Abstract—Lighting control systems deliver the correct amount of light at the right time and right place. Lights can automatically turn on, off or dim at set times or under set conditions. Facilities managers can make changes to lighting when appropriate or to meet financial incentives, and users can have control over their own lighting levels to provide optimal working conditions. Lighting control helps to reduce costs and conserve energy by turning off (or dimming) lights when they are not required. Energy savings resulting from daylight harvesting mean not only low electric lighting and reduced peak electrical demands, but also reduction in the load on the air conditioner. On the other hand thermal and visual comforts play a very important role regarding the satisfaction of occupants with their working environments. The most effective method to achieve thermal comfort in offices is to reduce cooling loads in order to avoid additional energy-consuming devices for cooling. Most daylight responsive lighting control systems save energy by reducing lamps output in proportion to the amount of available daylight while maintaining a given illuminance level on the working plane. In this paper, variation of room illuminance with daylight along with variation in room temperature is studied. It is proposed to reduce the total electrical load in a general office.

Index Terms—energy conservation, lighting controls, thermal comfort, visual comfort

I. INTRODUCTION

Energy efficiency has proved to be a cost-effective strategy for building economies without necessarily growing energy consumption. There are abundant opportunities to save 70% to 90% of the energy and cost for lighting, fan, and pump systems. Heating, ventilation and air-conditioning systems (HVAC) represent an important share of the electricity consumption (about 30%) in a building. This implies that important energy and economic savings can be achieved by improving the efficiency in these systems, and therefore a substantial reduction in the environmental impacts can be also achieved. Nowadays, due to the requirements for the indoor air quality, the visual and thermal comfort levels have been increased. For the building domain, there is still a need for developing optimal control strategies for rapid response of HVAC and lighting systems of buildings to achieve the desired comfort (including its effect on satisfaction and productivity) while minimizing energy consumption and cost. Efficient control for HVAC is the most cost effective way to minimize the use of energy in buildings[1].

The comfortable environment is the ideal life state which the people have pursued. The level of thermal comfort depends on both the environmental-dependent variables and personal-dependent variables. The environmental-dependent variables which contain air temperature, relative humidity, relative air velocity and mean radiant temperature, and the personal-dependent variables contain activity level and clothing[2].

Apart the behavior of human occupants, the lighting controls play a key role in this action. Lighting controls provide building operators with the means to manage the way lighting energy is used in buildings more efficiently. These systems use various control strategies to (i) reduce wasted hours of lighting in unoccupied spaces, (ii) automatically adjust electric light levels in synchrony with available daylight or age-related changes in luminaire output (iii) selectively shed lighting loads to moderate peak demand. Lighting control systems have been installed in a number of buildings worldwide and have been shown significant energy savings when the controls have been properly designed, specified, installed, commissioned and maintained [3].

Lighting Controls are also used as part of a high quality energy efficient lighting system that integrates daylight and electric light sources to provide a comfortable and visually interesting environment for the occupants of a space. Electric lighting controls are appropriate for a wide variety of spaces, from restrooms to large open offices, from conference rooms to classrooms. They can be incorporated with daylight to provide flexibility, energy savings, and ecological benefits. Although lighting controls are still most commonly used in commercial buildings, they are also increasingly being used in residential applications.

When electric lighting controls are used properly, energy will be saved and the life of lamps and ballasts can be extended. Lighting controls will help reduce energy by:

- Reducing the amount of power used during the peak demand period by automatically dimming lights or turning them off when they are not needed.
• Reducing internal heat gains by cutting down the use of lighting, which allows the reduction in HVAC system size and a reduction in the cooling needs of the building.
• Allowing occupants to use controls to lower light levels and save energy

Lighting controls are cost-effective, especially when one considers long-term life-cycle costs along with initial costs[4].

Thermal and visual comforts play a very important role regarding the satisfaction of occupants with their working environments. The most effective method to achieve thermal comfort in offices is to reduce cooling loads in order to avoid additional energy-consuming devices for cooling[5].

II. DAYLIGHT HARVESTING

Daylight harvesting, is the term used for a control system that reduces the use of artificial lighting with electric lamps in building interiors when natural daylight is available, in order to reduce energy consumption. All daylight harvesting systems use a light level sensor, a photo sensor, to detect the prevailing light level, luminance or brightness, in open-loop or closed-loop systems. Photo sensors are used to integrate an electric lighting system with a day lighting system so lights operate only when day lighting is insufficient. The signal from the photo sensor is interpreted by a lighting control system module, an automated light switching device, in the electric lighting system which can reduce the electric lighting, by shutting off or dimming fixtures as appropriate.

Daylight Harvesting = Intelligent Energy Saving Dimming

The basic concept of Daylight Harvesting is really simple: When sufficient daylight is available, the artificial light automatically dims to the appropriate level. The possible savings in a professional installation are impressive[6] – [8].

Several studies have recorded the energy savings due to daylight harvesting.

A. Guillemín et. al, has developed a lighting controller. Both artificial and natural lighting controllers have been designed in order to get the integrated approach for the desired illumination level. The shading device controller is split into two parts depending on the user presence. When the user is present, priority is given to visual comfort, and when he is absent, priority is given to thermal aspects (heating/cooling energy saving). The artificial lighting controller is used to complete the illumination in the room up to the level desired by the user, which is learned by the system through the user wishes[9].

To explore the potential of computational modeling applied to building operation phase, Ardeshr Mahdavi, (a) described the model-based building systems control idea, (b) reported on a prototypical implementation of a model-based lighting control strategy for visual comfort performance indicators only [10].

In order to improve the user acceptance of an automatic shading-device controller, user wishes concerning the blind position are learned and integrated in the automatic controller through an innovative adaptation system developed with the use of genetic algorithms (GA) by A. Guillemín et.al.[11].

Determination of the energy saving by daylight responsive lighting control systems by Sermin Onayg et.al, aims to find out how much energy can be saved by using a daylight responsive lighting control system in comparison with a conventional lighting system by evaluating the collected data during one-year[12].

A novel illumination model for distributed LED luminary control is presented by Sachin Bhardwaj et.al. A prototype system is designed and implemented using several LED luminaries and light sensors. Experiments carried out on the reading space use case show that the desired illumination can be achieved based on user preferences, irrespective of the existence of external light sources [13].

The application of fuzzy logic control technique to improve the energy efficiency of a dimmer light balance implemented in passive optical fiber day lighting system is demonstrated. Measurements of intensity and occupancy in a room are used by the fuzzy system to control both parameters in order to attain a constant level in the illuminance in the room[14].

III. THERMAL COMFORT

Almost half of the total energy produced in the developed world is inefficiently used to heat, cool, ventilate and control humidity in buildings, to meet the increasingly high thermal comfort levels demanded by occupants. The utilization of advanced materials and passive technologies in buildings would substantially reduce the energy demand and improve the environmental impact and carbon footprint of building stock worldwide. Materials for energy efficiency and thermal comfort in buildings critically review the advanced building materials applicable for improving the built environment. [15].

Buildings are currently designed to achieve comfort by creating static, uniform interior environments. In reality we know that neither indoor environments nor building occupants are static, and that the thermal environment experienced by an occupant in a building is often quite complex. In addition, new approaches to building conditioning require an advanced understanding of how occupants respond to thermal sensations in indoor environments. By better understanding occupant comfort in buildings, the building industry may increase revenues for building owners and tenants through improved employee health, satisfaction, and productivity[16].

Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment. There are large variations, both physiologically and psychologically, from person to person, which makes it difficult to satisfy everybody in a space. The environmental conditions required for comfort are not the same for everyone.

There are six primary factors that must be addressed when defining conditions for thermal comfort. A number of other, secondary factors affect comfort in some circumstances. The six primary factors are listed below.

• Metabolic rate.
• Clothing insulation.
• Air temperature.
• Radiant temperature
• Air speed.
• Humidity.

All six of these factors may vary with time. However, this standard only addresses thermal comfort in steady state. People who have prior exposure to different environmental conditions and/or activity levels may not find the conditions allowed in this standard comfortable upon entry to the space.
The effect of prior exposure or activity may affect comfort perceptions for approximately one hour [17].

To have "thermal comfort" means that a person wearing a normal amount of clothing feels neither too cold nor too warm. Thermal comfort is important both for one's well-being and for productivity. It can be achieved only when the air temperature, humidity and air movement are within the specified range often referred to as the "comfort zone".

Where air movement is virtually absent and when relative humidity can be kept at about 50%, the ambient temperature becomes the most critical factor for maintaining thermal comfort indoors. However, temperature preferences vary greatly among individuals and there is no one temperature that can satisfy everyone. Nevertheless, an office which is too warm makes its occupants feel tired; on the other hand, one that is too cold causes the occupants' attention to drift, making them restless and easily distracted [18].

Maintaining constant thermal conditions in the offices is important. Even minor deviation from comfort may be stressful and affect performance and safety. Workers already under stress are less tolerant of uncomfortable conditions.

An evaluation performed by using the EMCS (Energy Management and Control System) of different control strategies for HVAC split systems is presented by Guillermo Escrivá-Escrivá et.al. It analyzes the effect of different schedules for a common air-conditioning device and demand response strategies are tested in several situations [19].

An intelligent monitor and control of various facilities within the building so as to offer its users or occupants with effective security, improved productivity, human comfort, and efficient energy management is proposed by Yifei Chen et.al. Heat, Ventilation and Air Conditioning (HVAC), Lighting Systems, Life and Safety System, and Access Control are some of the typical systems that formed IBAS (Intelligent Building Automation System) in most modern building. HVAC and Lighting systems constitute the major energy consumer in an entire building that focuses particularly on the improvement of monitor and control of these Systems [20].

The connection between indoor thermal comfort conditions and energy demand for both heating and cooling has been analyzed by Stefano Paolo Corgnati et.al. with reference to a set of validation tests (office buildings) derived from a European draft standard [21]. Once a range of required acceptable indoor operative temperatures had been fixed in accordance with Fanger’s theory (e.g. $-0.5 < \text{PMV} < 0.5$), the effective hourly comfort conditions and the energy consumptions were estimated through dynamic simulations. The same approach was then used to quantify the energy demand when the range of acceptable indoor operative temperatures was fixed in accordance with de Dear’s adaptive comfort theory.

The adaptive coupling between computational codes for indoor thermal comfort analysis considering different levels of detail in space and time is addressed by Christoph van Treeck et.al.[22]. Influence of the coupling between day lighting and artificial lighting on thermal loads in office buildings as proposed by Christelle Franzetti et.al. deals with the foreseen energy balance of an office building with regards to the technological and architectural solutions. This work illustrates the importance of taking into account the interaction between lighting and HVAC system [23].

Fuzzy control system for thermal and visual comfort in building deals with dynamically controlled thermal and illumination responses of built environment in real-time conditions [24]. The aim of Ziva Kristl et.al is to harmonize thermal and optical behavior of a building by coordinating energy flows that pass through the transparent part of the envelope. The control algorithm for the thermal and optical process in the test chamber contained two basic control loops for thermal and for lighting regulation with the roller blind positioning. It had also two additional control loops for managing the heater and the ventilator in the framework of thermal control. The illumination control loop was given higher priority, since daylight has higher functional value. The roller blind position was managed by the illumination loop until the desired internal illumination level was achieved, then the thermal loop took over and optimized the indoor temperature. Thermal loop influences the position of the roller blind only within the limits of the admissible internal set-point illumination tolerance. This tolerance represents the acceptable "error" between the reference set-point profile and the measured internal illumination. The "error" is defined as deviation from the set-point illumination in percentages.

From the literature survey it is observed that

- Integration of thermal and visual comfort in an interior with due consideration of reduction on the air conditioner load has not been explored so far.
- The energy saving obtained from the above integrated approach is an area which has not been touched upon.
- Allowing optimum amount of daylight based on thermal and visual comfort demands of the occupant, is one area where further investigations may be carried out.

To address the above mentioned issues, the following scheme is proposed.

IV. PROPOSED SCHEME

In this scheme it is proposed to develop an Adaptive controller for thermal and visual comfort. This controller is based on daylight harvesting. The optimum amount of daylight is allowed inside the office, by controlling the blinds. The amount of daylight allowed not only takes care of visual comfort, but also minimizes the load on the air conditioner. The Energy saving achieved from the proposed method will be calculated, considering both lighting as well as air conditioner load. The block diagram of the proposed work is shown in Fig. 1.

![Figure 1. Block diagram.](image)

V. ANALYSIS

A. Experimental Analysis

For daylight and temperature analysis, a room with a west faced window is considered. The analysis was done on a
complete sunny day. The blinds were kept completely open. The readings of illuminance and temperature for every half an hour were recorded.

Fig. 2 shows the graph of time of the day versus temperature and illuminance. From the graph it is observed that as the illuminance value increases, the temperature also goes on increasing, which in turn will cause excessive heat in the room. The internal heat can be reduced by positioning the blinds using controller to optimal. By adjusting the blinds, the daylight entering the room reduces which affects the set point illuminance. Therefore, there is a scope for lighting control strategy to be adopted to achieve both visual and thermal comfort in an interior.

The readings for different blind positions and different seasons are to be taken for 1 year. The relationships between temperature and illuminance have to be analyzed for different blind positions and suitable measures have to be taken.

The comfortable environment is the ideal life state which depends on both the environmental-dependent variables and personal-dependent variables.

Apart the behavior of human occupants, the lighting controls play a key role in this action. Lighting controls provide building operators with the means to manage the way lighting energy is used in buildings more efficiently.

The potential for energy saving without sacrificing the comfort is huge. Continued increase in energy usage and competitive pressure for cost reduction has forced industries to look for novel ways to reduce overhead expenses.

Energy savings resulting from day lighting mean not only low electric lighting and reduced peak electrical demands, but also reduced cooling loads and potential for smaller heating, ventilating and air-conditioning (HVAC) plants.

ACKNOWLEDGMENT

We would like to thank Dr. RadhaKrishna S. Aithal, Professor in Electrical and Electronics Engineering Department, MIT Manipal, India, for his immense guidance throughout the study.

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