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RESEARCH PAPER

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Effect of green building certification on organizational productivity metrics

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ABSTRACT
There is increasing interest in understanding how office accommodation affects organizational productivity. Data on metrics of engagement, job satisfaction, job performance and facility complaints for thousands of employees ($n = 14{,}569$) of a large Canadian financial organization were analysed to explore differences in outcomes between those working in green-certified office buildings ($n = 10$) and those in otherwise similar conventional buildings ($n = 10$). Overall, green-certified buildings demonstrated higher scores on survey outcomes related to job satisfaction, value to clients and stakeholders, evaluation of management, and corporate engagement. There was also a tendency for manager-assessed job performance to be higher in green-certified buildings. Nevertheless, not all green-certified buildings outperformed all conventional buildings, and superior performance was not exhibited on all outcomes examined. A key observation is that such metrics are routinely recorded by organizations, but relating them to building characteristics is new. Recognition of such datasets opens up many promising avenues for buildings research.

KEYWORDS
commercial offices; green buildings; job performance; job satisfaction; occupants; productivity; sustainable design

Introduction

Background

There has been a long history of research establishing linkages between the physical office environment and the comfort and satisfaction of occupants (*e.g.* Brill et al., 1984; Sundstrom, 1986). People in positions of influence who demand economic indicators to inform decisions on office accommodation and environmental control choices have often sought information on effects beyond indoor environment comfort, *i.e.* metrics perceived to have a more direct effect on employee health and well-being, and organizational productivity. Organizational productivity, in its most straightforward definition, is the ratio between the value of an organization's outputs and the cost of its inputs. Property (real estate) may affect organizational productivity on the cost side of the equation (*e.g.* rent, maintenance, energy) and on the output side in affecting employees' ability to do their work, the quality of their work and their opinion of, and loyalty to, their employer. Such information is now growing in importance as enlightened employers seek sustainability options for their real-estate portfolios that go beyond energy efficiency.

The largest expenses for most white-collar organizations are staff (salaries, benefits *etc.*), buildings (leases, maintenance *etc.*) and information technology. An analysis of how the second category affects the first seems like an obvious activity in the context of financial due-diligence and budget-allocation choice, but is rarely undertaken. In part this is because the information for these analyses rests in different parts of organizations: human resources (HR) owns employee data, and facilities managers (FM) or corporate real estate departments have building data.

Although these are the top expense categories, the cost of staff typically dwarfs the cost of buildings. A widely cited breakdown of the costs associated with office workplace costs over a 10-year period assigns 82% of costs to staff, 10% to equipment and training, 3% to maintenance and operations, and 5% to building and furnishings (Brill, Weidemann, Allard, Olson, & Keable, 2001); although Ive (2007) proposes a different ratio, the predominance of staff costs remains the most significant cost. Another common rule of thumb that is often quoted is that the

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annual operational costs of an office space are, on average, US$300/ft^2 for staff payroll, US$30/ft^2 for space rent and US$3/ft^2 for utilities (*e.g.* Best, 2014). Thus, one would not want cost savings in buildings to come at the expense of staff's ability to do their work. Ideally an organization would identify building strategies that support the productivity of the organization, and are cost-effective as a whole. In other words, a relatively small investment in building design and operation can have a relatively big benefit on organizational productivity through positive effects on staff (and energy use).

Good-quality studies demonstrating linkages between building characteristics and organizational productivity are rare. This is partly because there has been no broadly accepted definition of what constitutes appropriate metrics, and thus suitable datasets have not been generated. At one time decision-makers sought very simple cause-and-effect relationships, *i.e.* 'If <BUILDING FEATURE X> is replaced with <BUILDING FEATURE Y> then productivity will increase by Z%'. This is partly a hangover from an industrial production line model of productivity in terms of the output of standard, directly countable units.

There is increasing acceptance that such a model is not applicable to most white-collar workplaces, where output is rarely measured in such terms. Instead, productivity in white-collar workplaces is better represented by a basket of metrics, sometimes measured in different units, that all influence the overall productivity equation in an organization. This is the efficiency definition of organizational productivity (Pritchard, 1992). Not all metrics can be defined in currency (or other common) units, and the relative value of each metric varies between industries and countries. This is a more complex and nuanced approach, but offers a realistic pathway to move forward in this domain that an overly simple metric does not offer. Furthermore, organizations are now familiar with the use of multi-metric (or 'balanced scorecard') approaches in other domains (Kaplan & Norton, 1992).

Two important industry publications have appeared recently that map out an approach to valuing better buildings with respect to organizational productivity using multiple metrics. The Continental Automated Buildings Association (CABA) White Paper *Improving Organizational Productivity with Building Automation Systems* proposed one such scorecard structure (Thompson, Veitch, & Newsham, 2014, tab. 1), inspired by food nutrition labels. Metrics included concepts related to environmental satisfaction, job satisfaction, health, staff commitment, absenteeism, business unit performance, environmental conditions, energy use and responsiveness to facility complaints. The choice of these metrics was not arbitrary; they were derived from a conceptual model of the interplay of workplace environment elements, employee effects and behaviours, and organizational outcomes established by a logical connecting of multiple studies addressing pieces of the model, as shown in Figure 1. No single study has ever measured this end-to-end network of variables and demonstrated their interaction.

The World Green Building Council (WGBC) in its publication *Health, Wellbeing & Productivity in Offices: The Next Chapter for Green Building* (Alker, 2014) provided an internationally agreed framework for evaluating the effect of buildings on organizational productivity metrics. This report was motivated by a desire to support a business case for green building[1] principles and certification beyond a simple payback on energy savings. The WGBC report also took a multi-metric approach in identifying outcomes that could be positively affected by enhancements to the built environment, including HR outcomes, workplace perception, complaints to the FM and physical measures of the indoor environment.

A key insight from the WGBC report was the recognition that data on many of these important metrics already exist in an organization and are collected routinely. In other words, one does not necessarily have to engage in an expensive or invasive data-collection campaign to explore the relationship between the built environment and organizational productivity in a given organization; rather, it may be a matter of securing permission to use existing data sources for this purpose, collating them, parsing them by building and associating them with local building characteristics.

For example, HR databases might already hold data pertaining to staff retention/turnover, absenteeism, and other aspects of employee health and wellbeing. The HR departments in many organizations also conduct regular employee opinion surveys (EOSs) that contain data on job satisfaction and organizational commitment. The marketing departments in large organizations might conduct customer satisfaction surveys, and the finance department will likely have data on business unit performance. Many office building landlords regularly administer tenant satisfaction surveys that contain items related to environmental satisfaction. The FM company (frequently a separate entity from the tenant and landlord) often maintains a database of complaints about the built environment registered by individuals, as well as the response time and cost. The FM might also keep historical records from the building automation system, which will provide data on some physical indoor environment conditions, such as space temperature and humidity, and zone-level CO_2 concentration.

This paper reports on analysis of a subset of such multi-metric data from one large private-sector

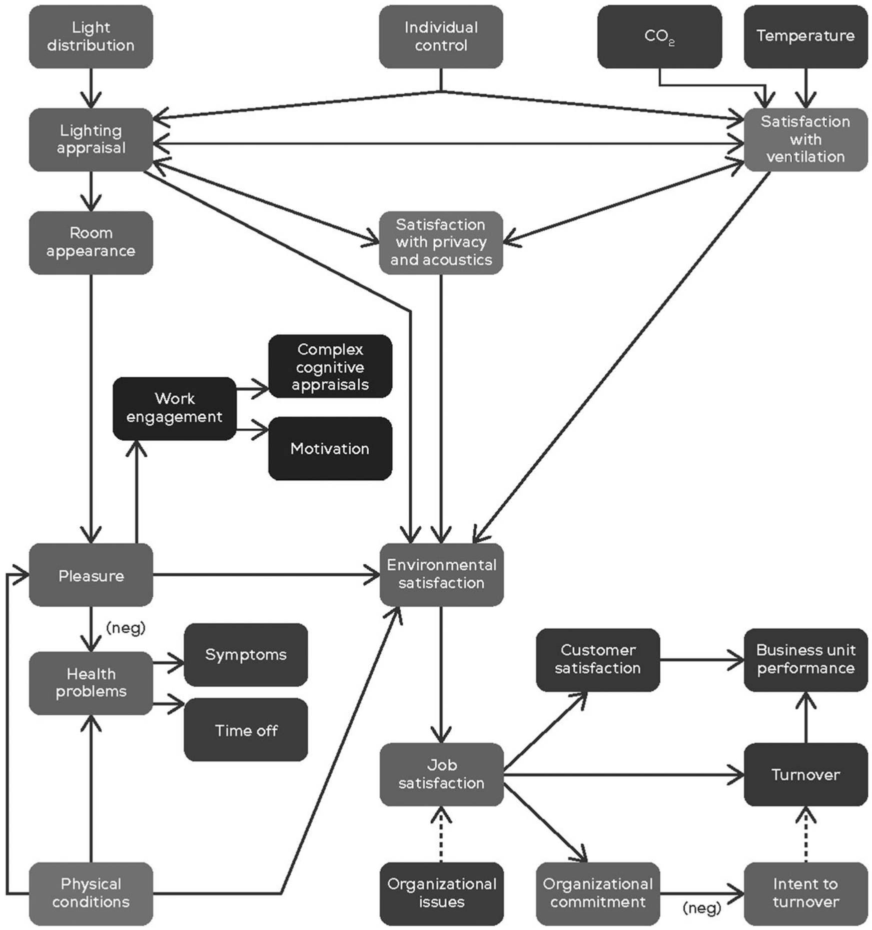

Figure 1. One possible detailed conceptual model showing how elements of the physical environment in an office building could affect job satisfaction and organizational productivity. *Source:* Thompson et al. (2014).

Canadian financial organization. At the time of the analysis some of the major office buildings occupied by the study organization had been green certified, and the analysis addressed the hypothesis that metrics related to organizational productivity were improved in green-certified buildings compared with otherwise similar conventional buildings. This hypothesis is promulgated by national green building organizations (*e.g.* the US Green Building Council and the Canadian Green Building Council), and has been supported by some (*e.g.* Frontczak et al., 2012; Newsham et al., 2013), but not all (*e.g.* Gou, Lau, & Shen, 2012; Thatcher & Milner, 2012), published field research. This study represents an early implementation of the proposed CABA/WGBC multi-metric approach to this hypothesis.

Method

Data preparation and cleaning

This study was an analysis of archival data from the study organization's records. Data files provided by the corporate real-estate group and the HR group were merged. Data confidentiality was of utmost importance. To prevent identification of individuals, all employee information was anonymized before it was delivered to the research team. Employee names were replaced by a unique, but meaningless, ID code that allowed data in multiple files to be linked, and applicable demographic characteristics were categorized.

The data from the corporate real-estate group included building characteristics (*e.g.* age, size, location, lease), green/Leadership in Energy and Environmental Design (LEED) credits for applicable major office buildings, work order history (*i.e.* complaints to the FM), and a mapping of employees to buildings.

The data from the HR group included employee demographics (*e.g.* age, gender, education, dependants, languages), job classifications, salaries and other financial compensation, staffing actions (*e.g.* hires, departures), manager-assessed performance ratings, and responses to the corporate EOS. The EOS is a survey containing over 100 items that the organization administers annually to all staff. The data received were composite scores on 16 scales created by the study organization from responses on the 100 items. The exact mapping of individual survey items to these 16 variables, and the method by which this was done, was not shared with the research team because it was proprietary to the external survey administrator engaged by the financial organization.

From the full set of data files two master files were created containing the subset of variables that were judged to be the most useful for the analysis goals. The first master data file collated information on the characteristics of each building, and the second master data file collated the information on each employee. An employee mapping file showed to which building each employee was assigned as their 'home' workplace in August 2015. These master files contained approximately 120 million data points.

Data were received up to September 2015, and this analysis focused on data from 2014–15, which may be termed the '2015 dataset' in shorthand. This choice was made primarily because it included the only point in time for which a direct and straightforward mapping of employees to buildings was available.

Nevertheless, even within this time period different datasets were separated in time, creating some unavoidable ambiguity or noise in the data. For example, the employee mapping came from August 2015, the EOS data came from February 2015, and the manager-assessed performance data from the nearest point in time came from November 2014. The implicit assumption was that an employee in a given building in August 2015 was in the same building when they answered the EOS, and when their performance was assessed by their manager. This might not have been the case, although movement between 'home' buildings was thought to be relatively small over this timeframe.[2]

In total, 70,958 employees were mapped to the study organization's 1640 North American buildings. Of these, 70 buildings were classified as 'major' office buildings with 40,573 employees. The dataset was narrowed down further to office buildings with more than 100 employees in the mapping file. This yielded 46 buildings.

Outcome measures

Employee opinions and manager-assessed performance were the focus of both building-level and individual analyses. FM complaints about heating, ventilation and air-conditioning (HVAC) issues per employee at the building level were also examined. The employee opinion variables in these analyses were derived by the research team from the 16 EOS scales that had been provided. After preliminary analyses, it was judged that a further grouping of the 16 EOS scales would create more reliable outcomes and aid in interpretation of results. Principal component analysis (PCA) with Varimax rotation was used as an aid to developing a smaller set of composite variables, although the process was also guided by thematic linking based on the wording of individual items. The final mapping of the 16 initial variables to four higher-level composites is shown in Table 1. 'Great Place to Work' is related to employee job satisfaction and corporate engagement. 'External Value' is related to how the organization interacts with the outside world. 'Management' is related to the employee's perception of the behaviours of the people to whom they report. 'Happy to be Here' relates to whether an employee's expectation of their job was fulfilled, and their desire to remain with the organization over a longer time period. The composite scales were means of the individual scales that made up the composite. They all had a numerical value from 0 to 1, with a higher value indicating a more favourable opinion. The internal consistency (as indicated by Cronbach's alpha) of the first three composites was very good, whereas it was poor for the 'Happy to be Here' composite. Nevertheless, this composite was maintained because of the face validity of linking the items, and the undesirable option of using individual scales given the uncertainty of how the individual survey items mapped to the scales.

Each employee had a performance assessment rating from their manager, made using a five-point scale. This scale was translated into a numerical value from 0 to 1, with a higher value indicating better assessed performance, consistent with the EOS scale (Table 2).

For FM complaints, the focus was on the subset of complaint types recorded in the data file that were associated with the HVAC system (Table 3). This was the category of complaints judged most likely to be affected by green-building practices.[3] The total number of complaints allocated to all four of these subcategories, divided by the number occupants, was used as the performance metric.

Independent variable: building type

Of the 46 buildings selected for analysis, there were 13 buildings that had been LEED certified (at some level) as of August 2015. This criterion was chosen because the research team could be sure that all green building features had been implemented and validated. The remaining 33 buildings formed the conventional buildings subset, although some of these were pending green certification at the time. For each green-certified building a matched conventional building was sought, and buildings pending green certification were excluded from the matching process; conventional buildings that were not matched to a green building ($N = 23$) were dropped

Table 1. Mapping of 16 initial employee opinion survey (EOS) variables to the four composite variables used in the analyses.

Initial EOS variable	Composite variable
Engagement	EOS_Great Place to Work ($\alpha = 0.94$)
Collaboration	
Enablement	
Talent management	
Engagement cluster	
Recognition and rewards	
Citizenship	EOS_External Value ($\alpha = 0.86$)
Competitiveness	
Client focus	
Vision values direction	
Confidence in the future	
Immediate manager	EOS_Management ($\alpha = 0.92$)
Leadership	
Performance management	
Employee expectation	EOS_Happy to be Here ($\alpha = 0.38$)
Retention	

Note: Scale reliability and internal consistency are indicated by Cronbach's alpha.

from further consideration in this analysis. The initial matching choices were based on building location (and thus similar regional conditions and climate), building age (of original construction date, not most recent renovation), and size.

Unfortunately, it was not possible to find an appropriately matched conventional building for every green-certified building. Of the 13 green-certified buildings only 10 could be matched with a conventional building, so the final dataset for analysis consisted of 10 matched pairs, with a sample totalling 20 buildings and 14,569 individual employees. The sample is described in Table 4, where the matched pairs are shown together; similar information for the larger office buildings not used in the analysis is shown in Appendix A in the supplemental data online. In some cases the host organization occupied the entire building; in other cases a 'building' refers to the floors occupied by the study organization within a large building. Nevertheless, each 'Building ID' in Table 4 refers to a unique address.

Table 2. Mapping of the manager-assessed performance rating scale to the numerical value used in the analyses.

Code	Description	Value
G1	Exceptional	1.00
G2	Outstanding	0.75
G3	High performance	0.50
G4	Lower performance	0.25
G5	Poor fit	0.00

Table 3. Four complaint categories from the facilities managers' (FM) complaints file that were summed to provide a total heating, ventilation and air-conditioning (HVAC) complaints metric used in the analyses.

Complaint description
HVAC – leak
HVAC – repairs
HVAC – too hot/too cold
General smell/odour in air

After the initial matching based on building location, age and size, a check was conducted to ensure that other building characteristics, including those of the occupants, were similar at the building average level (Table 4). Of course, all buildings were matched on employer, an important similarity criterion that is implicit in this study, but which has not been the case in other green buildings research. Matching among a relatively small population of buildings from a single portfolio, especially from a building type as relatively heterogeneous as large office buildings, can never be perfect. Nevertheless, this two-stage process yielded what the research team judged to be an acceptable set of matched pairs.

Statistical models

Two approaches to the data analysis were taken: examining differences at both the building level between matched pairs and at the level of individual employees between buildings in matched pairs.

At the building level, the outcome measures were the building average scores on the four EOS scales, manager-assessed performance and FM complaints. For example, if a building had 500 employees who responded to the EOS, then for a particular EOS metric the average of the 500 responses was taken as the value that represented performance at the building average level. The approach taken had been successfully applied in an earlier green-building study (Newsham et al., 2013). In that study, matched pairs of buildings were recruited that were as similar as possible in respects other than green certification, and then tested for statistical significance of differences in outcomes between the set of building pairs using the non-parametric Wilcoxon signed ranks test. This test is recommended when the sample size is relatively small and when there is no prior expectation that the data are normally distributed (Siegel & Castellan, 1988). Moschandreas & Nuanual (2008) also used this approach for their green-building study.

As a further step, a multivariate analysis of variance with covariates (MANCOVA) using individual employee

Table 4. Characteristics of the paired buildings used in the analyses.

Building characteristics								Characteristics of employees in each building										
Pair ID	Building ID	Green building	Region	Total area occupied by the study organization, range (ft^2)	Number of employees mapped to the building range	Density	Construction date	Gender	Age	Degree	Commute (km)	Dependant	Total pay ($)	Position	Report	FTPT	Tenure (years)	Action
A	A1	0	Northeast US	> 500,000	1001–5000	3.39	1981–90	0.79	38.5	3.6	14.5	2.6	260,828	5.9	2.5	1.00	4.5	0.9
	A2	1	Northeast US	200,001–500,000	501–1000	3.45	After 2000	0.67	42.0	3.4	33.3	2.5	155,854	5.3	2.8	1.00	5.0	1.1
B	B1	0	Western Canada	< 50,001	101–500	4.75	1971–80	0.57	42.5	2.9	12.0	2.4	72,518	4.3	3.0	0.99	7.9	0.7
	B2	1	Western Canada	< 50,001	101–500	3.06	1991–2000	0.75	37.8	3.2	10.9	2.3	116,000	5.5	2.4	0.98	6.1	0.8
D	D1	0	Southern Ontario	50,001–100,000	101–500	3.92	1971–80	0.57	42.6	3.0	14.2	2.2	66,414	4.3	1.4	0.98	7.4	0.9
	D2	1	Southern Ontario	< 50,001	101–500	4.49	1971–80	0.42	40.5	3.0	14.6	2.4	58,473	4.0	1.3	0.95	8.0	1.2
E	E1	0	Southern Ontario	200,001–500,000	1001–5000	4.05	Before 1971	0.46	42.0	3.0	31.6	2.3	59,159	4.0	7.0	0.89	8.2	1.0
	E2	1	Quebec	200,001–500,000	1001–5000	5.38	Before 1971	0.35	43.9	2.9	18.2	2.2	53,523	3.7	3.6	0.90	9.3	1.3
F	F1	0	Western Canada	50,001–100,000	101–500	5.70	1981–90	0.59	39.6	3.0	10.7	2.2	79,268	4.6	5.4	0.97	7.3	0.9
	F2	1	Western Canada	50,001–100,000	101–500	4.62	1981–90	0.52	42.2	3.0	11.7	2.4	68,265	4.6	3.7	0.99	8.0	0.8
G	G1	0	Southern Ontario	200,001–500,000	1001–5000	6.24	1981–90	0.65	44.6	2.9	38.2	2.4	94,548	5.3	4.8	0.99	8.3	0.8
	G2	1	Southern Ontario	> 500,000	1001–5000	4.75	1971–80	0.55	41.1	3.4	19.7	2.3	98,194	5.3	21.1	0.98	7.5	0.9
I	I1	0	Western Canada	< 50,001	101–500	4.06	Before 1971	0.52	42.4	2.9	10.1	2.4	59,741	4.2	2.9	0.96	8.9	0.9
	I2	1	Western Canada	50,001–100,000	101–500	3.00	Before 1971	0.48	43.1	2.9	12.2	2.3	66,978	4.6	15.5	0.89	9.2	1.1
J	J1	0	Western Canada	< 50,001	101–500	5.28	Before 1971	0.37	46.2	2.7	14.7	2.1	57,185	3.5	2.4	0.81	11.1	1.3
	J2	1	Western Canada	100,001–200,000	501–1000	3.79	1971–80	0.38	44.5	3.0	18.9	2.1	63,733	4.2	9.3	0.89	9.4	0.9
K	K1	0	Western Canada	< 50,001	101–500	2.61	1971–80	0.35	44.5	3.1	17.9	2.1	78,535	4.7	7.5	0.90	9.1	1.0
	K2	1	Western Canada	100,001–200,000	501–1000	3.67	Before 1971	0.38	44.2	3.0	17.2	2.1	70,786	4.4	6.8	0.89	8.6	1.0
L	L1	0	Southern Ontario	200,000–100,001	101–500	2.61	1981–90	0.83	41.9	2.7	41.2	2.4	77,784	4.7	2.2	1.00	8.3	0.8
	L2	1	Southern Ontario	50,001–100,000	501–1000	8.87	1981–90	0.33	44.3	2.9	32.3	2.3	58,414	3.9	2.9	0.97	8.8	1.2

Note: Shading indicates the green-certified building in a matched pair. Density = mapped employees/1000 ft^2; Gender = 'mean' gender (female = 0, male = 1) of employees in the building; Age = mean age of occupants; Degree = mean level of education reached (*e.g.* 3 = bachelor's degree); Commute = median commuting distance; Dependant = mean number of dependants in occupants' families; Total pay = median annual compensation (in Canadian $ for buildings in Canada; in US$ for buildings in the USA); Position = mean position in hierarchy (a higher value indicates a higher position); Report = mean number of direct and indirect reports; FTPT = mean ratio of full- to part-time employees (0 = all part-time, 1 = all full-time); Tenure = mean time employed at the study organization; and Action = mean number of staffing actions per employee.

Table 5. Mean and standard deviation (SD) of scores for each outcome for each building in the matched pairs, and total complaint counts.

Building information			EOS_Great Place to Work		EOS_External Value		EOS_ Management		EOS_Happy to be Here			Manager-assessed performance				
Pair ID	Building ID	Green building	Mean	SD	Mean	SD	Mean	SD	Mean	SD	EOS_n	Mean	SD	*n*	HVAC complaints	Total complaints
A	A1	0	0.694	0.184	0.736	0.169	0.767	0.187	0.579	0.197	1247	0.650	0.175	217	n.a.	n.a.
	A2	1	0.711	0.184	0.750	0.167	0.775	0.191	0.548	0.190	504	0.628	0.188	519	n.a.	n.a.
B	B1	0	0.725	0.180	0.778	0.153	0.769	0.206	0.628	0.208	137	0.509	0.112	85	4	105
	B2	1	0.738	0.141	0.776	0.133	0.782	0.161	0.622	0.156	95	0.592	0.190	19	8	82
D	D1	0	0.761	0.174	0.817	0.158	0.800	0.182	0.610	0.167	152	0.539	0.181	103	1	44
	D2	1	0.756	0.183	0.802	0.160	0.830	0.189	0.606	0.193	179	0.576	0.227	135	4	521
E	E1	0	0.780	0.180	0.814	0.159	0.840	0.191	0.612	0.182	772	0.554	0.181	775	164	1690
	E2	1	0.756	0.179	0.788	0.167	0.828	0.180	0.588	0.178	1803	0.561	0.189	1515	496	6783
F	F1	0	0.730	0.156	0.751	0.143	0.803	0.152	0.596	0.178	265	0.629	0.197	261	0	12
	F2	1	0.741	0.175	0.781	0.159	0.781	0.181	0.631	0.170	200	0.636	0.243	142	5	187
G	G1	0	0.709	0.197	0.743	0.183	0.773	0.210	0.562	0.189	1494	0.589	0.186	1594	156	2943
	G2	1	0.738	0.173	0.770	0.160	0.784	0.189	0.602	0.188	1966	0.639	0.204	1344	496	5708
I	I1	0	0.732	0.183	0.800	0.152	0.780	0.194	0.617	0.189	90	0.563	0.202	75	0	45
	I2	1	0.794	0.152	0.836	0.134	0.872	0.145	0.644	0.173	143	0.583	0.262	115	2	95
J	J1	0	0.689	0.208	0.747	0.196	0.799	0.200	0.568	0.179	218	0.574	0.176	183	36	366
	J2	1	0.780	0.168	0.813	0.150	0.840	0.176	0.624	0.178	436	0.595	0.225	401	16	614
K	K1	0	0.749	0.197	0.808	0.169	0.829	0.190	0.622	0.182	101	0.579	0.191	89	6	205
	K2	1	0.748	0.179	0.780	0.163	0.812	0.191	0.608	0.181	406	0.557	0.203	367	6	1113
L	L1	0	0.746	0.190	0.768	0.192	0.807	0.193	0.593	0.190	263	0.549	0.203	280	18	142
	L2	1	0.750	0.184	0.791	0.171	0.824	0.191	0.579	0.177	568	0.557	0.178	552	72	715

Note: Shading indicates the green-certified building in a matched pair. EOS_n = number of respondents to employee opinion survey (EOS) survey; HVAC complaints = total number of complaints used in the analysed heating, ventilation and air-conditioning (HVAC) complaints outcome; Total complaints = total number of complaints from all sources; and n.a. = not available

Table 6. Results of Wilcoxon signed-ranks tests for building average outcomes.

Outcome	Ranks positive	Ranks negative	Sum of ranks positive	Sum of ranks negative	Z	p-value (two tail)	Mean_green	Mean_conventional	Effect size
EOS_Great Place to Work	7	3	44	11	1.681	0.105	0.751	0.731	0.376
EOS_External Value	6	4	40	15	1.274	0.232	0.789	0.776	0.285
EOS_Management	7	3	40	15	1.274	0.232	0.813	0.797	0.285
EOS_Happy to be Here	4	6	33	22	0.561	0.625	0.605	0.599	0.125
Manager-assessed performance	8	2	42	13	1.478	0.160	0.592	0.573	0.330
HVAC complaints/ employee (REV)	7	2	32	13	1.125	0.301	0.073	0.057	0.265

Note: Ranks-positive = in how many of the matched pairs did the green-certified building have the higher outcome value? A higher value is a better for all outcomes except for heating, ventilation and air-conditioning (HVAC) complaints (signalled by the notation REV).

data was conducted separately for each matched pair of buildings. MANCOVA assumes that the individual outcomes scores in each building are normally distributed. With the building-level analysis the matching process implicitly controlled for factors other than the 'greenness' of the buildings. With MANCOVA on a building pair, data at the individual employee level were used to control explicitly and statistically for differences in the characteristics of individuals[4] in the two building populations using covariates. The result then indicates, for a given building pair, whether there was a difference in each outcome variable associated with the fact that one of the buildings was green. Repeating this process across all pairs may reveal a pattern of results that reinforces (or not) the analysis with building-level data.

The choice of covariates was directed at a reasonable subset of variables (with limited intercorrelation between themselves) that displayed some differences between building pairs even after matching. Thus, the difference in the covariates might be expected to explain some of the difference in outcomes between the building pairs. Covariates that would be good choices across all building pairs were desirable, to result in a consistent model specification. Gender and age are common choices for covariates in data coming from humans. However, in this case Table 4 shows that the matching process already led to building pairs with, in general, very similar occupant average age and gender balance. Therefore, position and reports were chosen (defined in Table 4) as covariates, as these might suggest differences in management hierarchy between buildings, which might be expected to influence these outcomes.[5]

Consistent with good practice in this domain, the starting point was a MANCOVA analysis on all six outcomes. If that revealed a statistically significant overall effect, the univariate analyses of covariance (ANCOVAs) were interpreted for each outcome separately.

Results and discussion

In interpreting these results, trends in the pattern of statistical tests across all outcomes, and across many tests and using several different statistical techniques, were examined to avoid giving undue weight to any one outcome. Several factors had increased noise in the data or reduced the statistical power of the analyses, such as the possibility of some EOS data and performance ratings having been measured while the employee occupied a different building, and it could not be ruled out that some buildings categorized as conventional nonetheless had some features of a green building. Therefore, this work should be considered exploratory, with consideration given to tests with $p < 0.1$ (more liberal than the standard 0.05) as potential contributors to larger trends. However, emphasis is placed only where several such tests reinforce each other and where they are consistent with prior research. Common effect size metrics were used to judge the practical importance of statistically significant effects.

Analysis at the building-average level

Table 5 shows the mean scores for each outcome for each building in the matched pairs; similar information for the larger office buildings not used in the analysis is shown in Appendix B in the supplemental data online. First, it is apparent that most building-level EOS scores were above 0.6 (on a scale from 0 to 1), suggesting that study organization employees on average were generally satisfied with their jobs.

The Wilcoxon test takes two aspects of these data into account in determining statistical significance of the overall effect: the number of pairs in which the difference in means between the buildings in the pair favour one building type; and the relative size of the differences

A summary of the statistical tests for each outcome is shown in Table 6. There was a consistent trend favouring green-certified buildings in the HR outcomes, though no effects achieved statistical significance. The EOS outcomes 'Great Place to Work' and 'Management' had higher average values in the green-certified building in seven out of 10 building pairs. Average 'Manager-assessed performance' ratings were higher in green-certified buildings for eight of the 10 pairs. Further, these effects were all medium-to-large according to the $Z/\sqrt{N}$ statistic suggested by Rosenthal (1984) as appropriate for the Wilcoxon signed-ranks test, indicating that the difference in the average scores between green-certified and conventional buildings for a given metric, though small in absolute terms, was relatively large compared with the range of building-level scores across all buildings.

However, not all outcomes were better in green buildings. There were more HVAC-related complaints to the FM per employee in the green-certified buildings, although, again, this effect did not achieve statistical significance.

Although there might be a trend for green-certified buildings to have higher ratings on average, not every green building had a higher average score than its conventional counterpart. Moreover, as shown in Appendix B in the supplemental data online, there were some buildings with higher average scores than any of the paired buildings. Exploration of possible reasons for these observations was beyond the scope of this research.

This analysis was repeated using the standard deviation (SD) of individual scores within a building as the outcome metric, rather than the mean. This was done to explore whether green-building characteristics affected the variability of outcome scores and not just their average. A summary of the statistical tests for each outcome is shown in Table 7. There were statistically significant effects on two EOS variables: the SDs for 'Great Place to Work' and 'Happy to be Here' were lower in green-certified buildings; there was also a trend for lower SDs in 'External Value'. Further, the lower SD was primarily due to fewer poor scores. This suggests that green-certified buildings supported more consistent work environments, with fewer relatively low scores. However, 'Manager-assessed performance' exhibited the opposite trend: there was greater variability in scores from green-certified buildings, with both more poor and more superior scores than in conventional buildings.

The researchers employed building-level analysis with matched pairs because this technique had been successful in teasing out green building effects in earlier work. The analysis here suggested interesting trends and effect sizes, but did not achieve statistical significance. The statistical power might have been limited by sample size, or by the fact that matching was done post-hoc, rather than the buildings being recruited in pairs. Therefore, we continued with MANCOVA to

Table 7. Results of Wilcoxon signed-ranks tests on the standard deviation of outcomes within buildings for the HR variables.

Outcome	Ranks positive	Ranks negative	Sum of ranks positive	Sum of ranks negative	Z	*p*-value (two tail)	Mean_green (SD)	Mean_conventional (SD)	Effect size	Mean_green (10th %ile)	Mean_conventional (10th %ile)	Mean_green (90th %ile)	Mean_conventional (90th %ile)
EOS_Great Place to Work	2	8	10	45	−1.784	0.084	0.172	0.185	−0.399	0.510	0.468	0.939	0.938
EOS_External Value	3	7	11	44	−1.681	0.105	0.156	0.167	−0.376	0.576	0.552	0.976	0.970
EOS_Management	4	6	16	39	−1.172	0.275	0.179	0.191	−0.262	0.565	0.542	0.994	0.996
EOS_Happy to be Here	1	9	9	46	−1.886	0.064	0.178	0.186	−0.422	0.391	0.364	0.830	0.830
Manager-assessed performance	9	1	50	5	2.293	0.020	0.211	0.180	0.513	0.350	0.400	0.830	0.750

Note: Rank-positive = in how many of the matched pairs did the green-certified building have the higher standard deviation. For all outcomes a lower value (*i.e.* less variability in scores within the building) was considered a better outcome.

Table 8. Summary of results of multivariate analysis of covariance (MANCOVA) tests comparing matched green-conventional building pairs at the individual employee data level.

		ANCOVA				
Pair ID	MANCOVA	EOS_Great Place to Work	EOS_External Value	EOS_Management	EOS_Happy to be Here	Manager-assessed performance
A	***	*			**	
B						
D	**					
E	***	***	***		**	
F	***		***		**	
G	***	***	***		***	***
I	***	**	*	***		
J	***	***	***	**	***	
K	**					
L	*					**

Note: Shaded cells with asterisks (*) indicate a better outcome for the green-certified building in the pair; unshaded cells with asterisks indicate a better outcome for the conventional building in the pair; empty cells indicate no significant difference between buildings in the pair on that outcome. Detailed statistics are shown in Appendix C in the supplemental data online. Significance (p-value): ***0.01, **0.05 and *0.1. Bold asterisk indicate that the effect size, expressed as Cohen's d, was > .20, or 'small'.

leverage the statistical power of data at the individual employee level.

Analysis at the individual employee level

Table 8 summarizes the findings of the MANCOVAs on each building pair; the detailed statistical tables are provided in Appendix C in the supplemental data online. In interpreting these results, the focus should not be on any single test, but on the overall pattern of results. In this context, the results are compelling and reinforce the trends in the building-level findings. First, note that there were statistically significant overall MANCOVA tests for nine of the 10 building pairs.

Turning to the univariate ANCOVA tests for these pairs, a preponderance of effects favouring the green-certified building in the paired buildings was observed. For 'Great Place to Work', there were effects meeting the statistical criterion for five of the 10 building pairs, and in four of five cases the green-certified building was more highly rated than its conventional counterpart. For 'External Value', there were effects for five building pairs, and in four of these cases the green-certified building was more highly rated. For 'Management', there were only two pairs with differences in scores, but in both cases the green-certified building was more highly rated. For 'Happy to be Here', there were effects for five building pairs, and in three of these cases the green-certified building was more highly rated. For 'Manager-assessed performance', there were only two pairs that met the criterion for statistically significant differences in scores, but in both cases the green-certified building was more highly rated.

These effects are all in the small or small-medium range as defined by the Cohen's d effect size statistic (see Appendix C in the supplemental data online for details). Nevertheless, small effects can have substantial practical impact, depending on the context (Cohen, 1988). The study organization's HR group can judge the importance of the differences observed between building types in this analysis. A senior HR manager at the host organization said the following:

> We are delighted to have partnered on this ground breaking study. The analysis shows how our sustainability policy and use of green buildings creates a positive environment that improves employee engagement. … We look forward to uncovering new insights to assist in developing physical spaces … .

Conclusions

Many organizations, including the study organization, have pursued policies to add 'green' features to their office building portfolios to support key corporate sustainability goals, including improvements to the working environment for their employees. The results of this study support such policies. Overall, green-certified buildings demonstrated higher values of corporate metrics related to organizational productivity compared with otherwise similar conventional buildings. Specifically, scores on the EOS, and manager-assessed job performance, were generally higher for green-certified buildings, with fewer instances of relatively poor scores.

These results support the hypothesis that being in a green (LEED-certified) building positively influences how occupants view their organization and conduct their work. This could be a direct effect (the employer is viewed positively because they have invested in a 'better' building for the respondents), or an indirect effect (the green building has a superior indoor environment, which facilitates better comfort, mood and working conditions). Nevertheless, it is important to note that not all green buildings outperformed all conventional buildings, and superior performance was not exhibited on all outcomes examined.

Overall, these results are consistent with other studies demonstrating the benefits of green buildings on occupant satisfaction (*e.g.* Newsham et al., 2013) and extend the causal chain from better buildings to job satisfaction and other outcomes of more direct relevance to organizational productivity (Alker, 2014; MacNaughton et al., 2017; Thompson et al., 2014).

Further, these results related to organizational productivity complement studies looking at other aspects of the financial benefits of green buildings. For example, several studies have analysed whether green buildings have higher real-estate value compared with otherwise similar conventional buildings (Devine & Kok, 2015). In some cases green buildings are conflated with other sustainability categories or simply energy-efficient buildings (*e.g.* Energy Star), but in general the results show that sustainable buildings tend to have lower vacancy rates, higher lease costs and higher resale value.

Although these findings were derived from a richer dataset than has been referenced in the green buildings research literature to date, they should be considered preliminary. The number of individual occupants who contributed data was very large, but the number of buildings forming a valid comparison set was still relatively small. The matching of buildings on characteristics other than green certification was reasonable for a practical set of buildings, but was imperfect. Results were also only based on a single year of data. Therefore, although the trends favouring green-certified buildings were consistent, other explanations for differences cannot be completely ruled out. Nevertheless, these findings suggest that further analyses of this kind should be encouraged, and are likely to be fruitful in confirming and extending these findings. The strength of the conclusions will be greater if future investigations have larger datasets, and clearer differentiation between green and conventional buildings.

While the great potential of leveraging pre-existing organizational data for buildings-related research was clearly demonstrated, some uncertainties in derivation of these data did reduce the strength of the analyses. For example, the exact mapping of EOS items to scales was not known. This is understandable given that the original EOS stakeholders did not have this end use in mind. The recognition of the supplemental value of these datasets shown by this work may lead to greater attention to how data are prepared and documented, thus increasing the utility of organizational data.

Finally, these promising results are associated with whole-building differences (green-certified versus conventional), which subsume much variation at the individual building system and indoor environment level. Further research to establish which specific green building features contribute to the observed benefits,[6] and which features dilute such effects, would be valuable to practitioners making design decisions.

Notes

1. The colloquial phrase 'green building' is shorthand to describe buildings with certified sustainable features. In the context of this paper, this means LEED-certified buildings.
2. One way to estimate the order of magnitude of the frequency of a change in building location, given the data available, was to look at the frequency of changes in reporting centre postal code, which in most, but not all, cases would be associated with a change in an employee's 'home' building. The five quarterly data loads from January 2014 to January 2015 were examined, in which there were complete postal codes for 18,993 employees in the 23 buildings later considered for inclusion in the green-conventional building pairs (and of which 20 were chosen for the final analysis). Of these, 17,665 (93%) demonstrated no change in reporting centre postal code over the one year period.
3. The number of complaints in other categories was generally very low, except for reporting of burnt-out lamps, which was not judged to be linked to green certification.
4. Differences in the characteristics of the buildings (other than green certification) are still controlled for implicitly via the matching process.
5. Another approach to analysis with data at the individual level is hierarchical linear modelling (HLM), in which individuals (level 1) are nested in buildings (level 2), which are nested in green-conventional pairs/groups (level 3). Conceptually, this method involves regressing the outcome variable of interest on predictors at level 1 (*e.g.* EOS outcome) and then the regression coefficients becoming the outcome variables for a regression at level 2, and so on. Predictor variables may then be applied at each level, *i.e.* properties of individuals at level 1 (*e.g.* age, gender), properties of buildings at level 2 (*e.g.* size, age), and properties of pairs/groups at level 3 (*e.g.* location/climate). This method has become particularly popular in research on student educational outcomes, where students (level 1) may be nested within classrooms with different properties, including, possibly, teacher characteristics (level 2), nested within schools

with different properties (level 3) (Raudenbush & Bryk, 2002). A challenge with this method is that it is 'data hungry', requiring simplification choices to be made in model specification, and the results can often be difficult to interpret. This method was applied to the data, with results that were consistent with the results of the other methods used, exhibiting the same trends. However, other methods are highlighted in this paper due to their relative conceptual simplicity and ease of interpretation.
6. And what features cause some conventional buildings to score highly on some HR-related metrics.

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