Entrepreneur

The economic benefits of green buildings a comprehensive case study.

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INTRODUCTION

In building design and construction, both green building and standard construction techniques are considered for many building projects. Final decisions are routinely made based solely on schedules and budgets, and the long-term effects often overlooked. The outcomes of these quick decisions can lead to short-term benefits; however, a careful compariso between the added first costs of construction against the recurring, long-term associated benefits and cost savings are needed to conduct a more thorough analysis. Although several industry and research groups are attempting to quantify benefits of green building construction--significant cost savings by gains in employee productivity, reduction in health a safety costs, and savings from energy, maintenance, and operational costs--the need for more comprehensive data is largely acknowledged (Fowler, 2004). Many key business sectors, such as developers, bankers, and appraisers, are anxious to structurally and monetarily understand and use green building metrics to make the case for greening the ma and integrating the benefits of green design into new and existing facilities. The assumption is that the benefits largely exceed any added initial cost of the green building. This research investigates the relationship between the above varia and green building features to further contribute to the development of green building metrics. The challenge of this research is statistically discerning the difference between green building attributes and normal changes to business operations in a non-controlled environment.

The businesses participating in this study are interested in understanding the linkages between green building features business performance, the return on investment of their current facility, and the key attributes that should be pursued ir green design of future facilities or expansions. The research in this article collects quantitative data and validates the da by conducting a self-reporting survey along with interviewing management in order to analyze the hypothesized relationship. The project, which started in May 2004, initially focused on developing relationships with local businesses, involvement in this research requires a time commitment in a lean business climate. Data from Castcon Stone, a preca manufacturing company, are presented in this article. Additional data are currently being collected from other business research partners.

This article begins by discussing the benefits of green building construction, followed by the approach and methodolog then examines the case study conducted at Castcon Stone including an overview of the company, its new green facility description of the research protocol, and final results. The article concludes with a discussion of the future direction for research.

LITERATURE REVIEW

Studies report savings associated with green building including gains in employee productivity, reduction in health and safety costs, and savings from energy, maintenance, and operational costs. Productivity is defined as the output of any process, per unit of input, so it directly relates to the performance of the process elements, including the workers. A nur of articles and case studies show a strong positive correlation between the work performance of employees and the building in which the process takes place. For example, Romm and Browning (1998) reported eight case studies that sl up to a 16% improvement in productivity between the employees in existing facilities and the employees in remodeled new facilities designed according to green building principles. Heerwagen (2001) found significant productivity gains a reported that the workers' "overall [positive] feeling about the environment" increased by 60%. Kats (2003) states that various study results show significant productivity increases both in commercial and educational areas. Wyon (1996) estimated that providing temperature control of +3[degrees]C to workers would increase work performance by 3-7%. F (2002) found significant estimated potential productivity gains from improvements in indoor environments in the United States ranging from $1-160 billion given reductions in health and increased performance. Table 1 shows the estimatec potential productivity gains from improvements in indoor environments in the United States.

Employee salaries constitute the major ratio of overall office buildings' expenditures. According to Kats (2003), employ cost is 89% of the total building costs and it is roughly 10 times the property related costs. Table 2 depicts the typical distribution of building costs. Therefore, a 1% increase in employee productivity would equal about a 15% decrease in property costs since the share of the employee costs (89%) is almost 15 times larger than the share of property costs

Health-related problems constitute the major portion of reasons that lead to lower productivity. Health problems affect productivity of employees directly in the work area or indirectly by causing absenteeism. Direct effects of health proble on productivity can be identified as employee discomfort. For example, allergies, sneezing, drowsiness, feeling tired, a similar symptoms might be related to health problems caused by low indoor environmental quality (IEQ). All these symptoms cause discomfort and may reduce productivity. As described above, Fisk (2002) reported potential producti loss due to these kinds of health problems. Absenteeism is an indirect effect of health problems on worker productivity Absenteeism due to health problems is called "sick leave" in the literature, meaning that employees do not show up or leave work early because of a particular health problem. Studies show that sick leave is one of the primary sources of productivity.

Since, on average, people spend 80-90% of their time in buildings, IEQ is an important building feature. Air quality, ventilation, temperature control, natural lighting, and office material/furniture quality are some of the building aspects th directly affect IEQ. IEQ refers to the interactions among many factors in indoor environments, including the quality of th (e.g., air flow, the presence of chemical or microbiological agents), physical conditions such as temperature and humic ergonomic factors, and stressors from social/psychological or work organizational factors (GBA, 2003a). Fisk (2002) summarizes two 1996 studies about IEQ and related health and productivity gains that report potential productivity gai from $6 to 14 billion by reducing acute respiratory illness, from $1 to 4 billion by reducing allergies and asthma, and fro $10 to 30 billion by reducing sick building syndrome (SBS) symptoms. Direct productivity gains from better lighting anc temperature control, without affecting worker health, are also reported to be $20-160 billion, considering only U.S. offic workers. Extensive research has been conducted on the relationship between health problems and IEQ levels. For example, Wargocki et al. (2000) report that as the ventilation rate increases, perceived air quality and productivity impr while the intensity of SBS symptoms decrease. Menzies and Bourbeau (1997) list some building-related illnesses such allergies, irritations, and infectious diseases and provide their sources related to the buildings with the support of seve case studies. Milton et al. (2000) found consistent associations of increased sick leave with lower levels of outdoor air supply and IEQ complaints. They also reported a loss of productivity of $22.8 billion per year on a national scale. Fang al. (1998) provide further information about IEQ, worker health, and productivity.

Maintenance and energy savings are some other potential benefits of green buildings. For example, an office building Cambria County, Pennsylvania, projected potential savings of $843,759 over the study period (GBA, 2003a). Another example is Herman Miller, the furniture manufacturer, which projected $6 million in savings over a 7 year lease. Herma Miller has also estimated reductions of 33% in building costs, 41% in operating costs, and 66% in churn costs (GBA, 2003a).

U.S. Green Building Council developed the LEED (Leadership in Energy and Environmental Design) Green Building R System[R], which is a voluntary, consensus-based national framework to standardize assessment of sustainable build performance and meeting sustainability goals. It emphasizes strategies for sustainable site development, water saving energy efficiency, materials selection and IEQ (U.S. Green Building Council, 2004).

CASE STUDY

Castcon Stone

Castcon Stone specializes in precast stairs and architectural products, which represent a special niche in the competit precast concrete market of western Pennsylvania. Founded in 1954 by Carl Huch, Castcon is now run by his two daughters, Laura Huch Kerckhoff and Sandra Ussia. Castcon moved from a conventional 17,000 [ft.sup.2] facility loca Cranberry, Pennsylvania, in March 2003 to a new 37,000 [ft.sup.2] green facility, designed by Perkins Eastman. The n $5 million facility (including processing equipment costs) is located on a brownfield site in Saxonburg, Pennsylvania, designated by the state as a Keystone Opportunity Zone (KOZ), which includes up to 10 years of tax abatement. The r facility was built in anticipation of expanding its markets as far as Illinois and Florida and doubling production in the fut (Marsh, 2003). Castcon is anticipating the United States Green Building Council's Leadership in Environmental and Er Design (LEED[R]) Rating 2.1 Silver (U.S. Green Building Council, 2002).

Site Selection and Environmental Considerations

Castcon decided to relocate to the 17-acre brownfield site. The industrial park received environmental liability clearanc under the Pennsylvania's Act 2 plan and tax incentives through the state's KOZ program. The decision to build on a brownfield site has inherent foundation and environmental risks, and Castcon encountered foundation problems that th turned into an opportunity. Specifically, about $150,000 worth of slag unearthed during foundation excavation was use grade the building's parking lot.

Design Collaboration and Employee Involvement

The integrated design process was comprehensive and collaborative from all aspects. Huch-Kerckhoff believes the ke the success of this project was early design planning and team building. Castcon worked with an industrial engineerin consultant who assisted in the facility layout and business functions. The layout ensured a footprint size and configura that maximized existing and future expansion. Next, a day-long design charette was conducted with many parties, incl the "client, user groups, designers, builders, and the site developer and engineers" (GBA, 2003b). Some of the issues examined were facility orientation with respect to the solar movement, wind directions, known brownfield site condition and existing grades. The employees also contributed to the functionality and amenities of the 37,000 [ft.sup.2] manufacturing facility and office building. Some contributions integrate the company's business ethics and operations; example, there is one entrance into the facility for both the plant workers and the office employees. This entrance inter a concrete walkway running from the plant, to the break room, and to the office. The entrance and concrete walkway promote communication between the workers, level the playing field, and promote a positive working environment. Th company's philosophy has been successful as measured by the low turnover rate of the employees.

Green Features

During the design process, a balance was struck between sustainable principles and financial considerations, achieve through the introduction of sustainability and green design early in the planning process. The new facility received LEE credits as outlined in Table 3. The new facility includes lighting sensors, an energy recovery wheel, natural ventilation operable windows, and an HVAC control system. The installation of clerestory windows in both the plant and office significantly increased the lighting quality. The paint and carpet in the office are VOC free, the carpet has recycled fibe and the partitions are made of recycled materials (Marsh, 2003).

APPROACH AND METHODOLOGY

Research Protocol

As mentioned earlier, this case study is part of long-term research to measure the benefits of green building constructi with local, diverse, and interested businesses. This multi-disciplinary team from the University of Pittsburgh's Departm of Industrial Engineering and Civil and Environmental Engineering is collecting and analyzing data in five major areas improvement: (1) gains in worker productivity, (2) reductions in health and safety costs, (3) improvements in indoor environmental quality, (4) reduction in maintenance costs, and (5) energy and water savings (Needy et al., 2004, 2005 Ries et al., 2004). The quantitative data is validated through a self-reported survey and interviews with management. T purpose of the data collection is to determine a relationship between green building construction and the five improven areas. The validation aspect is mainly in the form of collected survey data, observation, and discussions with manager The survey and other qualitative data collection techniques are validated through face validity, which is an assessmen method for the relevance of survey questions and other techniques by using knowledgeable individuals' opinions. In th research, company management reviews survey questions for their validity and clearness. In addition, the life cycle co the initial investments, costs, building, operational costs such as energy, and labor costs is estimated. A comparison is made between pre-and post-move facilities, traditional and green buildings, respectively. Future research will examine health care delivery at Children's Hospital of Pittsburgh, examining the effect of green buildings on numerous factors s as patient care and pharmaceutical accuracy.

Castcon was an optimum first case study due not only to its manageable size and timing, but also the layout and funct the facility. The layout and operation allowed for the investigation of production workers, mainly producing concrete sta and landings, and white collar workers, e.g., the computer-aided design (CAD) operators and administration staff in the office area. The size of Castcon, approximately 45 employees, was small enough to complete a detailed analysis of th entire facility. The timing of the move with respect to this research was positive. The length of time that Castcon occup the new facility was an important factor because the transition period has passed, the workers have settled into a routi and operations have stabilized, although employees can still recall the pre-move facility.

Four meetings with the owner were conducted to gain an understanding of facility layout, office operations, plant operations, data availability, and company policies. One meeting was held with the architect, Perkins Eastman, to gain understanding of major design decisions. The on-site employee survey was conducted in June 2005. Three significant dates emerged that are critical in the analysis: (1) Castcon implemented a mandatory drug testing policy in November to help reduce the number of Occupational Safety and Health Administration (OSHA) reportable accidents, (2) the mov occurred in March 2003, and (3) a new absentee incentive policy was implemented in September 2003 that gives bonu time off for the number of consecutive working months and monetary rewards in the form of gift certificates.

The research methodology included data collection and analysis (an effort that took approximately one year) for both t old and new facilities. The method included building performance surveys, data collection with statistical analysis, and interviews with management. The data collection variables are listed in Table 4 with a description of each following.

Employee Survey

The employee survey is one of the main data sources and validation instruments for this study. The development of th survey was one of the important efforts because it is used for validation of the quantitative analysis and for measuring employees' perceptions of the pre- and post-move facilities. The survey is based on the previously developed Post Occupancy Evaluation (POE) surveys by the Center for Built Environment (CBE) at the University of California, Berkel and Center for Building Performance and Diagnostics at Carnegie Mellon University [1]. However, since these surveys not specifically aim to measure green building impacts, the survey has been customized with additional as well as company-specific questions. The customization of the survey for different and future case studies is important since ea facility has different features that affect performance, usually depending on the specific use of the facility. The draft sur was piloted to determine approximate completion time and clarity. Next, the company-specific draft survey was issued Castcon Stone for review by management, and subsequently, revisions were made.

Upon written approval from the company, the survey and application was submitted to the University of Pittsburgh's In Review Board (IRB). The IRB reviews human subjects research instruments used by University of Pittsburgh research to ensure compliance with regulations, such as confidentiality, age discrimination, and methods.

Questions have one of three different response options: Yes/no, multiple choice, or a Likert scale (using a 5- or 7-poin scale depending on the type of question). Refer to Appendix for entire survey.

Castcon employees were divided into two main groups--office employees and production workers. The survey questio were customized for each group, which resulted in separate surveys. Production workers were also asked if they work primarily indoors or outdoors, which created two production worker subgroups. In addition, both employee groups were asked about their experiences in the old conventional facility as well as the new green facility. Four different surveys w created from the main Castcon POE survey:

* Office Survey--Old Facility

* Office Survey--New Facility

* Production Survey--Old Facility

* Production Survey--New Facility

The survey was paper-based and administered during an extended morning break at Castcon Stone. Included with the survey was an introduction explaining the project and a confidentiality statement. The research team read the introduc aloud and remained present while the employees were taking the survey. A glossary was also included to further clarif terms, and the researchers chose not to answer other specific questions so as not to bias the results.

Productivity

Productivity measures for both white collar workers (the CAD team) and plant workers were planned. For production workers in the new facility, productivity was measured as labor hours per pound of concrete poured per day or per mo In the old facility, productivity was only available aggregated as labor hours per pound of concrete poured per year. Th researchers were unable to quantitatively measure the CAD team's productivity due to lack of pre-move data. Producti and office employees' perception of productivity, collected through the survey, is presented in this article.

Health and Safety Including Absenteeism

Castcon collects absenteeism data in several categories: unexcused, excused, no call, workers' compensation, and si leave absences. Excused sick absences require a doctor's permission. No-call absences are when employees do not the company of their absence. The absenteeism data is reported weekly in total days, total production days, and total employees for both the new and old facilities.

Since Castcon Stone is not self-insured, evaluation of the potentially lower medical expenses due to improved working conditions was not possible. Castcon's insurance premiums are established independent of the company's total medic expenses. Although an explicit analysis was not done, generally, medical self-insurance for a company of this size is infeasible because of the risk of catastrophic illness. Workers' compensation is related to the number of claimed accid which can be related to reported accidents in OSHA logs and number of workers' compensation--related days absent the production component of the operation. OSHA log data was analyzed on a monthly basis for both the old and new facilities.

Energy, Water, and Sewage

Since electricity, natural gas, and water were on one meter for both the plant and office of both the old and new faciliti comparison by square foot was made. Utility bills were collected and analyzed. An overall energy analysis comparing energy usage of the old and new facilities was investigated, including gasoline and diesel equipment. In the old facility forklifts were mainly used for material handling; however, in the new facility, an overhead crane was installed, minimizi the use of the forklifts.

Indoor Environmental Quality (IEQ) and Building Performance Measurements

Employee survey data was used to assess changes in indoor environmental quality in both the old and new facilities. sub-sections were defined under the IEQ section: air quality and lighting. In the air quality section, the employees were asked how satisfied they are with the air temperature, relative humidity, and air flow speed in the new facility and how control they have over those variables. The perceived impact of air quality on the employee's productivity was also ask the survey. In the lighting section of the survey, the employees were asked to select the types of lighting they have in t work areas. They were also asked for their satisfaction with lighting and were asked to identify potential lighting-relate problems such as glare. Finally, employees were asked how the lighting affects their productivity.

RESULTS

The results are comprised of four sections: productivity, health and safety including absenteeism, energy, and IEQ. Th productivity and health and safety including absenteeism sections include both the results from the survey and the quantitative metrics.

The pre- and post-move survey responses are analyzed with paired t-tests to understand whether there is any statistic significant change in the mean values of the variables. The three groups of analyses reported are office employees on production employees only, and combined office and production employees. For each group, the mean values of the p and post-move responses are calculated. Then, any statistically significant changes within 5% type I error rate are test by employing paired t-tests on the responses for each question that is asked in both old and new facility surveys. Som questions do not apply for the old facility. For these questions, the t-test has been used to evaluate a 95% confidence interval for the mean value of the responses.

Productivity

Based on the results of previous work, one of the most significant impacts of green buildings is expected to be on emp productivity. However, productivity is usually one of the hardest concepts to measure due to data requirements or lack well-defined metrics, especially for white collar employees. In this study, a productivity metric has been developed for production workers but not for white collar workers. As described before, the employees' perceptions of productivity we elicited through the survey. The survey suggested several statistically significant factors that affect productivity positive The outside view from the work area, work area size, air temperature, relative humidity, and outdoor space including v from the lunch room have positive effects on the overall employee productivity in the new facility.

In the combined response for productivity, more employees said they were positively affected by factors such as the outside view from the work area ($p = 0.040$), the work area size ($p = 0.045$), the air temperature ($p = 0.012$), and relativ humidity ($p = 0.043$). Office employees reported that they were positively affected by the outside view from the work a $= 0.036$) as well as by the openness of the work area ($p = 0.037$). Production workers reported that they were more positively affected by the air temperature ($p = 0.040$) in the new facility than they were in the old facility.

Office employees reported more significant factors for increased productivity than the production workers, which sugge that the new green building has a greater impact on office employees. The large numbers of statistically significant su results are important, since it is often difficult to define clear and quantitatively measurable metrics for white collar employees.

Production data consist of monthly information on the pounds of concrete poured and the total labor hours, which was for the productivity metric pounds of concrete poured per labor hour. The company selected and provided data for May through August for five consecutive years. The monthly data was aggregated to annual levels in order to compare the income statement information with the actual production data. Figure 1 depicts five consecutive years (2001 through 2 of productivity information. 2001-2002 data represent productivity data in the old facility and 2003 data are for the trans period (moving from the old to the new facility). 2004-2005 data are for the new facility. The data suggest that there wa increase in productivity for the post-move period, with the lowest productivity during the actual move time (2003). It sh also be noted that the convex shape of the productivity curve was consistent with Castcon management's thinking. A significant portion of the workforce was used for non-production related work during the move; for example, assisting v the actual move into the new facility. A positive trend line for productivity was expected since Castcon managers said t they have spent some time settling down into the new facility. The quantitative data also match the survey results as b suggested increased productivity. However, the increased productivity cannot be fully attributed to the green building features. Other factors such as the new plant layout and mandatory drug-free policy have certainly had an effect on productivity. It was not possible to separately quantify the intensity of individual influences on productivity.

[FIGURE 1 OMITTED]

The survey also included question groups on employee satisfaction with their work areas and the building in general. Satisfaction questions are included in both the pre- and post-move surveys and paired t-tests are used to evaluate the General satisfaction with the work area, which is used to describe an individual work area such as a desk, a cubicle, o workstation, has increased from the old facility to the new facility. This trend was seen when all employees were consi (p = 0.016) and also for only office employees (p = 0.022). The general satisfaction is reported to be higher than neutra (4.80/7.00) for all employees combined and is even higher for office employees alone (5.42/7.00). In response to the amount of space at the work area, both the combined (p = 0.011) and the office employee responses (p < 0.000) show increase in satisfaction. The levels for the combined (4.92/7.00) and office (6.00/7.00) responses are above neutral. Th office employees reported higher satisfaction in the visual (p = 0.017) and acoustic (p = 0.011) privacy of their work are In addition, they responded positively to the new ability to adjust their work areas in order to suit their individual needs 0.003). Combined results show a satisfaction level for the ability to adjust the work area which is, again, higher than ne (4.74/7.00).

In terms of employee satisfaction with the building in general, combined group analysis shows that the occupants are r satisfied with the design and appearance of the building (p = 0.027), the cleanliness of the building (p = 0.006), the loc of the lunchroom (p = 0.001), the lunchroom itself (p = 0.001), and the fire and safety precautions provided by the build design and systems (p = 0.016) in the new facility. Office employees also reported that they are more satisfied with the location of restrooms in the post-move location (p = 0.010). Generally, production workers do not report a statistically significant increase in satisfaction with the location of the restrooms in the new facility. More specifically, however, thos production workers who reported working indoors reported an increase in their satisfaction with the location (p = 0.023 amenities (p = 0.030) of the lunchroom in comparison to the old facility. Combined results show that the satisfaction le are higher than neutral for all questions answered in this section excluding the security of the building, for which they v neutral for the new facility.

Health and Safety Including Absenteeism

The primary data collection for the health and safety/absenteeism category was absenteeism data, including both production and the office employees. The data covered the time period between May 2002 and May 2004, which was about one year before and after the move. Total absences are the summation of excused, unexcused, and no-call absences. Company-provided data reported absences on a weekly basis and employee hours on a daily basis. The w percentage absences were then calculated for all categories. The mean values for pre-move and post-move were aggregated and compared. Table 5 reports the corresponding statistical tests and the associated p-values at the 95 % confidence level. For absenteeism, equality of pre-and post-move means for each group are tested. The alternative hypothesis ([H.sub.a]) is determined to be either [[mu].sub.pre-move] < [[mu].sub.post-move] or [[mu].sub.pre-move] > [[mu].sub.post-move] depending on the actual values of means. For example, if pre-move mean for a group is larger th post-move mean for that group, the alternative hypothesis is set as [[mu].sub.pre-move] > [[mu].sub.post-move] and te against the null hypothesis ([H.sub.O]: [[mu].sub.pre-move] = [[mu].sub.post-move]).

The mean value of the weekly absenteeism percentages by group for the production and office employees are shown Figure 2 for both pre-move and post-move. The t-tests for the production workers support that there is a statistically significant reduction for the percentage of workers' compensation--related absences. However, reductions in the unexcused, no call, and total absences are not statistically significant. Figure 2 also shows some increase in the percentage of excused absences and absences with a doctor's excuse, but only the increase in sick leave is statistical significant. When sick leave information is incorporated, a statistically significant increase in the total absences is note The only statistically significant change on the office side is the increase in the excused absences.

[FIGURE 2 OMITTED]

In order to better understand the reductions in workers' compensation, the absenteeism due to workers' compensation plotted over the two-year period (see Figure 3). Included in the graph are the three main changes that occurred during period, namely, the implementation of a drug-free policy, the implementation of an incentive program for attendance, a the actual move to the new facility. In particular, management believed that the implementation of the new drug-free po would significantly reduce absenteeism. The graph supports the statistical results that show a reduction in workers' compensation. However, in the future the possible effects of green building and other system changes, such as the aforementioned policies and redesign of company processes should be isolated in order to identify what caused this reduction.

[FIGURE 3 OMITTED]

Castcon management's first thoughts were that a reduction in the absenteeism occurred after the move into the green facility. However, the data do not entirely support this idea. It is clear that more data and a longer study period would h reach more conclusive results. Employee satisfaction survey results suggest that in the post-move period, headache ra (p = 0.047), coughs (p = 0.047), nose and throat irritations (p = 0.047), blurring vision (p = 0.017), and eye irritations (p 0.025) were all reduced in comparison to the pre-move period for the office employees. The reduction in excused abse with a doctor's excuse for the office employees matches the survey results, but this reduction is statistically insignifican the other hand, production workers' sick leave responses in the survey do not suggest any statistically significant chan although data provides a statistically significant increase in sick leave for production workers. As is common with this t of research, one cannot conduct it in a completely controlled environment, i.e., although the employees are now workin a green facility, there have been other factors that have impacted absenteeism, productivity, and other various perform metrics. Examples of these factors include the mandatory drug testing policy, new absentee incentive policy, new manufacturing layout, and even simply the fact that they are located in a brand new facility.

Energy, Water, and Sewage

As mentioned in the Research Protocol section, changes in manufacturing operations from the old to the new facilities resulted in energy reallocation predominately from diesel and gasoline fuels for forklifts to an increase in electricity for powering overhead cranes. To determine the total energy usage in both facilities, the bills for electricity, natural gas, di fuel, and gasoline fuel were collected. Yearly totals of electricity in kilowatt hours (kWh), natural gas in million cubic fee (MCF), diesel in gallons, and gasoline in gallons were calculated. Conversions from each respective unit were made to British thermal units (BTUs), based on US Energy Information Administration (2006). Water and sewage were totaled f each respective facility on an annual basis. Comparisons between the 17,000 [ft.sup.2] old facility and the 37,000 [ft.su new facility were made on a square foot basis, due to the substantial difference in size. This information is summarized Table 6. In terms of total energy, the new facility requires one-third less energy per square foot to operate along with le water.

Indoor Environmental Quality (IEQ) and Building Performance Measurements

Better IEQ in the new facility is demonstrated by the increased ability of the workers to adjust their personal daylight le using blinds and shades in their work areas (p = 0.008). Office workers showed more satisfaction with the temperature during warmer (p = 0.002) and cooler (p = 0.033) weather and in general (p = 0.011) than they did in the old facility. Combined data support an increase in the satisfaction with the air temperature during cooler weather (p = 0.022). Altho production workers do not report a statistically significant increase in satisfaction with respect to these questions, indoo only production workers report that they are more satisfied with the temperature during cooler weather (p = 0.030) and general (p = 0.008). In terms of humidity, office workers stated that they are more satisfied in the new facility with the humidity levels both during warmer (p = 0.024) and cooler (p = 0.009) weather. On the other hand, indoor production workers report that they are more satisfied with the air flow speed during cooler weather (p = 0.025) and in general (p = 0.020). In terms of air quality, more believe that the air is not stuffy or stale (p = 0.048). Among the office employees, r believe that the air is not stuffy or stale (p = 0.006) and the satisfaction level is increased from 1.86 to 5.29 on a 7-poin scale. Office employees also state that the air is cleaner (p = 0.016), free of odors (p = 0.001), and that they are more satisfied with the air quality overall (p = 0.005) in the new facility.

Eighty-five percent of the employees report that they have both daylight and overhead light in their work area. More employees in the new facility say that it is not too dark in their work area (p = 0.012) compared to employees in the old facility. Employees as a whole also state that there is now an adequate amount of daylight (p < 0.000) and electric ligh 0.002) in the new facility. Employees were also more satisfied with the visual comfort of the new lighting (p = 0.001) an they concluded that the visual comfort enhanced their ability to work more efficiently (p = 0.009). Separately analyzed, office workers stated that there is an adequate amount of daylight (p = 0.010) and electric light (p = 0.005), greater visu comfort from lighting in general (p = 0.014), and that the visual comfort aids in working productively (p = 0.012). Produ workers responded that there is an adequate amount of daylight in the work area (p = 0.016) and that they are more satisfied with the visual comfort (p = 0.024). More specifically, indoor production workers reported an adequate amoun electric light (p = 0.022) and an increase in visual comfort which raises productivity (p = 0.011).

Synthesis of the Results--The Economics

An economic comparison was made between the two facilities by developing a base case model and examining the benefit-cost (B/C) ratios, the breakeven period, and net present value; in addition, a sensitivity analysis of key variable assumptions was performed. The sources of the economic information were the company's financial statements, productivity information, and absenteeism information. In order to make equal comparisons, models of the old and nev facilities were created. Essentially, Model N, the new facility, was based on company-provided data. Model O, the old facility, was not only modeled with company-provided data but was also adjusted with respect to size (17,000 [ft.sup.2] 37,000 [ft.sup.2]) and production capacity (100% to 50%); see Figure 4. When extrapolating the prior facility data, e.g., utility cost per square foot, to the model, 50% of the model value was based on the magnitude of change in building si: and 50% on the change in production capacity. In Model O, the building size increases from 17,000 to 37,000 [ft.sup.2 production is set at 50% of the larger building's theoretical capacity. For the base case, Model N's productivity is 240 pounds/hour and Model O's productivity is 220 pounds/hour, which are the lowest and highest productivity values for tl facilities, respectively. From the available data, the productivity values selected are conservative; that is, for the new fa a higher productivity value was reached in 2005 (272 pounds/hour), and in the old facility, the productivity in 2003 was pounds/hour. All monetary values are in 2005 dollar equivalents and are adjusted for the realized inflation rates during analysis period.

[FIGURE 4 OMITTED]

The cost components are manufacturing wages, office wages, utilities, building maintenance, equipment maintenance and initial investment. For Model N, office wages, utility, building maintenance, and equipment maintenance costs wer directly taken from the company's financial statement. Fuel costs were obtained from vendor invoices because fuel information was not explicitly listed on the financial statement. Manufacturing wages were calculated by determining a average hourly wage rate from production hours and manufacturing wages reported on the financial statement. Manufacturing wages were not taken from the financial statement because the calculated wages were dependent on productivity rate, which was held constant in this analysis with respect to the given model. Conversely, office wages w taken from the financial statement because other than self-reported survey information, productivity information was n available for the office workers. The initial investment for the new facility was $4,000,000, which does not include mate handling equipment. This cost was annualized with a discount rate of 7% and a time period of 50 years. For Model O, wages, utility, building maintenance, and equipment maintenance costs were taken from the company's financial state (for the old actual facility) and adjusted in accordance with the parameters of size and production. The fuel costs were obtained from vendor information and adjusted in a similar manner. Manufacturing wages were calculated with the hou average wage rate and production hours. The initial investment of $1,480,000 was estimated using R.S. Means (2006) was annualized with the same rate and time period. Information on annual operations costs is shown in Table 7 and T 8.

The annual benefits (the sales) for both Models O and N were also calculated from the company's financial statement, were only modeled with respect to size and production capacity; see Table 8. For total annual benefits indicated in the column of Table 8, total annual sales were subtracted from total annual operation costs without including the annual investment costs. This calculation of total annual benefits was necessary for the computation of the net present value (NPV) and subsequently the breakeven period shown in Table 9. NPV was determined from the difference between th models' total annual benefits of $308,514 over the 50-year study period with a 7% discount rate. The breakeven perioc calculated by utilizing the difference between the two models' total annual benefits and the difference between the initi investment costs of the two models ($2,520,000). Two B/C ratios were calculated. The first B/C was calculated by divi the NPV of total annual benefits by the additional investment cost. The second B/C was calculated by dividing the difference in total annual sales by the difference in total annual costs. The difference between the two B/C ratios was subtle, but important in terms of how companies may want to consider investments. Results are shown in Table 9, Bas Case column. The NPV of total benefits with a rate of 7% over 50 years is $4,257,718, which compares favorably to th $2,520,000 increase in initial investment; the breakeven period is 12.54 years. Both B/C ratios are greater than 1, indi that the company made the correct economic decision regarding the construction of the new green design facility.

Since assumptions were made with respect to the models, a sensitivity analysis was performed on relevant variables. additional cases were considered, four of which are shown in Table 9. Holding all other factors in the base case const the five cases were: (1) the usage factor was changed to 25% building related and 75% production related; (2) the usa factor was changed to 75% building and 25% production; (3) the productivity of the new facility was increased to 270 pounds/hours, the highest reported available productivity data for the new facility, and the productivity of the old facility decreased to 185 pounds/hour, the lowest available productivity data for the old facility; (4) the model capacity regardi both facilities was increased to 70%; and (5) holding the B/C ratios equal to 1, the time period was calculated. The scenarios were developed based on the key assumptions made during the modeling process. For example, the model assumes certain percentages or ratios so these assumptions were analyzed to understand the affect on the final outc While holding the B/C ratios to 1, the model time period was 12.5 years. In the third case, the costs in the old facility w greater than the costs in the new facility, making the B/C inappropriate. In the remaining sensitivity analyses, both B/C ratios were greater than 1, indicating several key points. First, the sensitivity analysis does not change the decision: th company made the correct decision in all cases examined. Changing the production capacity factor assumption affects

B/C ratios and the breakeven period, but does not change the preferred decision. In the second case, the B/C ratio (ar TAS and TAC) appears to be significantly larger because the cost difference of the two facilities is very small, while the benefit (sales) remains unchanged. The third case indicates that productivity is a significant factor. The fourth case indicates that changing the production capacity factor assumption from 50 to 70% maintains a B/C ratio greater than 1 therefore also does not affect the selection of an alternative.

CONCLUSIONS

Summary

A framework for evaluating the benefits of green building design and construction was developed for and used on a manufacturing facility, Castcon Stone, Inc., in Saxonburg, Pennsylvania. Castcon Stone's performance in their new gre facility was compared to their performance in their previous facility. The new facility offered advantages in daylight, air quality, and thermal comfort. The framework compared pre-move and post-move data and included collecting and analyzing company data on production in the manufacturing facility, absenteeism, construction costs, utility and maintenance costs, and administering and analyzing the results of four survey instruments. The results indicate that th employees generally agree that the indoor environmental quality of the new facility is superior to the old and that productivity is enhanced by the view to the outdoors, the size of the work area, the temperature, and the relative humic In general, employees are satisfied with their work area and the building in general. Absenteeism indicators generally s no statistically significant differences, with the exception of an increase in post-move excused absences for office work and an increase in excused with doctor's excuse for production employees. Statistically, workers' compensation for production employees is significantly less post-move.

The B/C ratios indicated that the correct economic choice was made. The calculations are very reliant on the productiv rates calculated for both the old and the new facilities. A conservative approach taking the lower of the new facility productivities and the highest of the old facility productivities still showed that the correct economic decision was made

In general, measuring impacts of the green building on the productivity, health and safety, absenteeism, energy saving and IEQ is very hard due to lack of a controlled test environment. In many cases, several factors that might affect thes research areas change simultaneously. In the Castcon case, the new drug-free policy, facility move, and new attendar incentive policy took place within a 6-month interval. Their impacts on the absenteeism and employee health and safet cannot be differentiated by analysis of only absenteeism and health data since neither of the impacts of these policies be controlled in a test environment. However, the survey provides an objective qualitative assessment of different parameters as a validation tool.

For productivity analysis, various factors including new work layout, new production equipment, employee psychology Hawthorne effect due to new facility), and green building affect the results. Employee surveys and management reviev play a very important role in validation of the results and understanding the impacts of these changes on productivity. I example, removing 2003 productivity data from the analysis so as not to bias the analysis due to the facility move was decided with Castcon management.

One important drawback for this research was the lack of data, especially for the pre-move period. For the statistical analyses and to reduce the variance of data, longer periods of data collection are very important for similar uncontrolle studies. More data points also help with understanding impacts of other factors on the studied areas since the impacts expected to stabilize in longer periods and some factors, such as Hawthorne effects, may diminish.

Despite the various challenges and drawbacks of conducting this type of research we are optimistic that in the final assessment, our research shows that the decision to build a green building made sense from both an environmental a economic point of view. We are therefore motivated to continue analyzing future green building endeavors.

Future Work

The research team is likely to conduct a follow-on study including read-ministering the survey instrument and conducti focus groups to extend the analysis. The team will also track and analyze ongoing manufacturing productivity data for new building. These extended analyses will aim to help Castcon management understand performance of the new gre building. In another effort in the near future, the framework will be used on additional green buildings of different use ty These will require adjustments to the survey instruments and metrics.

APPENDIX

University of Pittsburgh Green Building Employee Survey (adapted from CBPD (1) and CBE (2) surveys)

What Is a Green Building?

A green building is a place that is environmentally responsible and promotes a healthy environment. Today, in the Unit States, the Green Building Council (USGBC) certifies buildings that meet criteria established from their Leadership in Energy and Environmental Design (LEED) guidelines. Castcon Stone's new facility is a green building, which is anticip a LEED silver rating. In the Pittsburgh region and throughout the country, Castcon Stone is a leader in green buildings because Castcon Stone recognizes the benefits of this holistic design approach.

What Are the Proposed Benefits of a Green Building?

It has been reported that green buildings can:

* improve employee productivity,

* reduce health and safety costs, and

* offer other savings such as reducing energy, water, and maintenance costs.

What Are We Studying and Surveying?

The proposed green building benefits are often discussed, but the effects have not often been thoroughly measured or studied. Researchers from the University of Pittsburgh's Department of Civil and Environmental Engineering and Department of Industrial Engineering are studying the connection between the proposed benefits to employees and gr buildings.

These researchers have created this survey, which you are about to complete, to assist in understanding the proposed linkages. Castcon Stone's management has reviewed the survey and is interested in the results. Be assured that indiv responses to the surveys will be kept anonymous and confidential. There are no foreseeable risks associated with this project, nor are there any direct benefits to you. You will not receive additional payment for participation. Your participa is voluntary, and you may withdraw from the survey at any time. This study is being conducted by Dr. Kim Needy at 412.624.9838 and Dr. Robert Ries at 412.624.9548, if you have any questions.

This green building survey, which you are about to complete, should take approximately 20 to 30 minutes. If you have worked in both the old and new facilities, then your survey will be longer because we are asking you to recall your experience in the old facility.

You may not be familiar with all of the terms used in the survey. If a word is underlined, then a definition is available or last page. If you have any questions, then please ask the researchers.

Thank you for completing this survey!

Introductions (Castcon Stone)

Casccton Stone Inc. management and University of Pittsburgh are conducting this green building survey, which you are about to complete. The survey should take approximately 20 to 30 minutes. If you have worked in both the old and nev facilities, then your survey will be longer because we are asking you to recall your experience in the old facility. Individ responses to the survey will be kept anonymous and confidential. Please do NOT put your name or any personal identification anywhere in the survey.

You may not be familiar with all of the terms used in the survey. If a word is blue and underlined, then a definition is available on the last page. If you have any questions, then please ask the researchers.

Thank you for completing this survey!

1. INDIVIDUAL INFORMATION

1.1. What is your age?

Under 21 years--

21 to 30 years--

31 to 40 years--

41 to 50 years--

51 to 60 years--

61 to 65 years--

Over 65 years--

1.2. What is your gender?

Male--

Female--

1.3. How long have you been working for PNC/Castcon?

Less than 1 year--

1 to 3 years--

4 to i0 years--

11 to 20 years--

More than years--

1.4. How long have you been working at the new facility?

--years and-- months

1.5. What is your work status?

Full time--

Part time--

1.6. Do you work on Saturdays?

Yes--

No--

2. WORK DESCRIPTION

2.1. In which department do you primarily work?

Estimating--

Administrating/Accounting--

Drafting--

Sales--

Project Management--

Operations Management--

Other (Please specify)--

3. WORK AREA

3.1. On which side of the building is your work area located?

North--

South--

East--

West--

3.2. Which option best describes your work area?

Open office with partitions above eye level--

Open office with partitions below eye level while seated--

Open office with no partitions--

Other (please specify)--

3.3. How many people share your work area?

Less than 2 people--

3 to 6 people--

7 to 10--

More than 10 people--

3.4. Do you have outside views from your work area while either standing or seated?

Yes--

No--

Please answer Questions 3.5, 3.6, 3.7, and 3.8 if you checked "Yes" to above Question 3.4. If you selected "No," then proceed to Section 4

3.5. Which direction do you generally face while seated?

North--

South--

East--

West--

3.6. How close is your work area to an exterior window?

Less than 16 feet--

More than 16 feet--

3.7. Which direction does the window face?

North--

South--

East--

West--

3.8. How close is your work area to an exterior wall?

Less than 16 feet--

More than 16 feet--

4. GENERAL WORK AREA ENVIRONMENT SATISFACTION

4.1. I am satisfied with

Don't

Strongly Strongly Know/

Disagree Neutral Agree NA a) The amount of space at 1 2 3 4 5 6 7 0

my work area. b) The visual privacy of 1 2 3 4 5 6 7 0

my work area. c) The acoustic privacy of 1 2 3 4 5 6 7 0

my work area. d) The location and 1 2 3 4 5 6 7 0

performance of the

common office equipment. e) My work area in general. 1 2 3 4 5 6 7 0 f) The ability to adjust my 1 2 3 4 5 6 7 0

work area to suit

my needs. 5. GENERAL BUILDING SATISFACTION 5.1. I am satisfied with

Don't

Strongly Strongly Know/

Disagree Neutral Agree NA a) The design and 1 2 3 4 5 6 7 0

appearance of the

building. b) The cleanliness of 1 2 3 4 5 6 7 0

the building. c) The location of the 1 2 3 4 5 6 7 0

lunch room in the

building. d) The lunchroom in 1 2 3 4 5 6 7 0

the building. 5.2. I am satisfied with

Don't

Strongly Strongly Know/

Disagree Neutral Agree NA a) The location of the 1 2 3 4 5 6 7 0

building. b) The security 1 2 3 4 5 6 7 0

provided in the

building. c) The location of 1 2 3 4 5 6 7 0

restrooms in the

building. d) The fire and life 1 2 3 4 5 6 7 0

safety provided by

the building design

and systems.

6. TRANSPORTATION

6.1. How many miles do you travel to work (one-way)?

Less than 5 miles--

6 to 10 miles--

11 to 20 miles--

21 to 30 miles--

Over 30 miles--

6.2. What is your primary mode of transportation to work? (Check ONE that is most applicable.)

Personal automatic--

Light rail system (T)--

Bike--

Bus--

Car pool--

Walk--

Park and Ride--

Other (please specify)--

6.3. What other modes of transportation do you use on occasion? (Check ALL that apply.)

Personal automobile--

Light rail system (T)--

Bike--

Bus--

Car pool--

Walk--

Park and Ride--

Other (please specify)----

7. INDOOR ENVIRONMENTAL QUALITY SATISFACTION

Temperature, Humidity, and Air Movement

7.1. In my work area, I can personally adjust or control the following. (Check all that apply):

a) Daylight level i.e., with window blinds or shades--

b) Electric light level, i.e., with a switch or dimmer--

c) Air supply temperature i.e., with a thermostat--

d) Air supply volume and/or direction i.e., with an adjustable vent--

e) None of the above--

f) Other--

7.2. During warmer weather, I am satisfied with the temperature in my work area. Strongly Strongly Disagree Neutral A

1 2 3 4 5 6 7

7.3. During cooler weather, I am satisfied with the temperature in my work area. Strongly Strongly Disagree Neutral Ag

1 2 3 4 5 6 7

7.4. I am generally satisfied with the temperature in my work area. Strongly Strongly Disagree Neutral Agree

1 2 3 4 5 6 7

7.5. During warmer weather, I believe the air is too humid in my work area. Strongly Strongly Disagree Neutral Agree

1 2 3 4 5 6 7

7.6. During cooler weather, I believe the air is too dry in my work area. Strongly Strongly Disagree Neutral Agree

1 2 3 4 5 6 7

7.7. I am generally satisfied with the relative humidity in my work area. Strongly Strongly Disagree Neutral Agree

1 2 3 4 5 6 7

7.8. During warmer weather, I am satisfied with the air flow speed (not too drafty or too stagnant) in my work area. Stro Strongly Disagree Neutral Agree

1 2 3 4 5 6 7

7.9. During cooler weather, I am satisfied with the air flow speed (not too drafty or too stagnant) in my work area. Stror Strongly Disagree Neutral Agree

1 2 3 4 5 6 7

7.10. I am generally satisfied with the air flow speed (not too drafty or too stagnant) in my work area. Strongly Strongly Disagree Neutral Agree

1 2 3 4 5 6 7

7.11. Recalling the previous questions related to temperature, relative humidity, and air flow speed, I am generally sati with the thermal comfort in my work area. Strongly Strongly Disagree Neutral Agree

1 2 3 4 5 6 7

Air Quality

7.12

Strongly Strongly

Disagree Neutral Agree a) I believe the 1 2 3 4 5 6 7

air is not

stuffy/stale. b) I believe the 1 2 3 4 5 6 7

air is clean. c) I believe the air 1 2 3 4 5 6 7

generally is free

of odors.

7.13. I am generally satisfied with the air quality in my work area (i.e., stuffy/stale air, cleanliness, odor). Strongly Stror Disagree Neutral Agree

1 2 3 4 5 6 7

8. LIGHTING

8.1. What type of lighting is provided at your work area? (Check all that apply.)

Daylighting--

Overhead lighting--

Task lighting--

8.2.

Don't

Strongly Strongly Know/

Disagree Neutral Agree NA a) There is a problem 1 2 3 4 5 6 7 0

with glare in my

work area. b) It is too dark in 1 2 3 4 5 6 7 0

my work area. c) It is too bright 1 2 3 4 5 6 7 0

in my work area. d) There is an 1 2 3 4 5 6 7 0

adequate amount

of daylight in

my work area. e) There is an 1 2 3 4 5 6 7 0

adequate amount of

electric light in

my work area.

8.3. Considering the previous items in Question 8.2, how generally satisfied are you with the visual comfort of the light (e.g., light, glare, reflections, contrast)? Strongly Strongly Disagree Neutral Agree

1 2 3 4 5 6 7

8.4. Overall, does the visual comfort enhance or interfere with your ability to get your job done? Interferes Neutral Enhances

1 2 3 4 5 6 7

9 PRODUCTIVITY

9.1 Feature Importance

Don't

Not Somewhat Very Know/

Important Important Important NA a) How important is 1 2 3 4 5 6 7 0 the distance to

the windows to

you? b) How important is 1 2 3 4 5 6 7 0

the view outside

to you? c) How important is 1 2 3 4 5 6 7 0

the work area size

to you? d) How important is 1 2 3 4 5 6 7 0

the openness of

your work area

to you? e) How important is 1 2 3 4 5 6 7 0

the comfort of

the work area

chair to you? f) How important are 1 2 3 4 5 6 7 0

the work area

furniture finish

quality and colors

to you? g) How important is 1 2 3 4 5 6 7 0

the work area

furniture to you? h) How important 1 2 3 4 5 6 7 0

is the air

temperature

at the work

area to you? i) How important 1 2 3 4 5 6 7 0

is the relative

humidity at the

work area to you? j) How important is 1 2 3 4 5 6 7 0

visual privacy at

your work area

to you? k) How important is 1 2 3 4 5 6 7 0

acoustic privacy

at your work area

at the work area

to you? l) How important is 1 2 3 4 5 6 7 0

the cafeteria/the

lunchroom to you? m) How important is 1 2 3 4 5 6 7 0

the outdoor space

and views at the

cafeteria/the

lunchroom to you?

9.2. Effect on your productivity at work

Don't

Negative No Positive Know

effect effect effect NA a) How does the 1 2 3 4 5 6 7 0

distance to the

windows affect

your productivity

at work? b) How does the view 1 2 3 4 5 6 7 0

outside affect

your productivity

at work? c) How does the work 1 2 3 4 5 6 7 0

area size affect

your productivity

at work? d) How does the 1 2 3 4 5 6 7 0

openness of your

work area affect

your productivity

at work? e) How does the 1 2 3 4 5 6 7 0

comfort of the

work area chair

affect your

productivity

at work? f) How important are 1 2 3 4 5 6 7 0

the work area

furniture finish

quality and colors

affect your

productivity

at work? g) How does the work 1 2 3 4 5 6 7 0

area furniture

affect your

productivity

at work? h) How does the air 1 2 3 4 5 6 7 0

temperature at

the work area

affect your

productivity

at work? i) How does the 1 2 3 4 5 6 7 0

relative humidity

at the work area

affect your

productivity at

work? j) How does visual 1 2 3 4 5 6 7 0

privacy at your

work area affect

your productivity

at work? k) How does the 1 2 3 4 5 6 7 0

acoustic privacy

at your work area

feature affect

your productivity

at work? l) How does the 1 2 3 4 5 6 7 0

cafeteria/the

lunchroom affect

your productivity

at work? m) How does the 1 2 3 4 5 6 7 0

outdoor space

and views at the

cafeteria/the

lunchroom affect

your productivity

at work?

9.3. After moving to the new facility, how long did it take you to reach your prior productivity?

Less than a week--

One to two weeks--

Two weeks to one month--

One month to three months--

More than three months--

Do not know--

9.4. How do you think moving to new Castcon facility affected

Don't

Negative No Positive Know/

effect effect effect NA a) Your individual 1 2 3 4 5 6 7 0 productivity b) Work team 1 2 3 4 5 6 7 0

productivity

10. HEALTH RELATED SATISFACTION

10.1. How frequently do you have following health problems at your workstation? Please distinguish between problems triggered during working hours, and chronic problems not associated with your working environment.

Triggered during working hours

Several Several

Chronic Almost Times/ Times/

([check]) Daily Week Month General tiredness 1 2 3 General feelings of stress 1 2 3 Irritability 1 2 3 Headaches 1 2 3 Coughs 1 2 3 Nose and throat irritations 1 2 3 Eye strain 1 2 3 Blurring vision 1 2 3 Eye irritations 1 2 3 Soreness 1 2 3 Other-- 1 2 3

Triggered during working hours

Chronic Almost

([check]) Seldom Never General tiredness 4 5 General feelings of stress 4 5 Irritability 4 5 Headaches 4 5 Coughs 4 5 and throat irritations 4 5 Eye strain 4 5 Blurring vision 4 5 Eye irritations 4 5 Soreness 4 5 Other-- 4 5

GLOSSARY

Common office equipment: This term describes the office equipment used by several employees or departments in common, such as printers, faxes, photocopy machines, etc.

Daylighting: This term describes the sunlight entering the building through windows, glass roof, or glass doors.

Exterior wall: This term describes a wall which is adjacent to the outside of the building. This term does not stand for th internal walls which separate various departments, offices, or corridors.

Open office: This term describes an office area which is open and not separated from other areas with walls and doors (except corridors).

Overhead lighting: This term describes lighting provided by the fixtures on the ceiling or on the walls.

Personalization of the work area: This term describes your ability to personalize your work area such as by hanging pictures, notes or other personal items on your walls, by placing personal items on your desk, and changing the desigr your work area.

Task lighting: This term describes personal lighting provided by personal fixtures at one's work area.

Work area: This term describes the location where you work such as a desk, cubicle, operating a piece of equipment,

Work team productivity: This term describes the productivity of your work team including you, your co-workers, your subordinates and your managers.

(1) Center for Building Performance and Diagnostics, Carnegie Mellon University, Workplace Satisfaction Survey

(2) Center for Built Environment at Berkeley, Occupant Indoor Environmental Quality Survey

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KIM LASCOLA NEEDY is an associate professor of industrial engineering at the University of Pittsburgh. She receivec B.S. and M.S. degrees in industrial engineering from the University of Pittsburgh and her Ph.D. in industrial engineerin from Wichita State University. Prior to her academic appointment, Dr. Needy accumulated nine years of industrial experience while working at PPG Industries and The Boeing Company. Her research interests include activity based costing, engineering economic analysis, engineering management, and integrated resource management. Dr. Needy i member of ASEE, ASEM, APICS, IIE, and SWE. She is a licensed EE. in Kansas. Dr. Needy is the book and software editor for The Engineering Economist. Table 1. Potential savings from productivity gains and health benefits (adapted Fisk (2002))

Source of Potential annual Potential annual

productivity gain health benefits savings or gains Reduced respiratory 16 to 37 million avoided $6-14 billion

illness cases of common cold

or influenza Reduced allergies and 8 to 25% decrease $1-4 billion asthma in symptoms within

53 million allergy

sufferers and 16

million asthmatics Reduced sick building 20 to 50% reduction in $10-30 billion

syndrome symptoms health symptoms

experienced frequently

at work by ~15 million

workers Improved performance Not applicable $20-160 billion

from thermal and

lighting changes Table 2. Costs in California State employee-occupied office buildings (Adapted from Kats (2003))

Percentage of the Cost drivers total building costs (%) Employee 89 Rent 6 Operations & maintenance 4 Electricity 1 T
3. LEED[R] category information for Castcon Stone (GBA, 2003b) LEED[R] category General information Sustainable
Reclaimed brownfield site

Stormwater retention

and bioremediation ponds

Sustainable landscaping Water efficiency Rainwater cistern for irrigation Energy and atmosphere Motion sensor for fluorescent lighting

Tight envelope with Icynene insulation Resources and materials Used on-site slag for paving base

Minimal interior finish Indoor environmental quality Open, daylit design

Clerestory

Indoor air quality (IAQ) plan Innovation and design process Initial master plan and charette

Integrated design process Table 4. Castcon Stone data collection variables for old and new facilities

Area

Metric Office Production Productivity Self-reporting survey Man hours/daily pounds

of concrete Absenteeism, health, Total weekly absent Total weekly absent

and safety days days Safety N/A Accidents/month, nature

of accident Electricity kWh/sf (1) kWh/sf (1) Natural gas BTU/sf (1) BTU/sf (1) Water and sewage Gallons/sf (1) Gallon
(1) Equipment fuel Gallons/sf (1) Gallons/sf (1) IEQ Survey ratings Survey ratings Building performance Survey ratings
Survey ratings

measurement (1) New and old facility based on square foot comparison. There is one utility meter for both office and p
Table 5. Castcon absenteeism and sick leave t-test results [H.sub.0]:[[mu].sub.pre- move] = [[mu].sub.post-move] [H.s
(Office) p-Value % Excused absences [[mu].sub.pre-move] < 0.0043

[[mu].sub.post-move] % Unexcused absences [[mu].sub.pre-move] > 0.0790

[[mu].sub.post-move] % Absent no call [[mu].sub.pre-move] > 0.1612

[[mu].sub.post-move] % Total absences (1) [[mu].sub.pre-move] < 0.2113

[[mu].sub.post-move] % Excused with doctor's [[mu].sub.pre-move] > 0.4331

use [[mu].sub.post-move] % Total absences (1) with [[mu].sub.pre-move] < 0.2630

leave [[mu].sub.post-move] % Workers' compensation -- -- [H.sub.0]:[[mu].sub.pre- move] = [[mu].sub.post-move] [H.s
(Production) p-Value % Excused absences [[mu].sub.pre-move] < 0.0766

[[mu].sub.post-move] % Unexcused absences [[mu].sub.pre-move] > 0.0539

[[mu].sub.post-move] % Absent no call [[mu].sub.pre-move] > 0.0548

[[mu].sub.post-move] % Total absences (1) [[mu].sub.pre-move] > 0.3029

[[mu].sub.post-move] % Excused with doctor's [[mu].sub.pre-move] < 0.0001

use [[mu].sub.post-move] % Total absences (1) with [[mu].sub.pre-move] < 0.0099

leave [[mu].sub.post-move] % Workers' compensation [[mu].sub.pre-move] < 0.0001

[[mu].sub.post-move] (1) Total absences do not include excused with doctor's excuse or workers' compensation. Table
Old and new facility energy and water use and sewage generated

Old facility New facility Natural gas (BTU) 15,948,000,000 23,352,000,000 Electricity (BTU) 438,175,864 1,301,159,37
Gasoline fuel (BTU) 282,176,950 218,174,437 Diesel fuel (BTU) 342,246,200 130,007,202 Yearly total (BTU) 17,010,599,014 25,001,341,015 Yearly energy total/SF 1,000,623 675,712 Water (gal) 212,000 305,000 Sewage (gal) 97,571 282,776 Yearly water total/SF 12.47 8.24 Yearly sewage total/SF 5.74 7.64 Table 7. Annual costs for models C
N

Mfg. Office Bldg.

wages wages Utilities mnt. Model ($) ($) ($) ($) Model N 807,734 453,140 66,220 3,319 Model 0 875,439 375,215 95,
14,988

Total annual

Equip. Operation Costs

mnt. Fuel (TAOC) Model ($) ($) ($) Model N 33,839 4,887 1,369,139 Model 0 73,298 11,255 1,446,074 Table 8. Total annual benefits and costs for models O and N

Total annual Annual

operation costs investment Total annual

(TAOC) costs (AIC) costs (TAC) Model ($) ($) ($) Model N 1,369,139 403,437 1,772,576 Model 0 1,446,074 149,272 1,595,346

Total annual

Total annual benefits

sales (TAS) (TAS-TAOC) Model ($) ($) Model N 4,270,744 2,901,605 Model 0 4,039,165 2,593,091 Table 9. Results f base case and sensitivity analyses

Ratio Ratio

change change

Base case 25/75 (1) 75/25 (2) NPV ($) 4,257,718 2,945,186 5,570,249 Breakeven period (years) 12.5 25.9 8.5 B/C (additional investment) 1.7 1.2 2.2 B/C (annual TAS and TAC) 2.2 1.2 21.9

Production

Productivity capacity

change change

(270N,185O) (3) (70%N) (4) NPV ($) 7,858,776 5,410,315 Breakeven period (years) 5.5 8.8 B/C (additional investmer 2.2 B/C (annual TAS and TAC) N/A 2.8 Notes: All changes were made from the base case. (1) The ratio used to extrapolate data was changed to 25% building related and 75 % production related. (2) The ratio used to extrapolate d was changed to 75% building related and 25% production related. (3) The productivity was changed to 270 pounds/ho the new facility; and to 180 pounds/hour for the old facility. (4) The production of both facilities were modeled at 70% o capacity.

NOTE: All illustrations and photos have been removed from this article.