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Environmental perceptions and health before and after relocation to a green building

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ABSTRACT

Green buildings are designed to have low environmental impacts and improved occupant health and well-being. Improvements to the built environment including ventilation, lighting, and materials have resulted in improved indoor environmental quality (IEQ) in green buildings, but the evidence around occupant health is currently centered around environmental perceptions and self-reported health. To investigate the objective impact of green buildings on health, we tracked IEQ, self-reported health, and heart rate in 30 participants from green and conventional buildings for two weeks. 24 participants were then selected to be relocated to the Syracuse Center of Excellence, a LEED platinum building, for six workdays. While they were there, ventilation, CO_2, and volatile organic compound (VOC) levels were changed on different days to match the IEQ of conventional, green, and green+ (green with increased ventilation) buildings. Participants reported improved air quality, odors, thermal comfort, ergonomics, noise and lighting and fewer health symptoms in green buildings prior to relocation. After relocation, participants consistently reported fewer symptoms during the green building conditions compared to the conventional one, yet symptom counts were more closely associated with environmental perceptions than with measured IEQ. On average, participants had 4.7 times the odds of reporting a lack of air movement, 43% more symptoms (p-value = 0.019) and a 2 bpm higher heart rate (p-value < 0.001) for a 1000 ppm increase in indoor CO_2 concentration. These findings suggest that occupant health in green and conventional buildings is driven by both environmental perceptions and physiological pathways.

1. Introduction

Over the past century building design and operation has changed in response to social and economic stressors with unanticipated impacts to human health and well-being. For example, following World War II, buildings in Germany were rapidly reconstructed without allowing construction materials time to off-gas. The resulting health effects from exposures to these chemicals spurred the Building Biology field of study [1]. In the United States, two decades later, the oil crisis led to the construction of increasingly air-tight buildings, which require less energy to heat and cool [2]. The incidence of common heath symptoms ranging from viral infections to cognitive impairments were elevated in many of these buildings, and referred to generally as sick building syndrome (SBS) [3,4]. The economic costs of SBS in poorly ventilated buildings are significant and far exceed the energy savings [5,6]. In addition, research conducted by the Center for Indoor Environments and Energy at the Danish Technological University has demonstrated that increased symptoms and decreased performance are associated with a number of indoor design, operating, maintenance, and environmental exposure issues [7].

The indoor environment has been increasingly monitored since SBS was first identified. The Environmental Protection Agency (EPA) set out to characterize the Indoor Environmental Quality (IEQ) in typical office buildings in mid-90s through the Building Assessment Survey and Evaluation (BASE) study. They measured a wide array of environmental pollutants and building parameters in one hundred buildings in the U.S. [8]. 17% of the buildings had ventilation rates below the ASHRAE standard of 20 cfm per person

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and 40% were not operating the HVAC unit according to design specifications. Ventilation deficits contributed to elevated levels of other contaminants in the buildings investigated. An average total volatile organic compound (TVOC) concentration of 453 $\mu g/m^3$ was measured.

The health problems that arose from conventional buildings with inadequate ventilation contributed to the advent of sustainable design or green building strategies, such as the US Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) rating system. LEED aims to reduce the environmental footprint of buildings while simultaneously protecting occupant comfort and health. They provide credits to new and existing buildings for adopting green design, operation, and maintenance. LEED then classifies buildings with a rating depending on the number of credits a building qualifies for. While many of the credits are aimed at energy efficiency and environmental performance, the LEED rating system also includes a section on Indoor Environmental Quality (IEQ), which details guidelines for improving ventilation and filtration, using low-emitting materials, controlling indoor chemical and pollutant sources, improving thermal and lighting conditions, offering daylight views to building occupants, and monitoring ventilation [9].

These IEQ credits translate to IEQ improvements in green buildings [10]. Exposure assessments comparing conventional buildings to green buildings show reductions in several key pollutants associated with symptom reports including particles, nitrogen dioxide, volatile organic compounds, and allergens [11–13]. However, the IEQ improvements did not extend to CO_2 or air exchange rate, demonstrating the influence of energy efficiency on green building operation and design. Notably, the credit for increasing ventilation by 30% over the ASHRAE standard was obtained by only 40% of new constructions and 23% of existing buildings in LEED v2009 [6].

Several studies have found reductions in reported symptoms and improved health in home, school, and office settings in green buildings as a result of IEQ improvements [11,14–17]. These studies, and others, indicate health benefits in green buildings, but lack objective measurements of health or sufficiently large cohorts of buildings. Considering that participants in these studies were not blinded to their exposure group (i.e. whether they were in green or conventional buildings), they may also be biased when self-reporting their health [10].

This paper builds on the CogFx study, which found impacts on an objective measure of health – cognitive function – from exposure to different building conditions [18]. The IEQ, self-reported health, and heart rate of 30 participants in green and conventional buildings were tracked over the course of two weeks. 24 of the participants were then relocated to the Syracuse Center of Excellence (CoE), a LEED platinum green building, for six days. In addition to the naturally green environment, we simulated enhanced ventilation (green+) and typical VOC source (conventional) environments on different days of the study. This study design allowed us to test 1) the baseline difference in IEQ and health in a sample of green and conventional buildings, 2) how health is related to environmental perceptions and CO_2 and 3) how subjective and objective measures of health change in response to blinded and unblinded built environment interventions.

2. Methods

In a previous publication [18], we described the methods for a study of workers and cognitive function in the CoE. This paper focuses on other aspects of that study including: monitoring participants for two weeks at their place of work prior to relocation to the CoE, physiological measurements, and daily questionnaires. For readers not familiar with the previous publication, we briefly describe the methods of both phases of the study (Phase I = prior to relocation; Phase II = after relocation to CoE), and describe in detail the methods for the physiological measurements and questionnaires.

2.1. Study population

30 Knowledge workers (professional grade employees like architects, designers, programmers, engineers, creative marketing professionals, middle management, etc.) in the Syracuse area were recruited to participate in a longitudinal study of the built environment and health during the fall of 2014. The study population was restricted to non-sensitive persons by excluding current smokers and people with asthma, claustrophobia or schizophrenia. The 24 participants with the best compliance through Phase I were selected to complete Phase II of the study, which required spending six workdays in the CoE. The demographic distributions did not change significantly from Phase I to Phase II (Table 1). All participants were administered informed consent and compensated for their participation in accordance with the Harvard T.H. Chan School of Public Health Institutional Review Board.

2.2. Phase I

Participants worked in their regular work environment for the first two weeks of the study. They received a sensor package including a Netatmo Weather Station and a Basis B1 watch. They were instructed to place the Netatmo on their desk and wear the Basis for the duration of the study. The Basis measured distal skin temperature, skin conductance, heart rate, and acceleration. The Netatmo measured temperature, humidity, CO_2 concentrations in parts per million (ppm), and sound levels in decibels every 5 min. Instruments were calibrated before each phase of the study to 0 and 3000 ppm using an independently calibrated TSI Q-Trak model 7575. In addition, the Netatmo units were tested with 400 and 1000 ppm calibration gas after each phase of the study to determine if the sensors drifted during the two week period.

Table 1
Demographic breakdown of participants in each phase of the study.

	Phase I	Phase II
Gender		
Male	15	10
Female	15	14
Age		
20–30	9	8
31–40	5	3
41–50	7	6
51–60	5	4
61–70	4	3
Ethnicity		
White/Caucasian	26	22
Black or African American	1	1
American Indian or Alaskan	1	0
Latino	1	1
No response	1	0
Highest level of schooling		
High school graduate	1	1
Some college	2	2
College degree	14	13
Graduate degree	13	8
Job category		
Managerial	5	5
Professional	20	15
Technical	1	1
Secretarial or clerical	1	1
Other	3	2