A Framework to Analyze the Impact of Sustainable Infrastructure on Human Productivity

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ABSTRACT

The built environment has a profound impact on our natural environment, economy, health and productivity. As the majority of the people spent most of their time inside buildings, the environment in which they perform their daily activities will have an impact on their health and productivity. Studies have been conducted about the negative impacts of presence of non-favorable conditions to human health and well being. The term "Sick Building Syndrome" (SBS) is used to describe situations in which building occupants experience acute health and comfort problems that appear to be linked to their time spent in a building. Sustainable infrastructure rating systems have requirements intended to improve occupant productivity and health.While the impact of Sustainable Infrastructure in energy consumption and waste/water reduction can be measured using available tools, the impact on productivity remained as an assumption that is not clearly measured. The purpose of this research is to develop a framework to assess whether the impacts of the incorporation of features intended to improve occupants' performance and health such as: increased ventilation, lightning and thermal comfort serve their intended purpose.

Keywords: Sustainable Development, Green Buildings, Productivity.

1. INTRODUCTION

Contemporary research have found growing scientific evidence indicating that the air within homes and other buildings can be more severely polluted than the outdoor air in even the largest and most industrialized cities (EPA, 2010). It has ben found that people spend approximately 90 percent of their time indoors, people who may be exposed to indoor air pollutants for the longest periods of time are often those most susceptible to the effects of indoor air pollution (Fisk, 2000). Such groups include the young, the elderly, and the chronically ill, especially those suffering from respiratory or cardiovascular disease. Indoor air typically contains between 2 and 5—and occasionally greater than 100—times more pollutants than outdoor air. As a result, poor indoor air quality in buildings has been linked to significant health problems such as cancers, asthma, Legionnaires' disease and hypersensitivity pneumonitis. (Baum, 2007)

The term "sick building syndrome" (SBS) is used to describe situations in which building occupants experience acute health and comfort issues that appear to be linked to time spent in a building, but no specific illness or cause can be identified. The complaints may be localized in a particular room or zone, or may be widespread throughout the building. In contrast, the term "building related illness" (BRI) is used when symptoms of diagnosable illness are identified and can be attributed directly to airborne building contaminants (EPA, 2010). Indicators of SBS and BRI include: Building occupants complain of symptoms associated with acute discomfort, e.g., headache; eye, nose, or throat irritation; dry cough; dry or itchy skin; dizziness and nausea; difficulty in concentrating; fatigue; and sensitivity to odors, the cause of the symptoms is not known, most of the complainants report relief soon after leaving the building.

Sustainable or green construction requirements are intended to improve the health and comfort of occupants, a goal which was dubbed as the social benefits of "green buildings" by the Environmental Protection Agency (EPA). Green Building Initiative's Green Globes Sustainable rating system states that the owners of green homes compared to owners of traditional homes experience increased comfort, as green homes have relatively even temperatures throughout the home, with fewer drafts and better humidity control; also improved environmental quality, by following the attached guidelines, builders pay extra attention to construction details that control moisture, choose materials that contain fewer chemicals, and design air exchange/filtration systems that can contribute to a healthier indoor environment (Green Globes, 2010). Leadership in Environmental and Energy Design rating system requirement for Indoor Environmental Quality is to establish minimum indoor air quality (IAQ) performance to enhance indoor air quality in buildings, thus contributing to the comfort and well-being of the occupants.

Although there are existing tools widely available to assess the impacts of Sustainable Construction on the performance in energy of buildings and to determine the reduction on waste; from an exhaustive literature review, it has been found that there is no evidence of a study that shows the effects of green buildings, during long time of exposure, on the impact to human productivity, also there are no clear guidelines focused on developing a methodology to measure the impact of the requirements intended to improve human health and comfort. Even though that the benefits are presented by the different rating system institution, the way in which they can be measured and compared are not available.

2. RATING SYSTEMS REQUIREMENTS

Two of the most used rating systems for sustainable infrastructure have requirements intended to improve indoor air quality and comfort, a detail of the maximum total points required for Green Globes are showed on Table 1 Green Globes .

Table 1: Green Globes

INDOOR ENVIRONMENT	APLICABLE 180
Ventilation	50
Source control of indoor pollutants	35
Lighting	45
Thermal Comfort	20
Acoustic Comfort	30

Table 2 depicts the total points for indoor air quality for LEED certification. These two rating systems are used to compare how the requirements intended to improve indoor air quality and comfort are allocated in the total points summary. Using Green Globes one can obtain up to 180 points from 1000 maximum, meaning that this category accounts for 18% of the total points; meanwhile LEED has 15 points for this category accounting from 100 points total thus this category represents 15% of the total points.

The advantages and implementing these requirements as described in the intent of the credits, should be measurable, steps following a method to asses these benefits should be provided and a methodology described, based on previous research a proposed methodology is presented in the following pages, some of the early research on the impact of indoor air quality on productivity was done before the first sustainable construction rating systems where developed. Actual research should be focused on comparing the related credits from rating systems to the actual benefits on performance, confort and health. (I am not sure whats going on here, I am lost. Again, stay away from 6 line sentences, its is hard to understand)

Table 2: LEED. (again, this is not a table, make up one)

Indoor Environmental Quality		15 Possible Points
Prerequisite 1	Minimum Indoor Air Quality Performance	Required
Prerequisite 2	Environmental Tobacco Smoke (ETS) Control	Required
Credit 1	Outdoor Air Delivery Monitoring	1
Credit 2	Increased Ventilation	1
Credit 3.1	Construction Indoor Air Quality Management Plan - During Construction	1
Credit 3.2	Construction Indoor Air Quality Management Plan - Before Occupancy	1
Credit 4.1	Low-Emitting Materials - Adhesives and Sealants	1
Credit 4.2	Low-Emitting Materials - Paints and Coatings	1
Credit 4.3	Low-Emitting Materials - Flooring Systems	1
Credit 4.4	Low-Emitting Materials - Composite Wood and Agrifiber Products	1
Credit 5	Indoor Chemical and Polutant Source Control	1
Credit 6.1	Controlability of Systems - Lighting	1
Credit 6.2	Controlability of Systems - Thermal Comfort	1
Credit 7.1	Thermal Comfort - Design	1
Credit 7.2	Thermal Comfort - Verification	1
Credit 8.1	Daylight and Views - Daylight	1
Credit 8.2	Daylight and Views - Views	1

3. Evidence of Imporoved Productivity and Comfort from Previous Research

As compiled from Wargocki et al. (2000), experiments have been conducted to measure the impact on human performance, as a means of productivity, of increasing air quality in a simulated office space. The three independent studies referenced by Warcocki show that the performance of simulated office work improves when the air quality is increased. The performance was measured by using three variables describing common tasks done in a usual office day: text typing, proff-reading and addition operations. Average number of characters typed per minute, average number of correctly completed arithmetical calculations, and average number of lines that were correctly proof-read per minute. Comfort is a subjective measure which is based on perceptions that can't be measured quantitatively and where assesed through a questionaire to the subjects asking them about air quality acceptability, odor perceptions, irritations feelings on nose, eyes and throat, and humidity levels.

Table 3. Effects of the interventions on perceived air quality (2-tailed P values)

Study	Intervention	Perceived air quality			Effect of intervention
		acceptability	% dissatisfied	decipol	
1	source present	-0.18	68	11.7	P<0.0001
	source absent	0.18	25	1.9	
2	source present	-0.12	61	9.2	P=0.062
	source absent	0.04	40	4.1	
3	3 L/s per person	-0.09	58	8.2	
	10 L/s per person	0.14	29	2.4	P=0.010
	30 L/s per person	0.14	29	2.4	
Combined effect (all interventions) (1-tailed P): P<0.0001 (χ^2=33.23, df=6)					

Air quality was altered either by decreasing the pollution load, in the particular case of the study, by removing a pollution source at constant ventilation rate , or by increasing the outdoor air supply rate from 3 to 10 or to 30 L/s per personwhile the same pollution source was always present. Temperature, relative humidity, air velocity and noise level were constant

The effects and P-values of the individual interventions investigated by the 3 studies and the combined effect of all interventions on perceived air quality and performance are summarized in Tables 1 and 2 respectively. The results show that removing a pollution source or increasing the ventilation rate significantly improved perceived air quality (P<0.0001) and the performance of typing (P=0.0002), and tended to improve the performance of the addition (P=0.056) and proof-reading (P=0.087) tasks.

Table 4. Effects of the interventions on perceived air quality (2-tailed P values)

Study	Intervention	Performance		Effect of intervention
		not normalized	normalized	
Text typing (performance = characters typed per min)				
1	source present	136.1	139.6	P=0.002
	source absent	145.5	149.2	
2	source present	135.2	143.3	P=0.019
	source absent	137.3	145.5	
3	3 L/s per person	149.5	141.8	P=0.077
	10 L/s per person	152.5	144.6	
	30 L/s per person	154.9	146.9	
Addition (performance = units completed per h)				
1	source present	227.9	229.1	P=0.245
	source absent	231.4	232.6	
2	source present	204.5	227.8	P=0.139
	source absent	210.0	233.9	
3	3 L/s per person	238.0	222.1	P=0.063
	10 L/s per person	249.6	232.9	
	30 L/s per person	254.8	237.7	
Proof-reading (performance = lines read per min)				
1	not measured			
2	source present	3.62	5.08	P=0.245
	source absent	3.85	5.41	
3	3 L/s per person	6.02	5.05	P=0.070
	10 L/s per person	6.29	5.28	
	30 L/s per person	6.45	5.41	

4. PROPOSED METHODOLOGY FOR LONG TERM IMPACTS OF SUSTAINABLE DEVELOPMENT

An initial proposed model to assess the impact of Sustainable Infrastructure in human performance, health and comfort is structured. This model is part of an initial exploration of alternatives, and should be considered as a work in progress research. The goal of the proposed methodology is to assist researchers to determine the impacts of sustainable infrastructure on human performance, comfort and health. As previously described, past research have been made but only consider the variable of indoor air quality, the scope of sustainable building certification goes beyond air quality, involving thermal comfort, increased day light, and acoustic comfort. Through a comprehensive approach, all these aspects should be evaluated.

The first step is to determine the group of study, it has to be defined who is the subject of study in the assessment we want to conduct. The structure of rating system should be followed to divide the different types of infrastructure for certification, according to this we can define our group of study into three different categories: Schools (Students and Staff), Office (Employees, Staff), Hospital and Health Facilities (Patients, Employees, Staff), Commercial and Residential (Occupants). Under these categories we need to define a population of study which has to be clearly accounted and the circumstances in which they are involved in the building itself must be described.

The following step is to determine the problem of study, questions about what is going to be measured should be addressed, from this point of view we have to examine the factors that are going to be included in or study, the main factors identified in this model, that had not been properly addressed before are increased levels of productivity, comfort and well-being. A difference must be made between the quantifiable variables of performance and the relative perceptions of the subjects to changes that should be conducted thru surveys and interviews. The next step proposed is to determine the existing constraints and conditions is the different scenarios that are present within each category have to be defined, as they will consist of the frame and borders of our field of study.

In order to examine the available data and acquire additional data, we will have to perform a data mining which will be used to make an accurate analysis and obtain conclusions, in well-structured organizations these information will be available on each or certain department where databases can be used to select the valuable data; in other cases we will have to use data acquisition techniques to make an analysis, we can use surveys, structured interviews, run tests and record observations.

The final step will be to conduct a statistical analysis in which we will include our selected variables to make conclusions and predictions.

5. CONCLUSIONS

Sustainable construction or green building certification systems have requirements intended to improve human comfort and performance that should be able to be measured and quantified. From a extensive literature review it was found that there is no evidence showing the impact of practicing green building strategies in the long time performance of individuals. Recent efforts have been made to measure the response of controlled groups during relative short periods of time to changes in the environmental working conditions, i.e. increased ventilation and present/absence of pollutant sources.

Recent studies have measured the effect on productivity from variations in indoor air quality. Other dimensions of human interaction within indoor environments should be considered as variables in future studies based on the requirements from green building certifications with respect to thermal comfort, increased daylight and acoustic comfort.

Employee salaries exceed building energy and maintenance costs by a factor of approximately 100 and exceed annual construction or rental costs by almost as much (Woods, 1989). Even a 1% increase in productivity should be sufficient to justify an expenditure equivalent to a doubling of energy or maintenance costs or large increase in construction costs or rents.

With the increasing inventory of green buildings in the cases of facilities been renovated and infrastructure build to replace previous constructions, there is a good opportunity to evaluate the long run effect of green buildings on productivity. An excellent group of study may consist of recently renovated University's campus facilities or Schools, where the subjects of study are relative constant populations and the performance measures are standardized test scores.Productivity can be measured using different performance indexes, while comfort can be addressed thru determining perceptions which data can be acquired by using questionnaires and conducting interviews.

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