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Reflections on a retrofit: Organizational commitment, perceived productivity and controllability in a building lighting project in the United States

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ABSTRACT

The luminous environment affects how office workers perceive their work setting. However, research on how the lighting commissioning process associates with psychosocial variables relevant to office settings is lacking. This case study explored the extent to which employees working on a recently retrofitted floor of an administrative office building believed they could control the new lighting system. It also measured their levels of perceived productivity and affective organizational commitment to examine correlations between these variables and levels of satisfaction with the lighting commissioning process. Satisfaction with the commissioning process did not significantly correlate with perceived productivity, controllability, affective organizational commitment, or the average number of productive work hours reported after the retrofit. However, perceived productivity significantly and positively associated with perceived controllability and affective organizational commitment. Also, controllability and affective organizational commitment both significantly correlated with the number of productive work hours perceived. Results support interdisciplinary studies emphasizing the importance of lighting controllability in improving employees' perceived performance and satisfaction at work. Results also offer practical suggestions concerning the commissioning process used in the case study.

1. Introduction

Research in the fields of environmental and industrial/organizational psychology, environmental engineering, interior design, and business has explored associations between building occupants' preferences for, and perceptions of, environmental attributes at work and a number of psychosocial outcomes at various stages of the design cycle (e.g., [1–6]). While engineers and designers are becoming intent on creating high-performance buildings that offer occupants a sense of comfort and satisfaction [7,8], researchers and practitioners are understanding that the luminous environment significantly affects how employees perceive their work setting and their attitudes and behaviors within it.

While field research on how the lighting commissioning process associates with psychosocial variables is lacking (e.g., [2]), engineers and facility managers do commonly gather data from office workers about how the indoor environment affects their energy consumption, comfort, productivity, and efficiency [9–11,7,12,13]. Environmental psychologists are also interested in researching the ways in which building users perceive and utilize alterations in lighting environments. For example, the effects of different lighting designs on office workers' performance, wellbeing, and health have been investigated, and changes have been found with respect to peoples' performance associated with task visibility, practice, and fatigue (e.g., [2]). Bordass and Leaman [14] found that stable thermal conditions, usability of ventilation and lighting controls, operable windows, and views out of the building helped office workers feel satisfied and comfortable. Another study conducted after a lighting retrofit was done in a post office setting, as well as in a large manufacturing building, found that workers perceived themselves to be more productive after design changes [15]. Thus, an interdisciplinary approach to researching the effects of luminous environments on office workers, and how the lighting commissioning process plays a role in this relationship, is timely and prudent.

Indeed, after the construction or retrofit stage, the commissioning stage is arguably the most important in ensuring a buildings' proper function. Commissioning is often when a building's controls can be

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optimized, and when lingering or new issues can be identified and addressed [8]. The more effective the commissioning process is (or appears to be from an occupant's perspective), the better the outcomes will be with respect to building performance, as well as occupant wellbeing. Recent studies suggesting that daylighting, electric lighting, and glare are significant factors of occupant satisfaction with work settings (e.g., [16,7,17,18]) bolster the need to measure different psychosocial constructs experienced by office workers.

Although sector-specific studies on barriers to energy innovation, as well as integrated studies of influences on businesses' energy behaviors at the individual, organizational, and institutional levels, are underrepresented in the body of literature [19], we know that occupant behavior can impact a retrofit program's success [20] and that large organizations appear to be are responsible for a significant amount of greenhouse gas emissions—and this trend is on the rise [21]. Andrews and Johnson [19] state that both quantitative and qualitative methodologies should be utilized to address gaps in research, and that "several of the most informative [studies] to date include detailed case studies of particular organizations" (pg. 205). The present case study approaches some of these gaps with a mixed-methodology approach as it takes advantage of an opportunity to augment interdisciplinary knowledge about LED projects in the commercial building sector by investigating a number of variables concerning user experience during a lighting retrofit and commissioning process.

Others have investigated similar variables with respect to changes in lighting design. One case study formalized usability metrics in a post-occupancy evaluation (POE) of several buildings retrofitted with newer lighting technologies and advanced HVAC control strategies [22]. However, while this POE evaluated the effectiveness and efficiency of advanced energy retrofits, along with user satisfaction and related objectives, it did not formally consider occupant reactions to the commissioning process, or ask occupants about their perceived productivity or levels of commitment toward the organization for which they worked. Moreover, studies that address various user preferences for LED lighting (e.g., [23]; Perino et al., 2005; [24]), advantages and drivers of LED projects in the commercial building market (e.g., [25,26]), as well as barriers to successfully implementing LED projects (e.g., [27,28]), do not often combine all of the variables accounted for in the present case study.

Despite a growing body of literature, more work is needed to understand the complex determinants of human satisfaction and comfort in indoor spaces. The present case study tests whether three psychosocial variables meaningfully associate with each other, and with office workers' impressions of a recently completed lighting commissioning process, so that designers, engineers, and researchers alike can better understand how to incorporate occupant perceptions of a lighting retrofit into change management models. Given existing research findings, perceived productivity, perceived environmental controllability, and affective (emotional) organizational commitment ought to play more important roles in design and decision-making processes for architects, managers, developers, and other stakeholders interested in maintaining a luminous environment that employees feel is contributing to their success at work— this case study aims to explore this argument.

1.1. Perceptions of organizational commitment

Studies addressing the luminous environment in office settings can offer reliable data about employees' feelings, behaviors, and performance concerning the workplace, or organization in general [2]. In the context of physical changes made to a work environment, particularly after a lighting retrofit, investigating the psychological construct of organizational commitment may afford a better understanding about the relations between people and their place of work – especially because satisfaction with the physical environment often predicts job satisfaction and organizational commitment [29,30,4,31].

Organizational commitment is understood in organizational/industrial psychology literature as an attitude based on the degree of identification with, or attachment to, the organization for which one works [32–34] and often correlates strongly with job satisfaction [35,80,30]. Organizational commitment correlates reliably with employee motivation and satisfaction at work (e.g., [83–85]) when conceptualized as three key experiences: (1) acceptance of the values and goals of an organization, (2) willingness to exert effort for an organization, and (3) having a strong desire to remain affiliated with an organization [36].

To further delineate organizational commitment in workplace settings, Allen and Meyer [37] developed a three-component model composed of affective, continuance, and normative commitment, respectively. Briefly, they define affective organizational commitment as one's personal, emotive characteristics and experiences at work. Work experiences provide the strongest contribution to an individual's development of affective organizational commitment because they often fulfill a psychological need for comfort and competence in a professional social role [37]. Whereas, continuance organizational commitment is based on the magnitude and number of investments an employee has in his or her organization, together with a perceived lack of alternatives [38–40]. Finally, normative organizational commitment develops through experiences prior to, and following, entry into an organization [82]. Allen and Meyer [32] provide an example in which an individual with strong normative organizational commitment has a family member employed by the same organization that emphasizes the importance of organizational loyalty.

The three dimensions of organizational commitment appear to be experienced somewhat differently by employees (and an individual may experience each dimension to varying degrees; [32]. Essentially, employees with strong affective organizational commitment remain working for an organization because they *want* to, whereas those with strong continuance organizational commitment remain because they feel they *need* to, and employees with strong normative organizational commitment stay because they feel they *ought* to [32].

Relevant to understanding the extent to which employees feel organizational commitment in an office setting, especially after a design change, is the link between strong self-reporting of organizational commitment and organizational citizenship behaviors (OCBs; [41,42]). OCBs are characterized as discretionary actions that promote effective functioning of the organization but are not directly recognized by a formal award system [41]. Significant links have been revealed between employees' organizational commitment, their level of effort, and their performance at work (e.g., [43]) whereby the higher an individual's organizational commitment, the greater the effort the individual is willing to invest on behalf of the organization, and the better their performance. OCBs seem to become more likely as organizational commitment increases because employees identify with the organization's values and goals. This identification can manifest as a willingness to exert effort for the organization (or a certain floor, unit, or team within it) because of a feeling of investment and affiliation.

Because organizational commitment appears to predict more instances of organizational citizenship behavior in the workplace [41], measuring it in the present case study may provide insight for future research concerning pro-social attitudes and behaviors in settings where recent changes to the lighting design have been made – changes that are known to significantly affect employee satisfaction. For example, employees that are highly organizationally committed are better able to cope with stress [44], and those who feel organizationally committed at work are less likely to search for alternative positions [45]. Thus, if organizational commitment is strong among office workers surveyed after a lighting retrofit has occurred, and if levels of organizational commitment correlate with perceptions of productivity, and controllability of the new lighting scheme, it may be argued that the lighting commissioning process has been a success.

A reliable and standardized organizational commitment scale (the OCS) has been developed by Allen and Meyer [32] and used in studies

found in the bodies of industrial/organizational and environmental psychological literature [32]. The OCS measures the three components of organizational commitment using 24 items. However, given the successful application of the ACS in other work (e.g., [30,46]), and that it often correlates strongly and positively with job satisfaction (e.g., [30]), this single component of the overall construct of organizational commitment is an efficient mechanism to gather data about participants' emotional connection with their organization (without asking questions concerning job satisfaction that often relate to pay grade, inter-office relationships, and so on). In addition, there is some debate in the body of literature about the predictive ability of the two subscales measuring continuance and normative organizational commitment in comparison to the separate and distinct use of the ACS (see [34]). Therefore, we chose the ACS to assess employees' emotional attachment to, identification with, and involvement in the organization.

1.2. Perceptions of productivity and environmental controllability

Measuring the extent to which the physical work environment influences office workers' perceptions of their own productivity and sense of control over the setting is becoming more common (see [47]). However, relatively little research exists concerning lighting's effect on productivity [2]. Some of the results of studies that have been undertaken suggest that daylighting contributes to indoor environmental quality and, thus, can have a positive effect on occupants' perceptions of their own productivity and performance (e.g., [48]). Similarly, occupant control over systems found in building environments, such as windows, temperature set points, and lighting, can significantly influence how satisfied occupants report to be [49,6]. Having a sense of individual control over lighting seems to help maintain employee motivation and vigilance during the work day [2]. One study found that when office workers are able to control lighting conditions (i.e., dimming), they rated the lighting quality to be better, as well as an improvement in their feelings of satisfaction with the office environment [2].

These results, and others like them, are important to consider further because a high degree of environmental controllability perceived by employees has been shown to positively associate with components of organizational commitment, such as job performance and job satisfaction [50–52], as well as job satisfaction and stress reduction [53]. A sense of control over one's work environment has also been shown to contribute to employee sense of wellbeing [54]. Research like this helps to legitimize the instillation of individual controls for environmental attributes such as lighting, temperature, and ventilation in open-plan built environments [3]. It also supports including a perceived controllability scale in new research as a way of measuring attitudinal and behavioral responses to lighting characteristics after a retrofit.

In sum, affective organizational commitment, perceived productivity, and perceived controllability are cogent psychosocial variables to measure in interdisciplinary research concerning design changes made to office environments. The present case study accounts for each in an effort to understand how they relate to each other for office workers after a lighting retrofit, as well as how they relate to occupant satisfaction with the lighting commissioning process.

1.3. Project background and site details

This case study was conducted as part of a broader project at the University of Washington funded to collect qualitative and quantitative data about change management and the lighting commissioning process concerning a lighting retrofit to one floor (the 12th floor) of a 22-floor administrative building situated on the University of Washington campus in Seattle, Washington, USA. Each floor is rectangular-shaped with near-uniform indoor dimensions (approximately 30 m by 40 m) with significant window areas on the building's perimeter. All windows are non-operable and double paned with tinted glazing (see [55]), for further information about the building and the other projects done on the site).

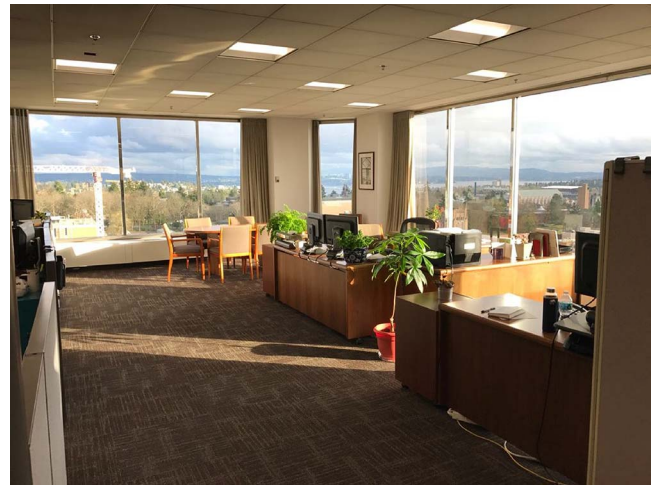

Fig. 1. Open-plan layout on the 12th floor; perimeter.

The building houses approximately 1800 employees working for the university in various administrative capacities. Approximately 80 employees work on the floor (see Figs. 1 and 2). The building is not a typical university office environment insofar as it is not where faculty offices and classrooms are situated. Rather, open-plan office spaces are occupied by employees doing tasks similar to office workers in non-academic work sectors. Thus, the site, and the results of the case study, are somewhat generalizable to similar office settings on a single floor of a multi-floor tower building.

Open office designs are sometimes preferred by organizations because they allow flexibility in the use of available workspace and can increase communication and collaboration among employees, often enhancing organizational effectiveness [56,52]. However, open-plan layouts can also be perceived by users as unsatisfactory, having a negative influence on productivity (e.g., [57]). Sharing ambient environmental features, such as temperature and light levels, can also negatively affect one's perception of controllability over the office environment. Occupants are often unaware of the design intentions and operational details of lighting control systems [58]. Given that the floor used in this case study had an open-plan layout, and a shared lighting environment, it was a sensible location to measure particular psychosocial responses of employees after a change in lighting design.

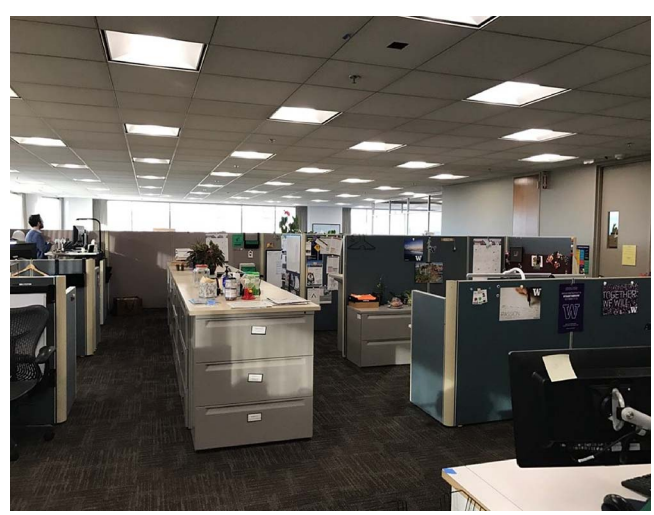

Fig. 2. Open-plan layout the 12th floor; interior.

1.3.1. Lighting design

Before the retrofit, the lighting design on the floor included suspended ceilings with 0.6 m by 0.6 m recessed parabolic light fixtures. All 261 of these fixtures were installed in 2011 and each consisted of two 30 W (rated) fluorescent T8 sized U-lamps (i.e., 30 W T8 U-lamps and QHE 2 × 32 T8/UNV ISL-SC) that required an input power of 51 W per fixture and exhibiting color temperatures of 4100 K (maximum output of 2800 lm). The fixtures were uniformly spaced approximately 2.4 m on-center and arranged on a staggered grid. During regular business hours, the fixtures could only be powered on or off; after-hours, they automatically shut off by a timer. Individual fixtures belonged to a lighting zone. Each zone was controlled by a single switch, accessible to all occupants, located in a utility closet near the stairwells on the east and west sides of the building. The zones were broadly split into two wings (east and west) and geometrically defined as concentric rings. For example, one switch corresponded to the outermost ring of fixtures on the east side, and the one on the west, and so on.

All existing fixtures were retrofitted between December 2015 and March 2016 with new fixtures featuring a single LED bulb rated at 20 W. In addition to replacing all 261 fixtures (without altering their positions) with lower power-demand Lithonia 2VTL2R-20L LED fixtures (rated at 20 W maximum but dimmable with a warmer color temperature at 3500 K and 1839 lm maximum output), eight photometric sensors with daylight harvesting and occupancy detection capabilities were installed. These sensors were equipped with wi-fi-enabled lighting controls that allowed for dynamic operation for individual or user-defined groups of fixtures, as well as a server terminal that collected and monitored real-time performance data (see Fig. 3). The photometric sensors were placed in locations to ensure communication with all fixtures, roughly in the center of each side or corner of the floor defined by the eight cardinal and inter-cardinal directions. Although advertised to reduce glare, occupants informally told facility managers that they perceived the new LED fixtures as producing more direct glare at full power (perhaps because the existing fixtures had been recessed farther into the ceiling; see Fig. 4).

Located in the basement of the building, the master control terminal digitally and dynamically controlled the operation of each zone and fixture. Each zone can feature its own set of rules for operating hours, brightness, and response to photometric readings. Although operators can choose to control each fixture individually, the facility managers defined the same set of rules for 11 zones: eight corresponded to cardinal and intercardinal directions, two super-zones included zones on the west or east side of the building, and one zone included all three conference rooms on the floor. Ultimately, the retrofit provided facility managers with increased flexibility in lighting control, but also an additional layer of complexity in terms of how they could define operating conditions.

1.3.2. A note concerning energy consumption

The cost of energy consumed in the building rose from $87,000 to approximately $100,000 per month (and regularly exceeded $1 million on an annual basis) between 2013 and 2015, based on utility bills from Seattle City Light. Manual lighting measurements taken on the floor on September 2nd, 2015 (prior to the retrofit) revealed that lighting levels in many workspaces exceeded the Illuminating Engineering Society of North America (IESNA) recommended illumination minimums, particularly for workspaces along windows. Indeed, the retrofit was initiated, in part, because of expressions of occupant discomfort, as well as by facility managers wishing to achieve passive and active energy savings with increased control and customization of the lighting environment.

In their selection of retrofit equipment, facility managers attempted to address nominal power requirements. At full power, the new fixtures should reduce passive power requirements by at least 50%, and the photometric sensors and custom zoning plans ought to provide additional granularity for customizing lighting conditions as well as savings from automatic dimming. However, difficulties exist when quantifying savings for lighting control energy conservation measures, as discussed in *authors withheld* [59]. In order to make appropriate choices during a retrofit project, stakeholders often wish to know the marginal benefits

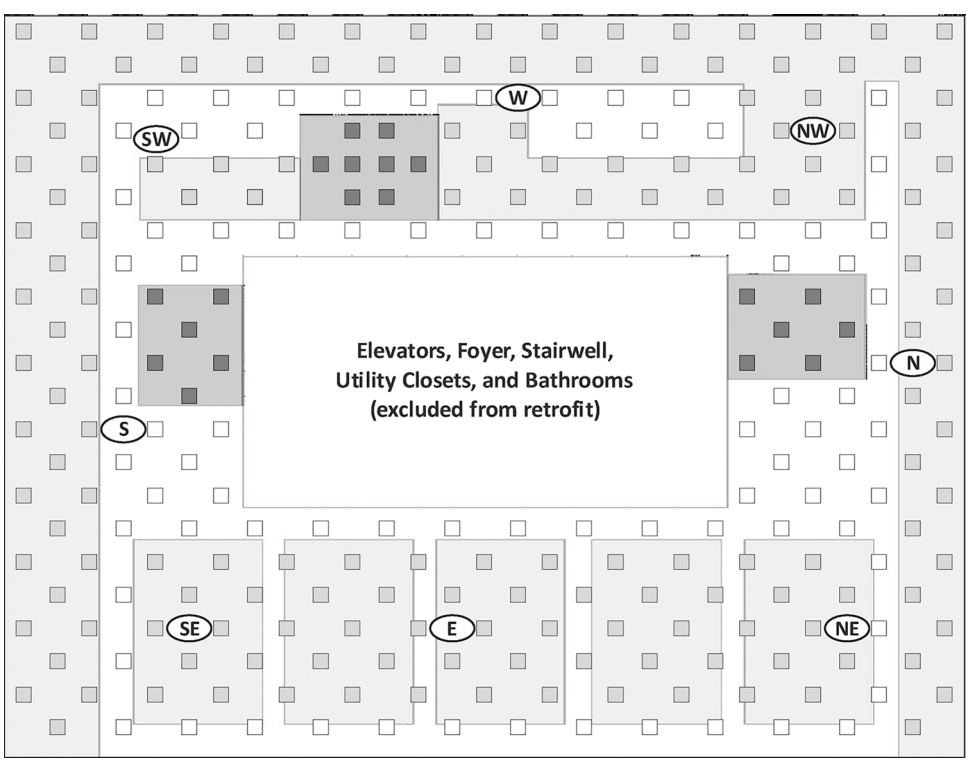

Fig. 3. Post-retrofit fixture plan consisting of 261 fixtures and 8 photo sensors. White fixtures indicate those covering primarily walkways; light grey fixtures indicate those over open work spaces; dark grey indicate those in enclosed conference rooms.

Fig. 4. Side-by-side comparison of existing and new fixtures at full power during Installation.

of replacing fixtures and adding advanced lighting controls. Not surprisingly, stakeholders often prefer to use such information in the selection process rather than wait for post-retrofit measurement and verification (M&V) reports from pilot studies.

For fixture replacement projects, it is generally assumed that ballast input wattage is the primary reason for energy savings. When controls are included, it is assumed that energy savings results from a combination of both ballast power and operating hours. However, the extent of this reduction is challenging to quantify accurately because each fixture can potentially exhibit very different operating hours in systems featuring daylight harvesting and auto-dimming controls. This is because lighting controls can change a fixture's power usage from being binary (on/off) to dimmable and, thus, energy cannot be calculated from total operating hours alone because of the variance in fixture operating power. Moreover, because electrical consumption is not submetered by floor, or energy end-use, it is difficult to isolate changes in performance based on a lighting retrofit on a single floor from an aggregated utility bill encompassing an entire building.

Given the challenges in isolating and measuring energy savings from the retrofit, we chose to estimate based on published literature. For example, on the west coast of North America, for office buildings with between 200,000–500,000 square feet of usable floor space, the Environmental Protection Agency (EPA) estimates that an average of 17% of electricity consumption is due to lighting. This portion of consumption is comparable to EPA's estimates for ventilation (16–25%), refrigeration (11–18%), and plug-loads (10–20%) in similar office building sizes.

1.3.3. The lighting commissioning process

The lighting commissioning process occurred over two days as lighting controls were optimized and calibrations of the fixtures were completed. Commissioning was initiated in the daytime on March 10th, 2015. The next day, the project team was informed that the daylight harvesting calibration had failed because of an accidental shut-off of building electricity. Consequently, calibration was performed again that evening.

With the conclusion of the commissioning process, the fixtures and controls were handed over to facilities personnel. Occupants and facilities personnel were given time to become accustomed with the new fixtures before they were asked to complete the questionnaire used in this case study. During this time, minor changes to the fixtures were made. For example, the team reduced and tested the overhead artificial lighting levels from 50% to 45%, and pilot tested color-tunable task lights for additional controllability. A further reduction of overhead artificial lighting levels was made (down to 25%) with the addition of color-tunable task lights, and an alteration to the sensitivity of motion detectors to 2 h (rather than 15 min) to avoid frequent automatic shut off. Daylight harvesting features were tested to reduce the temperature gradient across all zones on the floor (i.e., the difference in brightness between windows versus wall locations within a zone was less steep with the new fixtures compared to the old fixtures). In addition, different levels of daylight harvesting were executed to reduce the "sharpness" of this gradient so that differences in brightness might be less noticeable to occupants. Finally, the positions of sensors were reassessed to accommodate cubicle heights and sensitivity with respect to where occupants were working.

While the lighting commissioning process was not initially set up to be participatory (i.e., occupant ambassadors were not designated from the beginning of the project), facility managers and real estate managers responded quickly to occupant complaints concerning excessive amounts of visual discomfort after the retrofit was complete. For instance, facilities managers posted signs in the elevator lobby to communicate the intentions of the retrofit and the proposed schedule of changes to account for occupants' concerns. The managers also initiated meetings with occupants to explain the lighting retrofit project. Other complaints had to do with communication issues (i.e., some occupants felt that they were not given clear information about what the retrofit would entail) and issues concerning the commissioning schedule (i.e., commissioning was delayed and occupants noted that it seemed to be taking too long and that they lacked a clear explanation as to why).

Occupants commented via an electronic work order request form, as well as directly to facility managers and the researchers who were on site taking objective measurements of lighting quality. After a number of complaints from occupants had been raised, two lead administrators from the two departments situated on the floor were designated as "occupant ambassadors" to provide a central point of contact for employees who had further questions or concerns about the commissioning process. Ambassadors were provided with regular project updates via email from the researchers, as well as from facilities staff.

1.4. Case study hypotheses

H_1. Satisfaction with the lighting commissioning process will significantly associate with perceived productivity.

H_2. Satisfaction with the lighting commissioning process will significantly associate with perceived controllability.

H_3. Satisfaction with the lighting commissioning process will significantly associate with affective organizational commitment.

H_4. Perceived productivity will significantly associate with perceived controllability.

H_5. Perceived productivity will significantly associate with affective organizational commitment.

H_6. Perceived controllability will significantly associate with affective organizational commitment.

2. Method

2.1. Participants

Participants were 38 employees working on one floor of the building (6 men, 13 women; 19 individuals chose not to report their gender). Our sample was limited in size by the total number of employees working on the floor. Enough floor space was allocated for approximately 80 workstations but only 55–60 desks appeared to occupied when the questionnaire was distributed. Although all employees working at desks were invited to participate, we received responses from 38 tenants, yielding a response rate of between 63 and 69% (given the unknown exact total of occupied desks at the time of survey distribution). A *post-hoc* power analysis indicated that a sample size of 38 participants is sufficient to reveal significant two-tailed correlations between variables at the $p < .05$ level and a small-to-medium effect size, $f^2 = 0.30$ [60].

Of those that responded about their age, 53% of participants' self-reported to be "over 50 years old," while 27% reported to be "between 40 and 50 years old," 13% "under 30 years old," and 7% "between 30 and 40 years old." This data describes a total of only 15 participants in the sample because 23 individuals did not report their age at all (responding to demographic questions was optional in our questionnaire).

Of the 33 participants who selected an option on the item concerning the type of work that they do in the case study building, 63% self-reported to undertake a "combination of computer work, paper tasks, phone calls, and face-to-face meetings," while 21% noted that they engage in "computer aided design, engineering, or software development," and 3% did "people management, leadership, and/or training." No participant selected the "faculty management" option within the item.

2.2. Materials

2.2.1. Satisfaction with the lighting commissioning process scale

While other scales and methodologies exist to measure lighting in commercial offices and other building types (e.g., [61,62,13,63,64]), we created a brief 4-item scale for the present case study consisting of questions concerning participants' awareness of the timing of the lighting commissioning process and the ways in which it was to be completed. It also contained items concerning participants' levels of satisfaction about their options to express their lighting preferences and the way in which the commissioning process was handled (see Table 1). Each item was answered using a 5-point Likert scale where 1 denoted strong disagreement and 5 denoted strong agreement. No items were reverse coded; all 38 participants responded to each item. Items came together as an internally consistent scale with a good Cronbach's alpha of $\alpha = 0.77$ [65].

In addition, two open-ended items were included in the questionnaire to obtain qualitative data from participants concerning their opinions on the lighting commissioning process (e.g., "please provide any additional comments regarding how the lighting commissioning process could be different" and "please feel free to submit any other comments about your experiences with the lighting retrofits and controls below").

2.2.2. Perceived productivity scale

An 8-item scale was created for the present case study to invite participants to self-assess their levels of productivity at work, the extent to which the physical work environment affects this assessment, and whether they feel engaged, efficient, and positive (see Table 2). Each item was answered using a 7-point Likert scale where 0 denoted strong disagreement and 6 denoted strong agreement. No items were reverse coded and all participants responded to each item; the scale was revealed to be very internally consistent, $\alpha = 0.91$ [65]. In addition, one separate item asked participants to enter an estimated average number of hours they experience "productive work hours during a typical work week."

Table 1
Lighting Commissioning Process Satisfaction Scale Items.

I was adequately aware of when commissioning would occur
I was adequately aware of how commissioning would be performed
I am satisfied with my options to express lighting preferences

Table 2
Perceived Productivity Scale Items.

I consider myself to be productive at work
The physical environment in this unit allows me to be as productive as I would like
I feel engaged in my work while I am on this floor
I do not believe that I could be any more productive than I already am at work
I am motivated to create a positive atmosphere at work
I assist my colleagues in doing their jobs in more efficient ways
I am willing to take on more of a leadership role during a time of crisis at work
My colleagues look to me for setting a good standard for organization at work

2.2.3. Perceived controllability scale

Typically, POE practitioners measure occupants' perceived level of control through self-report methods, such as interviews and surveys (Kim et al., 2015; [81]. Thus, a 5-item perceived controllability scale was created for the present case study to measure participants' levels of self-assessed controllability of the new lighting program with respect to the 12th floor in general, to their personal workspace, and the workspaces of others (see Table 3). Each item was answered using a 7-point Likert scale where 0 denoted strong disagreement and 6 denoted strong agreement. No items were reverse coded and all participants responded each item. The scale was internally consistent, $\alpha = 0.60$ [65].

A separate question was asked to measure how often participants reported to have changed the lighting levels above their workspace. This item was posed nominally, using 4 categories (e.g., "0 times," "between 1 and 5 times," "between 6 and 9 times," and "10 times or more").

2.2.4. Affective organizational commitment scale

The affective organizational commitment scale (ACS; see Table 4) is a standardized 8-item sub-scale of the 24-item organizational commitment scale (OCS) [32]. Each item was measured on a 7-point Likert scale where 0 denoted strong disagreement and 6 denoted strong agreement. Four items were reverse coded and all participants responded each item. The scale was very internally consistent, $\alpha = 0.81$ [65].

2.3. Procedure

The project kickoff meeting lead by the research team occurred on February 17, 2015. Questionnaire development began after the meeting and Institutional Review Board applications were submitted to the researcher's academic institution for approval. The authors spent the next four months identifying the scope of the study and conducting a feasibility analysis of the proposed research design in relation to the floor's

Table 3
Perceived Controllability Scale Items.

I perceive that I have control over the lighting levels above my workspace
I am willing to change the lighting levels above my workspace even if a change affects those working nearby
I am comfortable asking those nearby whether they are comfortable with me changing the lighting level
I am tolerant of others making changes to lighting levels without asking me first
I know how to change the levels of overhead lighting above my workspace myself without assistance from anyone else

Table 4
Affective Organizational Commitment Scale Items.

I would be very happy to spend the rest of my career with this organization
I enjoy discussing things about this organization with other people
I could easily become as attached to another organization as I am to this one *(negatively-coded)*
I do not feel like 'part of the family' at this organization *(negatively-coded)*
I do not feel emotionally attached to this organization *(negatively-coded)*
This organization has a great deal of personal meaning for me
I do not feel a strong sense of belonging to this organization (negatively-coded)
I really feel as if this organization's problems are my own

physical construction. Objective lighting measurements were obtained in July 2015. The lighting vendor was selected in August 2015 and construction began in January of the following year.

In July 2016, seven months after the lighting retrofit began, an electronic link to the questionnaire (created using Google Docs) was placed in an email from the facilities manager to the employees working on the 12th floor. After approximately one week, two additional reminder emails were sent to employees in order to increase the number of responses.

Other studies that have collected user satisfaction and controllability data after an energy retrofit (e.g., [22]) did so more than half a year after a design change. Therefore, we believe the time between the start of the retrofit and the distribution of the questionnaire to occupants to be sufficient in affording participants time to experience the new lighting levels and controls. This time frame was also lengthy enough for participants to form opinions about the functionality of the new lighting program in relation to their physical and social work environments, and their organization in general (cf. [22]).

3. Results

3.1. Descriptive statistics

On average, participants reported their levels of affective organizational commitment to be mildly positive ($M = 4.10$, $SD = 0.91$ on a 7-point scale), but responded more neutrally concerning their satisfaction with the lighting commissioning process ($M = 2.91$, $SD = 0.80$ on a 5-point scale). Average responses were quite positive with respect to perceived productivity at work ($M = 4.5$, $SD = 1.01$ on a 7-point scale). The average number of productive work hours experienced during a typical work week was 31.80 ($SD = 11.05$).

However, participants reported mild dissatisfaction with their perceived controllability of the new lighting program ($M = 2.24$, $SD = 1.04$ on a 7-point scale). This below-neutral attitude concerning controllability was supported by the number of participants (87% of the sample) stating that they had made no attempt to change the lighting controls above their workspace (the other 13% of the sample stated that they had made an effort to control the lighting settings between 1 and 5 times). Although we do not know the specific ways in which occupants attempted to control the fixtures, we assume, given the results of qualitative data outlined in the "*Content Analysis*" sub-section, their efforts were in the form of communication with a manager, facility staff member, or with the commissioner during the two days he was on-site.

3.2. Correlations

A correlational analysis using Pearson's r revealed that participants' responses on the lighting commissioning process satisfaction scale did not significantly correlate with scores on the perceived productivity scale ($r = 0.14$, $p > .05$), the perceived controllability scale ($r = 0.18$, $p > .05$), nor the affective organizational commitment scale ($r = -0.05$, $p > .05$) In addition, participants' levels of satisfaction with the lighting commissioning process did not linearly associate with their perceived number of average productive work hours ($r = 0.01$, $p > .05$) Therefore, H_1, H_2, and H_3 were not supported.

However, participants' responses on the perceived productivity scale significantly associated with responses on the perceived controllability scale ($r = 0.37$, $p < .05$). In addition, participants' levels of perceived controllability significantly correlated with their perceived number of productive work hours during the week ($r = 0.38$, $p > .05$). Thus, H_4 was supported.

Further, participants' responses on the perceived productivity scale significantly associated with responses on the affective organizational commitment scale ($r = 0.46$, $p < .01$). Levels of affective organizational commitment also linearly associated with the perceived number of productive work hours during the week ($r = 0.35$, $p > .05$). Thus, H_5 was supported. Finally, participants' responses on the perceived controllability scale significantly associated with responses on the affective organizational commitment scale ($r = 0.32$, $p < .05$), supporting H_6.

3.3. Content analysis

A content analysis of the two open-ended items included in the questionnaire revealed themes expressed by participants about the lighting commissioning process and their general opinions about the lighting retrofit and controls. Because of the small number of comments, words and phrases were coded to extract meaningful themes by hand, without the aid of qualitative data analysis software (as per [66,67]).

The first open-ended item (i.e., "please provide any additional comments regarding how the lighting commissioning process could be different") yielded 13 comments in total (however, some individual comments contained words and phrases that fell into more than one theme). One response was "none," and one was not helpful to the analysis (e.g., "I was not here for the process. I probably wouldn't have participated if I was"). Out of the 11 remaining individual responses, four main themes emerged: "lighting problems" (33% of the data), "scheduling" (27% of the data), and "communication and expectation management" (27% of the data), and "controllability" (13% of the data).

Most comments within the "lighting problems" theme had to do with lights turning off unexpectedly and excessive brightness. Specific comments within the theme of "scheduling" concerning opinions that commissioning should have happened over the weekend to minimize impact on occupants, and that the process took too long. Comments within the theme of "communication and expectation management" had to do with poor communication about the timeline, as well as poor communication between administration and occupants about what to expect during and after the commissioning process. Participants felt that they were told information about controllability but received different outcomes after the process was complete. Finally, comments to do with the theme of "controllability" contained information about a perceive lack of control over lighting in workspaces and offered insight to participants wanting to be able to adjust lights for their own pReferences

The other open-ended item (i.e., "please feel free to submit any other comments about your experiences with the lighting retrofits and controls below") yielded 9 comments in total. total (however, some individual comments contained words and phrases that fell into more than one theme). Four main themes emerged, three of which were the same as those that emerged in the analysis of the previous item: "controllability" (46% of the data), "lighting problems" (18% of the data), and "communication and expectation management" (9% of the data). The new theme that emerged for this item was "positive improvement in conditions" (27% of the data); the theme 'scheduling' did not occur for this item.

Most comments within the "controllability" theme had to do with desires for desk lamps, localized adjustment, and more individual control over the new lighting system. Comments within the theme of

"positive improvement in conditions" had to do with the commissioning process being an interesting procedure and that no glare or health problems had been noticed (e.g., headaches or eye strain). Comments concerning the theme of "lighting problems" were included issues with overhead and background lighting and with some areas of the floor being very dark compared to other areas. Finally, the single comment to do with the theme of "communication and expectation management" concerned an inability to adjust the lighting locally, which was a promised attribute but was not perceived to be delivered by the retrofit.

4. Discussion

Understanding more about how high-performance buildings can conserve energy, as well as increase users' perceptions of their well-being, productivity, and controllability over building attributes is practical and important [68,7]. This case study aimed to augment knowledge about how three particular psychosocial variables relate to each other, and with occupant satisfaction with the lighting commissioning process, after a lighting retrofit had been completed in an office environment. Taken together, our findings highlight the need to better understand the strengths and limitations of the lighting commissioning process from the occupant's perspective in order to capitalize not only on its role in the design cycle, but also on the ways in which it influences the perceptions and environmental appraisals of building users.

Three of our six hypotheses were supported by correlational analyses. These three successful predictions concerned significant linear associations between each of the psychosocial variables: perceived productivity, perceived controllability over lighting, and affective organizational commitment, highlighting the methodological strengths of this case study because each construct has been shown in previous research to be related to one another in office settings. Because these variables are also correlated in the present work, it appears that some focus ought to be placed going forward on how best to positively correlate these variables with the lighting commissioning process. Indeed, the low level of perceived controllability felt by participants after the retrofit, coupled with the lack of support for the first three hypotheses that satisfaction with the lighting commissioning process may correlate with perceived levels of productivity, controllability, and affective organizational commitment, suggests that more can be done to link the lighting commissioning process to the psychosocial experiences of office building occupants.

Existing studies indicate that some of the barriers to successful LED retrofits in commercial buildings involve the omission of early planning efforts, poor communication strategies, and a lack of educational opportunities for building occupants. For example, Sloane et al. [24] found that despite the general appeal of LED technology, managers and stakeholders are often concerned that LED lighting systems are too complex for occupants to use and, as a result, will require additional human resources that may encumber primary occupational duties. Our findings mirror those outlined in Sloane et al. [24] in that user preferences (and misunderstandings) about a new lighting system can pose significant challenges during LED implementation projects, and that unanticipated consequences can occur because of particular design choices, unevenness in light levels, and differing occupant perceptions and reactions. Sloane et al. [24] also concluded that early planning is essential for a lighting project's success, and that having a demonstration area for occupants to experience light levels prior to a retrofit can be effective for later calibration. These 'lessons learned' are expressed in the quantitative and qualitative results of the present case study. Participants felt that issues to do with scheduling, communication, and expectation management were relatively important compared to a lack of controllability during, and after, the commissioning process. And, when asked to generally comment about the retrofit project as a whole, points about controllability (e.g., lack of adjustability for individual work spaces) and poor communication strategies about commissioning outcomes were frequently made.

Unfortunately, many building projects do not allow sufficient time and financial support for thorough commissioning [20,69,8,70]. One study investigating user participation during retrofits in the residential sector identified four key themes important to those involved with energy-efficiency retrofits: funding mechanisms, predicting performance, installation, and people [20] and that the challenges linked to funding mechanisms resulted in insufficient time to plan, publicize, implement, and evaluate retrofits. Moreover, complex controls are often installed in high-performance buildings that require careful adjustment to provide users with comfort while maintaining efficient energy usage [71]. If the person–system interface for these controls is too complicated (e.g., [72]), they may be set improperly or ignored altogether by occupants. This can create a work environment where users lack perceived control, feel unproductive (e.g., [71]) and, ultimately, become dissatisfied with the commissioning process such that affective organizational commitment will also be affected.

Environment-behavior research indicates that offering design-related choices about the work environment can lead to desirable psychological outcomes for employees [5,3], and that the provision of control over interior lighting in office spaces to employees can improve their performance and mood at work [73,5,74]. Perino et al. (2015) developed a monitoring protocol for evaluating the overall performance of lighting retrofits that treats occupant perception as a key indicator of a successful retrofit. The results of that research highlighted the need to form a comprehensive monitoring plan well in advance of commissioning to minimize disturbances to occupants. Thus, it seems that some of the positive outcomes a sense of control affords building users extends to the lighting commissioning process. In this case study, average levels of perceived controllability were quite low, and satisfaction with the commissioning process was neutral. Given the results of the content analysis, choosing a more extensive participatory approach toward the planning and implementation of a lighting commissioning process by involving (rather than simply informing) building users would be worthwhile in the future. This recommendation is similar to one made in a previous study based on a portion of the larger project of which this case study is a part [55], whereby highly involved and localized tenant "ambassadors" are suggested to help advocate for occupants' preferences from the start of the design cycle. In fact, including specific stakeholders as "coaches" or "facilitators" on energy retrofit project teams to communicate with building occupants has been found to be beneficial [75].

Furthermore, occupants themselves ought to be given the opportunity to help with the commissioning process, as well as receive (and provide feedback on) information about what may happen during the process in more detail than often occurs in standard practice. Similar strategies have been undertaken in earlier projects on the site of this case study [55], as well as in other work (i.e., [22]) whereby thorough and frequent communication is ensured between building occupants and facilities managers in advance of, and during, a retrofit to set expectations about the inevitable "trial-and-error" period that follows the lighting commissioning process.

In one study concerning building occupants' organizational commitment to their "green" workplace, organizational social norms played a major role in the promotion of pro-environmental and energy-related behaviors [21]. Visibility of pro-environmental values through strategies such as regulations, policies, interventions, language, and displayed behavior of organizational leaders also helped build a shared perception of organizational support [21]. This finding supported results found in other studies (e.g., [76,77]) and may be extrapolated to the present study insofar as occupants may participate in, understand better, and comply with a lighting commissioning process when strong internal communication exists to contribute to appropriate organizational behaviors in the building. Indeed, Dumitru et al. [21] state that by creating "autonomy-supporting contexts and an organizational culture that treats workers' input as a valuable and necessary part of the

organizational performance, both public organizations and private companies have a chance to create an environment that not only encourages compliance with environmental policy, but also promotes active citizenship and engagement in organizational change" (pg. 58). Other strategies have been studied in relation to peoples' perceptions of changes to energy systems over time. One recent study found that listening to, and telling, stories about energy-related topics can play a powerful role in affording engagement in policy issues that may be complex at first glance and, perhaps, intimidating for occupants to discuss [78]. And, Freeman and Yearworth [79] found a general mismatch between key stakeholders' power and interest in a low-carbon vision of city life. They note that investigators ought to consider the benefits of energy systems for different social groups by asking research questions that consider problem creation, ownership, and fairness in energy and design-related decision-making. Overall, the benefits of affording opportunities for occupants to offer their input before, during, and after energy-related design changes are numerous, and a need exists for comparative research between studies using various participatory approaches before, during, and after a commissioning process concerned with energy use and behavior change.

While the psychosocial variables measured in this case study correlated with each other in expected ways, they did not associate strongly with users' satisfaction with the lighting commissioning process. On average, participants responded positively about their affective organizational commitment and perceived productivity after the retrofit. However, they reported only neutral levels of satisfaction about the lighting commissioning process itself, and quite negatively in terms of their perceived controllability over the lighting after commissioning was complete. As noted in the introduction, because organizational commitment was, on average, moderately strong among office workers surveyed after the lighting retrofit had occurred, and because levels of organizational commitment correlated with perceptions of productivity and controllability of the new lighting scheme, perhaps the lighting commissioning process undertaken in this project was viewed by occupants, in some respects, as a success. However, without the ability to compare data collected in the present case study with data collected before the commissioning process, occupants' psychosocial experiences in the building cannot be fully understood. However, many items in this case study's questionnaire asked participants to consider the lighting commissioning process itself, as well as their physical work environment. In addition, instructions given before each psychosocial scale included directed wording, depending on the nature of the scale (e.g., "When answering questions in Part III, please think about your work environment as it is today"). While this form of survey methodology does not offer causal data, the questionnaire as a whole was made clear to be about participants' satisfaction with the recent changes to the lighting at work and, thus, we believe that participants' responses indicate their reactions, in part, to the lighting commissioning process. Future research using a repeated measures design may reveal whether the lighting commissioning process affects psychosocial variables over time.

Finally, one key contribution of this case study may be the ways in which it asked office workers about their perception of lighting design changes during the commissioning process. Many studies do not measure together the psychosocial variables highlighted in the present work but, instead, conduct quasi-experimental studies where groups of occupants are exposed to varying levels of luminous conditions before being asked about preference. Thus, our findings may afford a practical methodological template for facility managers and other stakeholders wishing to measure occupant perceptions and attitudes about design changes during the commissioning process for similar projects.

4.1. Limitations

One limitation to this research is the lack of pre-occupancy (i.e., pre-retrofit) data about participants' perceived levels of affective organizational commitment, productivity, and controllability. As noted in the *Project Background and Site Details* section, this case study is part of a broader project that has afforded data for a number of published and unpublished studies. Formal collaboration between the authors of the present work did not occur until a later stage in the project's timeline. Thus, psychosocial variables were not measured until after the retrofit had begun. This is why affective organizational commitment, perceived controllability, and perceived productivity are measured on 7-point Likert scales while the satisfaction with lighting commissioning process scale used a 5-point Likert scale. Because the ACS is a standardized scale [32], we did not alter its structure and created the other two psychosocial scales to be consistent with it. While the three psychosocial scales include a zero at their lowest response option, the satisfaction with lighting commissioning process scale (created early in the project) does not and, therefore, we did not feel it psychometrically appropriate to transform it. All scales are continuous; associations found between variables can be understood as linear.

4.2. Conclusions

This case study communicates to building engineers, owners, facilities managers, and users alike that changes to lighting, as well as employees' perceptions of their own attitudes, preferences, and behaviors at work, remain important variables in design cycle research in office environments. Results support the notion that psychosocial variables often studied in office settings, such as perceived productivity, affective organizational commitment, and controllability, are strongly correlated and should continue to be accounted for in interdisciplinary environment-behavior research and design initiatives. Results also suggest that the ways in which a lighting commissioning process is perceived by building occupants are important to research further. A participatory approach to the commissioning process, as well as efforts to inform occupants of outcome predictions and scheduling changes as commissioning occurs, may afford engineers, designers, and social scientists a better understanding of how to optimize users' experiences of the resulting office setting, along with the commissioning process itself.

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