BUILDING A SUSTAINABLE OCCUPANT’S PERFORMANCE BASED MODEL FOR INSTITUTIONAL BUILDINGS

Dalia Salem1,3, Emad Elwakil1, and Amr Kandil2
1 Building Construction management, Purdue University, USA.
2 Construction Engineering Management, Purdue University, USA.
3 dsalem@purdue.edu

Abstract: The Sustainable buildings main objectives are to reduce, or avoid, depletion of resources like energy, water, and materials; prevent environmental degradation caused by facilities during the life cycle of the building. Lighting is one of the major energy consumption in institutional buildings. At 2012, the commercial sector, which includes commercial and institutional buildings, and Public Street and highway lighting, consumed about 274 billion kWh for lighting or about 7% of the USA consumption. Most of the research works have focused predominantly on the environmental and physical factors and have neglected the daily activities of the occupants. This study examines the effects of environmental, physical, and daily activities on occupants’ performance in the institutional buildings as well as develops a model to predict the occupants’ performance using Regression analysis technique. The data was collected from the institutional buildings occupants and building facility experts using questionnaire. The model has been validated with 92% Average Validity Percent (AVP) and R square of 0.83 which is a satisfactory result. The developed research model benefits both architects and practitioners to choose the appropriate workplace design due to the occupants’ preferences to enhance performance, and energy efficiency.

1 INTRODUCTION

Buildings are one of the major energy consumers in the U.S. as shown in Fig 1. Both commercial and residential buildings account for 42% of the national U.S. energy consumption. The majority of commercial buildings energy consumption is attributed to lighting (25%), space heating and cooling (25%), and ventilation (7%) (Azar and Menassa 2011a).

Lighting and HVAC energy used in buildings are considered the main consumers of the total buildings energy consumption. Nearly lighting energy used is responsible for 23%, Heating, ventilation and cooling accounting for 38% (Guo et al. 2010). In a recent study, in US commercial building, 25-40% of the total electricity energy consumption is from electrical lighting (Ihm et. al., 2009).
Building professionals’ significant role is how to reduce energy consumption as well as considerably maintain comfort to the occupants. Artificial lighting systems are considered as a major consumer of energy in buildings and contribute significantly to building cooling load. Daylighting has two fold; contributing in determine the overall environmental quality in buildings as well as saving energy (Alashwali and Budaiwi 2011). Before 1940s, daylighting was considered the main light source in buildings design. Recently, in sustainable buildings, daylighting is considered as energy and environmental aspect (Edwards and Torcellini 2002). In case of office lighting, the switching patterns along with the outside conditions are at the core of investigation from the occupants’ behavior point of view. One of the studies has culminated into the fact that as much as 40% energy conservation can be realized if natural light is relied upon compared to the artificial one (Bourgeois, Reinhart, and Macdonald 2006).

Therefore, the scope of the present study is to investigate the lighting preferences in commercial buildings with focus on the institutional buildings and develop a framework for predicting occupant’s performance.

2 RESEARCH OBJECTIVES

The objectives of the present study is to build a sustainable occupant’s performance based model for institutional buildings which can be summarized as follows:

i. Investigate and identify the factors affect occupants usage of lighting.

ii. Data collection from a real workplace

iii. Determine the significant factors that mostly contribute to the Lighting intensity in the workplace.

iv. Determine the factors that affect the occupants’ performance

v. Develop a model / framework based on these factors.

vi. Validate the developed model / framework

3 BACKGROUND

The most significant factors that influence the energy and indoor environmental performances of buildings are outdoor/indoor climate, building characteristics, and occupant behavior. The most important factor is human behavior, followed by building design. Indeed, there is often an obvious discrepancy between real
total energy use in buildings and what is predicted. The reasons for this gap are a general need to understand the role of human behavior within the buildings (Fabi et al. 2011).

Several studies (Carrico and Riemer 2011, Dietz et al. 2009, Henryson, Håkansson, and Pyrko 2000) have taken two different approaches can typically be used to reduce buildings’ energy use: First, the technological approach deals with more energy efficient building systems and equipment. Second, the behavioral approach focuses on understanding building occupant presence and behavior to measure actual energy consumption and develop best practices to encourage conservation (Azar and Menassa 2011b).

3.1 Occupants behavior

Occupants behavior definition is; “the result of a continuous combination of several factors crossing different disciplines.” The factors effecting occupant interactions with building control systems are classified into external and internal. The external factors which related to the building science area (e.g. outdoor and indoor temperature) can be categorized in two categories: the physical environment and the context. The internal drivers concern the social science area can be defined into three categories: physiological, social and psychological.

These External and Internal factors influence occupant behavior, defined as “Drivers.” Drivers can be defined as: “the reasons leading to a reaction in the building occupant and suggesting him or her to act.

3.2 Occupants interactions with indoor environmental controls

Several studies have investigated occupants’ preferences of the windows in their workplace; window size, position in the walls, and its degree of transparency (Galasiu and Veitch 2006). Many studies investigate the occupants interact with the lighting system without providing the occupants satisfaction or performance in the workplace.

These models predict how occupants interact to the lighting system depending on the lighting intensity, the occupant’s schedules and the surrounded factors to predict the occupant’s use of lighting, and therefore predict the lighting energy consumption as a result (Reinhart 2004; Bourgeois et. al. 2006).

It can be deduced here that the previous studies investigated the occupants’ behavior inside the workplace and the interactions with the environment; otherwise, the impact of the interactions on the consumption. These studies however seem to have overlooked the effect on lighting preferences in the workplace due to the difference in environmental, physical, occupants activities and the policies on the occupant performance.

To that effect, this study proposes the occupants’ preferences in the commercial building regarding to the lighting in the workplace has a significant effect on the occupants’ performance.

4 ACTORS AFFECT OCCUPANTS USAGE OF LIGHTING INCORPORATED IN THE CURRENT RESEARCH

Based on the above review of literature and focusing on the institutional buildings, the lighting preferences in institutional buildings that affect the lighting intensity in the workplaces are identified and selected as shown in Table 1. These factors are considered in the present study. Fourteen factors are incorporated in this research, which represents the environmental, physical, activities, and policies factors. The factors that influence occupants’ usage of lighting are hard to quantify and thus a qualitative approach is followed.
The factors selected to be incorporated in Regression analysis model are clustered into four main categories and their factors, as shown in Figure 3. The four main categories include environmental, physical, users and Tasks lighting required. Each category includes several factors.

5 RESEARCH METHODOLOGY

To achieve the objectives of the present research, several steps are accomplished as shown in the schematic diagram Figure 4. The proposed framework for this project consists of 5 main steps. It starts with a comprehensive literature followed by data collection, which in itself consists of two parts studying the lighting factors that affecting the occupants usage and a semi structured questionnaire and open ended interviews is adopted in order to identify the occupants' artificial lighting preferences due to environmental, physical and activities. A Regression Analysis model is developed using model information data which is then underwent a verification process. The next part of the research methodology is to develop a daylighting usage scale which will guide the architects to best design their office buildings. The model is used to assess daylighting efficiency in private and two-person offices.
Then develop lighting behavioral modeling using Regression Analysis. The last step is the conclusion and future research.

Figure 3: Hierarchical factors affect occupants’ usage of lighting

Figure 4: Research methodology
6 DATA COLLECTION

After identifying the lighting preferences factors that may affect the occupants performance, a questionnaire was prepared to assess the effect of these factors on occupants performance. The data is collected via a questionnaire collected form 87 occupants in the institutional buildings at Purdue University. The questionnaire was designed to identify factors that affect lighting intensity in the workplace and then to predict the occupants performance in an abstract approach. It had two parts where the first part (1) was asking the occupants how strongly the factors contributes to the daylighting intensity as shown in Figure 5. Part (2) was asking the occupants using a specified 5 point subjective scale to represent their performance. The data collected is the weights of various factors to be incorporated in the model and the performance of each factor.

This paper presents findings from a web-based survey on the current use of in building design. The survey was administered from October 2014 to December 2014. Two hundred and thirty four individuals from 5 institutional buildings at Purdue University completed the survey. The respondents are Faculty, staff and students have an office at Purdue University. They worked in offices with or without windows in the workplace.

Among those participants 134 about 59% who have windows in their workplace. The rest of them 92 respondents has no window and skipped from the questionnaire. The total respondents who complete the questionnaire are 87 respondents about 37% of the total respondents. See Fig 5 as sample of the questionnaire and Fig 6 the Questionnaire statistics.

![Sample of Questionnaire questions](image)

Figure 5: Sample of Questionnaire questions
7  DEVELOPMENT OF LIGHTING PREFERENCES MODELS

Regression analysis is used to develop the prediction model for the occupants’ performance in the workplace regarding to the lighting preferences. The model is developed based on the previously specified/selected lighting preferences. It is developed in order to represent the collected data.

7.1 Regression-Based Occupants Performance Model

For the implementation of the model MINITAB is utilized to develop a regression model. MINITAB is a general statistical technique that has capabilities of basic and advanced data analysis in a wide range, such as analysis of variance, basic statistics, correlation and regression, and multivariate analysis (Minitab 2006). To select the best number of variables, we used step-wise regression analysis in the model.

MINITAB is utilized to develop a regression model for occupants' performance as a function of the previously selected lighting factors in the commercial buildings. Four selection criteria are used to distinguish between different proposed models. These criteria are R-square, adjusted R-square, mean square error (S or MSE), and Mallow’s Cp. The best model that can represent the collected data set is selected according to the largest R-square and adjusted R-square, the minimum mean square error (MSE), and the closest Cp to the number of independent variables. Therefore, the selected model has the highest R2 of 0.85 and adjust R2 of 0.83, the Cp value of 8.2 close to 9 (i.e. number of variables), and the minimum MSE value of 2.2524. The best obtained formula describing the organization performance as a function of CSFs is given by Equation 1.

[1] \[ Y = 5.7 + 0.326 \times x1 + 0.083 \times x2 - 0.056 \times x3 - 0.179 \times x4 - 0.023 \times x5 - 0.124 \times x6 - 0.034 \times x7 + 0.507 \times x8 + 0.510 \times x9 + 0.394 \times x10 - 0.125 \times x11 - 0.090 \times x12 - 0.120 \times x13 + 0.347 \times x14 + 0.173 \times x15 + 0.350 \times x16 \]

The dependent variable (Y) denotes the occupants' performance expressed as a percentage and Xs denote the lighting factors that shown in Table 2 and the subscript refers to their numbers in the table. For example, X5 denotes number 5 which is “Window size to Wall Ratio.” The built model is checked for its statistical validity. The main diagnostics in this regard are R square (coefficient of multiple determination), F-test, and t-test for model coefficients.
Table 2: Analysis of Variance for the Developed Regression Model

<table>
<thead>
<tr>
<th>Factor X</th>
<th>Predictor</th>
<th>Coefficient</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Orientation</td>
<td>0.326</td>
<td>0.459</td>
</tr>
<tr>
<td>2</td>
<td>Time of Day</td>
<td>0.083</td>
<td>0.839</td>
</tr>
<tr>
<td>3</td>
<td>Sky Condition</td>
<td>-0.056</td>
<td>0.900</td>
</tr>
<tr>
<td>4</td>
<td>View out</td>
<td>-0.179</td>
<td>0.668</td>
</tr>
<tr>
<td>5</td>
<td>Window size to Wall Ratio</td>
<td>-0.023</td>
<td>0.951</td>
</tr>
<tr>
<td>6</td>
<td>glazing color</td>
<td>-0.124</td>
<td>0.789</td>
</tr>
<tr>
<td>7</td>
<td>Seating position regarding to the window</td>
<td>-0.034</td>
<td>0.931</td>
</tr>
<tr>
<td>8</td>
<td>Window size is big</td>
<td>0.507</td>
<td>0.295</td>
</tr>
<tr>
<td>9</td>
<td>Window size is medium</td>
<td>0.510</td>
<td>0.279</td>
</tr>
<tr>
<td>10</td>
<td>Window size is small</td>
<td>0.394</td>
<td>0.407</td>
</tr>
<tr>
<td>11</td>
<td>Windows facing the seat</td>
<td>-0.125</td>
<td>0.599</td>
</tr>
<tr>
<td>12</td>
<td>Windows next to the seat</td>
<td>-0.090</td>
<td>0.715</td>
</tr>
<tr>
<td>13</td>
<td>Non-computer based activities</td>
<td>-0.120</td>
<td>0.510</td>
</tr>
<tr>
<td>14</td>
<td>Word of Mouth</td>
<td>0.347</td>
<td>0.414</td>
</tr>
<tr>
<td>15</td>
<td>Energy awareness campaigns</td>
<td>0.173</td>
<td>0.629</td>
</tr>
<tr>
<td>16</td>
<td>Financial Incentives</td>
<td>0.350</td>
<td>0.425</td>
</tr>
</tbody>
</table>

7.2 Validation of Developed Occupants Performance Model

The validation process is to guarantee that the developed models best fit the available data. In order to determine the efficiency of the developed model to derive real world results, the model is tested statistically, logically, and practically. The collected data are divided into two data sets, model building (80%) and validation (20%). The validation data set, that is 20%, selected randomly and kept away while modeling the regression analysis. After developing the regression analysis model, the validation data set is used to test the capability of the developed lighting factors model to predict the occupant’s performance. The developed model is validated by comparing the predicted results with the actual values of the validation data set.

\[ \text{AIP} = \{ \sum 1 - I \left( \frac{E_i}{C_i} \right) \} * \frac{100}{n} \]

\[ \text{AVP} = 100 - \text{AIP} \]

Where AIP is the Average Invalidity Percent, AVP is the Average Validity Percent, \( E_i \) is the \( i^{th} \) predicted value, \( C_i \) is the \( i^{th} \) actual value, and \( n \) is the number of observations.

Equation 2 expresses the average invalidity, which indicates the prediction error, while Equation 3 presents the average validity percent. The AVP values for the developed performance prediction models regression is 92.55%. These values indicate that the obtained results are satisfactory.

8 CONCLUSIONS AND FUTURE RESEARCH

Lighting energy consumption is considered a highly energy consumer in commercial buildings. Achieving higher energy efficiency at commercial buildings demands considering the lighting preferences to the users and their performance in their workplace. It is difficult to measure the occupant’s performance due to their diversity and complexity. The proposed framework is an effective methodology for developing an institutional building sustainable occupant’s performance based model. This model will help the decision
makers and the designers at different levels to design the work places that accomplish the required levels of visual comfort for the users, while saving energy used in lighting. A multi-dimensional study on performance of the occupants in the commercial buildings has been conducted using 87 surveys obtained from intuitional buildings. The obtained data are analyzed using regression-based performance model and predict the performance of occupants. The developed model benefit both architects and practitioners to choose the appropriate workplace design due to the occupants’ preferences to enhance performance, and energy efficiency. It also provide energy modeling professionals with the various essential factors that affect occupants performance and how it can be assessed/predicted, i.e. performance assessment/prediction tool. The model has been validated with 92 % Average Validity Percent (AVP) and R square of 0.83 that is a satisfactory result. The research study shows a room for improvement for future study like modeling and simulate the occupant’s interaction.

Acknowledgements

The authors wish to acknowledge Assiut University, Egypt for its shared-fund for this research study.

References


