Impact of Green Building on Productivity of Offices

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Abstract

Green buildings certifications claim that it can improve the productivity of employees in a workplace. India service sector is a key driver of economy. With the growing mandate of applying green buildings norms in Indian buildings, there is no such analysis that could tell the affects. As there is no exact methodology to calculate productivity, this study uses real time data collection, through questionnaire surveys and instruments to get a self-assessed perception of the architecture employees in the offices in composite climate of India and using a multiple linear regression model for the comparison. The results show an improvement in the relative productivity by 38.96%. The study, can be used as a base for understanding aspects of IEQ in the workplace productivity in Indian conditions.

Key Innovations

- The paper discusses that the green building certifications are being really able to improve the productivity of the employees at the grass root level.
- The questionnaire helps to get the occupants perspective and also takes into consideration if the occupants are acclimatized to the condition.

Practical Implications

For this type of analysis, it has to be kept in mind that occupant should be tested in the workspace itself, so there are no assumptions made, outrider conditions should be avoided and effect of acclimatization should be incorporated.

Introduction

Productivity of a person is the ability to enhance the quality and/or quantity of a service or product i.e. less time to complete a work, which reduces the operational cost (Leaman & Bordass, 2000) (Mansinghka & Mohan, 2021).

A sustainable and green building helps to increase the productivity of the employee in the workplace (Mishra, 2020) (GRIHA, 2008) (IGBC, 2014). Maximum comfort may not lead to maximum productivity, but healthier environment would help by decreasing absenteeism and complaints (Abdou, Kholy, & Abdou, 2017).

In an office building the building related costs are 12%, but the labour cost share is 82%-85%, the companies try to optimize the productivity of the employees and cost-effectiveness as a whole (CABE, 2005) (Brill, Weidemann, Allard, Olson, & Keable, 2001) (Newsham, Veitch, & Hu, 2018). A small change in performance of employees can have massive impacts (Yousef, et al., 2016).

Conductive and efficient buildings help in increasing productivity by reducing absenteeism through healthy environment. LEED covers the Indoor Environment Quality (IEQ) parameters, but still green building guidelines lack in directly focussing to the issue (US Green Building Council, 2004) (Potbhare, Syal, Arif, & Khalfan, 2009).

Most of the time human spent is indoors. Also, the majority of the population in the world stays in urban areas and work in offices. In India also, the service sector is a key economic driver (ASHRAE, 1993) (Indian Brand Equity Foundation, 2021). So, a better IEQ understanding for office spaces is important as the influence and the consequences are large (Leaman & Bordass, 2000). According to Romm & Browning (1994), green design technologies enhance IEQ, making the environment comfortable and increase the employee performance. Hence, it is needed to investigate the relationship between productivity and IEQ (Yousef, et al., 2016).

Productivity

Productivity can be defined as a ratio of output to input, where output measures service, product, etc. and input measures, energy, work environment, etc. It is dependent upon 4 cardinal aspects, organisational, social, environmental and personal. The data collection of all aspects is difficult, but evidence show that environmental factor indirectly improves productivity (Oseland & Bartlett, 1999) (Clements-Croome, 2000).

The productivity, being a hypothetical construct, cannot be directly measured, but can be estimated through performance indicators and criteria (Wallbaum, Feige, Windlinger, & Janser, 2013). This can be resolved using subjective productivity measurement. It is based on own assessment of a personnel than absolute quantitative values, using survey questionnaire (Kemppila & Lonnqvist, 2003).

Productivity and Work Environment

Employees being the knowledge producer are an important asset to the organisation, so the office can be the important place, affect due to productivity (Meulenbroek, et al., 2018). Anything around the

employee that may affect his performance is under work environment (Al-Omari & Okasheh, 2017).

IEQ affects employee's innovation level, error rate, team spirit, absenteeism and finally time of stay in a job, therefore it affects company's ability to retain people (Massoudi & Hamdi, 2017). In USA and UK, 38 billion dollars and 15 billion pounds, losses respectively are due to illness and reduced productivity of the employees (Mujan, Andelkovic, Muncan, Kljajic, & Ruzic, 2019). The new thinking is to encompass productivity of employee and health benefits in evaluation as up to 92% annual investment can be affect due to this (Fuller , 2010).

Challenges of Productivity Calculation

In modern offices the IEQ calculation is a challenge as inputs and outputs are not clear (Haynes, Suckley, & Nunnington, 2017). The self-assessed measure of productivity is considered a better approach than nothing in hand (Clements-Croome, 2000) (Leaman & Bordass, 2000).

IEQ and Green Guidelines

BREEAM from UK, LEED from USA and Green Star from Australia, in recent years have adopted the occupant's satisfaction category of IEQ. These are not yet fully characterized, and were triggered because worker's salaries started to have a larger impact than operational and investment cost (Mujan, et al., 2019). Guidelines like WELL rating have started to focus on IEQ and well being of the occupants.

Parameters of Workspace Design affecting Productivity

As an employee spends a large amount of time in offices, his work environment can either improve his efficiency or may harm it.

Various literature talk about the parameters like temperature, acoustic comfort and noise, indoor air quality, lighting and daylight, humidity, office layout, colour, location and amenities, biophilia and view, look and feel, office furniture, visual comfort, visual privacy, cleanliness, etc.(Chen et al., 2020; Feige, Wallbaum, Janser, & Windlinger, 2013; *Health, Wellbeing & Productivity in Offices The next Chapter for Green Building*, 2014; Kamarulzaman, Saleh, Hashim, Hashim, & Abdul-Ghani, 2011; Kim & de Dear, 2012; Liang et al., 2014; Mulville, Callaghan, & Isaac, 2016; Thompson & Jonas, 2008).

Parameters of Green Building Certification affecting Productivity

Under LEED certification the IEQ factors contains the mechanical aspects that affects productivity and comfort of the occupants (Yousef, et al., 2016), are shown in Table 1.

By comparing the parameters of the workspace and green building certification, that affect productivity, following parameters were shortlisted for the further study: Indoor air quality, temperature, humidity, lighting, acoustic and office layout.

BROAD CATEGORY	EXACT POINT	CREDIT POINT	CUMULATIVE CREDIT POINT
Indoor Air Quality	Minimum Indoor Air Quality Performance	Required	8
	Environmental Tobacco Smoke Control	Required	
	Enhanced Indoor Air Quality Strategies	2	
	Low-Emitting Materials	3	
	Construction IAQ Management Plan	1	
	Indoor Air Quality Assessment	2	
Thermal Comfort (Temperature and Humidity)	Thermal Comfort	1	1
Lighting	Interior Lighting	2	6
	Daylight	3	
	Quality View	1	
Acoustic	Acoustic Performance	1	1

Table 1 LEED credit points of IEQ : (LEED, 2021)

Methods

Calculation of absolute value of productivity has no particular fixed method and involves many challenges. Researchers all around the globe use techniques to convert the qualitative data into quantitative one. For data collection a self-assessed subjective assessment through questionnaire survey was the approach shortlisted, followed by multiple linear regression was deployed on the data collected (Chadburn, Smith, & Milan, 2017; Chen et al., 2020; Haapakangas, Hallman, Mathiassen, & Jahncke, 2018; Huang, Robertson, & Chang, 2016; Kang, Ou, & Mak, 2017; Liang et al., 2014; Lipczynska, Schiavon, & Graham, 2018; Mulville et al., 2016).

Area of Study

The area of study was limited to the composite climate according to National Building Code of India 2016, under which it was worked upon architecture offices in Lucknow (Capital of Uttar Pradesh) and New Delhi (Capital of India).

The reason for limitations was that due to external climatic conditions the IEQ may get affected, leading to skewness in the data collection. The body also gets acclimatized to the conditions around, so the same weather conditions and similar workplace city were chosen.

The questionnaire contained questions on various aspects of IEQ, hence architecture offices were chosen, so the responses can be more accurate from a lot that already has knowledge about these parameters.

Questionnaire Design and Analysis

The questionnaire was in two parts: Part-I contained the weightages to be provided to all the shortlisted parameters on a 5-point likert scale, where 1 being least important to 5 being most important. This data was collected through 110 architectural employees with 13 office buildings and senior architects, ranging from 21 years to 68 years of age.

The Part-II contained an self-assessed subjective form that asked the employees to mark their satisfaction on the likert scale where 1 being high dissatisfied to 5 being highly satisfied.

At the end the relative productivity was calculated by multiplying the individual results with the weightages and the results were averaged, to get the final relative productivity value of the office space.

Real-Time Point Calculation of Parameters

The parameters were calculated in real time while the survey was being taken. The devices were placed at the

near-center position of the workspace at a height of 1.2m-1.5m so that it may achieve the seated human height. The description of the devices are shown in Table 2.

Regression Model

The next step included data cleaning, to remove outliers, followed by residual analysis to demarcate that the data is fit for multiple linear regression. The multiple linear regression was done through Minitab software.

TOOL	NAME	COMPANY	PARAMETERS	RANGE
	CAIR +	PRANA AIR	PM 2.5	0 - 2000µg/m3
			PM 10	0 - 2000µg/m3
			CO2	0-2000 PPM
			HCHO	0-2 PPM
			TVOC	0-20 PPM
			HUMIDITY	0 - 99%
			TEMPERATURE	-30'C to 60'C
	LX1330B	DIGITAL INSTRUMENTS	LIGHTING	0.1 - 200000 Lux
GOOGLE PLAY STORE	DECIBAL X	SKYPAW CO. LTD.	ACOUSTIC	30 - 130 dBA

Table 2 List of devices used for measuring the parameters in an office space

Results

In the starting simple linear regression model was run to see any particular impact that a single parameter makes on the relative productivity condition. The adjusted r^2 ranges from 0.00% to 40.97% as shown in Table 3.

S.NO.	PARAMETERS	EQUATION	R-SQ (ADJ)
1	ACOUSTIC	Y = 75.6 + 0.52X1	0.00%
2	TEMPERATURE	Y = 168.3 – 2.29X1	0.00%
3	LIGHTING	Y = 92.06 + 0.0596X1	14.40%
4	AIR QUALITY INDEX	Y = 111.8 - 0.0435X1	0.00%
5	PM 2.5	Y = 112.1 - 0.086X1	0.00%
6	PM 10	Y = 110.5 - 0.047X1	0.00%
7	TVOC	Y = 117.57 – 20.27X1	40.97%
8	CO_2	Y = 117.24 – 0.00838X1	15.20%
9	HUMIDITY	Y = 106.5 + 0.015X1	0.00%
10	AIR SPEED	Y = 115.60 – 10.32X1	1.06%
11	OFFICE LAYOUT, AMENITIES & UTILITIES	Y = 93.0 + 22.6X1	0.00%

Table 3 Simple linear regression output, where X1 = Parameter

The results show that none of the individual parameter cannot significantly predict the relative productivity value.

In the multiple linear regression part, when all the parameters were placed together there was a large amount of covariance between the parameters. After various permutation and combination of the parameters, that lead to maximum adjusted r^2 with significant predictability is 78.27%. The resulted VIF (Variance Inflation Factor) values for various parameters is also less than 5, i.e., there is no multiple collinearity.

$$Y = 134.3 + 0.44X1 – 0.82X2 – 0.0419X3 – 0.2851X4 + 0.430X9$$

Where,

Y = Productivity
X1 = Acoustic (dBA level)
X2 = Temperature (ºC level)
X3 = Lighting (Lux level)
X4 = AQI (Index level)
X9 = Humidity (% level)

Parameter Analysis

Acoustics:

It can be understood as the value is positive, so the productivity increases as the dBA level increases, but it should be kept in mind that higher acoustic levels are also not favourable. As the highest level of Acoustic is 67.6 dBA in the data set, so the values up to that can be assumed to have positive impact on increasing, but nothing can be said for values higher than that.

Temperature:

It can be understood as the value is negative, so the productivity decreases as the ºC level increases, but it should be kept in mind that lower temperature levels are also not favourable. As the lowest level of Temperature is 24.1ºC in the data set, so the values greater than that can be assumed to have negative impact on increasing, but nothing can be said for values lower than that.

Lighting:

It can be understood as the value is negative, so the productivity decreases as the Lux level increases, but it should be kept in mind that lower lux levels are also not favourable. As the lowest level of Lighting is 83 Lux in the data set, so the values greater than that can be assumed to have negative impact on increasing, but nothing can be said for values lower than that.

AQI:

It can be understood as the value is negative, so the productivity decreases as the AQI level increases. As the lowest level of AQI is 36 in the data set, so the values greater than that can be assumed to have negative impact on increasing, but nothing can be said for values lower than that.

Humidity:

It can be understood as the value is positive, so the productivity increases as the % level increases, but it should be kept in mind that higher humidity levels are also not favourable. As the highest level of Humidity is 63% in the data set, so the values up to that can be assumed to have positive impact on increasing, but nothing can be said for values higher than that.

Validation of the Model

CASE NO.	Y	X1	X2	X3	X4	X5	X6
	PRODUCTIVITY	Acoustics	Temperature	Lighting	AQI	PM 2.5	PM 10
14	119.667	61.2	30.2	418	94	57	77
15	97.78	58.4	29.8	450	156	100	115

X7	X8	X9	X10	X11	CALCULATED	Y1 - Y
TVOC	CO2	Humidity	Wind Speed	Office Layout	PRODUCTIVITY (Y1)	
0.56	555	61	0.6	0.8	118.3804	-1.2866
0.66	482	60	0.9	0.6	98.03	0.25

Table 4 2 Case data for validation of the equation

Through 2 case data as shown in Table 4 a real time survey and measurements were performed. The results from the survey were compared with the one acquired from the regression model and the results were within a tolerance level. This allows the equation to be used in the similar conditions.

Comparison: Impact of Parameters on Productivity of a Green Building and a Conventional Building

For the green building under LEED certification the value of productivity through the equation was:

Parameters / Sub Parameters	Units	Values
Acoustics	dB	59.8
Temperature	°C	24.4
Lighting	Lux	426
Indoor Air Quality		
AQI	Index	32
Humidity	%	59

For the given Values of the parameters the value of productivity / comfort due to these variables is –

$$Y = 134.3 + 0.44X1 – 0.82X2 – 0.0419X3 – 0.2851X4 + 0.430X9$$

$$Y_G = 134.3 + (0.44*59.8) – (0.82*24.4) – (0.0419*426) – (0.2851*32) + (0.430*59)$$

$$Y_G = 134.3 + 26.312 – 20.008 – 17.84 – 9.1232 + 25.37$$

$$Y_G = 139.0108$$

And for conventional building under similar condition

Parameters / Sub Parameters	Units	Values
Acoustics	dB	62
Temperature	°C	28.2
Lighting	Lux	450
Indoor Air Quality		
AQI	Index	138
Humidity	%	46

For the given Values of the parameters the value of productivity / comfort due to these variables is –

$$Y = 134.3 + 0.44X1 – 0.82X2 – 0.0419X3 – 0.2851X4 + 0.430X9$$

$$Y_C = 134.3 + (0.44*62) – (0.82*28.2) – (0.0419*450) – (0.2851*138) + (0.430*46)$$

$$Y_C = 134.3 + 27.28 – 23.124 – 18.855 – 39.3438 + 19.78$$

$$Y_C = 100.0372$$

From the value of the productivity in the green building and in conventional building, it can be seen that the value of productivity / comfort is higher than that of the conventional building.

$$\% \text{ increase in Productivity of Green Building over Conventional Building} = ((Y_G - Y_C) / Y_C)*100$$

$$= ((139.0108 – 100.0372) / 100.0372) * 100$$

$$= (38.9736 / 100.0372) * 100$$

$$=0.3896 * 100 = 38.96\%$$

The result shows that over the given conventional building, the green building has a 38.96% improvement in the productivity level due to Indoor Environment Quality.

Discussion

The results show that there is an improvement of productivity 38.96% in a given green building over a given conventional building. This clearly show that there is a scope of improvement due to indoor environment quality parameters.

The parameters to be kept in mind are that the productivity calculated is not the overall productivity of an employee, it is the impact on the productivity of an employee due to IEQ parameters. The increase in 38.96% is due to a single case, it may vary from building to building. The data collected is in the moderate climate, covering the city of Lucknow and Delhi.

The LEED certificate is able to show a positive result, but other parameters like the colour, biophilia, view, furniture, privacy, cleanliness, etc. are important factors that may affect the productivity of a workplace and should be considered as marking criteria if the certification has to claim about increase in productivity levels as their priority.

In future study one may focus upon the sensitivity of these parameters to understand that what all parameters can be used to get better productivity results through the office design.

The overall study shows that these IEQ parameters do impact the productivity of the workplace and the green building as have a better set of parameters, help in productivity improvement over the conventional building.

Another point to keep in mind is the aspect of acclimatization. Employees in a workplace usually get acclimatize according to the surroundings, they start to feel comfortable in higher temperature or carbon dioxide values.

Conclusion

The study is an attempt to compare the productivity difference between a conventional building and a green rating certified building. As the green building certifications claim that the green building's workplace can improve the productivity of the employees (Mishra, 2020) (GRIHA, 2008) (IGBC, 2014).

The study is limited to environmental factors like IEQ parameters. Effect of the parameters on the productivity is assessed on own by the employees for their workplace. This study is limited to a particular climate zone, i.e., composite zone in accordance to NBC of India 2016, so the variations due to outer climate do not pose many variations. For better responses the respond group is chosen as architectural employees in the architecture office, as they already have a knowledge about the parameters.

The data was analysed and converted in a multiple linear regression equation which was validated and used for comparison. The results show that a green building has better productivity of the employees.

There is a need to properly define a methodology that may take into consideration all the parameters that affect probability and green building certifications should also form an audit tool to measure the well being and productivity of the employees in an office building.

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