EnvironMoores: Efficient NoVel Intelligent Reliable OccupatioN Monitoring for IndOor light-comfORt adaptivE System

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***Abstract*—Comfort, a state of mind expressing satisfactory adaptation with the immediate environment, is always of prime concern in the design process of buildings. Initially, the prime focus is on meeting the needs of lighting, heating, ventilation,and air-conditioning. In recent years, due to growing low-cost sensing solutions, the provision of both lighting and thermal comfort has been widely increased to existing and future smart buildings to aid productivity, health,and wellbeing. However, the current sensing solutions seriously lack real-time intelligent monitoring and thus adaptively control lightning and thermal systems of smart buildings and most of the existing systems only consider quantitative variables. Therefore, this paper aims to develop a novel solution based on the fusion of wireless lux sensors and intensity adjustable lights to monitor and yield uniform light in real-time and thus aiding comfort. This paper presents the pilot study simulation results of the proposed system. The simulation clearly shows the improvements of comfort and strong potential of implementing this in practice.**

Keywords—Lightningcomfort,Lumen Method,DIALux, Room light levels, Adaptive lightning

I. Introduction

Modern houses and buildings are primarily focused on improving comfort for both lighting levels and thermal conditioning. Lighting comfort focuses on providing uniform lightning in a room with anadequate amount of its levels, normally measured in lumens [1]. Traditionally, lightning systems are designed using Lumen or Cosine method in uniform geometry and the selected lamps have fixed intensity [2]. Normally, these lamps are not individually controlled in association with the normal daylight coming from windows. The result is non-uniform intensity and color rendering of light in a room. This gives a lot of discomforts, especially to aged or disables people. Also, normally people spend a large portion of their daily lifetime indoors when compared with the outdoor environment [3]. Thus, comfort monitoring is of prime concern in the design process of buildings.

The term comfort refers to a state of mind expressing satisfactory adaptation with the immediate environment [4]. Itis a subjective parameter and depends upon the individual. Therefore, it is very difficult to develop a fixed system which can provide comfort to all people. This highlights the importance of comfort monitoring for both lightning and thermal. Therefore, this project focuses on developing a novel comfort monitoring and regulatory system, which can monitor and adaptively regulate the lightning and heating levels quickly to closely meet the needs of the individual. A pilot stage of the proposed system is implemented using simulation studies in Revit and DIALux and the results obtained for lightning level comfort are discussed in this paper.

II. Comfort Monitoring

Comfort monitoring in homes is usually researched by the field of the built environment. This field initially gained attention in the early 1920s, when the evidence of mechanical controllers made it possible to partially controlthe climate of the indoor environment. In early days, the heating is provided using the fireplaces or stoves; and, standard tungsten bulbs are used to provide lightning. However, in the second half of the twentieth century, various electromechanical and electronic controllers were developed which along with the laws of thermodynamics and Lumen method helps to initiate the design of thermal and lightning systems in a more controlled way, andthus leads to the evolution of comfort monitoring. For example, theFanger's comfort model based on the approach of physically based determinism results inadaptive comfort modeling. The quality of air movement and sophisticated models which map both physics and physiology of the human body were also developed to build the coherent, global thermal perception. These developmentsarealso driven by energy efficiency[5][6]. Another important driver is the impact of global climate change [7][8][9].

Recently, the focus is on developing adaptive control systems which can interact with human behavior and control comfort (both lightning and thermal) of their surroundings [10]. This can be done in both simulations and practice due to the evidence of recent low-cost sensing solutions [11][12][13]. Various adaptive control algorithms can be developed. However, most of the existing algorithms only consider quantitative variables (e.g. temperature and relative humidity), whilst qualitative variables (e.g. metabolic activity and clothing) are not considered [14][15][16]. The current sensing solutions also lack real-time monitoring. Therefore, this project focuses on developing a novel solution based on the fusion of wireless sensors and controllers to adaptively control lightning and thermal temperature in real-time. The number of sensors depends upon the size and characteristics of the building. A large number of sensors may result in Big Data. These sensors are connected using the internet of things for ease of collection of information and its processing. This paper currently presents the simulation model and has a few limitations due to the software. However, the work is in progress for developing the physical system which will collect both environmental and human interpersonal data (e.g. metabolic rate, age,health condition,and clothing level index of occupants). The overall goal is to provide uniform lightning and temperature in a living space (e.g. room). The proposed system is mentioned below.

III. Light Designing

The proposed system based on Lumen method is shown in Figure 1. The system uses the standard Lumen method to design the required lightning of living spaces. In the proposed system, the standard light sources (e.g. bulb) are replaced by controlled dimmable lights (e.g. dimmable LED[17]). These lights are used because their intensity can be controlled electronically. Each luminaire is fitted with a light lux sensor to measure the lux levels it produces at the workbench level.

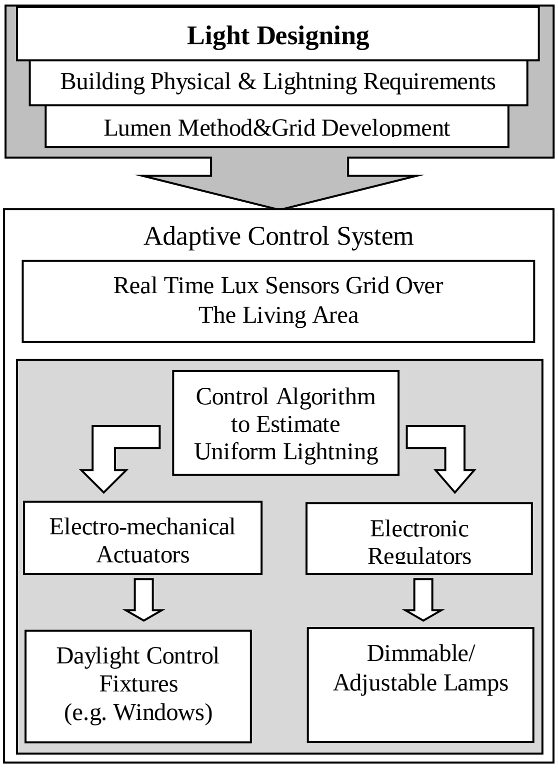

Fig. 1. Proposed system design diagram

A grid of light sensors is also connected at physical fixtures (e.g. windows) to measure the natural light. The lux level data is used to control the electronics of dimmable light sources and the actuators of windows to maintain uniform levels of light. A weighing matrix-based algorithm is used to maintain light levels. In this algorithm, there are three matrices (S, W, C). Matrix S represents the sensor data. W represents the weighting matrix and C represents the controlled matrix, which is obtained from uniform lux requirements of the living space. Each element (say i, j) of weighing matrix (W) is computed as follows:

$$E_{W(i,j)} = C_{W(i,j)} - S_{W(i,j)} \quad (1)$$

This value of $E_{W(i,j)}$ gives the value of step size to change the intensity of dimmable light sources using perturbations in the followingcycle. The error is also computed at each cycle and is used as a correction factor for the successor cycle. In the standard perturbation based adaptive algorithms, the step size is normally constant. However, in this approach the step size varies for each dimmable light source, which helps to control the system more efficiently, resulting in uniform light. The other benefit of this approach is that the step size can also be linked with the human interpersonal data (e.g. metabolic rate and age). For color rendering, the standard RGB color model is used. The same perturbation based algorithm is used for each color (R,G,B), aiming for uniform color rendering.However, the color rendering of light is not reported in this paper.

The lightning systemis designed using Lumen method, in which the number of lamps required to illuminate the spaceis computed as:

$$N = \frac{E*A}{n*F*UF*LLF} \quad (2)$$

where,

N = The number of lamps required
E = Required illuminance (Lux level required on a working plane)
A = Area of room to be lit (m^2)
n = the number of lamps in every luminaire
F =Total lumens output per lamp
UF=Utilization factor which is the function of the luminaire properties and room geometry (can be accessed from the luminaire table to be used)
LLF/MF = Light Loss Factor/ Maintenance Factor; which is the function of the depreciation over time of lamp output, ballast factor, dirt accumulation on the fitting and the room surface (walls and ceiling) of the building

The utilization factor is the factor which measures the effectiveness of the lighting plan. It is the amount of luminous flux given off by the lamps that reach the working plane.Maintenance factortakes into account ofthe loss of light from the output of the lamp due to the collection of dirt, dust, room surfaces and aging of the lamp. It varies with time and comprises of four factors: lamp lumen maintenance factor, lamp survival factor, luminaire maintenance factor and the room surface maintenance factor.In order to get the utilization factor from the lamp table, the room index is first computed using:

$$Room\ Index = \frac{(L*W)}{H_m(L+W)} \quad (3)$$

where

Room index = The number representing the ratio of the rooms length, width,and height.
L = room length
W = room width
H_m = mounting height of luminaire above working plane

Using the above Lumen method, the number of lamps per space is computed and is then arranged in the mesh grid. A lux sensor and light intensity controller is connected to each lamp. The lux sensor measures the light and then feeds it to the controller which adjusts the intensity of the lamp to provide a uniform intensity in the space.

IV. Lightning System Implementation And Discussions

In order to simplify the development process, the designed model is implemented through simulations using DIALuxEvo 8.1 software environment for ease of verification of the control algorithm, prior to its implementation in practice. The simulations are implemented for the proposed lighting model for a standard room with a double bed, study desk and chair. The room has three standard windows opening to free space and a door opening in the inner of a building.Using the Lumen method, 4 number of dimmable LED luminance is computed to illuminate this room. The intensity of each lamp can be controlled individually to achieve lighting comfort. Numerous lighting scenarios can be generated; however, these are divided into the following three categories for ease of understanding. The details of the simulation parameters are given in Table 1 below.

Table 1. Simulation Parameters and Values

Simulation Parameters	Values
Room Size	12.7m^2(4.7m x 2.7m)
Ceiling Reflectance	75%
Wall Reflectance	50%
Floor Reflectance	20%
Maintenance factor	0.80
Clearance Height	2.6 m
Workplane Height	0.76m
Window size (each)	0.83 m^2 (0.91m x 0.91 m)
Desk	1.53 m x 0.76 m
Luminaire type	Thorn Lighting Dimmable POPPACK LED 5000-840, max output 5100 lm x 4
Target Lighting	≥ 300 lux [18][19]
Site Location	London, U.K., 51.51°N 0.13°W

1. Case I: Natural sunlight

Numerous scenarios of natural sunlight coming through three windows can be generated. However, for ease of illustration, an example is shown in Figure 2; where the Sun is in almost equidistant from three windows. Its corresponding uneven luminance pattern can be seen in Figure 3. The pattern clearly shows uneven lightning. This also means that human in any position in this room will perceive different parts of space covering this room differently; resulting in discomfort. The intensity of this discomfort will vary with the individual.

2. Case II: Natural sunlight and artificial fixed light

In this case, the model is expanded to be able to represent the room with artificial lighting. An example of the model using just the artificial lighting can be seen in Figure 4. There is no natural light as it represents the nighttime or the situations when the window curtains or blinds are completely closed. This lighting arrangement produces even lighting condition which gives lighting comfort. The evenly distributed luminance pattern can be seen in Figure 5. However, this lighting system produces uneven lighting condition when combined with the presence of the sunlight. The simulation results and corresponding pattern can be respectively seen in Figures 6 and 7. This also means that the traditional system gives compensation by adding the window curtains or blinds to get the even lighting condition, as previously shown in Figures 4 and 5. This approach will also lead to inefficient energy usage.

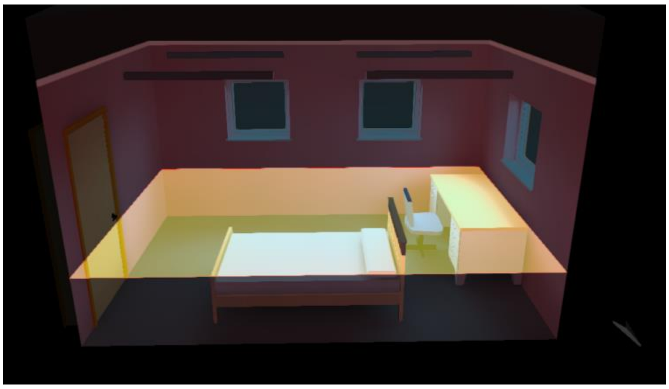

Fig. 2. Model of the ambient sunlight light simulation in DIALuxEvo 8.1

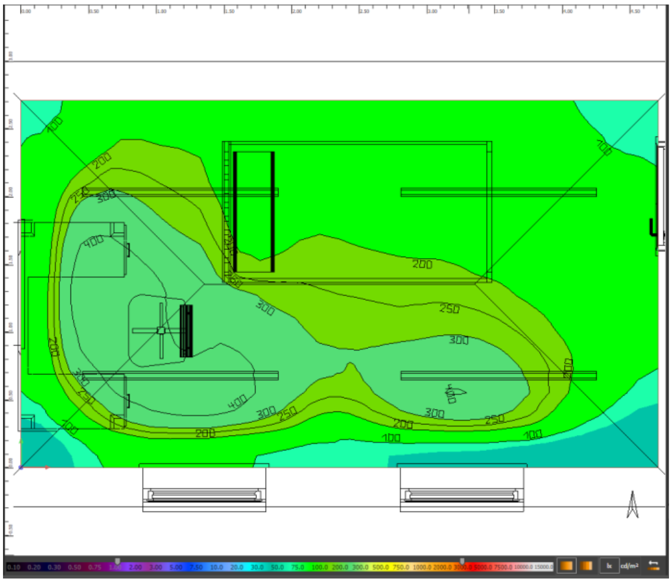

Fig. 3.The corresponding uneven pattern of the ambient sunlight light simulation in DIALuxEvo 8.1.

Fig. 4. Model of an artificial lighting simulation with no sunlight.

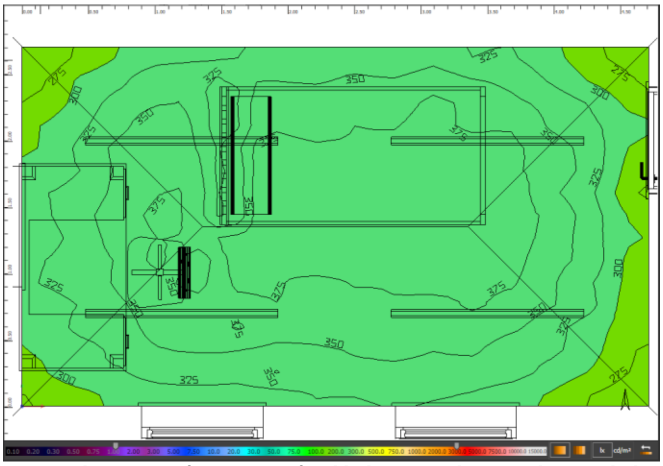

Fig. 5. The pattern of an even artificial lighting simulation with no sunlight

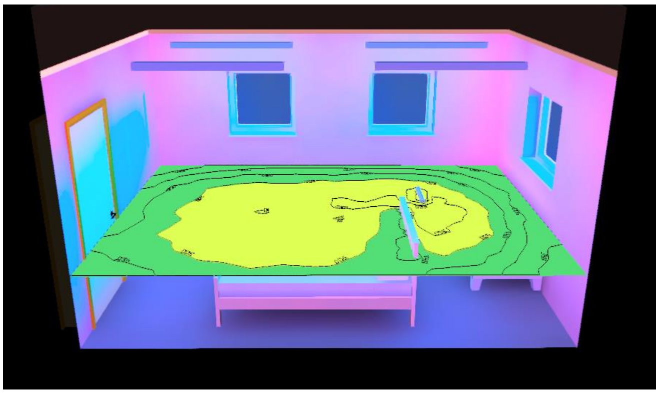

Fig. 6. Model of the traditional lighting system which combine sunlight and artificial light.

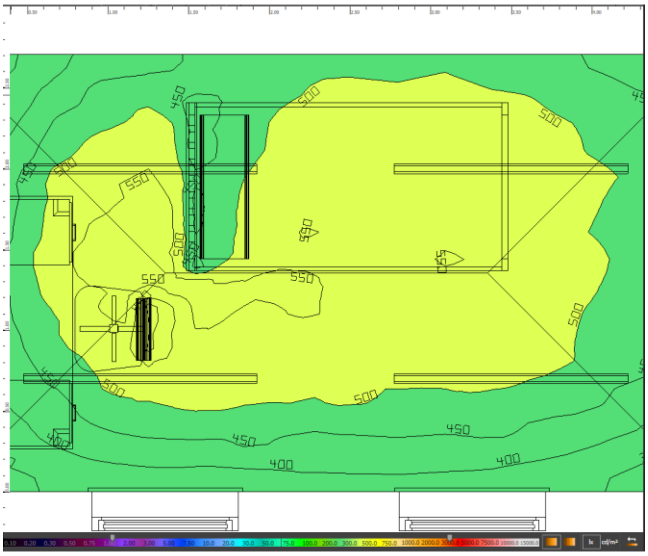

Fig. 7.The uneven pattern of the traditional lighting system which combinesunlight and artificial light.

Case III: Natural sunlight and artificial dimmable light

In Figures 6 and 7, the sunlight cannot be used optimally to conserve energy. The solution can be achieved by using the proposed smart independent controllable dimmable LED system which can give correct compensation for the uneven lighting conditions along with the use of window curtains or blinds automatic controller. The system automatically adjusts the intensity of the light produced by the bulb or LEDs. Numerous cases can be simulated depending upon the intensity and pattern of the natural light coming from the window. An example of the simulation results of this lighting system can be seen in Figures 8 and 9. With the individual smart controlled luminaire, the pattern of light is adjusted according to the ambient light and still produce even lighting pattern. The ambient light can be used optimally and the use of energy can be minimized while still maintaining the human comfort factor.

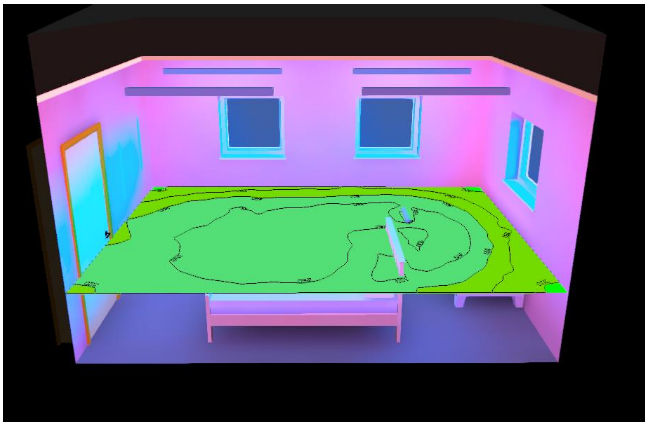

Fig. 8.Model of the smart independent controlling dimmable LED system which combinesunlight and artificial light.

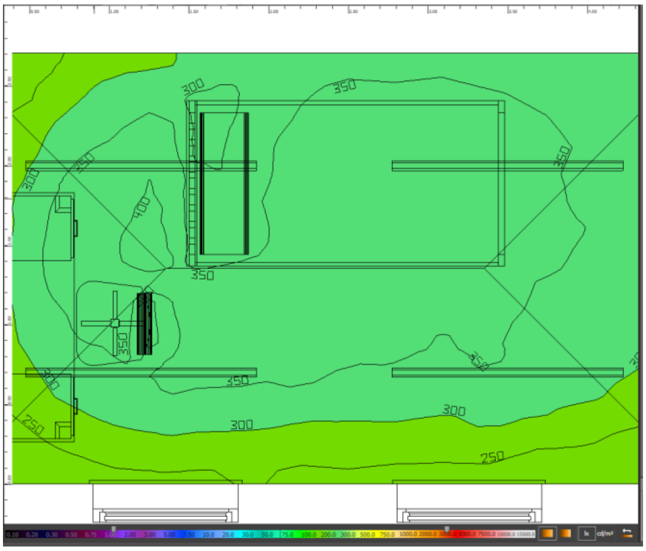

Fig. 9.The balanced pattern of the smart independent controlling dimmable LED system.

V. CONCLUSION

This paper developed a novel solution based on the fusion of wireless lux sensors and dimmable lights to monitor and maintain uniform light indoors in real-time. Several cases were considered and analyzed to understand the performance of the simulated system and the same is found satisfactory.This system can be extended to big structures. However, because of the large number of lights in big structures and sensors, it may result inBig Data. Further work is in progress to analyze this Big Data. The sensing system will be further enhanced to collect both environmental and human interpersonal data. The data will also focus on age and health (disability) condition of occupants.

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