MATLAB-BASED MODELLING FOR OPTIMIZATION OF DAYLIGHTING IN OFFICE BUILDING

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ABSTRACT: *It is quite impossible to get required natural illumination inside a building without rise of indoor temperature. In this study, the illumination level and thermal comfort inside a building was maintained by balancing the amount of solar radiation and indoor temperature. The daylighting was enhanced by means of opening the windows without any structural modification. The MATLAB-based modelling was carried out to predict the indoor temperature and formulated model was employed to determine the optimum number of daylighting hours by observing the level of indoor temperatures against ambient temperatures. It was found that the optimum hours of window openings were 665 hours/year in the examined building, which can save 1198 kWh/year per year. The predicted model results were verified using measured data of same area with similar environmental conditions.*

Keywords: Influence of windows, Annual outdoor temperature, Curve fitting tool using MATLAB, prediction of indoor temperature, optimum daylighting hours, energy saving.

1. INTRODUCTION

Throughout history, daylighting has been a primary source of lighting in buildings [1]. It was supplemented initially with burned fuels and in middle of 20thcentury with electrical energy. Since the last quarter of the 20thcentury and early years of this century, architects and designers have acknowledged the significance and value of introducing natural light into the buildings [2]. It is because the buildings are responsible for 20 to 40 percent of energy consumption in developed countries [3]. The daylighting is one of the potential areas to maximize visual comfort and to reduce energy use in the building structure [4-6]. Energy savings can be attained by reduction of electric (artificial) lighting or from passive solar heating or cooling [7]. The utilization of electric lighting can be reduced by application of natural daylighting for illumination purpose [8,9]. Energy can also be saved by dimming or switching-off electric lights automatically in response to the presence of daylighting [10]. Natural daylight harvesting provide various benefits to the occupants such as better health, reduced absenteeism, increased productivity, financial savings and less stress [11-14]. Besides benefits, it may also have some negative effects, if allowed to penetrate inside the building in extreme levels [15,16]. Unnecessary usage of daylighting can lead to unpleasant conditions to work within the structure, which can reduce productivity and increase employee absenteeism due to the possibility of extremely high lighting levels, excessive glare, and high temperatures [11,12]. Extreme daylighting may also result in undesirable heat gains, particularly in hot areas. Since, it is quite impossible to increase the amount of light without rise of indoor temperature [17,15]. Therefore, the utilization of daylighting is acceptable up to some extent without compromising the thermal comfort of the occupants [18-20]. Different techniques (such as, admitting daylight from more than one side of a space and controlling direct sunlight) can be used to maintain the acceptable level of indoor temperatures [21,22]. Window shadings and film glazing can also help to diffuse direct sunlight reaching inside of the building and to minimize heat gain [23,24]. Such treatments can reduce overall cooling loads, eliminating the need for a larger cooling system, resulting in additional overall savings [15]. But if the shading systems are fixed, then they can effectively control solar heat gain and reduce glare, however, they do not address variable sun angles. Therefore, they greatly diminish daylighting potentials [25,26]. The present study will focus on opening and closing behavior of windows having fixed overhang shades on daylighting and indoor temperature.

Many researches worked on different aspects of building structures of newly planned buildings. However, less literature is available for application of energy saving strategies of existed buildings without any alteration. This study focused on the optimization of daylighting in existing building without modification or alteration of its structure, shape and form, just by means of windows opening and closing in different time periods. The findings of this study could be helpful for possible saving of energy with little awareness of building occupiers by maintaining indoor temperature, illumination level and thermal comfort inside the building.

2. MATERIAL AND METHODS

Initially, the energy audit was conducted to determine the total electrical load and energy requirement of the building. The total electrical load of the selected building was calculated by observing the number and type of appliances with their power ratings. The energy requirement of the appliances was determined by computing their operating hours. A plan was made to minimize energy consumption of lighting appliances and to optimize the utilization of daylighting inside building without compromising the thermal comfort and illumination level. First, the outdoor temperature of study area from all selected locations of the building were recorded at an interval of one hour, during office hours from 0800 am to 0200 pm on a daily basis. Then, the level of daylighting illumination versus indoor temperature was determined with opening and closing of windows. Then, MATLAB Software was used to predict indoor temperature by developing the equation model for the relationship between indoor and outdoor temperature in selected location. The predicted temperature was compared with comfort temperature to determine optimum hours for daylighting utilization in different months of the year.

Subsequent, the model predicted results were then employed for determination of optimal daylighting hours. The optimization of daylighting was carried out by computing the time period of opening and closing of windows for the entire year. Finally, the energy savings were calculated by keeping the lighting, appliances switched off while exploiting daylighting through opening of windows without compromising on thermal comfort, illumination level and altering of windows structures.

3. EXPERIMENTAL PROGRAM

Two approaches were applied for determination of illumination level and indoor temperature of the laboratories and classrooms. In the first approach, all numbers of lighting appliances were switched on with closing all windows, whereas, in the second, all numbers of lighting appliances were switched off with opening all windows.

The building of Energy and Environment Engineering Department, Quaid-e-Awam University of Engineering, Science and Technology Nawabshah, Pakistan was selected for this study. Four classrooms of first floor and four laboratories in ground floor of the building were selected for optimization of indoor illumination level and thermal comfort of the building. There were six numbers of windows having overhang shades and six tube lights were in each four classrooms and same number of windows with 10 energy savers in each laboratories.

4. RESULTS AND DISCUSSION

The preliminary energy audit confirmed that lighting appliances consumes 16.1% of total electrical energy demand excluding air-conditioning load in the examined building. The total connected power requirement of the lighting appliances was 5891 W.

4.1 Outdoor Temperature of Study Area

Generally, indoor temperature depends on outdoor temperature. Once the outdoor (ambient air) temperature is known, the indoor temperature can be predicted and maintained as per requirements. The outdoor temperature of the area was in the range of 8^0C to 48 ^{0}C during office hours for the whole year. The hourly average monthly outdoor temperature for the year 2014 is shown in Fig. 1a and the trend of hourly outdoor temperature is given in Fig. 1b.

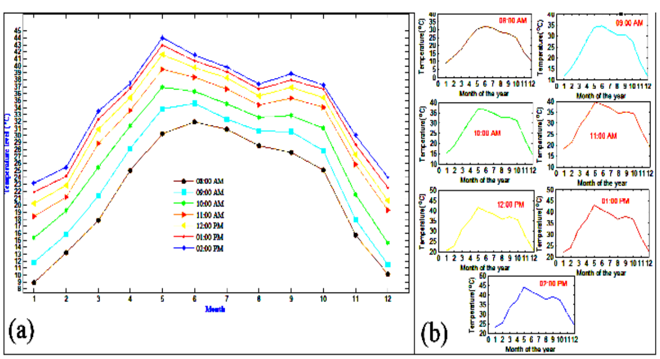

Figure 1: Hourly average monthly and trend of hourly values of outdoor temperature

4.2 Daylighting versus Indoor Temperature

The indoor temperature and illumination level was recorded by applying both approaches in the laboratories of the selected building. In first approach, the illumination was provided by installed energy savers with closing of all windows. The minimum level of illumination recorded was 102.7 lux while the maximum value was 116.5 lux as shown in Fig. 2a. In second approach, the natural illumination produced by opening of windows was utilized. The minimum level of illumination was 123 lux and maximum was 140 lux inside the laboratories. It was found that the increase of illumination level increased the indoor temperature up to 37^0C which becomes more than application of first approach with 32.7 ^{0}C as shown in Fig. 2b.

Similarly, both approaches on the classrooms were applied. In first approach, the values of indoor illumination and temperature levels were in the range of 211 to 224 lux with 29^0C to 33^0C respectively. In second approach with the application of daylighting, the indoor illumination level was between 229 and 242 lux, whereas, the temperature was 30.3^0C to 39.7^0C in the four classrooms when all the windows were opened as shown in Fig. 3a and Fig. 3b.

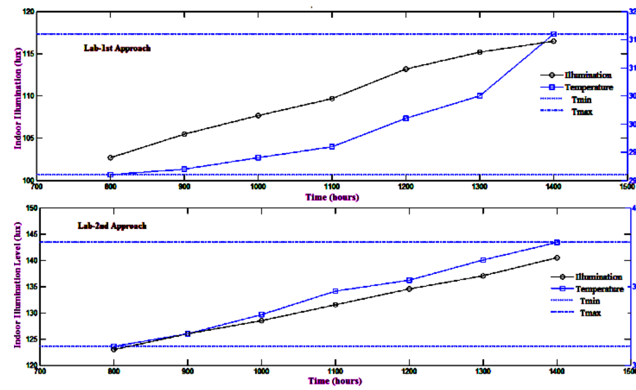

Figure 2: Illumination Level and Indoor Temperature of Laboratories with Closing and Opening of windows

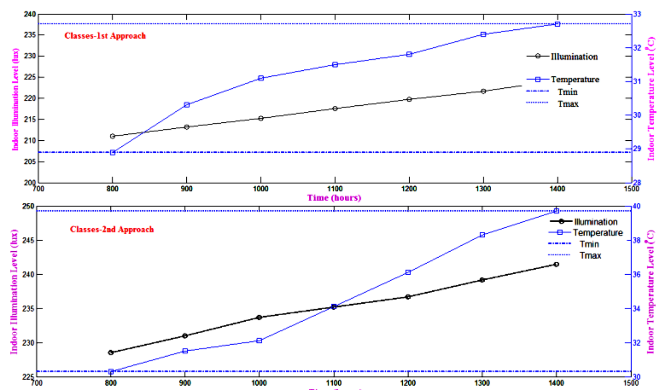

Figure 3: Illumination Level and Indoor Temperature of Classrooms with Closing and Opening of windows

4.3 Prediction of Indoor Temperature

Curve fitting tool in MATLAB was used to find the best fit between indoor temperature (I_T) and outdoor temperature (O_T). The data points were fitted by means of Gaussian line curve as shown in Eq. (1). The best fit was chosen to develop the model. To implement this model, first the relationship between Indoor and Outdoor Temperature was derived. This is obtained by plotting the scatter diagram between both the parameters. Based on the developed relationship indoor temperature was predicted to determine the optimum hours of daylighting to save energy as well as to keep indoor thermal comfort. As shown in Fig. 4, the line marked with square is the measured values and with circle are the model predicted values with 95% confidence intervals. It was revealed from the study that if the outdoor temperature was in the range of 22^0C to 30^0C, the indoor temperature level inside the building will be 20^0C to 28^0C respectively.

$I_T = 44.51 * \exp(-((O_T-58.54)/ 41.77)^{\wedge}2)$ **Eq. (1)**

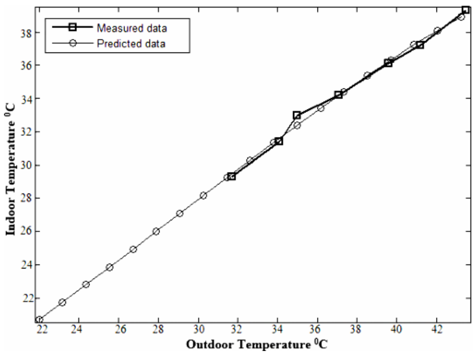

Figure 4: Predicted indoor temperature based on outdoor temperature

4.4 Determination of optimal daylighting hours

Since the selected locations have overhang shades fixed in all windows, the level of temperature was not within permissible limit during both the approaches. If selected locations had dynamic window shades then indoor temperature could have maintained. To maintain thermal comfort in building having fixed window overhang shades, the daylighting was optimized with the help of predicted indoor temperature values of model results. Meanwhile the ambient temperature varies throughout the year. The optimal daylighting hours for all months of year were analyzed to utilize natural illumination while maintaining the thermal comfort inside the building. According to the findings windows should not be opened throughout the year and should be opened until the indoor temperature is comfortable which may be achieved if windows are opened when Outdoor temperature is on the range of 22^0C to 30^0C. Furthermore, the time period of windows opening is different for different months of the year. Fig. 5 shows the optimal daylighting hours for different months which totaling the 665 hours in an entire year.

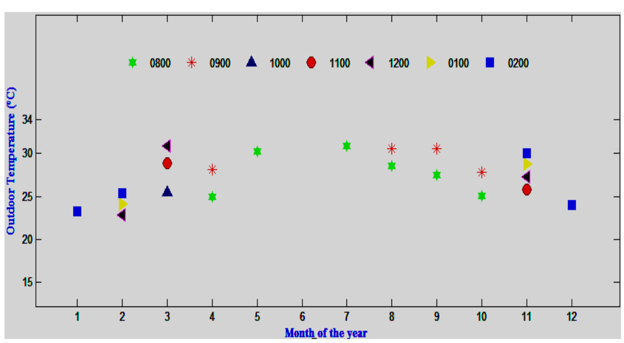

Figure 5: Optimum daylighting saving hours for all months of year

4.5 Energy Saving from lighting appliances

The energy saving was calculated by switching off the lighting appliances in the selected positions of the building without using any technology and alteration in building structure. The total load of lighting appliances in four classes and four laboratories were 960 W and 920 W receptively. These lighting appliances were consuming 4738kWh electricity per year. It was found that energy consumption can be reduced up to 3540 kWh by switching off the lighting appliances and opening of windows. It was found that the optimization of daylighting in the building can save 1198 kWh of electricity per year as shown Fig. 6. The results revealed that the maximum saving will be in months of November and March, and the minimum will be in the months of January, May, July and December, whereas, no electricity can be saved in the month of June, because of extreme ambient temperature conditions in the study area.

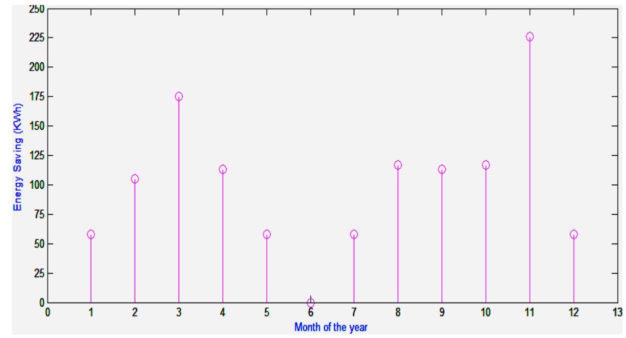

Figure 6: Monthly energy saving from lighting appliances in the building

4.6 Verification of Formulated Model

The model Eq. (1) was formulated based on the measured indoor temperature data of June, 2014 for prediction of indoor temperature of any day of the year to maintain thermal comfort inside any building. The formulated model equation requires only the input of outdoor temperature data. Therefore, the required outdoor temperature from January 2014 to September 2015 was acquired for input of formulated model. The indoor temperature of September 2015 is estimated as well as measured to verify the formulated model results. The model predicted that the daylighting utilization will be feasible only for two hours from 08:00 AM to 10:00 AM in the month of September. The actuals results also showed the utilization of two hours in month of September with ±10 minutes as shown in Fig. 7. The model results were found to be acceptable for prediction of indoor temperature and maintenance of thermal comfort inside the building.

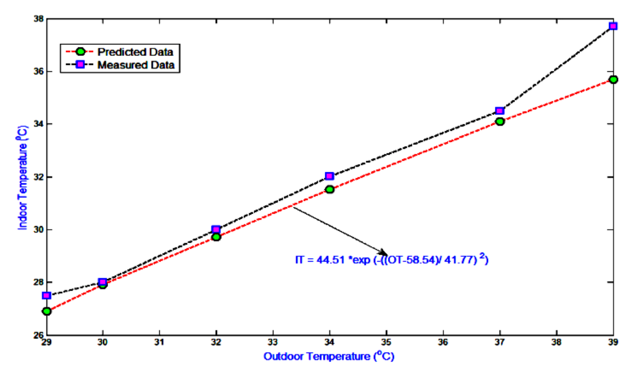

Figure 7: Comparison between predicted model and actual measured result for September, 2015

5 CONCLUSIONS

The necessary illumination level and thermal comfort inside a building was maintained by regulating the amount of solar radiation and ambient temperature through application of a traditional approach. The daylighting was enhanced by means of opening and closing of windows without any structural modification. The measured data was used to formulate a model using recorded data of ambient air temperature to predict the level of indoor temperature for maintaining illumination level and thermal comfort inside the building. Two approaches were examined. In the first approach, all numbers of lighting appliances were switched on with closing of all windows, whereas, in the second, all numbers of lighting appliances were switched off with of opening all windows. It was found that the penetration of solar radiation increases the illumination level inside the building as well as indoor temperature proportionally. If the outdoor temperature was in the range of 22^0C to 30^0C, the indoor temperature level was estimated to be 20^0C to 28^0C. The study confirmed that 1198 kWh/year electricity can be saved by keeping the windows of examined building open for 665 hours. The maximum saving could be made in the months of November and March, whereas, the minimum in the months of January, May, July and December. Since, no electricity could be saved in the month of June, because of extreme ambient temperature conditions in the study area.

ACKNOWLEDGEMENT

The authors acknowledge the support provided by authorities of Quaid-e-Awam University of Engineering, Science and Technology Nawabshah for conducting research in the building of Energy and Environment Engineering Department.

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