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The impact of working in a green certified building on cognitive function and health

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ABSTRACT

Thirty years of public health research have demonstrated that improved indoor environmental quality is associated with better health outcomes. Recent research has demonstrated an impact of the indoor environment on cognitive function. We recruited 109 participants from 10 high-performing buildings (i.e. buildings surpassing the ASHRAE Standard 62.1–2010 ventilation requirement and with low total volatile organic compound concentrations) in five U.S. cities. In each city, buildings were matched by week of assessment, tenant, type of worker and work functions. A key distinction between the matched buildings was whether they had achieved green certification. Workers were administered a cognitive function test of higher order decision-making performance twice during the same week while indoor environmental quality parameters were monitored. Workers in green certified buildings scored 26.4% (95% CI: [12.8%, 39.7%]) higher on cognitive function tests, controlling for annual earnings, job category and level of schooling, and had 30% fewer sick building symptoms than those in non-certified buildings. These outcomes may be partially explained by IEQ factors, including thermal conditions and lighting, but the findings suggest that the benefits of green certification standards go beyond measureable IEQ factors. We describe a holistic "buildingomics" approach for examining the complexity of factors in a building that influence human health.

1. Introduction

Thirty years of public health science and building science have demonstrated that buildings play a key role in shaping our health [1–5]. Buildings have the capacity to create conditions that are harmful to health or conducive to health: they determine our exposure to outdoor pollutants, by either facilitating entry of particles of outdoor origin indoors, or acting as a barrier and removing them through enhanced filtration [6]; they govern exposure to chemicals of concern, such as volatile organic compounds (VOCs), flame retardants and polyfluorinated compounds, which can be ubiquitous or nonexistent, depending on the decisions we make regarding building materials and products [7,8]; buildings either protect us from noise or contribute to the problem through the introduction of indoor sources, poor noise insulation, or poor acoustical design [9,10]; they can induce eye strain or improve alertness through impacts on circadian rhythm, depending on the lighting system [11,12]; buildings can protect us during heat events, or create environments that magnify the problem through solar heat gain [13,14]; and buildings can either wall us off from nature or connect us to it [15,16].

The scientific literature around buildings and health has identified the foundations of a healthy building including factors such as ventilation, air quality, thermal comfort, noise and lighting, and this body of research has served as the basis for green certification standards to define their indoor environmental quality (IEQ) guidelines. A review of leading, global green-building standards - LEED New Construction 2009, Green Star Office v3, BREEAM New Construction 2012, BCA Green mark for new non-residential buildings v4.1 2013, and DGNB New Office v2012 - demonstrates the approach of these certification standards toward IEQ. All of the rating systems offer credits for thermal comfort, indoor air quality (IAQ) and lighting; all but LEED NC 2009 have credits for acoustics;

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and Green STAR v3 and LEED NC 2009 have credits specifically for ventilation. However, building owners and developers can opt for certain credits, and IEQ represents only 4–20% of the total score a building can obtain. Of the reviewed rating systems, only LEED NC 2009 has mandatory IEQ credits, for minimum IAQ performance and environmental tobacco smoke control [17].

The adoption rates of the optional IEQ credits in LEED NC 2009 give an indication of how building owners are prioritizing certain aspects of IEQ [17]. We extracted the data and found that the vast majority of projects obtain credits for low-emitting adhesives, paints and flooring systems (Table 1). Increased ventilation is much less widely adopted, despite strong evidence for health and performance benefits of higher ventilation rates [18,19]. While some credits are preferentially adopted and others not, buildings that seek LEED NC 2009 obtain on average 9 of the 15 possible IEQ credits, not including the required fundamental commissioning credit under the energy and atmosphere credit category.

The literature suggests that these credits translate into improved IEQ. Our previous review of green buildings and health identified 17 studies and found that, overall, occupants report better IEQ and fewer health problems in these buildings compared to non-certified buildings. These studies found lower levels of VOCs, formaldehyde, allergens, nitrogen dioxide, and particulate matter in green buildings, which have been separately shown to impact health. Six of the reviewed studies tracked the health of occupants in addition to IEQ, and all six found improvements in the green buildings [20]. These include reduced asthma and allergy symptoms in offices [21]; reduced respiratory symptoms, fewer sick building symptoms, and better self-reported well-being in public housing [22–24]; and fewer medical errors and decreased mortality in hospitals [25]. Of these studies, Newsham et al. used an approach similar to this study by recruiting green and conventional office building pairs and measuring IEQ. They found an improvement in IEQ, a reduction in symptoms, and better reported sleep quality in the green buildings [26]. A follow up paper by Colton et al. published since the time of our review found that in addition to fewer asthma symptoms, hospital visits and school absences were reduced in the green certified public housing development [27]. Comparisons of buildings in poor condition to green buildings provide an opportunity to see the biggest potential effect, but may falsely attribute benefits to certification.

As part of our efforts to determine the factors that drive better human health in buildings, we previously conducted a study in a controlled setting to investigate several IEQ factors – ventilation, CO_2, and VOCs – and their impact on cognitive function scores. We found significant impacts on human decision-making performance related to all three of these factors (Allen et al., 2015). Others have also found independent effects of ventilation, CO_2 and VOCs on cognitive function and other physiological responses at levels commonly found in indoor environments [19,28–31]. In this current study, we looked at buildings that are high-performing across these indicators of IEQ and investigated the potential for additional benefits of green certification on cognitive function, environmental perceptions, and health.

2. Methods

2.1. Study design - Overview

Workers from 10 office buildings in five U.S. cities (two buildings per city) were recruited to participate in a week-long assessment. 12 participants were initially recruited from each building. Participants completed surveys about their health and environmental perceptions and took a cognitive test on the Tuesday and Thursday of the assessment. All buildings are high-performing buildings, defined as buildings surpassing the ASHRAE Standard 62.1–2010 minimum acceptable per person ventilation requirement and with low (<250 μg/m3) TVOC concentrations; however, six of the buildings were renovated to green via the LEED certification framework while the remaining four did not seek green certification during renovation [32].

2.2. Participant and building recruitment

The building assessments took place in urban areas of the following cities: Boston, Massachusetts (9/29/2015-10/2/2015); Washington DC (10/26/2015-10/30/2015); Denver, Colorado (11/9/2015-11/13/2015); San Jose, California (11/30/2015-12/4/2015); and Los Angeles, California (12/14/2015-12/18/2015 and 2/1/2016-2/5/2016). In each city, the buildings were matched strictly by tenant and loosely by age and size (Table 3). In the first four cities, the buildings were also matched by the dates of assessment, and the buildings were recruited such that one building was LEED-certified and the other not. The goal of matching was to select two high-performing buildings in each city that were as similar to each other as possible with the key distinction being that one pursued LEED certification. In the last city, Los Angeles, two green certified buildings were recruited and the assessments occurred on different dates due to an earlier enrolled building dropping out of the study prior to the assessment; a second building was subsequently recruited. The study team visited each building prior to the assessment to: 1) perform a an initial assessment of the heating, ventilation and air conditioning (HVAC) systems, 2) ensure that the building classification as high-performing was valid, and 3) recruit participants.

After obtaining permission from the building owner, building management and tenant, 12 participants were recruited to participate in a five day health assessment in each building. Final

Table 1
Credit adoption rates for select optional IEQ credits in 5490 LEED New Construction 2009 certified buildings (USGBC, 2016).

Credit	% Adoption
EQc2: Increased ventilation	40.9%
EQc4.1: Low-emitting materials - adhesives and sealants	86.5%
EQc4.2: Low-emitting materials - paints and coatings	94.4%
EQc4.3: Low-emitting materials - flooring systems	79.1%
EQc4.4: Low-emitting materials - composite wood and agrifiber products	58.6%
EQc5: Indoor chemical and pollutant source control	40.7%
EQc6.1: Controllability of systems – lighting	66.4%
EQc6.2: Controllability of systems - thermal comfort	39.1%
EQc7.1: Thermal comfort – design	79.4%
EQc7.2: Thermal comfort – verification	59.2%
EQc8.1: Daylight and views – daylight	19.5%
EQc8.2: Daylight and views – views	38.3%