Enhancing and Designing of Energy Efficient Lighting System in Existing Buildings: A Fundamental Approach

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Abstract – It has become gradually more important to improve the energy efficient lighting system of building operation. Toward the end, competent daylight-responsive systems for illumination of buildings including installation of automatic lighting control systems can provide a considerable contribution. This research aims to define a new methodology for the design of lighting systems in the existing buildings. The experimental phase, focused on a specific study, is based on the evaluation between the energy consumption for the lighting control in the actual situation without control system and one designed with automation systems. A fundamental analysis of the state of the art about sustainability and voluntary protocols, modernization in field of energy saving, lighting automation systems, visual comfort, illumination and vision has been developed. Innovative design tools for lighting systems have been elaborated: specifically, the methodological approach for the energy efficiency evaluation which includes design methodology, software tool outputs evaluation methodology, data analysis method and the application for technological system choice of multiple criteria decision analysis; the development of specific model sheets to monitor and analyze visual comfort conditions.

Index Terms – Efficient Lighting System, Illumination, Design methodology.

1. INTRODUCTION

Climate changes are one of the main challenges that our society will face in the incoming years. An early definition of sustainable development was formulated in 1987 by the World Commission on Environment and Development. After twenty years, the importance of environmental issues has become a key aspect of political and scientific debates around the world.

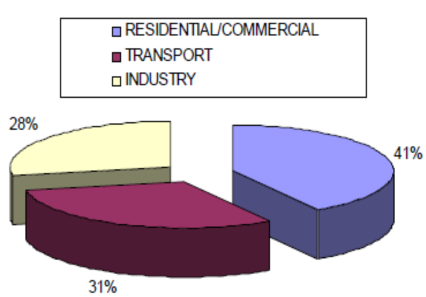

Fig. 1 Proportion of Energy consumption around the world.

Given concerns regarding global warming, the urgency of reducing CO_2 emissions is growing. Thereby the built environment plays an important role: the residential and commercial sectors account for more than 41% of end energy consumption and are thus responsible for an important part of carbon dioxide emissions systems [UNEP, 2007].

Lighting has a substantial impact on the environment recent studies carried out for the European Commission have shown that between 31% and 51% of electricity used for lighting could be saved investing in energy-efficient lighting systems. In most cases, such investments are not only gainful but they also maintain or improve lighting quality. [2]. The world programmatic actions activated to prevent environmental catastrophes and the declarations to apply solutions for a sustainable development have been presented in numerous recent international conferences [e.g. International Conference Sustainable Building 2006-2007 and 5° meeting "EPBD Concerted Actions", Budapest, 8-9 May 2006].

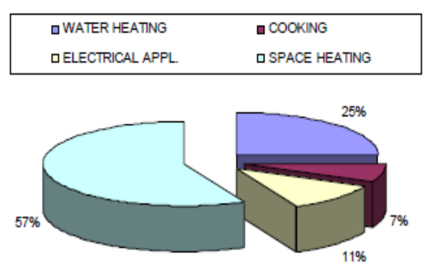

Fig.2 Structure of Energy consumption in residential sector

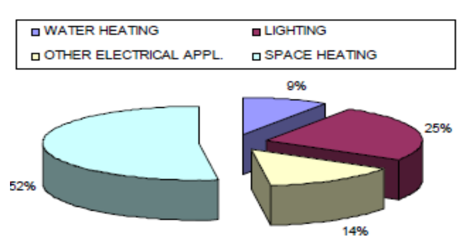

Fig.3 Structure of Energy consumption in Non-residential sector

It is imperative to accentuate that Smart House includes the digital home, intelligent home, connected home, and networked home. Smart House includes any “smart” activity, service or application in the Smart House including any form of “office” or working environment in the Smart House (but the smart office in commercial premises is excluded). Smart House covers any residential premises where people live (e.g. house or apartment) but excludes commercial and existing building premises. [6]. A primary universal estimate of lighting energy use, costs, and associated greenhouse-gas emissions has been presented in recent research activities carried out at the IEA (International Energy Agency) [12]. As indicated in DELight study [Environmental Change Unit, 1998]: “Electric lighting is used in practically all households all the way through Europe and represents a key component of crest electricity demand in many countries. There is already a fine urbanized energy-efficient technology available on the market, in the form of compact fluorescent light bulbs (CFLs), which could carry substantial savings. Such savings could be accessed quickly due to the rapid turnover of light bulbs in the stock and the confront is to get the more proficient technology installed and guarantee the savings.” Building automation is a automatic, mechanized, intelligent network of electronic devices that monitor and control the mechanical and lighting systems in a existing building. The objective is to create an intelligent building and reduce energy and maintenance costs [1]. Home automation (also called domotics) is a field within building automation, specializing in the specific mechanization necessities of private homes and in the application of automation techniques for the comfort and security of its residents. Even though many techniques used in building automation (such as light and climate control, control of door and windows shutters, safety and surveillance systems, etc.) are also used in home automation, additional functions in habitat automation comprise the control of multi-media home entertainment systems [4]. Day lighting calculation methods can be categorized into two types depending on their form: graphic methods and numerical calculations. Based on their theoretical approaches, the numerical calculation techniques can be further divided into two groups [10]. By the mid-1980’s, av amount of software packages were under expansion to predict day lighting performance in buildings, in particular illumination levels in day lighted spaces. The evaluation of these first tools demonstrated that none of this software then accessible was competent of predicting the simplest of real day lighting designs [19]. Day lighting prediction software is frequently reviewed as a subset or attribute of lighting design or energy simulation software, although attention has also been paid to these programs as visualization software, already from the ninetieths years. [13,14]. Additionally after that, articles on the performance and features of individual software packages appear regularly in the lighting press, publications, computer graphics and architectural journals [11]. Lighting conditions can affect our comfort and efficiency. While lighting designers and engineers are constantly urged to reduce energy and limit CO2 emissions, this would be productive if it had a unfavorable effect on the ergonomics of the end user’s environment. [3]. The Progress on lower-cost, reliable, integrated control technologies to provide the responsiveness needed for comfort and energy savings [15]. A review of research studies on day lighting covering the period from 1965 and 2004 reveals the boundaries of current knowledge about how people respond to daylight, and particularly how they react to robotic photo controlled lighting and shading controls [8,16,17].

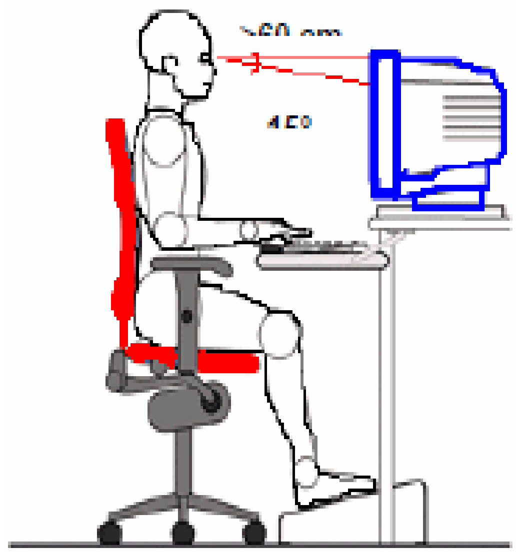

Fig. 3 Eye to Screen distance and Vertical location (Michela Chiogna, 2008)

Measurements carried out from Carter research [5] showed a high preference for day lighting and electric light levels below the current standards. Buildings cost less than employees, so any environmental condition that decreases individual performance (either in quantity or quality), increases absenteeism, or contributes to turnover, is more expensive to organizations than the capital and operating costs of better indoor environments [16]. Some more detailed recommendations for monitor placement and lighting are based on the latest scientific research [9].

2. DESIGN TOOLS FOR LIGHTING SYSTEM

Nowadays two items have a very great importance in the realization of a correct project, both concerning the building in a general acceptation and in the choice of the specific typology for the work and study areas. The first one is related to the environmental sustainability and takes into account energy demand control issues and the use of renewable resources in relation with the Kyoto protocol. The second is the way in which the project solutions meet the user’s needs, in terms of comfort and system usability.

A sustainable building process concerns the plan, the construction and the management of a building through criteria that assure environmental balance, the sustainable management of energy and material fluxes, the meditated use of natural resources, that should be renewable and not noxious.

Comfort is the particular psychophysical condition that occurs when a person is satisfied with the microclimate. Specifically we can speak about tactic, acoustic, visual comfort, thermal comfort in the winter or summer season, respiratory and olfactory comfort and air quality. In particular by visual comfort we mean the optimal level of luminosity that can assure the best conditions for the human eye in order to improve the visual perception in relation with the ongoing activities. The desirable luminosity level is therefore strictly connected to the different activities in terms of intensity, quality and distribution.

The control of the inside luminance depends on a pondered regulation of the natural luminance, on the artificial illumination and on the shading systems in order to improve the visual perception avoiding glare phenomena. The use of automation systems can be a solution to improve the performance of the lighting system both energy saving and user comfort. There are several simulation tools currently available for the lighting design with technological solutions. They intend to simulate and estimate the potential energy saving, but until now they cannot include correctly the use of automation systems. The research goal is to individuate and to quantify the dissimilarities between the calculated model and the real behavior of a monitored building with automated lighting system in order to improve the actual available design tools to introduce smart devices for lighting.

The developed methodology focuses on the following issues:

1- Definition, programming and monitoring of different scenarios for the lighting control system

2- Simulation, calculation and discussion about outputs of different software tools

-Adeline, Relux and Dialux- and comparison with data monitored for a specific case study

3- Elaboration and statistical analysis method of the users' behaviour, in order to introduce improvements in the modelling process.

4- Evaluation of the visual comfort maintained and perceived by the users in relation with the illumination levels standard, in order to verify if the proposed model allows the visual comfort users requirements.

3. DESIGN METHODOLOGY

This research defines a new methodology for the design of lighting systems in lecture halls, finalized to minimize the energetic consumption of the building. In order to carry out this analysis it is necessary to compare environments homogeneous or normalized by specific factor that simulate the same boundary conditions.

The method developed is divided into four phases:

1- Analytical phase: monitoring and analysis of existing situation

In order to analyze exhaustively the existing situation the criteria described in the following section have been adopted.

2. Programmatic phase and performance control: definition of project objectives and system requirements. The main goal of this research step is to define Scenarios configuration in order to control and reduce the energy demand in the analyzed space and to guarantee at the sometime the visual comfort improvement.

In order to do so, the following factors have been considered:

- Control of the users presence in the space , as a necessary condition to turn on the light

- Parameter of the artificial light, in relation to the natural light level

- Partial switching off of the light system, if only a part of the space is occupied

- Improvement of the luminaries efficiency

3- Propositional phase: system solution

In this phase the automated system architecture, the devices to be installed and their position and the supervision software program implementation has to be defined.

This entails the elaboration of an architectural/domotic design, that includes drawing boards and technical reports for the adopted solutions, including both the activation typology (function of each single actuator: on/off, dimming, and so on) and the activation modality (definition of the interaction among the devices system) of the automatic control system, and the definition of position and technical characteristics of the devices installed and integrated in the automation system.

4- Evaluation phase: evaluation and verification

This phase described the verification of the photometric parameter standards for the designed system using model software, in compliance with the regulations in force. The model output data will be compared with the values monitored in real life conditions. The evaluation of the user satisfaction for the new control system will be examined also, as well the energy demand comparison between systems with or without the intelligent devices.

4. EVALUATION OF ENERGY EFFICIENT LIGHTING AND ENERGY SAVING IN EXISTING BUILDINGS

The energy saving percentage for each scenario described above has been calculated in comparison with a reference level of energy demand considering the manual control of the lighting system, hereafter named ML (maximum level).

As ML, it could be assumed that during a normal working day, the light could be turned on for the whole working day (maximum 10 hours considering a working time from 8.00 until 18.00), hypothesizing in this way a continuous use of the artificial light (including lunch and coffee break). This way to define the maximum energy demand for a standard user attitude could differ from the real human behavior.

The energy consumption of both automated systems and traditional one has been recorded, in order to use these last data to calculate the ML energy consumption level to be compared with the ones of different scenarios (SL1, SL2, SL3 levels).

The geometrical parameters checked in order to guarantee the same conditions in terms of built space are:

- Geometric base case (orientation, dimension, geographical position, etc.)
- parameters for the base case selected
- materials for walls, ceiling(s) and floor(s)
- openings (windows, roof lights) and their position
- outside obstructions for the windows defined
- luminaries

The energy consumption of the i-nth room has been recorded in Wh/m2. This data has been divided by a defined operating time interval, so that it has been calculated in W/m2.In order to have a continuous profile of energy demand, a system with a significant detection interval has to be used. For this issue an impulses counter has been interfaced to a static active watt-hours meter.

A detection time interval has to be fixed. The discrete number of Wh cumulated in this time interval has been recorded and displayed by the supervision system.

$$ec_i = \frac{\left({}^{1}\!/_{N} \sum_{j=1}^{N} \frac{ec_{i,j}}{t_j} \right)}{s_i}$$

where:

eci,j = energy consumption of the i-nth room during the j-nth time interval, for the observed operating period, in W/m2

j = j-nth time interval

si = the surface in m2 of the i-nth room

N = number of intervals in a day

The energy consumption for the ML during the j-nth interval, expressed in Wm-2, has been calculated as follow:

$$ML = {}^{1}\!/_{N} \sum_{i=1}^{N} ec_{i,j}$$

where:

eci,j = energy consumption of the i-nth room operated by manual system during the j-nth time interval, in W/m2

j = j-nth time interval

si = the surface in m2 of the i-nth room

N = number of the room operated by manual system considered.

Nevertheless the comparison of the energy consumption amount is not sufficient in order to make a correct calculation of the energy saving using intelligent devices, if it has not been linked to three factors: the observed occupancy time, the outside luminance level and the visual comfort values.

5. CONCLUSIONS

Based on the literature overview, it is becoming more and more significant to establish a realistic baseline of the actual lighting energy consumption in buildings for the diverse scenarios nowadays used by both manually and automatically operated which incorporates occupant behavior. At the same time, it is strategic to explore and quantify the benefits of typical energy saving design measures called automated systems and when compared with a traditional operation system called the manual system. The features of lighting simulation tools nowadays available underline the importance of defining suitable reference cases for benchmarking the performance of automated lighting control. In the referred research thesis a new design methodology has been developed and verified, that relates energy saving and visual comfort. The research method includes, as referred in the summary, the definition of the methodological approach for the energy efficiency evaluation (design methodology, software tool outputs evaluation methodology, data analysis method) and the development of specific innovative design tools for both lighting system design and visual comfort evaluation.

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