings, and may inform future policies and processes that promote new, healthier buildings.

This paper presents a snapshot of preliminary findings from the study to illustrate the interplay between the empirical and self-reported subjective data collected. This initial discussion focuses on two primary areas of research: 1) measured and perceived indoor environmental qualities such as thermal comfort and 2) physical activity as related to stair usage.

BULLITT CENTER AS A SITE

The Bullitt Center is a 6-story, 52,000 sq. ft. commercial office building in Seattle, Washington. As the first commercial office certified as a Living Building, it was recognized as the "most sustainable building in the world" by World Architecture News in 2013 (Bullitt Center 2015) In addition to the design intent for net-positive environmental impact, human health was a major consideration in the Bullitt Center's design. Measures intended to enhance occupant health and wellbeing include bike amenities in place of on-site parking to encourage alternative transportation choices, attractive stairs to promote physical activity, passive systems that reduce air pollution, and environmentally sensitive building materials. The vast majority of the building's lighting needs are met by daylight and its essential components are built to last 250 years.

The Bullitt Center aims to drive the building industry toward a greener future and is uniquely positioned as a research site in that it already serves as a living laboratory for high-performance building research. This study contributes to this body of research in hopes of underscoring the centrality of human health and wellbeing in sustainable buildings.

TYPES OF DATA COLLECTED

The research team employed a dualistic methodology—comprised of both objective measurement and qualitative surveys—in order to investigate quantitative data in relation to occupant perceptions. The types of data collected include:

Direct Measurement of:

- Indoor Environmental Quality (i.e. temperature, light, and humidity)
- Physical Activity (i.e. stair and elevator usage)
- Microbiome (i.e. air and dust samples)

Survey for Users' Perceptions of:

- Indoor Environmental Quality
- Physical Activity
- Well-Being

Occupant perceptions were gathered using a compilation of three peer-reviewed surveys, which were distributed to Bullitt Center occupants a total of three times throughout the study period, once before Bullitt Center occupants moved to the new building and twice after the building was occupied, thereby creating a comparison between previous work spaces and the Bullitt Center. These surveys include 1) the Occupant Indoor Environmental Quality Survey, developed by the Center for Built Environment at UC Berkeley (Center for the Built Environment 2014), 2) the International Physical Activity Questionnaire (IPAQ) (Hagströmer, Oja & Sjöström 2006), and 3) the Satisfaction with Life Scale, created by Ed Deiner (Pavot & Deiner 1993). These surveys have been used in a variety of research capacities thereby proving useful not only for internal analysis, but also as a dataset that can be compared across the literature. The three survey periods had respective response rates of 100% (n=16), 77% (n=24), and 64% (n=25).

Prior to occupation of the Bullitt Center, preliminary data was collected at two intended tenants' workplaces between February and April of 2013. After tenants' relocation, the bulk of the Bullitt Center data was collected over the course of 9 months, between April 2013 and January 2014, with additional temperature and relative humidity recordings collected over the following 9 months. In the Bullitt Center, the two primary tenant office environments were sampled for physical measurement, while surveys were distributed to all building occupants.

The diagram in Figure 1 charts the types of data collected, the duration of collection and the number of samples collected. The y-axis organizes collection events by location and the x-axis is organized by month. Single data sample events are represented with a point, while data gathered over a time-period are shown as lines.

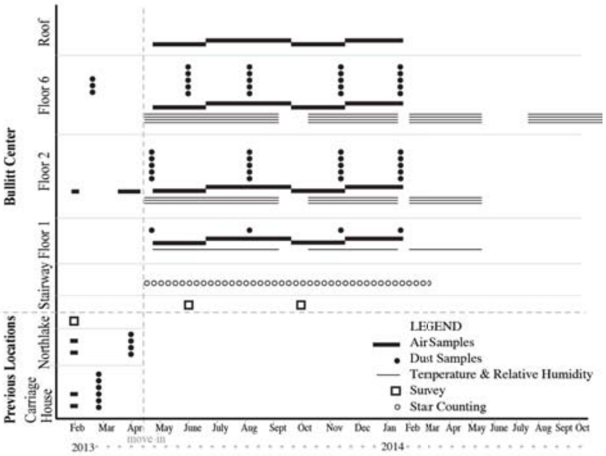

Figure 1: Timeline showing the duration of data collection by data type and data sampling location.

Physical data were collected primarily on the first, second, and sixth floors of the Bullitt Center. HOBO devices to measure temperature, humidity, and light were placed strategically within the office spaces to measure IEQ variables near the perimeter of the workspace as well as near the core of the building. For microbiome testing, dust samples correspond as closely to the HOBO device locations as possible, and air filters were placed on each study floor with an additional filter on the roof to measure outdoor air. People counters for measurement of stair and elevator usage were mounted at the base of the main staircase and elevator entrance on the second floor, and at the top of the stairs and entrance to the elevator on the sixth floor.

INDOOR ENVIRONMENTAL QUALITY

Indoor environments in offices, schools, and other workplaces do not merely impact physical comfort, but also have wider-reaching effects on psychological health. Building design is a crucial determinant of the indoor environmental quality (IEQ), with design decisions—including building orientation and form, materials selection, and window operation—working together to govern the general indoor environment. Factors such as the quality and quantity of daylight, outdoor views, fresh air, temperature, humidity, and acoustic conditions are all directly affected by building design.

The Bullitt Center implements unique strategies to create a comfortable indoor environment minimizing the energy demand of the building. Some examples of the Bullitt Center's innovative comfort measures include:

- An extremely well insulated and thermally broken envelope with triple-pane high-performance glass to regulate the interior during both the summer and winter
- Operable windows that open during moderate outdoor temperatures to allow for 100% natural ventilation
- An automated building management system that controls window operation and exterior blinds
- Passive interior temperature control through water-based radiant heating and cooling systems embedded in each floor providing thermal comfort to spaces from below
- Reliance on natural light for 80% of interior lighting needs, managed by interior and exterior shades that prevent heat and glare from the sun from disturbing occupants
- Positioning regularly occupied work stations near the perimeter and maximizing skylights when possible
- Avoiding 362 toxic chemicals (e.g. cadmium, mercury, PVC) within the building

Though this study collected data on a variety of IEQ considerations, the key findings presented here focus on thermal comfort.

Thermal comfort proves a challenging quality to measure, as it depends on much more than air temperature alone. Environmental variables such as relative humidity, air movement, and thermal source in combination with personal characteristics such as metabolism and clothing choice, similarly influence occupants' perception of comfort. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) uses a widely adopted model for thermal comfort that sets a standard across all building types and climates intended to satisfy 80% of sedentary or slightly active occupants - known as the Predicted Mean Vote (PMV) methodology (ASHRAE 2009). Adaptive models of comfort, such as UC Berkeley's Center for the Built Environment (CBE) Comfort Tool take into account seasonal and individual variables, allowing for a broader range of acceptable indoor conditions (Hoyt et al. 2013). Factors such as occupant control over indoor temperature, and mechanical versus natural ventilation influence perception of comfort (de Dear & Brager 1998). Similarly, the manner in which solar radiation enters a building directly effects occupant comfort, with occupants experiencing both short- and long-wave radiation sensing comfort differently from occupants without access to sunlight (Huizenga et al. 2006). These phenomena suggest that buildings designed to allow for occupant control, natural ventilation, and quality daylight can improve and expand the conditions necessary to feel comfortable in the workplace. Another methodology takes into account radiant sources of heating and cooling. Using Mean Radiant Temperature (MRT) calculations, operative temperatures measurements are determined, which can influence the PMV or perceptions of occupant comfort. This study considered multiple models of thermal comfort in order to investigate how the Bullitt Center performs relative to conventional measures. The study did not calculate operative temperatures due to the inability to measure surface temperatures and the specific location and orientation of occupants throughout the study period.

IEQ THERMAL COMFORT RESULTS

In order to assess the relationship between the physical indoor environment and occupant perception of comfort, data from eight onset HOBO loggers was compared to occupant survey responses, collected both before and after occupancy of the Bullitt Center. Data from the HOBO devices indicate a wide variation in temperature within different areas of the building, with a significantly wider range of temperatures measured near windows, and more consistent temperatures in spaces near the core. Despite an extremely high-performing envelope, temperatures measured near windows often exceeded ranges indicated as comfortable by the ASHRAE standards.

Indoor temperatures were plotted against relative humidity at four interior locations (Fig. 2) in order to analyze interior conditions during occupied hours. These graphs reveal that, even in central locations, the thermal conditions fall outside of zones identified as comfortable by both the ASHRAE and CBE models. While air temperature generally stays above 68 degrees, relative humidity falls well below 50%, making the air feel cooler. According to the ASHRAE Predicted Mean Vote approach, at least 20% of people are assumed to feel uncomfortably cold during these conditions. Temperatures near windows dip lower than at central locations, reaching as low as 65 degrees with a relative humidity below 50%. There are also instances during which air temperature exceeds 80 degrees with a relative humidity between 15%-50%. In these conditions, at least 20% of occupants would likely feel uncomfortably warm.

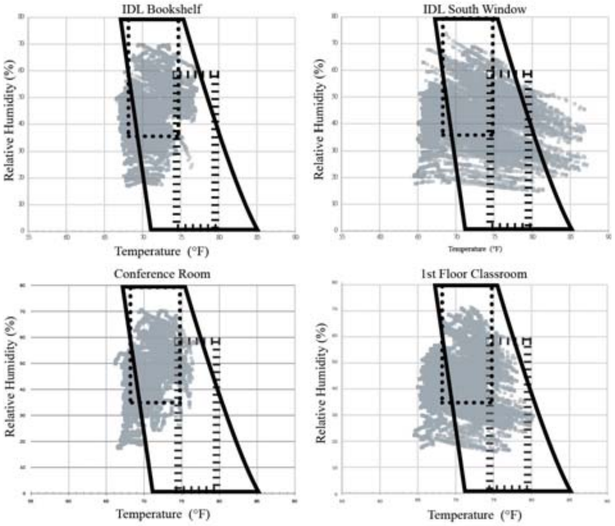

Figure 2: Relative humidity plotted against air temperature during occupied hours superimposed with ASHRAE and CBE Comfort Ranges.

This physical data is substantiated by responses regarding thermal comfort in the occupant survey. Overall, occupants reported feeling slightly greater satisfaction with office temperature in the Bullitt Center than in their previous office location. The survey reveals a wide distribution of comfort within the Bullitt Center, with most occupants reporting that thermal conditions have a “neutral” impact on their ability to get their jobs done (Fig. 3). There are, however, a number of survey participant comments that communicate dissatisfaction with thermal comfort primarily related to workspaces that run too cold.

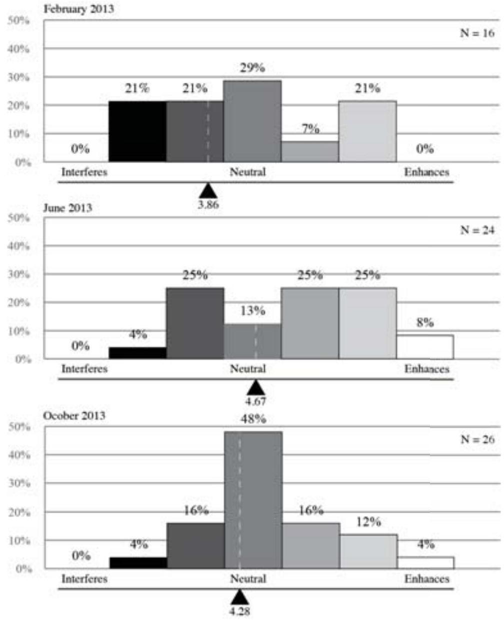

Figure 3: Survey responses from building occupants answering the question: "To what degree does thermal comfort enhance or interfere with your ability to get your job done?" The survey distributed in February 2013 was in response to occupants' previous work environments; surveys distributed in June and October 2013 ask about comfort at the Bullitt Center.

The survey data from the Bullitt Center collected in June and October 2013 (Fig. 4) corroborates the physical findings: during occupied hours that fall outside of the thermal comfort range, it is expected that 20% of occupants would express discomfort. During this study period, 29% of respondents expressed dissatisfaction in June and 20% in October.

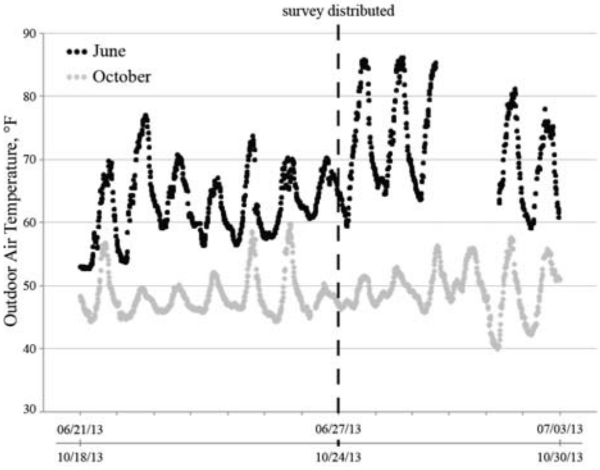

Figure 4: Outdoor air temperature (°F) recorded in the week prior to and following survey distribution in June and in October 2013. Data from the weather station is missing for July 1, 2013.

Beyond the numeric tabulation, respondents included anecdotes that more closely aligned with being too cold, rather than too hot, commenting for example, "the temperature is consistently rather cold," or "fingers too cold to type. I find myself drinking a lot of tea and snacking to stay warm." This methodology aligns measured conditions and human perception, thereby allowing for a more comprehensive analysis of human comfort and presenting a framework for approaching such study in future assessments of human wellbeing in relation to building design. Following this study period, the Bullitt Center raised its threshold for average indoor temperature during the winter season, and further study is needed to assess the impact of this temperature shift on thermal comfort.

PHYSICAL ACTIVITY

Physical activity is a critical determinant of human health, with proven health benefits associated with increased physical activity including lowered risk of chronic diseases, improved cardiovascular strength, and body fat mitigation (Center for Disease Control 2014). Despite the inarguable advantages of incorporating physical activity into one's daily routine, physically active jobs account for only 20% of America's workforce and a mere one in five American adults meet the recommendations for activity published in the 2008 Physical Activity Guidelines (American Heart Association 2015, Center for Disease Control 2014). In light of this trend toward sedentary lifestyles across the US, mounting attention is being paid toward the built environment's influence on physical activity, at both the infrastructural and building scales. Physical activity can be accumulated throughout the workday by daily decisions in and around the workplace (e.g. climbing stairs rather than riding the elevator) and as a result of larger commuting patterns to and from the workplace. This suggests that building-related opportunities for everyday activity may have a tremendous positive impact on building occupants' health.

This study examined the stair usage patterns of occupants within the Bullitt Center in tandem with a more expansive investigation of occupant perceptions of their own physical activity, gathered through self-reported behaviors in a survey.

Stair climbing is shown to produce measurable health benefits when regularly incorporated into occupant workday behavior. This study understood stair climbing using the Metabolic Equivalent of Tasks (MET), a measure used to quantify the relative vigor of various human activities with one MET equal to the general energy cost of sitting quietly (Ainsworth et al. n.d.). The high MET value of climbing stairs (8.8 METs) relative to standing (1.3 METs) or desk work (1.8 METs) leads to numerous health benefits if performed on a consistent basis. For example, it has been shown that, in general, two additional minutes of stair climbing per day can lead to an annual weight loss of 1.2 pounds per year, enough to mitigate the average one-pound weight gain of the typical American adult (Zimring et al. 2005).

Despite the advantages of stair climbing, the decision between using the stairs or an elevator may be driven by other environmental factors including building design. One general strategy for encouraging stair usage is designing stairs to be more prominent without impairing elevator access for those who rely on elevators for mobility. The Bullitt Center embraced this thinking through the design of its "irresistible stair," which features steps made from locally sourced Douglas Fir timber and is encased with glazing that provides expansive views to the Seattle skyline and the Puget Sound beyond. This team's question was: Is the "irresistible" stair really irresistible, and as such, how often is the stair being used as compared to the elevator?

PHYSICAL ACTIVITY RESULTS

At the Bullitt Center, stair usage was measured with bi-directional people counters placed at the bottom and top of both the main staircase and the elevator. The devices provide a tally of people moving past the threshold of the counters in either direction. Weekly counts were collected at each of the devices, with each tally counted as one ascending or descending "trip" (Fig. 5).

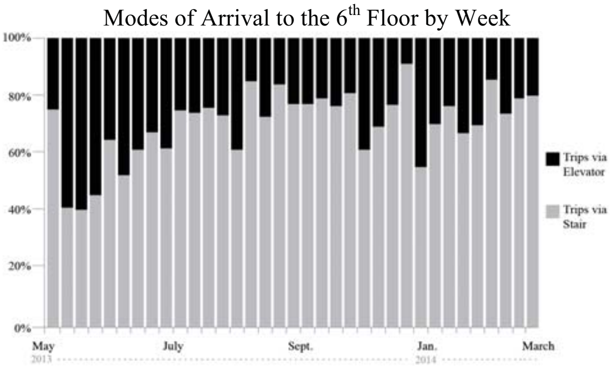

Figure 5: The relative percentage of trips taken to the 6th floor using the main stairs or the elevator, by week.

Data reveal that the Bullitt Center occupants tend to use the stair over the elevator. 75% of trips taken to the 6th floor were taken via the stairs versus 25% of trips were taken via the elevator. Furthermore, the data indicate that the "irresistible stair" is used to initiate 68% of entire ascents from the 2nd to the 6th floor, showing a persistent tendency toward stair usage for multiple-flight trips (Fig 6). The high elevator usage in May 2013 is potentially skewed due to the number of building tenants that were still in the process of relocating to the Bullitt Center during that month.

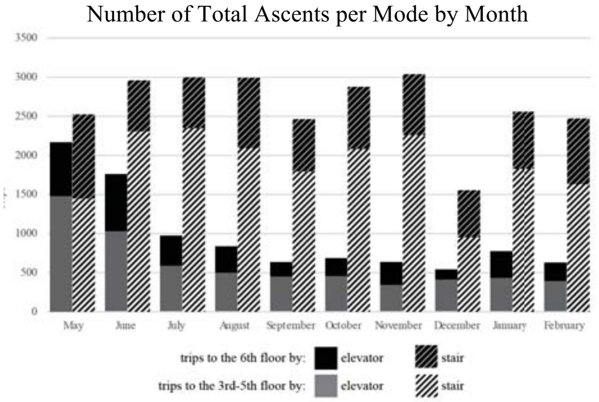

Figure 6: The total number of ascending trips via elevator and stair, per month.

The data indicate a very favorable outcome when compared to the literature, including a study that reports stair climbing to average 17-23% of total ascending trips average over a typical day in a commercial office building (Olander & Eves 2011). Furthermore, the trend toward stair climbing persists throughout the 10-month period, suggesting that stair preference is not simply a result of novelty, but a habitual behavior.

EMERGING CONCLUSIONS

The Bullitt Center aims to serve as a model for how a commercial office building can provide a high-quality comfortable, healthy workspace while demonstrating net-zero energy consumption. The data collected by this study indicates that many of the design strategies implemented in the design of the Bullitt Center positively impact occupants' physical health and perceived comfort. The "irresistible staircase" is revealed as a highly successful building feature that increases occupant physical activity and reduces energy consumption by elevators. Similarly, measures such as operable windows that maximize daylight reduce heating and cooling energy loads, and are revealed to foster a workspace in which occupants feel generally satisfied and productive.

Yet the physical and qualitative data also reveal that there are a small number of areas in which the Bullitt Center's design need further fine tuning to achieve maximum occupant wellbeing, namely related to thermal and acoustic comfort. In both of these areas, occupants expressed relative discomfort in their work environments. These findings underscore the value of studies such as this for locating and addressing such concerns both for catalyzing solutions within the targeted building, as well as for incorporation such considerations in future designs.

FURTHER ANALYSIS

This paper outlines the data through collected through this study and presents highlights of a sub-set of emerging conclusions. There is significant room for further exploration of these data, especially related to the microbiome. While air and dust samples were regularly collected, these samples still require pointed analysis in relation to the building design and will help to illuminate the effect of natural ventilation and sustainable materials on microbial populations, and thereby human health. As the data continue to be refined, correlative analysis between sampling methodologies, such as the impact of life satisfaction on IEQ perceptions and the relationship between temperature, humidity, and the microbiome will lend further richness to the framework for assessing human health set forth in this study.

This framework also leaves room for future exploration, such as incorporating focused investigation on commuting modes, measurement of the acoustic environment, and fine-grained measurement of occupant activity in the workplace. Looking forward, the methodology implemented in this paper has the potential to be applied to additional study sites in order to craft a more comprehensive portrait of human health in relation to sustainable building design.

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