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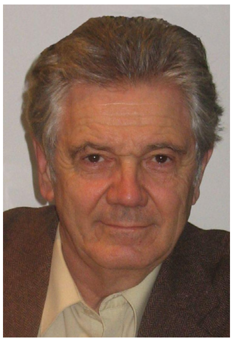
Conferinţe şi simpozioane

Informaţii

LIGHTING BETWEEN THE ENERGY EFFICIENCY IN RESIDENTIAL SECTOR AND THE IMPACT ON ELDER PEOPLE



Dr. Florin POP,
Professor

This issue presents papers devoted to the residential energy efficiency, daylighting analysis. It is edited with the financial support of ENERGOBIT SCHREDER LIGHTING.

Adriana ALEXANDRU and members of the research team of the CREFEN project present the targets and preliminary results of a Romanian project devoted to create an informatic system for energy efficiency in residential sector. The project aims to develop an advanced modeling and simulation software system-tool of electric energy consumption and of economical effects, and to implement an application with databases, an interactive educational application and electronic book in the field of energy efficiency use in order to influence the consumers' options in selecting energy efficient appliances for environmental protection. A *Questionnaire Summer 2006 campaign* was realized. A total of 204 questionnaires were obtained from a large geographical area. The first data regard the attitude of the questioned people to the energy efficient domestic appliances topic - more than 70% agree that the decision to buy an appliance should be based on energy efficiency class as well. CREFEN *web-based application* is designed and will be implemented with the goal of enabling people to access energy and performance information for 12 household appliances sold in Romania, via the Internet. The system is based on information contained within the Energy Labels and their associated Sheets.

D. CARTER, the Chairman of the CIE committee that produced the CIE Report 173:2006, explains what to expect in the document and describes interesting new work on how to configure daylight guidance systems to give maximum user satisfaction. The report contains a tried and tested method of prediction of illuminance resulting from daylight guidance system output within a building. The daylight contribution is expressed in terms of daylight penetration factor (DPF) an internal illuminance as a percentage of the simultaneous external illuminance. The luminous flux entering a guide collector is estimated as a function of the total collector area and an assumed external horizontal illuminance. Flux entering the room is determined making allowance for light lost in transport along the guide – a function of the geometric and reflective properties of the guides, and the output devices. Recent work at Liverpool University has gone some way towards unravelling the human response to daylight guidance systems. Analysis of user views showed differences in response to installations with and without windows and this gave some clues as to the impact of the guides on the perception of daylight. The daylight guidance with electric lighting could if configured to deliver daylight in sufficient quantity to provide users with a ‘day-lit interior’, so creating a lit environment with adequate task illuminance and the most of the perceived benefits of a day-lit space. Such a system would have levels of DPF close to 2%, an electric lighting design illuminance of the order of 300 lx and continuous daylight linking.

H. JUSLÉN analyses the influence of the colour temperature and illuminance level of the lighting on the preferred lighting levels and on the productivity in an industrial work environment. The effect of the time of the day on the illuminance selected was tested and showed very small differences. The performed experiment indicates that for increased productivity, the colour temperature increase of 3500 K to 4400 K is a more important factor than the illuminance increase from 500 lx to 800 lx. The results of this study suggest that for a lower use of energy as well as for higher productivity, the colour temperature of the dimmable task lighting system should be around 4400 K rather than around 3500 K.

C. ŢICLEANU presents a prototype of a branched natural lighting system emerged from the need of distributing daylight in several points along the light-pipe, approaching new applications, such as multi-floor buildings with similar superposed spaces, i.e. bathrooms, corridors, kitchens. Therefore, a T-ramification was created in order to bring daylight from the vertical main duct by means of a horizontal secondary duct to an interior space located between the diamond dome and the ceiling diffuser installed on the main duct. The pipe system was analysed by the illuminance measurements, the modelling equation and the light losses within the vertical main duct caused by the branch, as well as the light amplification within the branch. The experimental research undertaken by the author shows an important potential of light transmission towards these interior spaces.

C. MADA and Inge GAVĂT proposes a new scheme of the constant current regulators for light intensity level control of the airfield lighting systems lamps. It allows a modulation strategy for the output voltage and input current harmonic content reduction. A variant with radio wireless remote control is also presented.

C. ŞUVĂGĂU continues his very interesting and exhaustive column The Lighting in The New World, with the presentation of an innovated technology on street lighting dimming. The *Lumen IQ* technology provides a 0.8:1 reduction in power consumption for a corresponding reduction in lumen output due to electrical losses of magnetic ballasts. Laboratory testing has shown that at a 50 percent level of lumen output, power input is reduced by approximately 40 percent. In the presented case study, the City of Prince George, British Columbia, Canada, the savings were approximately 47,000 kWh/year on dimming to lower pedestrian conflict rates only. The payback of the installation is expected to be about 7 yrs non-considering the maintenance benefits.

Ambient assisted living for the ageing population (ALADIN) is a FP6 programme, Priority 2 “Information Society Technologies”**.** ALADIN aims at developing an intelligent assistive system based on ambient lighting to support mental alertness and memory performance as well as relaxation in specific situations. The system is also expected to assist with regulating circadian rhythms.

CREFEN – AN INFORMATIC SYSTEM FOR ENERGY EFFICIENCY IN RESIDENTIAL SECTOR

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Both in the European Union countries and in Romania the residential sector represents a very important potential for reducing the energy consumption by introducing some efficient non-pollutant technologies and an advanced energy management. The electricity consumption in residential sector is mainly focused on lighting and domestic appliances. The efficient use of electricity in houses is still a neglected issue, missing both the necessary statistic data and the methodologies and tools for assessing, prognosis and training the specialist and consumers. The aim of CREFEN project is to achieve, at the current level of the European researches in the filed, an integrated software system able to meet the requirements mentioned above. The system is part of the field S/T 5.8 Power efficiency and energy saving. The project has a marked multi-disciplinary character, involving experts in energy, software engineering, environment, and statistics. The system integrates the economical, social and environment impact, as well. A special issue is to develop the necessary databases of equipment and endowments from residential sector using the market surveys and questionnaires. The experts and consumers training will be performed in a large range of activities: web-based system with databases, electronic card, workshop, leaflets.

Keywords: energy efficiency, residential buildings, energy saving, software application.

1. Introduction

The electricity consumption in domestic sector has a continual tendency of increasing at the international level. In Romania, this consumption reaches 8.2 TWh in 2003, that represents 22% of the final energy consumption. The consumption per habitant has reduced values (356 kWh/habitant comparatively with 1600 kWh/habitant - the medium consumption for the 25 EU member states), so that the tendency of growing will continue and increase. It is essential that this increasing to be achieved in terms of efficiency.

The energy policy strategies and measures agreed by EU start from the idea that the market offers a large range of products that perform the same services, with highly different energy consumptions. If the buyer wants to buy a certain product, he receives at the first sight the information concerning the price. In order to take right decisions, he has to be informed on energy consumption and, also, to be trained for processing and interpretation of this information. Thus, the market has to be not only studied, but also formed, trained for stimulating the achievement of the strategic objectives on long terms (particularly the energy efficiency performance and sustainable development).

Thus, in 1991 the Council of EU adopted the program SAVE having the objective of promoting the energy efficiency in all sectors, including residential sector. Government actions, including promoting and informing campaigns, voluntaries agreements, legislations and standards, have been promoted through this program.

The program “Intelligent energy for Europe” is currently running. Its goal is to remove non-technological (social, cultural, institutional, legislative) obstacles in promoting the power efficiency. The program includes four subprograms: SAVE, COPENER (payment conditions, legislations), STEER (power efficiency in transportation sector) and ALTENER (efficiency in producing electricity and heat). The first two subprograms (SAVE and COPENER) explicitly contain efficiency promoting actions in residential sector.

The aim of the current research-development policy in energy sector of EU reflected by FP6 is to achieve a sustainable development also by increasing the energy efficiency.

In the last months, the European Commission adopted two important documents: “Green Paper on Energy Efficiency or doing more with less” and “Green Paper on European Strategy for Sustainable, Competitive and Secure Energy”. These documents consider that the lack of information is the main bottleneck for the energy efficiency.

The first actions have been undertaken in Romania starting with the first half of the last decade. It was distinguished the project PHARE “The energy labeling of the domestic appliances” performed by an international consortium led by the NIFES company from England.

Romania was a partner in European projects focused on the energy efficiency promotion within the SAVE and ALTENER programs, as: ELDA – Development of the European information system on the domestic electric appliances; EADE – Extension of the database on the European level for the web access with the energy efficient appliances data; PENELOPE-BACCHUS – Promotion of the energy efficiency at the local administration level by the dissemination of the results of the European projects and partners. Cooperation acts towards an improvement of the efficiency of the energy use in structure funds.

Many projects financed by the Romanian Ministry of Education and Research focused on the energy efficiency. For example, INFRAS program – Impact study of the European directives in the field of the electric and electronic appliances, and ORIZONT 2000 – Analyses of the

European experience on the energy efficiency indicators 2001.

The National Strategy in the energy efficiency field adopted by the HG 163/2004 underlines that the residential sector has a primary energy saving potential at 3.6 million tones equivalent petrol through 6.8 million tones of the total final consumers; it means more than 50%. This potential can be capitalized by the buildings heating rehabilitation, the improvement of the heating and lighting systems and of the electric domestic appliances. The EU Directives related to the labeling of the energy parameters for many electric appliances have been used in order to be implemented in the Romanian legislation.

The Government Program on the following years 2005-2008 states the necessity to accomplish the legislative and institutional frame in order to apply the flexible mechanisms adopted by the Kyoto Protocol, to pursue the implementation of the technical and economical measures for the reduction of the greenhouse gases emission, in accordance with the features of the National Plan for the Allocation of the Emission Quotas, the development of the National Plan for the Climatic Changes Action, the improvement of the energy efficiency and the promotion of the renewable energy sources.

In this frame and in accordance with the EU policies, there is a priority for Romania "to remove the non technological barriers by the market formation and education" by developing:

- Campaigns at the national levels for the people education and information concerning the energy efficiency concept, the significance of the energy efficient electric appliance choose (related with the appliance energy label), the opportunities to obtain important reductions of the energy consumption in residential sector with low levels of their costs;
- Education and information campaigns in general and high schools, universities and even children gardens concerning the energy savings.

2. Objectives of the CREFEN project

The problems to be solved by the project deal with energy efficiency and saving energy field (specific objectives):

- Drawing up of scenarios and prognosis of electricity consumption in residential sector;
- Achievement of an advanced modeling and simulation software system-tool of electricity consumption in residential sector and of economical and environmental effects;
- Using a tool for defining the potential of energy saving, prognosis and scenarios of consumption evolution;
- Improvement of the degree of taking into consideration by the consumers, decision factors and specialists of the opportunities, advantages of promoting new technologies in electricity consumption in residential sector, in the framework of a sustainable development integrated at the European level;
- Designing and implementation of a web application with databases for domestic and lighting appliances available on the Romanian market, which include information from the energy label and fiche;
- Design and implementation of the software for an interactive system and an electronic book.

As measurable objectives we mention:

- Influence of the consumer decision concerning electricity saving at residential level and acquisition of energy efficient appliances;
- Consumer education, in general, and young people, in particular, for environment protection and reduction of greenhouse effect;
- Interconnection of Romanian research in electric energy efficiency field in residential sector to similar European projects (for example DG JRC project, IES, Ispra, "Energy

Efficiency Potential in Buildings, in New Member States and Candidate Countries”).

The CREFEN project is connected with energy efficient use according to EU directives from one side and with the implementation of database applications using web-based technologies to assist and influence the people decision in selecting the households appliances from the other side, that leading to sustainable environment management.

The proposed project is part of the field 5 “Energy - 5.8 Energy efficiency and saving” of Romanian CEEX program, contributing to the efficient use of the energy for reaching the EU standards and to the development of software applications aimed to assist the citizen decisions and determine it for the already mentioned objective with environmental impact.

3. Methodology and software

Modeling and simulation in energy field and web-based applications with databases is a complex and dynamic domain, leading to an important research and development potential with important practical implications. The project aims to develop an advanced modeling and simulation software system-tool of electric energy consumption in residential sector and of economical effects, to implement an application with databases, an interactive educational application and electronic book in the field of energy efficiency use in order to influence the consumers’ options in selecting energy efficient appliances for environmental protection by reducing the CO_2 emissions. This approach is quite new in Romania. The scientific knowledge in the field (algorithms for calculation of energy consumption, IT technologies) is connected with technical aspects concerning its implementation as a web-based application containing in its database the most of the technical features of domestic and lighting appliances available in Romania.

The Application is complex both by its multidisciplinary and proposed IT solution. The accessibility will be solved by using web-based solutions. The user needs only a browser in order to be connected to the system without other specific applications. It is also possible to use public terminals with touch screens. The performances of this application take into consideration the user friendly interface, the reliability, data security, high speed provided by Microsoft SQL Server 2000 DBMS. The data protection will be assured both by specific Internet control access mechanisms (proxy server) and by internal mechanisms of the relational DBMS Microsoft SQL Server 2000. The application will be available also on stand-alone computers for locations without Internet connection. The proposed software system will include a complex of interconnected databases, a software system for the management of these data and a system for accessing them via Internet. The most recent platforms and software products for developing the Internet-based applications with databases (ASP.net, SQL Server, Java, OLAP) will be used.

The application architecture will be a modular one, with the possibility of its extension with new functionalities, without perturbing the other components or requiring the reorganization of the system data.

4. Results after the first year of the project

4.1 Analysis of the energy consumption in the residential sector

The energy consumption in the residential sector was analyzed at international level using the statistical data from “Energy Efficiency Policies and Indicators“ project of World Energy Council, ADEME (Environment and Energy Management Agency), APERC (Asia Pacific Energy Research Centre), OLADE (Latin American Energy Organization), to monitor and evaluate the energy efficiency politics and their impact at the world level. The results of the latest report, published in August 2004, presented the conclusions of energy efficiency policies in 63 countries.

The situation of Romania was also analyzed through a people survey. Energy efficiency and energy consumption in the residential sector is a topic issue in Romania. A European study signaled that promoting energy efficient appliances may lead in Romania to 0.4 TWh/year savings in the electricity consumption. The domestic and lighting appliances are the major energy consumers in a dwelling. Therefore, the actions for home energy saving are directed to them.

A few options considered by CECED to be the main elements of a strategy to reduce the total energy consumption of domestic appliances have been taken into consideration.

The statistic data [12] for the period 2000 – 2004 allow us to determine the variation of total household consumption, total number of household consumers, average consumption per household consumer; the specific household consumption kWh/m^2 per year is presented in Figure 1.

During November 2005 a preliminary study has been realized on the CREFEN project using feed-back reply forms concerning the usage degree of different household appliances; we were also interested in the GSL and CFLs use in households in Western Romania. We received 295 replies, namely 220 apartments (with 1–4 rooms - living room and bedrooms) and 75 houses (with 2–more than 7 rooms - living room and bedrooms). The equipping degree with CFLs is approximately two units per household. The average installed power in residential lighting is presented in Figure 2.

The analysis of the presented data allows us to estimate a few characteristics of electric energy consumption of households. The annual electric lighting household consumption in Romania in 2004 was about 6.71 kWh/m^2/ year. This number is based on the average consumption of 1003 kWh/household/ year, the average household surface of 37.39 m^2 and the average contribution of the consumption on the lighting circuits, by 25% according to the study [4].

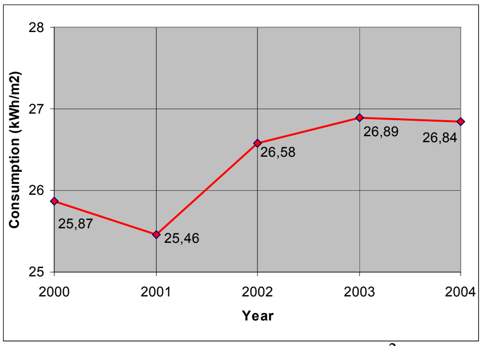

Figure 1 Household consumption per m^2 in Romania - [9, 12]

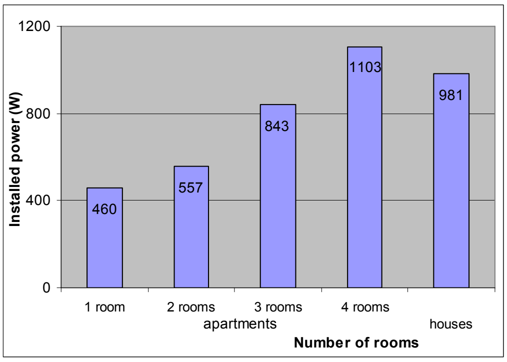

Figure 2 Average installed power in residential lighting - [9]

4.2 Evaluation and prognosis of the electricity consumption

The research activity focused on household electricity consumption evaluation techniques and on the selection of a methodology to be applied in Romania. After analysis of *different models for electricity consumption evaluation and prognosis* (econometric, time series), it is suggested a bottom-up approach, starting from the consumption of appliances and lighting in dwellings.

The aggregated electricity demand is:

Electricity demand = Σ Ownership x Dwellings x Device consumption

The primary data are to be obtained by questionnaires, acquiring information as: ownership rate for each appliance, rated power, average operation period and others (efficiency, resources consumption). The households' composition is desegregated by urban multi-apartment block, single urban dwelling and single rural dwelling. The households' distribution is made according different criteria as: geographic site, rural or urban environment, family income, dwelling size.

A *Questionnaire Summer 2006 campaign* was realized. A total of 204 questionnaires were obtained from a large geographical area (see Figures 3 to 6.)

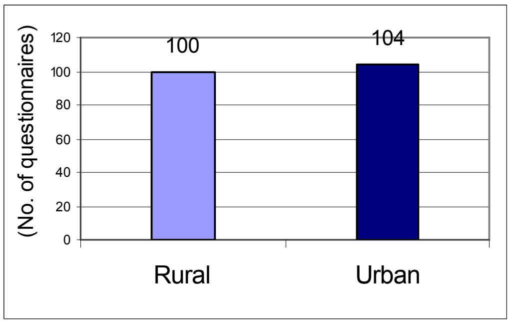

Figure 3 Distribution of questionnaires according the rural or urban area

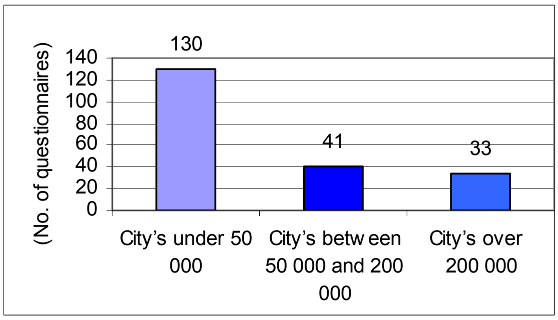

Figure 4 Distribution of questionnaires according the size of localities

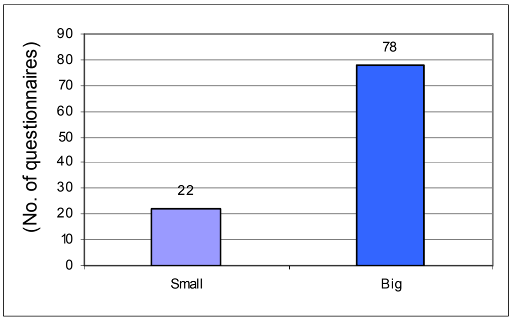

Figure 5 Distribution of questionnaires in rural area according the size of household

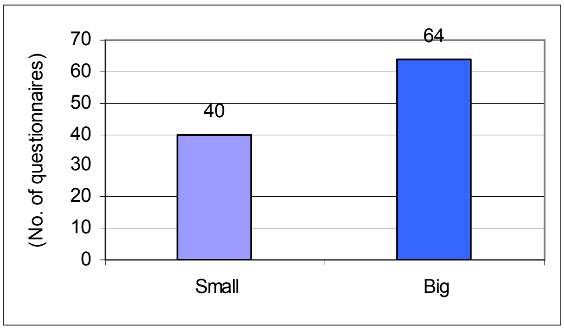

Figure 6 Distribution of questionnaires in urban area according the size of household

The first obtained data regards the attitude of the questioned people to the energy efficient domestic appliances topic - more than 70% agree that the decision to buy an appliance should be based on energy efficiency class as well. The consumption in the household utilities is presented in the Figure 7. The motivation of the CFLs use is presented in Figure 8.

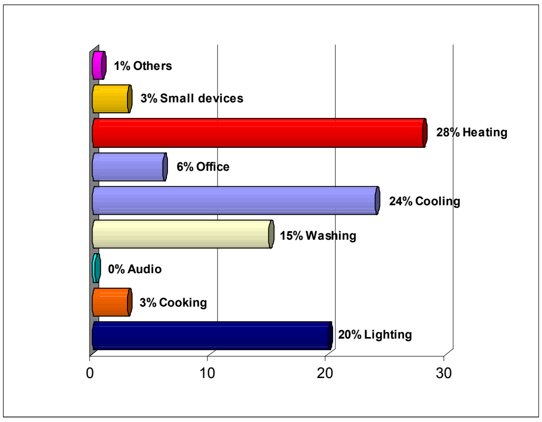

Figure 7 Consumption of household appliances

In further works, after receiving and processing the data, the reference status of the residential electricity consumption at the level of the year 2006 will be obtained. The residential electricity demand will be estimated

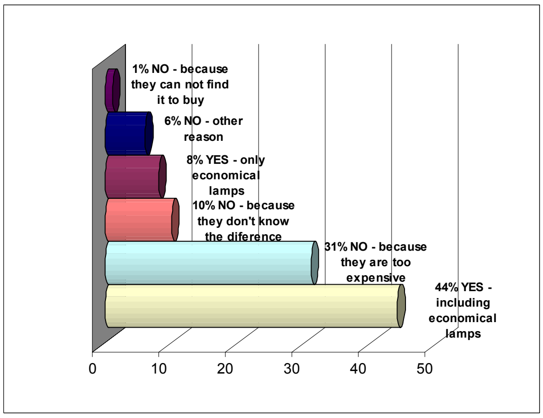

Figure 8 Motivation of the CFLs use

using the MAED model elaborated by the IEA, following development scenarios on medium and long terms.

4.3 CREFEN web-based application

CREFEN *web-based application* is designed and will be implemented with the goal of enabling European citizens to access, via the Internet, energy and performance information for 12 household appliances sold in Romania. The system is based on information contained within the Energy Label and its associated Sheet.

The three-layered architecture was chosen. The presentation layer assumes that the user only needs a web browser to access all applications provided within the system. The second layer encompasses the server layer, both the web server preparing documents for the presentation layer and the server realizing authentication, authorization and ensuring integration with data layer. The data layer is a repository of all kinds of data gathered by the system. The database is included in the third layer.

The application is designed to perform the data supply and application layer onto the server side in the backend. Only the presentation is left over to the client computer. The clients will use a traditional web browser requesting the dynamic ASP pages over the server.

The server is a standard PC. The software used is Windows 2000 Server as operating system and MS-SQL Server 2000 as DBMS to develop the database [Micr 2000; Mcse 2000]. The interface was developed in Macromedia Dreamweaver, Java script and ASP (Active Server Pages). The architecture contains a firewall (who processes every network request for server, ensuring the system with a higher security level and also protecting the database).

The database content is the following:

- All white goods appliances currently stocked by the manufacturers or by the retailers which are or will be energy labelled.
- All energy efficient models (A-C) manufactured by the suppliers of Romania.
- Consumer electronics and office equipment.
- Appliance groups which have recently been labelled such as ovens, lamps and room air conditioners.

Each appliance type and model has a set of information extracted from the energy label and information fiche, which provides information which enables one to characterise a particular appliance model and to compare with other models.

The main functions of the web-based application are:

1. The Web-Interface for Data Acquisition can be accessed for the users on the base of an ID and a password. User's accounts are created by the site administrator without the possibility of automated user registration, in this way being eliminated the possibility of creating unauthorized accounts and registrations.

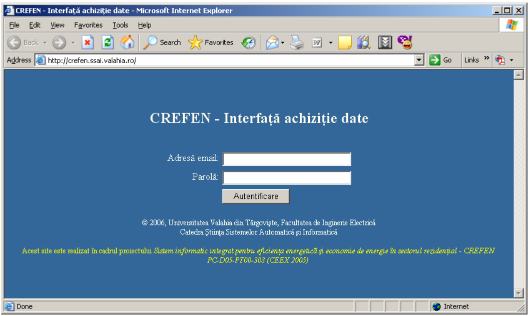

Figure 9 The home page of the on-line data acquisition interface CREFEN.

The home page of the on-line data acquisition interface is presented in Figure 9.

After the authentication, the authorized user can choose here one of the web forms designed for data acquisition, specifically for each electrical appliance: fridge/two doors deep freezer, fridge/one door deep freezer, fridges, chest freezer, upright freezer, washing machine, washer drier, tumble drier, dishwasher, air conditioner, oven, luminaire (lamp).

After the addition of equipment characteristics, the user can introduce data in the same form or go back to the web-page for choosing of another form.

The validation of the data included in the web form is made function of the type of the fields as following:

- the possibility to choose one of the valid alternatives offered by the web form, being so eliminated the risk of introducing invalid data;
- testing the required text fields for null value;
- testing the value of the numerical fields for not allowing non-numerical values inside.

2. Selecting energy efficient appliances: The EU label and fiche allows one to select a model in terms of its characteristics such as size or volume, performance, energy and water usage. This information is stored in a database which can be consulted once you have defined your specific needs. The search mechanism in the database is perhaps the most useful service [Quer 2001]. Searching can use one or more criteria:

- Appliance selection criteria in terms of: Type, Size, Performance and Price Range. These parameters narrow the resulting set of appliances. Some useful hints help the user and assist selection.
- Manufacturer: useful when searching for the whole group of an appliance of one manufacturer.
- Product name: used when searching for a specific appliance.

3. Database outputs: Based on the searching parameters, the search mechanism generates a list of matching appliances along with all the data set that is stored in the database. The search output is listed in tabular form containing groups of 5 products plus the typical 10 years old model. For each appliance the following general information is provided: manufacturer/model, size, energy efficiency class, energy consumption and some specific information characterizing a group of appliances.

The models are listed in order of lowest to highest energy consumption. The user has to select at least one product to see Lifetime Costs and Savings.

4. Lifetime cost: The lifetime cost is calculated based on usage of electricity, water and detergent (where applicable) and compared with the operating cost of a typical 10 year old appliance. This indicates how much energy and money you can save with a new appliance and what contribution this will reduce greenhouse gas emissions. This module is perhaps the most important of the system because it offers information about the energy efficiency of the appliance based on a 15 years lifetime.

The user can see both lifetime savings financial and lifetime savings CO_2. Energy efficient appliances have a lower running cost because they have been designed to use electricity, water and detergent more effectively [Alex 2001, p. 4; Alex 2002, p. 60; Jita 2002, p. 105; Alex 2005, p. 96]. This lower running cost can offset part or all of the higher initial cost. The comparison is made not only between the 5 products presented on the screen, but also with a typical 10 years old model. The user can then obtain detailed information about a specific model.

5. Conclusions

Electricity saving through the change of the consumers' behavior represents a priority both at EU and at national level. The project fits perfectly in the politics concerning the reducing the energetic intensity and the greenhouse emissions in Romania and in Europe. Any action at the level of the electricity consumers will be found in important savings of the fossil combustibles. Under the circumstances of the increase of the primary energy tariffs, the actions of energy saving at the final consumers' level have great chances of success. A monetary unit invested for the realization of this project can finally lead at savings in primary resources consumption quantified between 5 to 10 monetary units. The economical efficiency of the funds utilization is certain and leads to fast money recovery.

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RECENT DEVELOPMENTS IN DAYLIGHT GUIDANCE SYSTEMS

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Daylight guidance has over the past few years become an exciting addition to the lighting designer's range of options. Little authoritative design guidance currently exists for this technology but this gap is about to be plugged by a new Commission Internationale de I'Eclairage (CIE) Report that is now available. David Carter, the Chairman of the CIE committee that produced the report, explains what to expect in the document and also describes some interesting new work on how to configure daylight guidance systems to give maximum user satisfaction.

Keywords: daylight, daylight guidance, design, human response to daylight.

Introduction

Daylight guidance technology redirects daylight into areas of buildings that cannot be lit by conventional glazing. They consist of a light transport section with, at the outer end, a device for collecting natural light and, at the inner end, a means of distribution of the light within the interior. Light collection is usually at roof level either by 'heliostats' that actively track and focus sunlight, or passive devices that accept sunlight and skylight from the whole sky (see Figure 1).

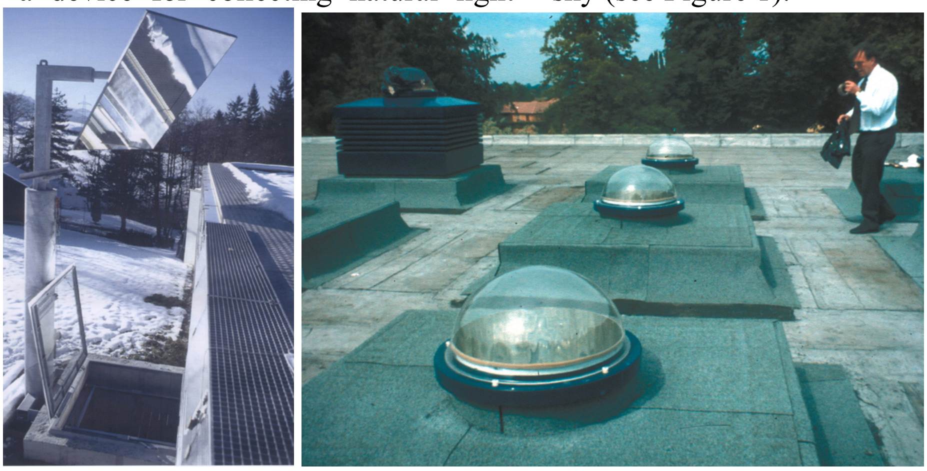


Figure 1

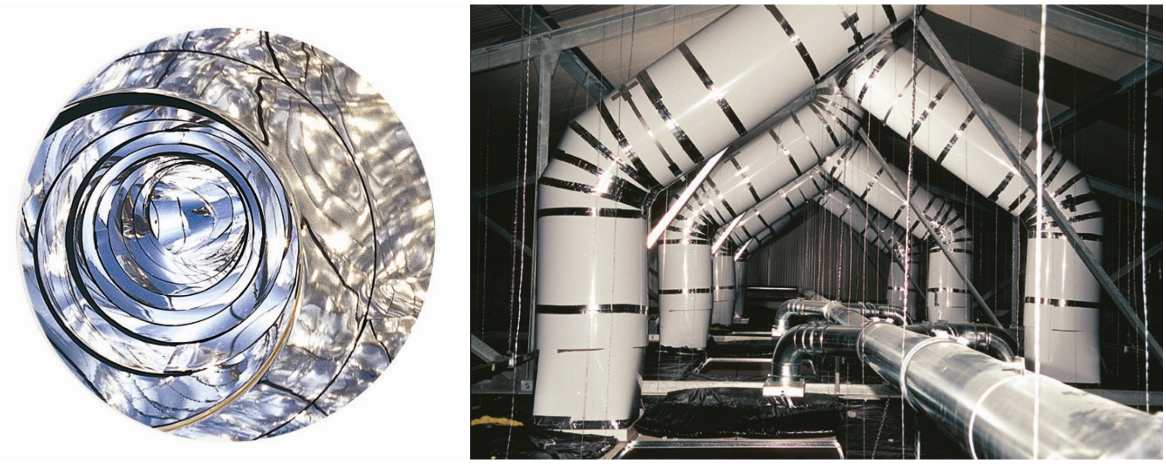


Figure 2

Figure 3

The transport element is usually a tube lined with highly reflective silvered or prismatic material and light is distributed in an interior by output components, commonly diffusers made of opal or prismatic material (see Figures 2 and 3).

The most commercially successful type of daylight guidance is tubular passive zenithal -marketed variously as ‘daylight tubes’, ‘sunpipes’, ‘tubular skylights’, ‘tubular rooflights’, ‘sun tunnels’ – and these are manufactured and installed in large quantities worldwide. Although the largest market is user owned domestic buildings, where typically a single guide lights a living or ancillary space, they are now being installed in commercial, industrial and health care buildings - interiors in which a good visual environment for employees is a major factor in a safe and productive workplace.

Design guidance for conventional glazing sets out desirable window properties, room proportions and surface treatments, and allowable daylight levels and distributions to give satisfactory conditions for users. Similarly electric lighting codes attempt to create comfortable conditions using recommended planar illuminance levels and limits on surface and source luminance. Daylight guidance systems however share few of the physical characteristics of either electric lighting or windows. No independent specialist design information for daylight guidance has been developed in the ten or so years that the technology has been commercially successful. This means that in the absence of both standardised methods of photometry or system design and of independent design guidance, evaluation of the range of alternatives on the market by potential customers is at best very difficult and in some cases impossible. A glance at manufacturers' websites shows, for example, a proliferation of methods of describing guide performance information, often incomplete, and with little indication of the source of that data. This sits uneasily in an industry where standardised methods of product data exchange (e.g. utilisation factors, luminous intensity tables and glare ratings) are demanded. Also unsubstantiated claims about performance by a minority of daylight guidance manufacturers threaten to discredit a technology that potentially offers both energy savings, and user comfort and satisfaction. For these reasons CIE set up a Technical Committee at its 2001 meeting in Reykjavik to produce authoritative and independent guidance.

CIE Report 173:2006 [1]

The Report includes a review of the technology of all types of daylight guidance systems. The main sections in the report are on photometry of components and systems, design methods, cost and benefits, human factors and architectural issues relate to passive zenithal systems. A number of well illustrated case studies demonstrate good practice.

The review of the types of technology available is intended as a guide for strategic decisions. It sets out the physical and performance characteristics of each type of daylight guidance component and their limitations – what they can and can't do. Generally active collection systems do not represent good value in temperate latitudes since they have high capital cost, require costly control and structural systems and maintenance, and have implications for the external appearance of the building. The bulk of the design related material in the document relates to passive zenithal, the most commercially successful systems, which are installed in large numbers worldwide.

The Report puts forward a method of photometry that is

- capable of handling components of the range of sizes used in daylight guidance (length and diameter up to 1m and 5m respectively)
- capable of generating reproducible results
- is not dependant on large scale test house standard goniophotometer equipment.

The photometry equipment is illustrated diagrammatically in Figure 4. The requirement for reproducible results means that an electric light source is used, natural skies being unsatisfactory for this purpose. The source consists of a diffusing material illuminated by tubular fluorescent lamps to give a specified luminance within a defined angle of view as illustrated in Figure 4. It should be noted that much of the existing published manufacturers' data is tested under natural skies and thus is site specific and not capable of being meaningfully compared with other data. The equipment is low cost and can be used to test the light transport characteristics of all components. Figure 4 illustrates its use for straight guides but the same equipment can be used for measurement of collector efficiency, output device efficiency and bend efficiency.

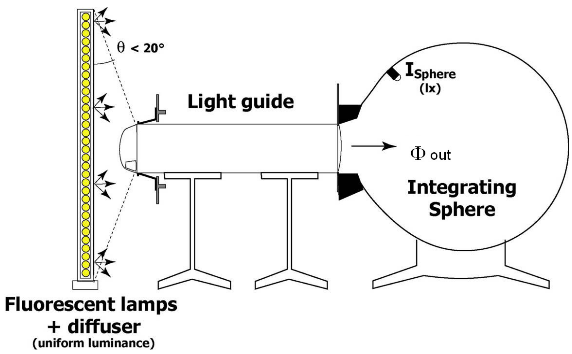
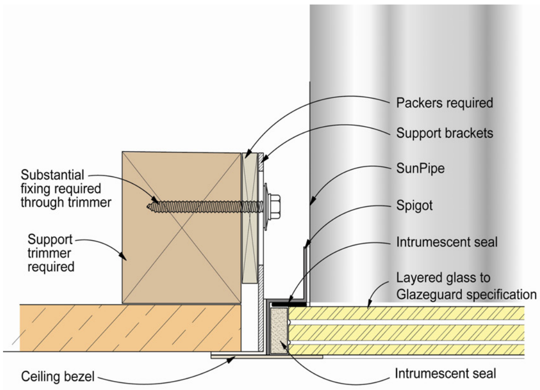


Figure 4

The report contains a tried and tested method of prediction of illuminance resulting from daylight guidance system output within a building. The daylight contribution is expressed in terms of daylight penetration factor (DPF) an internal illuminance as a percentage of the simultaneous external illuminance. Since daylight guidance utilizes both skylight and sunlight, global illuminance is used in the calculation of DPF. In summary the CIE 173:2006 method estimates the luminous flux entering a guide collector as a function of the total collector area and an assumed external horizontal illuminance. Flux entering the room is determined making allowance for light lost in transport along the guide – a function of the geometric and reflective properties of the guides, including bends, and the output devices. Average work plane illuminance is determined using the utilization factor method similar to that used in electric lighting design. Advice on appropriate maintenance factors at the design stage and on physical maintenance of systems during life is given.

The report discusses a number of architectural issues relating to daylight guidance systems. As conduits of daylight into a building, guides penetrate the exterior envelope of a building but, unlike windows, they may also pass through internal structural or construction elements. They thus make demands in terms of structural support and fire protection – fire compartments, fire stopping and internal and external spread for flame – that other lighting systems do not. From the fire point of view they are akin to ventilation systems and use similar fire stopping methods. Figure 5 shows the use of intrumescent sleeves to crush a guide in case of fire and also laminated glass output devices which are also fitted with intrumescent seals. The internal space required to accommodate TDGS components may affect building space planning in terms of loss of useful floor area or need for ducts. (See Figure 6).



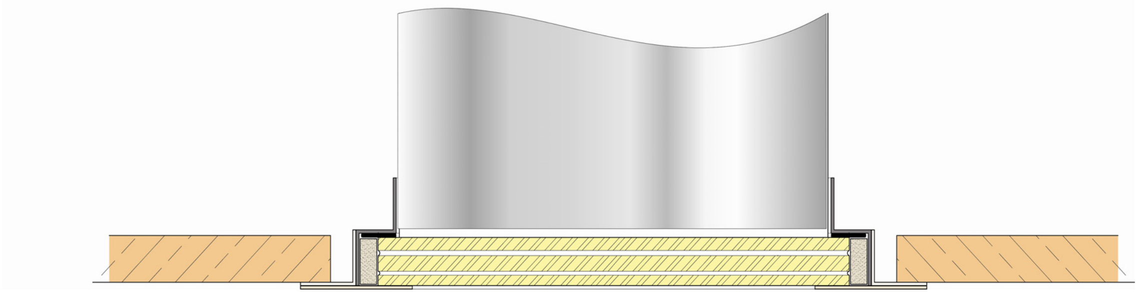


Figure 5 a

Recent work at Liverpool University has gone some way towards unraveling the mystery of human response to daylight guidance systems [2]. The general approach was to visit working buildings lit by daylight guidance and measure lighting levels outside and in, and, by means of questionnaires, find out user views on quantity and quality of the lit interior. Statistical techniques were then used to link the two data sets.

Information on lighting hardware, control systems and achieved lighting conditions, was gathered from fifteen office buildings located in the UK.

The rooms were in either single story buildings or on the top floor of multi-storey buildings and were equipped with electric lighting in addition to guided daylight. Eight of the installations were windowless. Two installations had daylight linked to continuously variable electric lighting, a further site had control of individual luminaires, but the majority of the sites had no additional control of electric lighting.

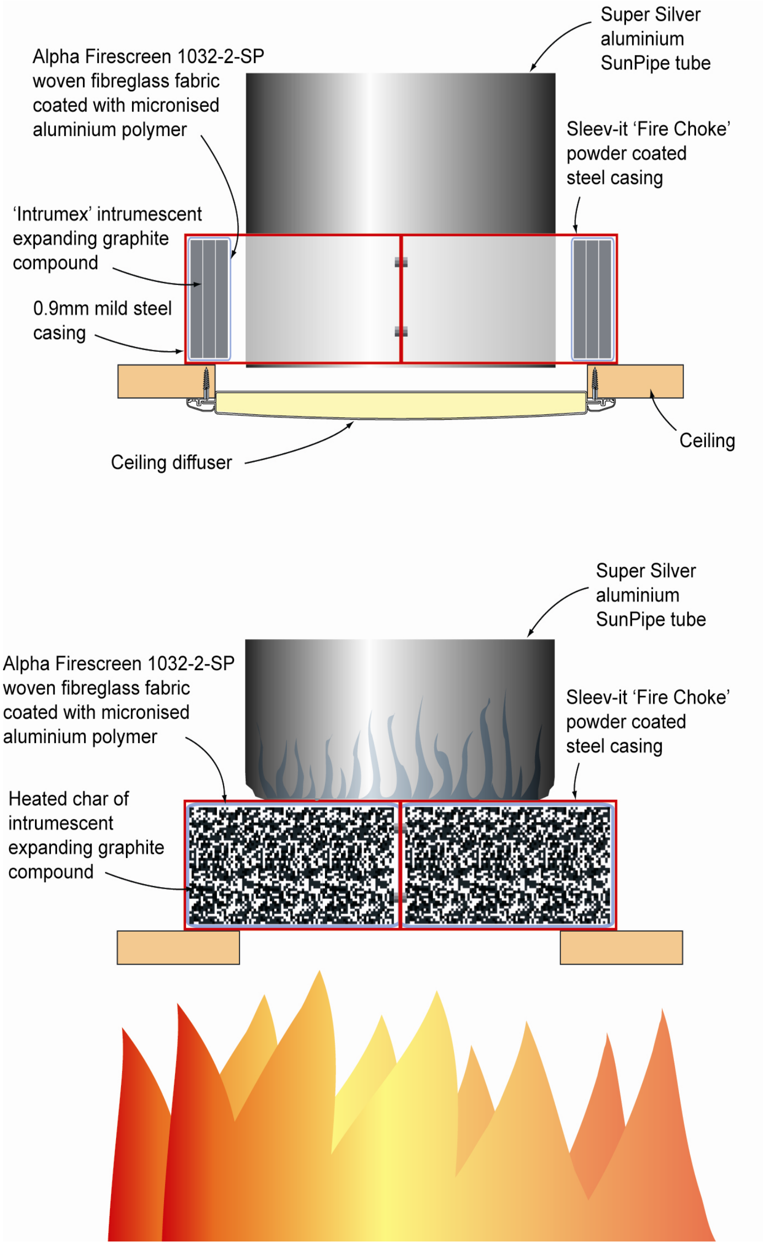


Figure 5 b

Measurements at each workstation of total (i.e. electric lighting and daylight) illuminance and, if possible, daylight only were made. There was a very wide range for both total and daylight values. About 16% of the total occupants were working below the Society of Light and Lighting recommended values for offices (300 - 500 lux), but some 50% were working in illuminance values above this range [3].

Figure 6

It could be argued that the majority of installations are over-lit in their working state and that the daylight systems are contributing to this. Only 10% of the measured daylight levels would on their own satisfy SLL illuminance requirements for offices and for these the daylight contribution represents between 10% and 40% of total illuminance. A major reason for this is that the number of luminaires exceeded the number of daylight output devices in all installations, in some cases greatly so. Also there is a big difference between the light outputs of the luminaires and the daylight output devices. The most common type of luminaire used – 600 mm x 600 mm downlight with four PL lamps has a typical light output of approximately 4800 lumens. The daylight output of the devices typically ranged from approximately 1000 lumens in prevailing temperate overcast conditions to 8500 lumens under a midsummer clear sky with sunlight. Examination of likely daylight illuminance levels during working hours in the UK suggests that, for most of the year, each daylight device provides less than half the light output of the luminaires used.

Analysis of user views showed differences in response to installations with and without windows and this gave some clues as to the impact of the guides on the perception of daylight. The total workstation illuminance was generally assessed as too low but only considered satisfactory in installations with windows. Also much higher levels of dissatisfaction with daylight than for total illuminance were evident particularly in windowless installations. Although there was a strong correlation between window/guide area and DPF there was only a weak correlation between perception of daylight and guide area. Installations with windows also elicited more favourable responses to perceptions of shadows and distribution of light. The DPF values were generally below 1%, some way below the 2% value considered necessary to give a ‘well day lit’ space. A pattern thus emerged that although daylight guidance devices were regarded as providers of daylight they were inferior to windows in delivery of both quantity and quality (mainly view and illuminance variation). User response to questions on the appearance of the systems suggested that although they are not unduly visually intrusive they had little aesthetic appeal either.

The lack of daylight linked control meant that diurnal variation increased illuminance above the electric lighting design values. Although this permitted temporal illuminance variation it prevented energy saving being realised even in summer conditions when daylight was capable of providing more than SLL recommendations but in no instances did switch off occur in these circumstances

An ideal specification for daylight guidance?

The research provides evidence that daylight guidance systems are acknowledged as sources of 'daylight' and appreciated as such by users. The current systems do not however produce a 'well day lit' space, and their light output makes only a modest contribution to task illuminance. Notwithstanding this, although some of the components of 'daylight' may be absent, they seem to provide users with some of the benefits.

It is possible to speculate that daylight guidance with electric lighting could if configured to deliver daylight in sufficient quantity to provide users with a 'day-lit interior', so creating a lit environment with adequate task illuminance and the most of the perceived benefits of a day-lit space. Such a system would have levels of 'daylight penetration factor' close to 2%, a electric lighting design illuminance of the order of 300 lux and, crucially, with continuous daylight linking. The control system would have to permit electric lighting substitution but allow some diurnal variation to satisfy users.

This is very much work in progress. The author would welcome comments on the work, user experiences of daylight guidance and, particularly, details of any sites where daylight guidance is to be installed such that a 'before and after' study could be made. He can be contacted on eb09@liverpool.ac.uk.

Acknowledgements

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INFLUENCE OF THE COLOUR TEMPERATURE OF THE PREFERRED LIGHTING LEVEL IN AN INDUSTRIAL WORK AREA DEVOID OF DAYLIGHT

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The first objective of the study was to find out if preset colour temperature and illuminance level affects the preferred lighting levels in an industrial work environment. The second objective was to measure if the illuminance or colour temperature has an effect on productivity. A dimmable task-lighting system was installed above eight individual industrial assembly workstations. Four preset "switch-on" settings were employed (4400 K/350 lux, 4400 K/820 lux, 3500 K/350 lux, 3500 K/820 lux). The system allowed the workers to change the illuminance but not the colour temperature using IR-controllers after the lighting was switched on. The values selected by the (regular) workers were recorded. It was found that slightly lower task-lighting illuminances were selected when the colour temperature was higher, and a much higher illuminance was selected when the preset switch-on illuminance was higher. The productivity of the workers was significantly higher (5.7 per cent) when the higher colour temperature was in use. The switch-on illuminance did not affect productivity.

Keywords: lighting, productivity, colour temperature, preferred illuminances.

1 Introduction

In most cases, lighting is designed to meet the minimum norms and up until now most of the lighting research has neglected to study the lighting preferences of industrial workers. It is worthwhile to build up knowledge with respect to the preferences of workers regarding lighting level and light colour and to establish whether there are any differences between workers. This information could help to create lighting conditions that workers prefer, thus increasing their well-being and indirectly influencing productivity.

Inside Europe there are differences between the colour temperatures preferred. More lamps with a warmer colour temperature are sold in northern Europe and more lamps with a cooler colour temperature in the south. This is typically explained by the differences in weather and temperature conditions. In areas with a lot of daylight, the colour temperature of the artificial lighting is not so evident because of the contribution of the daylight. In office-lighting studies, where people's control behaviour has been studied (Maniccia et al. 1999; Escuyer and

Fontoynont, 2001; Moore et al. 2003; Love, 1998; Boyce, 1980; Jennings et al. 2000; Begemann et al 1997), daylight has been available. In industry, the daylight contribution is quite often missing. Control-behaviour studies (Juslén et al. 2005) in industrial environments not encompassing changes in colour temperature show that workers have their individual preferences for the level of the lighting, but the difference between individuals is large.

Recent findings of non-image-forming, psycho-biological effects of light via a photo-biological pathway in the brain (Brainard et al. 2001, Hattar et al. 2002, Berson et al. 2002) and the increasing demands for higher productivity have made the issue of lighting and productivity in industrial environments topical once again. As shown by melatonin-suppression tests, the sensitivity of intrinsically photosensitive retinal ganglion cell (ipRGC) has a peak in the area of 420 nm - 490 nm. (Qiu et al. 2005, Panda et al. 2005, Melyan et al. 2005, and Newman et al. 2003). This could mean that higher colour temperatures might be more effective for alertness and productivity.

2 Methods

2.1 General

In this work, two aspects were studied. Firstly, by installing a dimmable task-lighting system (illuminance and colour temperature), the aim was to see what kind of illuminances workers would select and whether the switch-on colour temperature or illuminance would influence their choice. Secondly, by monitoring productivity figures, it would be observed whether the illuminance or colour temperature had any effect on productivity.

2.2 Lighting and work in the test area

2.2.1 The situation before the test installation

The study was conducted in two types of workstations in a German luminaire factory. Before the lighting change, general lighting (4000 K) was always on when people were working in the area. It produced 500 lux horizontal illuminance on the working plane and 200 lux vertical illuminance at eye height over the total floor area, without shadows.

Type 1 workstation (Figure 1a)

Work

In this area, the workers were assembling control gear, lamps, end caps and wires in the luminaire housings. Materials were mainly white in colour, and the visually most demanding part was the wiring. The tasks were mainly on the horizontal plane. In the European standard for this kind of work, namely EN 12464-1 (2.6 electrical industry, 2.6.2 assembly work, medium), the minimum maintained illuminance required is 500 lux.

Breaks

Workers in this area were working in one or two shifts, depending on the work load (06:00-14:00 and 14:00-22:00 hours). There were three scheduled breaks: 09:00-09:15, 12:00-12:30 and 18:00-18:30 hours.

Workers

During the productivity measurement period (8 months), 26 female workers (average age 45 years) were working in the area. Before the productivity measurements (5 months) and after them (3 months), workers' presence was not monitored. This meant that during the total period the number of workers was actually slightly higher (around 30) and the average age somewhat lower (summer workers).

Lighting

Prior to the test installation, there was no task lighting in these workstations. General lighting provided 300-400 lux horizontal at the middle of the table. (2*58 W TLD 840 lamps, open reflector). There was no daylight available.

Type 2 workstation (Figure 1b)

Work

In this area, luminaire optics were assembled manually. The material was relatively glossy aluminium. Workers put together lamellae to side reflectors. The tasks were mainly on the horizontal plane. In the European standard for this kind of work, namely EN 12464-1 (2.6 electrical industry, 2.6.2 assembly work, medium), the minimum maintained illuminance required is 500 lux.

Breaks

Workers in this area were working one shift (06:00-14:00 hours) incorporating two scheduled breaks: 09:00-09:15 and 12:00-12:30 hours. Normally only two or three workers were present at these workstations per shift.

Workers

Six female workers (average age 41 years) were working in these workstations. The presence of individual workers was not monitored.

Lighting

The old task-lighting system before the change delivered 400 lux horizontal illuminance at the middle of the table (1*58 W TLD 840 lamps, prismatic optics). General lighting provided 400 lux horizontal at the middle of the table (2*58 W TLD 840, open reflector). There was no daylight available.

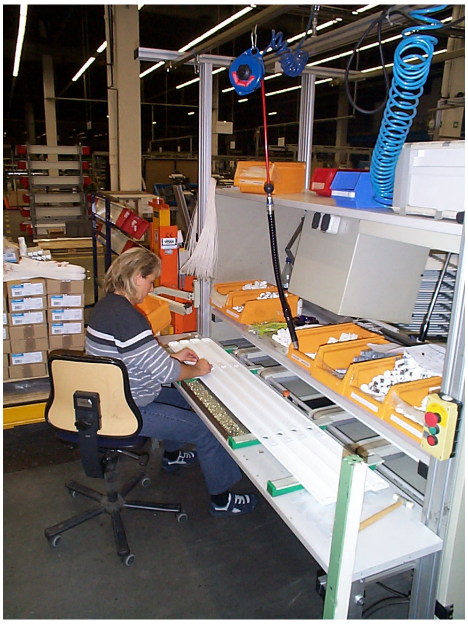

Figure 1, **a** (top): Type 1 workstation before the lighting change. **b** (bottom): Type 2 workstation before the lighting change.

2.2.2 The situation during the study period

The work and workers remained the same before and during the study. Only the lighting installation was changed. Figures 2a and 2b show the workstation after the change (during the study period.) New dimmable lighting was installed in both types of workstations. There were two lamps (Philips 54 W T5) with different colour temperatures (2700 K and 6500 K) in this the task-lighting luminaire, and the balance between them could be changed to achieve different colour temperatures. To make colour temperature differences more visible and to limit the effect of the task lighting on the other adjacent workstations, a white canopy and a partial-separation wall were added. The general lighting remained unchanged, but these new screening structures reduced the amount of general lighting available at the workstation.

Type 1 workstation (Lighting installation during the study - Figure 2a)

The luminaires were installed at a height of 225 cm above the floor, and the table height was 70 cm. The general lighting provided a constant illuminance of 200-300 lux at the middle of the tables, while the task lighting provided a maximum of 700 lux in addition to this.

Type 2 workstation (Lighting installation during the study - Figure 2b)

The luminaires were installed at a height of 218-230 cm above the floor and the table height was 93-98 cm. The general lighting provided a constant illuminance of 200-300 lux at the middle of the tables, while the new task lighting provided a maximum of 900 lux in addition to this.

Figure 2, a (top): Type 1 workstation during the study. **b** (bottom): Type 2 workstation during the study

2.3 Data logging and changing the control possibilities of the workers

In order to induce the workers select their preferred illuminances, the dimmable task lighting was regularly switched off automatically. Table 1 shows the switching schedule. Part of the automatic switching was during the official breaks. Those switch-off moments described as being 'extra' were discontinued after the first eight months of monitoring, since the workers were bothered by them. The short 'on' period in the morning was to warm up the lamps before the workers entered the area.

Table 1 Switching schedule in the study area

Time	Command	Remarks
5.50	On	Warming the lamps before work
6.00	Off	Warming the lamps before work
7.30	Off	extra off
9.10	**Off**	**break**
10.30	Off	extra off
12.25	**Off**	**break**
14.00	**Off**	**break**
15.15	Off	extra off
16.30	Off	extra off
18.15	**Off**	**break**
19.30	Off	extra off
21.00	Off	secure switch-off after work
22.00	Off	secure switch-off after work

In order to restore the lighting after switch-off, the workers had to switch it on again using their infrared transmitters. They could then set the lighting level to their preference. The switch-on level of the lamps was varied between four different situations, which are shown in Table 2. Changing of the switch-on situation was normally done on Friday evening. During the 16-month measuring period, the settings were changed 44 times. Each time, one of the four settings was on for an average of somewhat less than two weeks. The workers were able to readjust the lighting level whenever they felt like it, but they could not change the colour temperature. To increase or decrease the level, the workers had to press the button until the lighting level was the level they wanted. From the lower presets it took more than four seconds to reach maximum. The luminaires' DALI ballasts were connected to a LON bus system (Local Operating Network), and the selected output of the lamps was monitored between March 2004 and June 2005. For every 10-minute period, the dimming values of both lamps in the luminaire were recorded. The illuminances under the different dimming voltages at the middle of the different tables were measured. Based on these measurements, data-logged dimming levels have been transformed to the illuminances presented in this paper.

Table 2 Switch-on levels. The values in workstations types 1 and 2 are a combination of the task lighting and the general lighting and averages of values on similar tables. The table-top colour temperature is measured from white paper placed in the middle of the table, while the wall value is measured from the middle of the vertical screening wall between working areas. Illuminance values are measured from the same places.

		Lamp dimming		Test area 1 (General + Task lighting)				Test area 2 (General + Task lighting)			
	Task luminaire	Warm	Cold	Table		Wall		Table		Wall	
	CT (K)	%	%	CT (K)	E (lux)	CT (K)	E (lux)	CT (K)	E (lux)	CT (K)	E (lux)
High warm	3500	85	55	3500	740	3500	350	3600	990	3700	460
High cold	4400	52	88	3900	760	4100	360	4000	970	4300	500
Low warm	3500	12	8	3700	310	3700	90	3800	410	3700	120
Low cold	4400	7	13	3700	310	3800	90	3800	400	3800	120

3 Results

3.1 Selected Illuminances

The workers used practically the whole illuminance scale available. The values selected ranged from 250 lux to 1200 lux, peaking at around 800 lux (horizontal illuminance at the table). Since the presence of workers at a given workstation was not followed continuously, it is difficult to say exactly how often task lighting was used. Based on the workers' verbal comments, it is clear that some workers did not always use task lighting. However, based on the data gained during the productivity measurement period, when presence was also partially monitored, it can be said that during more than 75 per cent of the working time these lights were in use. There were differences among the individuals: some used task lighting nearly all the time, while others used it only rarely. The amount of data regarding the illuminances selected at the different colour temperatures correlates with the number of days that a given preset was in use. This indicates that colour temperature did not markedly influence the frequency of use of the task lighting.

The influence of preset colour temperature and illuminance on employee's choice has been studied by considering all the selections made by the workers. The statistical means of the illuminances selected depending on the preset value are shown in Figure 3. Factorial ANOVA (analysis of variance) was used for the analysis of the data.

For the task-lighting illuminance (dependent variable: task lighting illuminance; factors: colour temperature and switch - on illuminance), the ANOVA

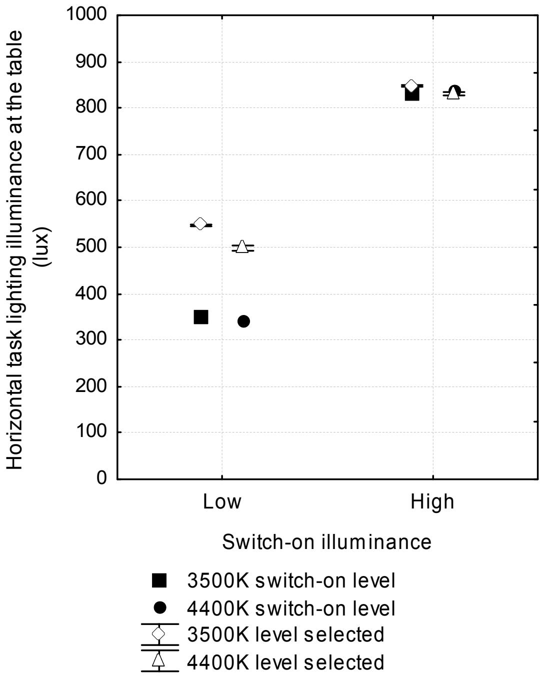

Figure 3 The influence of the colour temperature and the switch-on illuminance on the illuminances selected (task lighting + general lighting for all selections made on both workstation types).

showed a significant main effect for the factor colour temperature ($F(1, 48213)= 295.8$, $p<0.01$). Also the main effect for for the factor switch-on illuminance was significant ($F(1,48213)=26294$ $p<0.01$). And the interaction between colour temperature and switch-on illuminance was also significant ($F(1, 48213)=62.8$, $p<0.01$).

The preset colour temperature at switch-on had a significant effect on the illuminance selected by the worker. When the colour temperature of the task-lighting luminaire was 3500 K, workers selected illuminances that were 5 per cent higher than when it was 4400 K. The influence of the switch-on illuminance of the task lighting was considerably more noticeable. When this was high, workers selected task-lighting illuminances that were 60 per cent higher than when the switch-on illuminance was low.

When preset illuminance values were high, the difference in the selected illuminances was small under different colour temperatures (Figure 3). When lower preset illuminance values were in use, workers tended to increase the task-lighting illuminance, so influencing the mixed colour temperature on the table and wall. However, the average colour change on the table was less than 100 K towards a colder value when the starting value of the illuminance was low and the colour temperature of the luminaire was 4400 K, and less than 100 K towards a warmer value when the starting value of the illuminance was low and the colour temperature of the luminaire was 3500 K.

The effect of the time of the day on the illuminance selected was tested by using the data type 1 workstations - in these workstations, employees also worked in the evening. The results of one-way ANOVA (independent variable: illuminances; factor: time) showed very small differences. During the morning shift, average illuminance values per hour varied between 621 lux and 643 lux. During the evening shift, the variation was from 603 lux (1800-1900 hours, this time the evening shift included a meal break) to 670 lux (2100-2200 hours - last working hour). Evening-shift differences in selected illuminance were statistically significant ($p<0.05$) but still small.

The data from the Type 1 workstations were also employed to find out if selections during bright months (May, June, July and August) differed from other periods. When the switch-on value was high, there were no real differences. The same was true for the low switch-on value when the colour temperature was 3500 K. However, when the colour temperature was high and the switch-on level was low, there were statistically significant differences in selected illuminances (bright months on average 580 lux; other months on average 380 lux).

3.2 Productivity

The influence of the preset colour temperature and illuminance on productivity was studied by collecting productivity figures from type 1 workstations between August 2004 and April 2005. A total of 26 individuals were working in the area during that period. Productivity of the assembly work is calculated by comparing planned and real working time. The nominal value is 60 minutes, so if a worker does 150 minutes work in 100 minutes, the productivity value is 90 minutes. If the same work were to take 200 minutes, the value would be 45 minutes. So the higher the value, the higher the productivity. Values in Figure 4 are average daily values and they have been shown for the different switch-on colour temperature and switch-on illuminance values. Factorial ANOVA (analysis of variance) was used for the analysis of the data.

For the productivity (dependent variable: productivity; factors: colour temperature and switch-on illuminance), the ANOVA showed a significant main effect for the factor colour temperature ($F(1, 323)= 4.9$, $p<0.05$). The main effect for the factor switch-on illuminance was not statistically significant ($F(1,323)=0.32$, $p=0.57$). The interaction between colour temperature and switch-on illuminance was not significant (F(1, 323)=0.33, p=0.57).

The colour temperature of the task-lighting luminaire had a significant effect on productivity. When the colour temperature was 4400 K, productivity was 5.7 per cent higher compared to when it was 3500 K. The switch-on illuminance did not significantly affect the productivity.

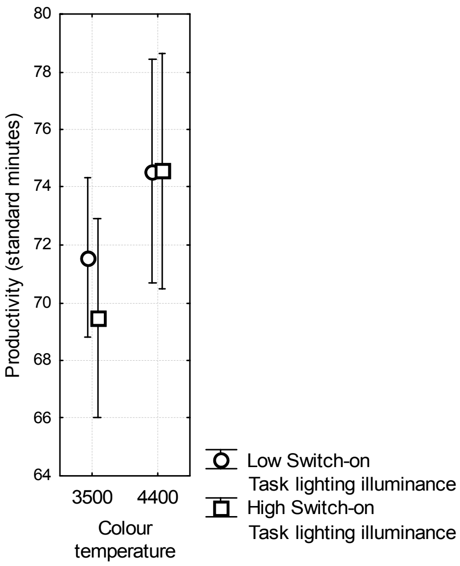

Figure 4 The influence of the colour temperature and the switch-on illuminance on the productivity. Higher value means higher productivity. Vertical bars denote 95 per cent confidence intervals.

4 Discussion

The possible errors in the illuminance values that are presented in this paper are caused mainly by the temperature behaviour of the lamps and the differences between the workers. T5 lamps are very temperature sensitive. When the worker switches on the cold lamps and chooses a lighting level, the lamps will warm up (slowly) and after some time the light output will increase. This is especially true at low dimming levels. The main difference between workstations was their location with respect to the general lighting, which was therefore slightly different at each workstation. Part of the results presented here are therefore averages for all eight workstations. The most important "error" factor was most probably the individual worker - way of working, hairstyle, colours of the clothing, etc., influence the lighting level on the task area. Also, shadows cast by the worker result in a lower lighting level in the task area than that measured on the empty table, which was the value employed in this work.

The presence of the workers at workstations was not monitored during the whole test period. It is known (Juslén et al. 2005) that workers in similar situations might select very different task-lighting illuminances. But since employees' positions are not exactly known, no firm conclusions can be drawn regarding seasonal or hourly differences between the lighting levels employed or the frequency of use of the lighting.

It is interesting that the higher colour temperature seemed to result in a lower preferred illuminance. However, the 5 per cent difference mentioned earlier (Sec. 3.1) is not large enough to be discernible (perceived by the eye). The 5 per cent differences in illuminance could also be attributable to measurement errors. But since every workstation was measured individually and in the same way, it is not likely that any errors would be in favour of one colour temperature. So even if a 5 per cent error in illuminance were possible, the direction and size of the error should be the same for both colour temperatures.

It is not possible to say why colour temperature influenced the selected illuminance. However, when controlling luminaires by IR remote control it is usual to look at the luminaires whilst doing so - is something happening? does the pushbutton work? It might be that the luminaire with the 4400 K setting was seen as being brighter than the same luminaire set to 3500 K. This "brightness" difference might have created the illuminance difference when workers were actually aiming for more or less same the same value. Some early studies provided evidence that the higher the colour temperature of a lighting, the higher is its perceived brightness (Harrington, 1955; Alman, 1977). But also some more recent studies have been carried out that show that this connection does not exist (Boyce and Cuttle, 1990; Hu et al. 2006). It might be that the connection is more complicated than just colour temperature - colour rendering might also have an effect (Fotios, 2001)

The differences in selected illuminances under different colour temperatures are interesting, especially since the higher colour temperature resulted in higher productivity. So for productivity as well as for energy reasons, these results seem to indicate that a higher colour temperature (4400 K) is a better solution for task lighting than a lower colour temperature (3500 K). Colour-temperature differences are small at the workstation (400 K at the table between higher illuminance presets). On the wall, in front of the workers, differences are a little bit higher (600 K between higher illuminance presets), because less general lighting and more task lighting enters that area. Illuminance differences at the workers' eyes are probably greater since wall and canopy cut off most of the direct general lighting. Light entering the workers' eyes comes directly from the task-lighting luminaire or via reflection from the wall (mainly task lighting) or from the table. Laboratory studies have shown that bright light influences the alertness and cortisol suppression of people (Scheer and Buijs, 1999; Leprout et al. 2001). It is also stated that bright light improves vitality and alleviates distress in healthy people (Partonen and Lönnqvist, 2000). When we examine the results of recently-found action spectra of the photo-biological effects (Brainard et al. 2001), we see that the productivity results of this present study might be explained by this. A higher colour temperature might have resulted in higher productivity by increasing the alertness of the workers. However, the temperature difference is quite small (3500 K/4400 K) and it is unlikely that the result is purely biological. Another possible reason for higher productivity could be improved visual acuity. There is some evidence that a higher colour temperature improves near-visual acuity (Berman et al. 2006). However, since employees used 5 per cent lower illuminances in the higher colour temperature situation compared to those used in the lower colour temperature situation, this is not likely to be the only reason.

The illuminance selection results were different in this work compared to that described in the study by Juslén et al. (2005), where the subjects were using more or less the same lighting level whatever the preset values or dimming speeds. In this case, the preset value clearly influences the illuminance selected. With a high preset level, the workers just switch on the light, whereas with low presets they increase the lighting, but not to such a high value as with high preset levels. However, the difference was only 300 lux. The total range in this study (300–1000 lux) was small compared to the 200–3000 lux range that was employed in the study of Juslén et al. (2005).

5 Conclusions

The results of this study suggest that for a lower use of energy as well as for higher productivity, the colour temperature of the dimmable task lighting system should be around 4400 K rather than around 3500 K. The results indicate that for increased productivity, the colour temperature increase of 3500 K to 4400 K is a more important factor than the illuminance increase from 500 lux to 800 lux. It can be concluded that in these circumstances:

- The 4400 K preset colour temperature resulted in a 5.7 per cent higher productivity than did the 3500 K preset value of the task lighting.
- Illuminance (520/820 lux) did not influence productivity.
- The 4400 K preset colour temperature led to 5 per cent lower illuminance selection than did the 3500 K preset value of the task lighting.
- The lower preset illuminance led to significantly lower selected illuminances than did the higher preset illuminance.
- Dimmable task lighting was actively employed.
- Selected illuminances of the dimmable task lighting varied considerably.

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APPROACH ON NUMERICAL MODELLING OF BRANCHED DAYLIGHT GUIDING SYSTEMS

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Among the numerous daylighting strategies, there are only few of them bringing natural light within deep spaces inside buildings and even fewer being capable of guiding daylight to blind spaces having no connection to the outside. There has been a continuous challenge in increasing the efficiency of such daylight guiding techniques; however, because of the light losses, it is still difficult to build branched light pipes that should lit different interior spaces using daylight from a main supplying duct. This paper shows the results of such an experiment, based on natural lighting systems using a 98% reflectance pure silver based aluminium, which makes promising any initiative in constructing a branched daylighting system.

Keywords: daylight guiding system, branched pipe system, numerical model.

1. Introduction

The light-pipe is a secondary light source that transmits light from the primary (natural or artificial) source within interior spaces, to a specific target or on specific reflecting or transmitting surfaces [1].

Light transmission is done at the end of the light-pipe, where light is distributed and directed depending on task particularities, or by side transfer towards specific targets. Light-pipes transmit light radiation through total internal reflection.

The light-pipe is perhaps the most technologically exciting of innovative daylighting systems because of the long distances over which it can operate. In principle, light-pipes collect, direct, and channel daylight into virtually any area of a building. The system consists of three main components: heliostat or light dome (collecting and concentrating unit), transport system (reflective conducts) and emitter (distributing light into the targeted space). The use of light-pipes can increase energy savings, but generally system efficiency is low because of light losses within ramification or direction changing [8].

There are specific light-pipe systems for roof applications, known as solar tubes. These systems maximize the concept of renewable energy by reflecting and intensifying sunlight and even normal daylight, down through a highly reflective silver mirror-finish aluminium tube. As compared to heliostat collecting units, the solar tubes have the advantage of collecting sunlight and skylight by fixed domes. These domes collect daylight for any sun position in the sky, without consuming energy for lens rotations.

Other systems are basing on the micro-prismatic film performing total internal reflection and having 0.98 reflectance. The internal reflectance is produced within the structure of the 0.5 mm thick optic film, made of transparent acryl or polycarbonate [7].

2. The SunPipe natural lighting system

This system developed by the British manufacturer Monodraught Ltd. is a revolutionary new way to pipe natural daylight from the rooftop into the building to brighten areas from dawn to dusk where daylight from windows cannot reach, even on overcast days [4].

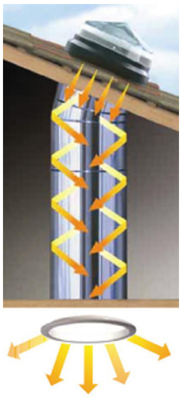

Figure 1 How the SunPipe works.

The diamond dome specially designed to maximise the capture of sunlight collects both direct sunlight and diffused daylight. The faceted top surface catches sunlight from any angle and the vertical prisms at the base of the diamond dome capture low level light, i.e. early in the morning and late in the afternoon.

Global daylight is piped down into the desired room by means of silver-coated aluminium pipes with a mirrored surface internally. At ceiling level, the diffuser has the ability to distribute the light in every direction, giving an even spread of light throughout the interior space (see Figure 1).

A SunPipe can be almost any length that is needed, but loses 6% of light for every metre. There are different SunPipe diameters, from 230 mm to 1000 mm, typically lighting up areas of 6 to 70 sq. metres. SunPipes have a 98% reflectance, which means that there is 2% loss on every bounce, so the longer the light-pipe, the greater the loss is and in addition, there are losses through the roof dome or light collector and the ceiling diffuser.

Nevertheless, the performance of a light-pipe is remarkable and typically, the 300 mm diameter SunPipe can light up an area of 10 sq. metres to a normal daylight level, that is, without the need for electric lighting during normal daylight hours [5]. Larger light-pipes, of 450 mm and 530 mm diameter, are used in larger offices and buildings with higher ceilings.

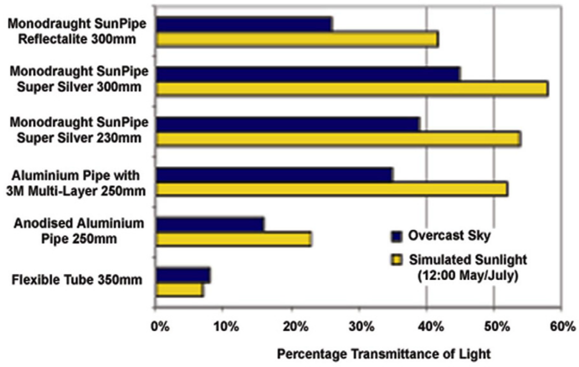

Figure 2 Results of the test on SunPipe.

Tests carried out by the BRE (Building Research Establishment) showed a 68% increase [5] of the lighting performance on the 300 mm diameter for the new Super Silver SunPipe as compared to the original anodised aluminium SunPipe (see Figure 2).

3. The branched SunPipe prototype

The lighting performances of the SunPipe are indeed remarkable and make this system a revolutionary solution for the lighting of many interior spaces that otherwise would need electric lighting.

The idea of creating a prototype of a branched SunPipe emerged from the need of distributing daylight in several points along the light-pipe. Therefore, a T-ramification was created in order to bring daylight from the vertical main duct by means of a horizontal secondary duct to an imaginary interior space located between the diamond dome and the ceiling diffuser installed on the main duct.

Figure 3 Branched SunPipe prototype.

A Super Silver 300 mm diameter SunPipe was used as vertical main duct and a Super Silver 230 mm diameter SunPipe was used as horizontal secondary duct (see Figure 3).

Firstly this prototype branched system was supplied with electric light from an incandescent lamp imitating the diamond dome collecting unit. Horizontal illuminance and vertical illuminance were measured along the axis of the main pipe and along the interior wall of the main pipe respectively, both with and without the 230 mm diameter branch.

Basing on the measured values, a modelling equation was created using the Levenberg-Marquardt method to solve nonlinear regressions. The light losses within the vertical main duct caused by the branch, as well as the light amplification within the branch were carefully assessed.

4. The Levenberg-Marquardt method

This method combines the steepest-descent method and a Taylor series based method to obtain a fast, reliable technique for nonlinear optimization [2]. Neither of the above optimization methods are ideal all of the time; the steepest descent method works best far away from the minimum, and the Taylor series method works best close to the minimum. The Levenberg-Marquardt (LM) algorithm allows for a smooth transition between these two methods as the iteration proceeds.

In general, the data modelling equation (with one independent variable) can be written as follows:

$$y = y(x;\vec{a})$$

The above expression simply states that the dependent variable y can be expressed as a function of the independent variable x

and vector of parameters *a* of arbitrary length. Note that using the LM method, any nonlinear equation with an arbitrary number of parameters can be used as the data modelling equation. Then, the "merit function" we are trying to minimize is

$$\chi^2(\vec{a}) = \sum_{i=1}^{N} \left(\frac{y_i - y(x_i;\vec{a})}{\sigma_i} \right)^2$$

where N is the number of data points, x_i denotes the x data points, y_i denotes the y data points, σ_i is the standard deviation (uncertainty) at point i, and $y(x_i,a)$ is an arbitrary nonlinear model evaluated at the i^{th} data point. This merit function simply measures the agreement between the data points and the parametric model; a smaller value for the merit function denotes better agreement. Commonly, this merit function is called the chi-square. From the area of pure optimization, two basic ways of finding a function minimum are a Taylor series based method and the steepest-descent method. The Taylor series method states that sufficiently close to the minimum, the function can be approximated as a quadratic. A step from the current parameters a to the best parameters a_{min} can be written as

$$\vec{a}_{\min} = \vec{a}_{cur} + H^{-1} \cdot \left[-\nabla \chi^2(\vec{a}_{cur}) \right]$$

where H is the Hessian matrix (a matrix of second derivatives). If the approximation of the function as a quadratic is a poor one, then we might instead use the steepest-descent method, where a step to the best parameters from the current parameters is

$$\vec{a}_{\min} = \vec{a}_{cur} - c\nabla \chi^2(\vec{a}_{cur})$$

This equation simply states that the next guess for the parameters is a step down the gradient of the merit function. The constant c is forced to be small enough that a small step is taken and the gradient is accurate in the region that the step is taken. Since we know the chi-square function, we can directly differentiate to obtain the gradient vector and the Hessian matrix. Taking the partial derivatives of the merit function with respect to a gives

$$\frac{\partial \chi^2}{\partial a_k} = -2\sum_{i=1}^{N} \frac{y_i - y(x_i;\vec{a})}{\sigma_i^2} \frac{\partial y(x_i;\vec{a})}{\partial a_k}$$

To obtain the Hessian matrix, take the gradient of the gradient above (so that we have a matrix of partial second derivatives):

$$\frac{\partial^2 \chi^2}{\partial a_k \partial a_l} = -2\sum_{i=1}^{N} \left[\frac{1}{\sigma_i^2} \frac{\partial y(x_i;\vec{a})}{\partial a_k} \frac{\partial y(x_i;\vec{a})}{\partial a_l} - \right.$$
$$\left. - \frac{y_i - y(x_i;\vec{a})}{\sigma_i^2} \frac{\partial^2 y(x_i;\vec{a})}{\partial a_l \partial a_k} \right]$$

Now, for convenience, define the gradient vector and the curvature matrix as

$$G_k = -\frac{1}{2}\frac{\partial \chi^2}{\partial a_k} = \sum_{i=1}^{N} \frac{y_i - y(x_i;\vec{a})}{\sigma_i^2} \frac{\partial y(x_i;\vec{a})}{\partial a_k}$$

$$C_{kl} = \frac{\partial^2 \chi^2}{\partial a_k \partial a_l} = \sum_{i=1}^{N} \left[\frac{1}{\sigma_i^2} \frac{\partial y(x_i;\vec{a})}{\partial a_k} \frac{\partial y(x_i;\vec{a})}{\partial a_l} \right]$$

Note that the second derivative term in C will be ignored because of two reasons: it tends to be small because it is multiplied by $(y-y_i)$, and it tends to destabilize the algorithm for badly fitting models or data sets contaminated with outliers. This action in no way affects the minimum found by the algorithm; it only affects the route in getting there. So, the Taylor series method (inverse Hessian method) can be written as the following set of linear equations:

$$\sum_{k=1}^{NP} C_{kl}\delta a_l = G_k \qquad (1)$$

where NP is the number of parameters in the model that is being optimized. This linear matrix will be the workhorse for this method after some modification; it can be solved for the increments δa that, when added to the current approximation for the parameters, gives the next approximation. Likewise, the convenient definitions can be substituted into the steepest descent formula to obtain

$$\delta a_l = cG_l \tag{2}$$

Neither of the aforementioned optimization methods are ideal all of the time; the steepest descent method works best far away from the minimum, and the Taylor series method works best close to the minimum. The Levenberg-Marquardt (LM) algorithm allows for a smooth transition between these two methods as the iteration proceeds.

The first issue in deriving the LM method is to attach some sort of scale to the constant c in the steepest-gradient method - equation (2). Typically, there is no obvious way to determine this number, even within an order of magnitude. However, in this case, we have access to the Hessian matrix; examining its members, we see that the scale on this constant must be $1/C_{ll}$. But, that still may be too large, so let's divide that scale by a non-dimensional factor (λ) and plan on setting this much larger than one so that the step will be reduced (for safety and stability).

The second issue to formulate the LM method is noting that the steepest-descent and Taylor series methods may be combined if we define a new matrix M_{ij} by the following:

$$\begin{cases} M_{ii} = C_{ii}(1+\lambda) \\ M_{ij} = C_{ij},\ i \neq j \end{cases}$$

This matrix combines equations (1) and (2) into a convenient and compact form. So finally, we have a means of calculating the step δa in the parameters by the following system of linear equations:

$$\sum_{k=1}^{NP} M_{kl}\delta a_l = G_k \tag{3}$$

When λ is large, the matrix M is forced to be diagonally dominant; consequently, the above equation is equivalent to the steepest descent method - equation (2). Conversely, when the parameter λ goes to zero, the above equation is equivalent to the Taylor series method - equation (1).

Therefore, we vary λ to switch between the two methods, continually calculating a parameter correction δa that we apply to the most recent guess for the parameter vector. The steps that are taken in the LM algorithm are as follows:

1. Compute $\chi^2(a)$
2. Pick a conservative value for λ
3. Solve the linear equations for δa
4. Evaluate $\chi^2(a+\delta a)$
5. If $\chi^2(a+\delta a)>=\chi^2(a)$, increase λ by a factor and go back to step 3
6. If $\chi^2(a+\delta a)<\chi^2(a)$, decrease λ by a factor, correct the parameter vector by $a=a+\delta a$, and go back to step 3

Iteration is stopped when

$$\left|\chi^2(a+\delta a)-\chi^2(a)\right| < \text{tolerance}$$

5. The modelling equations

The first goal was to find a recurrence law for the light transmission. Therefore, the horizontal illuminance within the axis of the main light-pipe was measured at certain distances from the diamond dome. In order to assess the potential of light distribution through the horizontal branches, vertical illuminance on the inner wall of the light-pipe was measured at certain distances from the diamond dome.

Basing on these values, a recurrence law was found to predict the illuminance at a certain point of the light-pipe for a certain value of the external horizontal illuminance at roof level.

If E_0 is the external horizontal illuminance at roof level, then the horizontal illuminance $E_{h,l}$ within the light-pipe axis at the distance l from the diamond dome will be

$$E_{h,l} = E_0 - \varphi(l) \tag{4}$$

where $\varphi(l)$ is the recurrence function determined using the CurveExpert 1.3 software based on the Levenberg-Marquardt method of nonlinear regression.

The same applies for the vertical illuminance $E_{v,l}$ on the inner wall of the main light-pipe, which at the distance l from the diamond dome will be

$$E_{v,l} = E_0 - \psi(l) \tag{5}$$

where the recurrence function $\psi(l)$ was determined using the same method as above.

Beside the light transmission of the main light-pipe, the transmission characteristics of the secondary branch pipe were assessed. Basing on the same algorithm, the illuminance $E_{b\delta}$ at the distance δ from the ramification within the axis of the branch was expressed as a function of the initial illuminance E_b at the entrance in the branch and the distance δ:

$$E_{b,\delta} = E_b - \beta(\delta) \tag{6}$$

where the recurrence function $\beta(\delta)$ results using the same algorithm as for the main light-pipe.

The first measurements were taken using a 75 W incandescent lamp as the light source for the main duct. The illuminance within the axis of the light-pipe at the distance L=23 cm from the lamp socket's base plane was considered as the initial illuminance E_0. Several measurements were taken and the mean values are shown in the table below.

Horizontal illuminance within pipe axis			
L, cm	l, cm	$E_{h,l}$, cm	ΔE_h, cm
23	0	31,500	0
33	10	29,533	1967
43	20	28,467	3033
53	30	27,733	3767
63	40	25,833	5667
73	50	24,333	7167
Vertical illuminance on pipe's inner wall			
L	l	$E_{v,l}$	ΔE_v
23	0	12,000	19,500
33	10	9750	21,750
43	20	8850	22,650
53	30	8425	23,075
63	40	8150	23,350
73	50	7875	23,625

L is the distance from the socket's base plan at which the horizontal and vertical illuminances $E_{h,l}$ and $E_{v,l}$ are measured, l is the length at the measurement point relative to the point where the initial illuminance E_0 is measured, and ΔE_h and ΔE_v are the differences of illuminance E_0–$E_{h,l}$ and E_0–$E_{v,l}$ respectively.

In order to see the light amplification effect specific to the SunPipe, the table below shows the illuminance generated by the same incandescent lamp at the same distances as above, but in the absence of the SunPipe, and the amplification factor *AF* of the SunPipe:

Horizontal illuminance generated by the 75 W incandescent lamp			
L, cm	*l*, cm	$E_{h,l,il}$, lx	*AF*
23	0	5600	5.63
33	10	2250	13.13
43	20	1380	20.63
53	30	950	29.19
63	40	730	35.39
73	50	520	46.79

The light amplification factor *AF* is given by $E_{h,l}/E_{h,l,il}$.

For the measured values, the CurveExpert 1.3 software generated the recurrence functions using the Levenberg-Marquardt method of nonlinear regression for 23 regression models.

The most accurately found form for the horizontal illuminance function was:

$$\varphi(l) = a(l-b)^c \qquad (7)$$

if using the shifted power fit, with 0.9919 correlation coefficient, where:

a=39.358572
b=-10.332781
c=1.2648536

The most accurately found form for the vertical illuminance function was:

$$\psi(l) = (a+bl)^{-1/c} \qquad (8)$$

if using the Bleasdale model of regression, with 0.8927 correlation coefficient, where:

a=0.80990555
b=-5.5413364e^{-005}
c=0.021229594

Afterwards, the branched SunPipe system was supplied with daylight from the diamond dome light collecting unit. The horizontal branch was located at three metres from the roof level and two situations were assessed:

A – branch without mirror
B – branch equipped with mirror

The mirror was made of the same material as the SunPipe (Super Silver mirrored aluminium) and was installed at the entrance of the branch at 45 degrees rotation relative to the horizontal (see Figure 4).

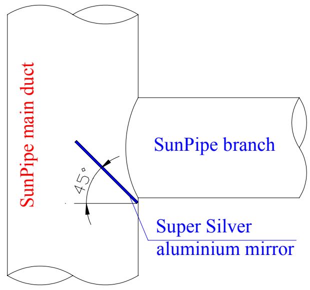

Figure 4 Mirror-supplied SunPipe branch.

The mean values of the illuminance measured within the axis of the branch for the two situations, at the same level of external horizontal illuminance at roof level of 85,000, are shown in the table below.

Branch illuminance, lx		
δ, cm	without mirror	with mirror
0	8600	13,000
17	8400	13,300
27	9100	14,800
37	8900	13,700

For the branch supplied with light directly from the main light-pipe, without a mirror, the most accurate form for the branch illuminance function, found by means of the same CurveExpert 1.3 software, was:

$$\beta_1(\delta) = \frac{ab + c\delta^d}{b + \delta^d} \qquad (9)$$

if using the MMF model of regression, with 1.0000 correlation coefficient, where:

a=8489.2571
b=17470121
c=9048.3439
d=5.4168508

For the mirror-supplied SunPipe branch, the most accurately found form for the branch illuminance function was:

$$\beta_2(\delta) = \frac{a}{1 + b + e^{-c\delta}} \qquad (10)$$

if using the logistic model of regression, with 0.6605 correlation coefficient, where:

a=14280.823
b=0.10273775
c=0.058167573

6. Conclusions

The idea of creating a branched SunPipe natural lighting system allows approaching new SunPipe applications, such as multi-floor buildings with similar superposed spaces, i.e. bathrooms, corridors, kitchens.

The experimental research undertaken by the author shows an important potential of light transmission towards these interior spaces.

It is essential to emphasize that the 300 mm diameter used for the main SunPipe is only the second from the range of SunPipe diameters. The 450 mm diameter would double the light transmission potential, while the 530 mm diameter would triple it. Therefore, the quantity of light that may be distributed at each floor grows significantly.

There is a light loss in the main SunPipe duct at each ramification, which is estimated at approximately 10%. However, the author will carefully examine this loss in future experimental research work.

The use of Super Silver aluminium mirror at the entrance of the branch will increase the quantity of light distributed by the branch by approximately 56%.

Future work will be carried out by the author to improve the modelling equations so that accurate estimates can be made for any length and diameter of the SunPipes. Nevertheless, a computer programme for dimensioning a branched SunPipe system for any application will be developed too.

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MODERN AIRFIELD LIGHTING SYSTEMS

Constantin MADA[1], Inge GAVĂT[2]
1. S.C. IPA S.A.; 2. POLITEHNICA University of Bucharest

The modern stationary and portable airfields lighting systems has as advantages high energetic efficiency, low line voltage distortion, PC control and monitoring, remote control by the serial signal or radio wireless signal.

1 Introduction

The airfield lighting systems are composed of the light fixtures (runway lights thresholds lights, approach lights) and precision approach path indicators (PAPI), the constant current regulators (CCR) for light intensity level control which provide a fixed current as independently of loads be connected to their outputs. Either CCR output current levels can be selected by the front panel switch or this switch is in remote position, controlled by remote unit (Figure 1 and Figure 2).

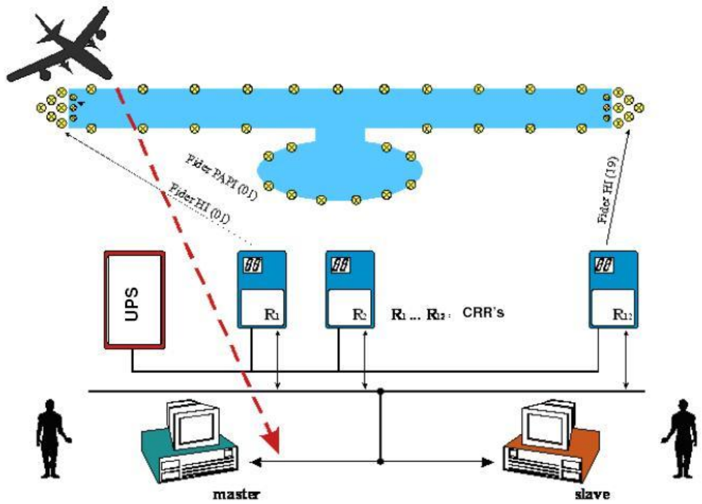

Figure 1 Airfield lighting system block diagram with remote control units [5]

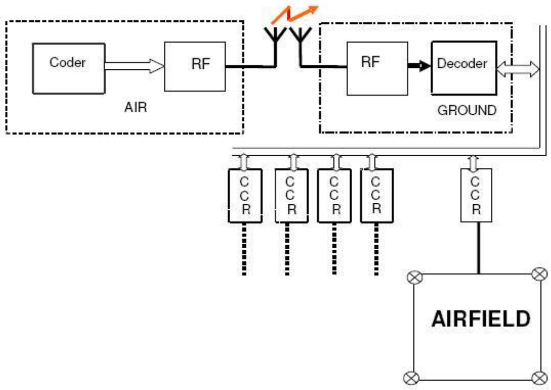

Figure 2 Airfield lighting system (heliport) block diagram with VHF wireless remote control unit [6]

2 Constant current regulators solutions

Classic solution

In classic variant [1], the power part of the CCR is by thyristor phase shift electronic switching control (Figure 3).

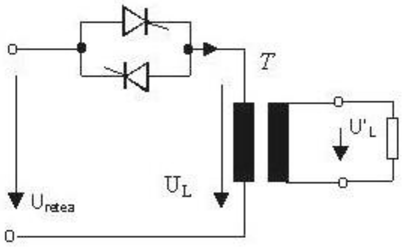

Figure 3 Diagram of the AC thyristor controller

The dependence of the output voltage harmonic content of the thyristor phase shift switching is presented in Figure 4.

The classic system [5], working by Oradea airport, is composed is in conformity of Figure 1 diagram and that concerns: the light fixtures and PAPI modules, the until 20 kW power CRR's with 5 intensities levels and communication interface, and the remote control unit for

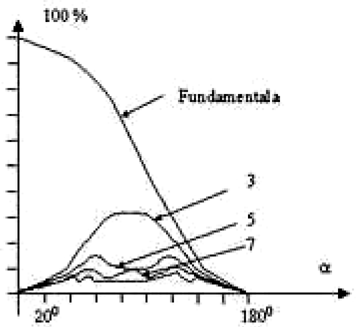

Figure 4 The output voltage harmonic content of the AC thyristor controller.

transmission of the serial signal (RS 485). The system interface indicates real-time airfield lighting status and allows users to program automatic and pilot controlled lighting options. The airfield lighting system poster is in Figure 9 presented [6].

The great disadvantage of this solution is the accentuated dependence of the output power and of distortion factor by the phase shift angle α. Expensive auxiliary equipments are necessary for the reactive power and harmonic content compensation.

Observation: For portable airfield lighting system, for optimal packing and storage, system and light fixtures are stored in two separate trailers. The first trailer is a system trailer, carries all necessary cabling and control devices and second trailer is used to store the light fixtures.

Proposed solution

In proposed solution we utilize a PWM AC IGBT chopper [2], [3] (see Figure 5).

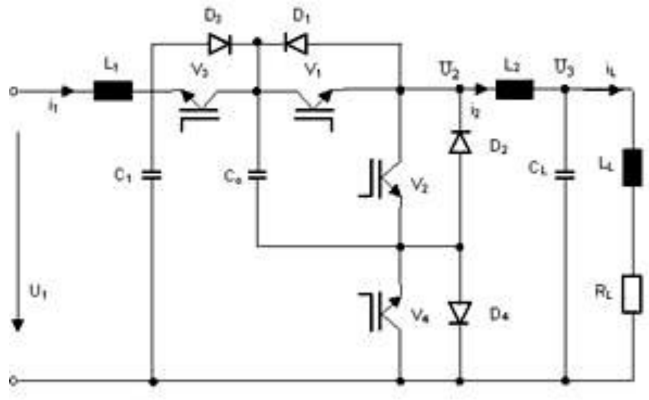

Figure 5 The diagram of the PWM AC IGBT chopper

The solution allows a modulation strategy for the output voltage and input current harmonic content reduction (see Figure 6). A residual filterable harmonic content remains (the 11, 13, 15, and 17 harmonics).

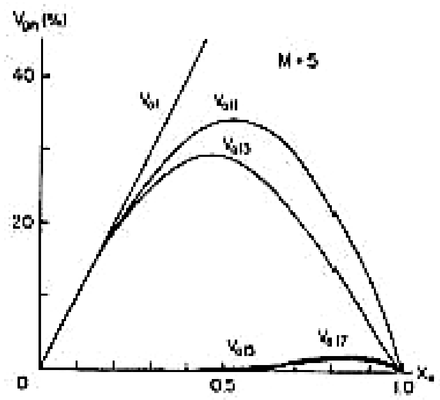

Figure 6 Output voltage harmonic content of the PWM AC chopper

Remote control of the airfields lighting systems (heliports)

A variant [4] with radio wireless remote control in Figure 7 is presented. This is a simplified variant of the figure 2 solution.

System light intensity levels can be remote controlled by any air band radio wireless, which usually exists as on board transceivers (in conformity of I.C.A.O. – International Civil Aviation Organization requirements). By clicking known number of times on – off the PTT switch, light intensities are changed. In the radio receiver control box, a microcontroller board with decoder manages the communication and controls the lights. In Figure 8 an example for the receiver decoder is presented.

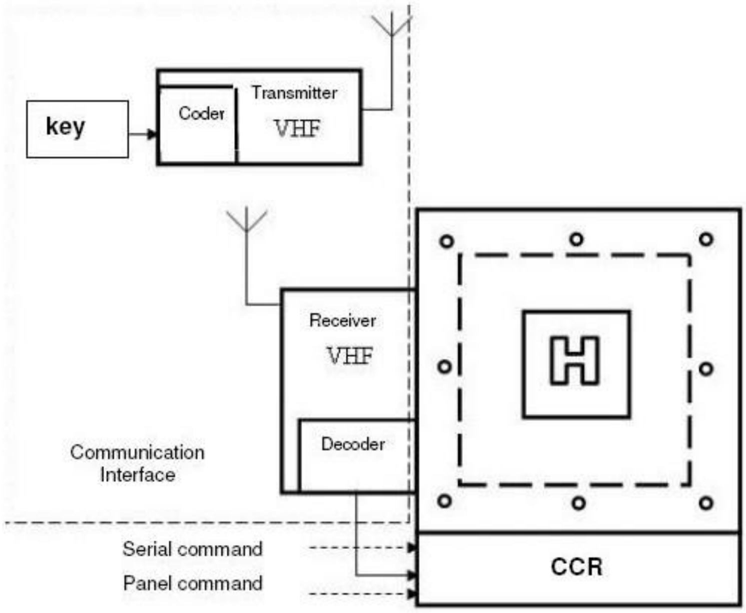

Figure 7 Radio wireless remote control and the communication interface block diagram

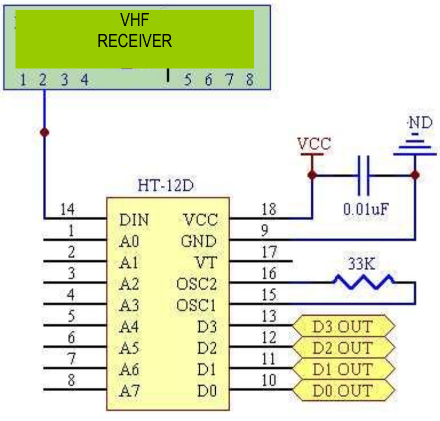

Figure 8 The diagram of the experimented receiver decoder

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Annex 1

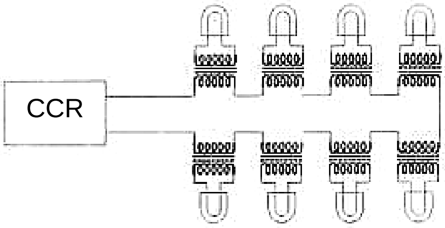

Figure 1A1 Serial powered circuits

Runway edge fixture: 30/45 W portable (clear), include transformer, 50 pcs
Approach light fixtures: 100 w portable (clear), 6 units
Taxiway light fixtures 30/45 W portable (blue)
Papi: 2x200 W portable, 2 units
Light bulbs: 45 W, 100 W, 200 W halogen
Constant current regulator: 5 kW
Cable: 3000 V, 200 kG/1000 m

Annex 2

The Fourier coefficients of the $U_L(\omega t)$ by thyristor phase shift electronic switching control (Figure 1A2) are:

$$U_L(\omega t) = \sqrt{2}U\sum_{n=1}^{\infty}\left[a_n \sin(n\omega t) + b_n \cos(n\omega t)\right]$$

$$a_n = \frac{1}{\pi}\left\{\frac{1}{n+1}\left[\sin(n+1)\alpha\right] - \frac{1}{n-1}\left[\sin(n-1)\alpha\right]\right\}$$

$$b_n = \frac{1}{\pi}\left\{\frac{1}{n+1}\left[\cos(n+1)\alpha - 1\right] - \frac{1}{n-1}\left[\cos(n-1)\alpha - 1\right]\right\}$$

$$c_n = \sqrt{a_n^2 + b_n^2}$$

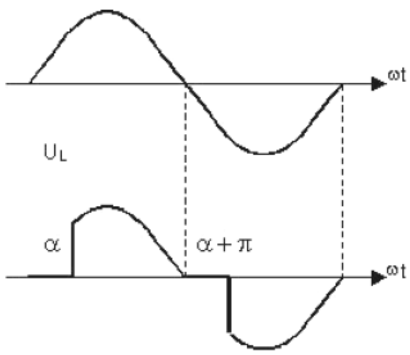

Figure 1A2 The wave forms for the AC thyristor phase shift chopper

The Fourier coefficients of the $U_2(\omega t)$ by PWM AC IGBT chopper (see Figure 6) are:

$$U_2(\omega t) = \sqrt{2}U_1 \sum_{n=1}^{\infty} \left[a_n \, sin(n\omega t) + b_n \, cos(n\omega t) \right]$$

$$a_n = \frac{1}{\pi} \sum_{k=1}^{2M} (-1)^k \left[\frac{sin(1-n)\alpha_k}{1-n} - \frac{sin(1+n)\alpha_k}{1+n} \right]$$

$$b_n = \frac{1}{\pi} \sum_{k=1}^{2M} (-1)^k \left[\frac{cos(1-n)\alpha_k}{1-n} - \frac{cos(1+n)\alpha_k}{1+n} \right]$$

$$c_n = \sqrt{a_n^2 + b_n^2}; \quad \varphi_n = arctg(b_n / a_n)$$

Observation: for $2M=1$, we find the AC thyristor chopper relations.

The switching commutation pattern is:

$$0 \le \alpha_1 \le ... \le \alpha_k \le ... \le \alpha_{2M} \le \pi$$

If we impose the conditions:

$$n = 1: \quad c_1 = x_0 = U_2 / U_1$$

$$n > 1: \quad c_n = 0 \quad for \quad n = 3, 5, 7, ..$$

we obtain $2M$ equations (M is the pulses number in half period), and the switching pattern (α_k and the V_m wave form) for $2M - 1$ harmonics cancellation. The Figure 6 presents the evolution of the residual harmonics for 5 pulses/half period in function of the x_0 parameter (Figure 2A2).

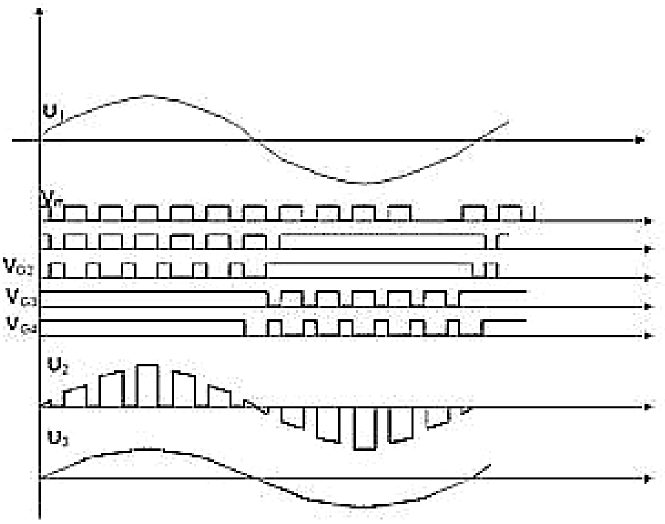

Figure 2A2 The wave forms for the AC PWM chopper (V_{Gk} are the gate drive impulses and V_m the modulation signal

LIGHTING IN THE NEW WORLD

Cristian ŞUVĂGĂU
BC Hydro, Vancouver

STREET LIGHTING DIMMING

The recent blackouts throughout North America as well as an increasing demand for power have opened our eyes to what we often take for granted – reliable electricity. Unfortunately we can't continue using electricity at will without considering an increase in power conservation. Utilities and municipalities and consumers must seek out new and innovative ways to reduce our power demands to ensure future generation can benefit from what we have enjoyed – uninterrupted delivery of reliable electrical power. In fact all communities should be strongly encouraged to find innovative ways to save power.

A significant emerging innovation that will save significant amounts of power involves the dimming of street lights. This new technology, developed by Streetlight Intelligence (STI) from Victoria, British Columbia, Canada allows street lights to be dimmed at night. The system brings two more additional benefits:

- asset management by tracking luminaire outages and highlighting using mapping software via the Internet
- accurately measure actual energy consumed by each luminaire.

While one might question the overall impact of dimming street lighting, it is estimated outdoor roadway lighting accounts for as much as 30% of the average municipality's electricity consumption throughout North America.

Current standards produced by the Illuminating Engineering Society (IESNA) used throughout North America set minimum standards which are often exceeded by designers. There is little evidence to show lighting beyond these standards has any benefit. If the majority of street lights in North America could be dimmed even 10%, the amount of energy saved would be significant. This conservation effort alone could delay or even preclude the construction of additional power generating and distribution infrastructure, resulting in significant dollar savings and reduced environmental impacts.

Estimate 64 million street lights in North America. Estimated power consumed in a year would be approximately 51,000 GWh. Just imagine 20% reduction in off peak evening hours: that is over 5,000 GWh per year, enough to power over 500,000 homes annually.

The Hardware Technology

The dimming of street lights has been reviewed and considered by various organizations over the past 30 years in

North America. Due to the high cost of the necessary hardwiring, however, it has not been viewed as a cost effective option. The new technology provided by STI uses industry standard wireless technology to make a luminaire dimming/asset management system cost effective (Figure 1).

- ***The dimming unit.*** The STI technology includes a *Lumen IQ* unit that would be retrofitted into each existing "cobra head" street light housing within the project area. Each *Lumen IQ* unit controls the single street light in which it is installed. Functions controlled by the unit include:
  - traditional night/day on and off functions based on ambient light levels,
  - dimming based on programming and feedback provided by a sensor unit.
- ***Field Data Collectors*** (FDC) consolidate and manage the information from groups of *Lumen IQ* units via wireless communication. The FDC is mounted in a separate external enclosure on one of the street lighting poles in the group (one FDC unit can manage up to 500 dimming units).
- ***The Central Data Collector*** (CDC) represents a communications software used by the central Data Server to manage data from each *Lumen IQ* unit.
- ***The Data Server*** (DS) stores all of the data from each *Lumen IQ* unit in a series of linked databases, and provides information to and from the street lights and the customer's computer through a web interface. The server includes also specialized GPS mapping software for coordinating poles' location.
- ***The Customer PC*** monitors and interacts with teach *Lumen IQ* unit via Internet. Via the browser interface, the PC sends and receives data to and from the CDC, which in turn communicates with the appropriate FDC and each *Lumen IQ* unit.
- ***Handheld Data Collectors*** (HDC) are Pocket PC units with wireless capabilities used in the filed by maintenance crews to communicate with each individual *Lumen IQ* unit via the 900 MHz band. Electricians can set up new units, adjust the dimming ranges or download information regarding the functionality of the lamps, ballasts and luminaires from the ground, saving thus considerable maintenance resources.

Communications

- ***Wireless RF Network.*** Multiple *Lumen IQ* units form a wireless network. Each unit includes a custom 900 MHz wireless RF communications module. HDCs also communicate with the *Lumen IQ* units by RF.
- ***Cellular Telephone Network***. Each FDC is connected to the server by typical mobile phone technologies used throughout the world: Global System for Mobile Communications (GSM) or Code Division Multiple Access (CDMA) cellular telephone connections.

The Dimming Patterns

The *Lumen IQ* technology provides a 0.8:1 reduction in power consumption for a corresponding reduction in lumen output due to electrical losses of magnetic ballasts. Laboratory testing has shown that at a 50 percent level of lumen output, power input is reduced by approximately 40 percent.

The *Lumen IQ* dimming technology allows for 60 steps of dimming at approximately 1 percent increments. This allows the unit to dim the street light from 100 percent of output (no dimming) to 31 percent of full output.

The *Lumen IQ* unit also monitors the luminaire for cycling, and turns the street light off if cycling occurs to preserve other components (ballast, ignitor, etc.). The dimming technology can be used with MV, MH, HPS, Fluorescent or LED light sources and power supplies, including electronic ballasts.

If the luminaire has been turned off due to cycling, a trouble code is provided and sent via the wireless network to the central database which would provide the information to the municipality or the highway authority maintenance personnel. A flashing LED indicator, which can be seen from the street, is then activated, indicating to maintenance personnel that the luminaire requires maintenance.

The *Lumen IQ* units also monitor actual energy consumption. This allows owners to monitor the amount of energy used by the individual street light, paying only for power that is used.

Benefits of Managed Street Lighting

The application of *Lumen IQ* technology or similar will provide numerous benefits to owners and the public:

- ***Energy conservation.*** This dimming technology can provide savings up to 40% reduction in energy consumption. Considering that street lighting accounts for between 18% and 30% of municipal electrical load, it could lead to significant economy in demand and energy consumption. For utilities and governments, the main issue with respect to dimming may be reducing peak load to delay the need to build energy infrastructure, including generation facilities which are increasingly difficult to permit and fund.
- ***Reduction in obtrusive light during periods when luminaires are dimmed.*** Reducing light output from a street will reduce obtrusive light, including spill light, sky glow and glare. This will reduce light pollution, helping astronomers who may be able to schedule their observations during hours of increased dimming.
- ***Improved maintenance efficiency.*** Monitoring individual street lights from a PC for conditions requiring maintenance will allow owners to provide maintenance in a more efficient manner. All faulty equipment is signalled promptly to the server allowing the electricians to prepare efficiently for intervention. Moreover, the GPS tag identify each pole and literally "puts it on the map" allowing for easy location coordination. Moreover, the mapping software can also generate daily maintenance routes for the electricians in order to save them time and resources.
- ***Electrical component protection for cycling luminaires.*** Cycling lamps are a current concern for maintenance crews, wasting equipment, as well as time to identify the exact light location. When cycling is detected the *Lumen IQ* unit turns off the street light, energizes a flashing LED indicator visible from the street and communicates with the server noting the event.
- ***Accurate measurement of power usage.*** Most streets in North America are not metered, the utilities charging the owners a flat rate based on the lights input power and a time consumption of approximately 4100 hours per year. The present dimming system will allow accurate measurements of power consumption (regardless if the lights are dimmed or not), ending thus the shortcomings and abuse of the flat rate system and making full financial benefit of dimming available to the owners.
- ***Equipment performance data.*** Presently, owners of street lights have difficulties in keeping accurate detailed records with respect to individual street lights characteristics: equipment health, lumen performance and maintenance, lamp quality, etc. With this dimming system, logging and keeping multiple tracks of information on equipment and trouble issues will be a very simple job. It will allow owners to even compare how similar equipment, but from various manufacturers, performs in time, for relevant design, purchase and operation activities.

Street Lighting Dimming Applications

The installation of street lighting is an engineering decision whose goal is to provide quick, accurate and comfortable visibility at night. Considering all the above mentioned benefits, the use of this technology could serve these possible applications:

- ***Roadways with varying pedestrian conflict level.*** The amount of light provided by a street lighting system is typically based on the classification of the road (function of the level of traffic: highways, collector, residential, etc) and the level of pedestrian conflict (activity). The standards are constant, regardless of the time of the night, day of the week and weather. In reality, the traffic is heavily influenced by these factors, and a given road can change classification over the night from major road with heavy traffic to collector status with minor traffic between 1AM and 4 AM for example. The pedestrian changes even more drastic with the progression of the night and inclemency of the weather. The opportunity for reducing energy on a typical urban roadway is to reduce lumen output to a medium or low pedestrian conflict level. Thus the lumen output could be reduced 30% and 50% respectively leading to energy savings up to 40% (at 50% dimming).
- ***Dimming to the maintained level.*** High Intensity Discharge (MV, MH, and HPS) lamps, the main technologies used for street lighting, depreciate considerably over their useful life. To account for this depreciation (could be up to 40%) designers must provide an initial level of lighting higher than the minimum maintained level. The dimming units could then decrease the initial output until the minimum levels is maintained, resulting in considerable energy savings. In time, as the lamps normally depreciate, the system will dim up to maintain the required light levels.
- ***Dimming over lighted areas to meet uniformity requirements***. Because HID lamps have fixed wattages, or municipalities require standardized pole heights or luminaire distribution, some areas become over lighted to meet the uniformity criteria, which is the driving factor in luminaire spacing. The dimming system could perform local dimming where these situation arise, resulting thus in significant energy savings.

Case Studies

The City of Prince George, located in northern British Columbia, Canada has commissioned in 2005 a *Lumen IQ* installation featuring over 170, 250 W HPS street lights (single light poles) on a four-lane, inner city roadway. The pedestrian conflict level was deemed high until 8PM and then variable from medium (60% of the poles) to minor (40% of the poles) through the areas along the road. The savings were approximately 47,000 kWh/year on dimming to lower pedestrian conflict rates only. The payback of the installation is expected to be about 7 yrs non-considering the maintenance benefits. Considering the very low cost of electricity for Prince George (CND 0.06/kWh), the same installation in California or New York state (where cost are 3-4 time higher) could be amortized in less than 2 years.

Another project is in development in Vancouver, British Columbia, Canada. Years ago, a CCTV monitoring system has been installed along the Trans-Canada highway within urban corridors. The designers had to supplement lighting (400 W HPS lamps rather than 250 W for usual) to accommodate for the lumen requirements of the CCTV camera of that time, resulting in over lighted environment (over 500 poles). However, the CCTV system have been recently upgraded in preparation for the 2010 Winter Olympic Games, and the new cameras require no additional light (than traffic).

The STI system will then dim half of existing light levels from 8:00 pm to 5:00 a.m., adjusting for the seasons. This application would equate to 62% of the current power consumption (savings of 180 watts per fixture) resulting in approximately 35% energy savings.

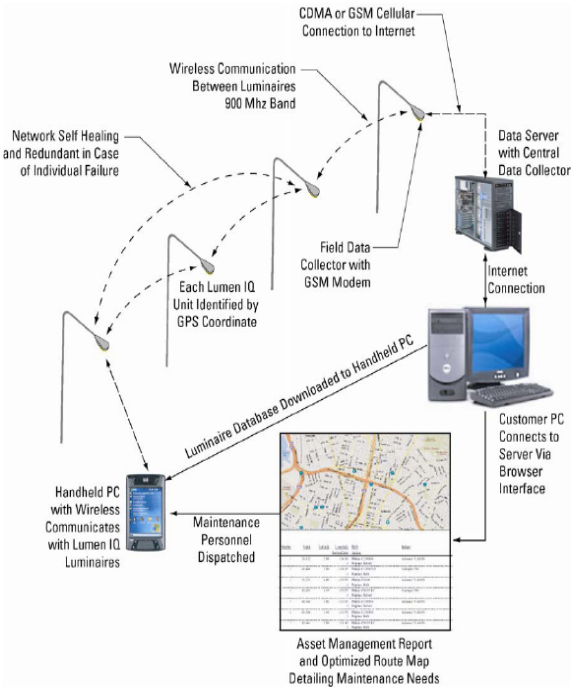

Figure 1 The Lumen IQ system overview

Conclusion

STI is only one of the lighting companies that are investigating the significant dimming potential of street lighting. Other systems from Cooper Lighting, GE and others are emerging. While their technical approaches may be varying, the benefits and the applications remain the same.

There is however some work needed on new design and operation developments, for these dimming systems to spread healthy:

- adaptive lighting standards and design criteria
- master planning to optimize the application of dimming
- new tariffs/ agreements between the Owner and Utilities.

The author wishes to recognise the contribution of Don McLean from DMD & Associate, mainly his study on the Prince George STI project.

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AMBIENT ASSISTED LIVING FOR THE AGEING POPULATION (ALADIN)

Project consortium: **FHV Austria** (coordinator), **BLL Austria, BMT Germany, LMU Germany, BME Hungary, Apollis Italy, UPB Romania**

The overall aim is to extend our knowledge about the impact of lighting on the wellbeing and comfort of elder people and translate this into a cost-effective open solution. Adaptive lighting can contribute considerably to sound sleep and a regular sleep-wake cycle, which are essential to preserve and enhance people's comfort and wellbeing. This will assist older adults in living at home autonomously for a longer time and contribute to their quality of life.

1 Project objectives

ALADIN aims at developing an intelligent assistive system based on ambient lighting to support mental alertness and memory performance as well as relaxation in specific situations. The system is also expected to assist with regulating circadian rhythms.

The capturing and registering signals such as skin conductance, heart rate or body temperature as well as mental activity and muscle tension has to happen continuously and be integrated into people's normal living environment. For this purpose, we intend to use smart biosensors. At the same time we want to explore the possibilities of environmental sensors such as camera based thermography. Analysis and interpretation of the signals captured from these sensors make the system aware of the events and activities in its surroundings.

The system will receive the information about the impact of differences in the luminous environment on one single person's affective and cognitive state as reflected in the psycho physiological signals in one single room. It monitors if and to what extent these signals approximate previously defined target values for relaxation or mental performance. Subsequently, artificial intelligence techniques such as genetic algorithms, fuzzy systems, neural networks and case based reasoning are used to achieve the lighting best suited to the individual and/or to a particular situation. It will not be necessary to know in advance what kind of lighting is to be achieved when conceiving the adaptation algorithms. Instead, optimisation will be incremental and happen in an evolutionary manner in response to and in accordance with the biosignals the system receives.

2 The features of the ALADIN prototype

The ALADIN prototype will work with single individuals living in single-person households. (in the future: The ambient lighting assistance will work with several people (and possibly with groups).

ALADIN prototype will use subliminal light stimulation. (In the future: Lighting will be used not in a subliminal way but in an explicit manner (e.g. as a guidance system)).

ALADIN will focus exclusively on ambient lighting. (in the future: The assistive system will be extended to other contextual variables such as temperature, humidity, acoustics or displays).

Smart psycho physiological sensors will be attached to the human body (In the future: measuring technology without attachment to the body, (thermography).

Software applications will be installed on mobile computers (e.g. handhelds) but will be stationary (in the future: Software application will be implemented in computer networks).

Lighting is used to enhance mental alertness as well as comfort and well-being (in the future: Lighting is applied for navigational support and guidance, e.g. in outdoor spaces or cars, or to combat depression).

ALADIN prototype is intended for use by elderly people. (in the future: The ambient lighting assistance can be used by other user groups e.g. shift workers incl. nursing staff, air traffic pilots, office workers.)

3 The components of the ALADIN prototype

An intelligent open-loop control and biofeedback system which can adapt various light parameters such as intensity, light directions or color in response to the psycho-physiological data, which are continuously registered by the system.

A control system that can be manually adjusted via graphical interfaces and allows the resetting of all light parameters to their default values. To achieve truly ageing friendly interfaces design-for-all principles will be applied which take into account changing levels of capability due to age.

An application that can assist older people in better understanding their own affective-cognitive states including their circadian rhythms and enable them to take responsibility for regulating them. This, in turn, will help them accomplish their daily activities.

4 S & T objectives of the Project

Investigate by means of quantitative and qualitative methods such as questionnaires, in-depth interviews and ethnographic observation in a real-life environment which activities/situations and their related emotional-cognitive states in older people are susceptible to the influence of lighting.

Measure the psycho-physiological reactions, e.g. increased alertness or relaxation, of older people to light and lighting parameters such as contrast or intensity within one single closed room. These data will be gathered in the course of lab experiments using the whole range of psycho-physiological measuring techniques.

Correlate these measurements with the results obtained when test persons perform the activities or find themselves in situations determined in O1 and thus ascertain which psycho physiological processes or states trigger or accompany the desired effects such as increased concentration. Develop a general model for the correlation of light parameters with the desired emotional and cognitive states.

Taking into account the most recent scientific findings from the fields of gerontology, medicine and psychology as well as relevant research results of partners about the connection between health and lighting, we will compile the advice to be given about preserving the mental and physical fitness of older people.

Investigate how psychological phenomena (e.g. attention or concentration, drowsiness vs. alertness) can be continuously measured with older people by means of physiological indicators (e.g. heart and electro dermal activity, muscle tension) in an unobtrusive way. Apart from non-invasive sensor devices we shall also examine the application of thermography.

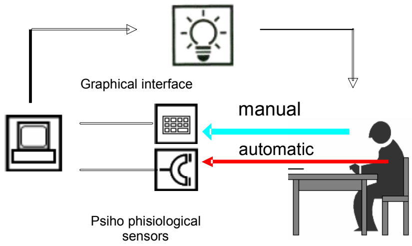
Select/develop the algorithms to enable the computer system to adapt light parameters automatically to subliminally induce the desired effects in older people. In the case of the biofeedback system this will be achieved by means of genetic algorithms, fuzzy systems and Markov models, whereas neural networks and case based reasoning will be used when it comes to manually adjusting the light settings.

Develop interfaces that allow users to easily change the parameters of ALADIN prototype and to apply the biofeedback application. The software applications will be based on open source solutions. The usability and accessibility of graphical interfaces will be ensured and optimised through iterative user tests and expert reviews.

Visualize the psycho-physiological data in a way that makes it easy to understand how physiological, psychological and physical/bodily conditions as well as people’s life style are interrelated. Again, software applications will be based on open source solutions and data visualization optimised via user tests (e.g. eye tracking) to achieve the desired results.

As an accompanying measure, recent findings in medicine and psychology on the factors influencing older people’s mental and physical fitness and comfort will have been gathered, analysed and categorised paying particular attention to the role played by lighting (e.g. artificial vs. daylight). This will be translated into a series of general recommendations and suggestions that people can follow in response to the psycho-physiological conditions visualised by the above-mentioned application. In the course of our user requirements analysis, the most appropriate form for imparting this knowledge will be ascertained.

Investigate if older people become better at performing daily activities (e.g. cooking, solving crossword puzzles, relaxing, sleeping), enjoy more social contacts, and experience an overall higher quality of life after implementing adaptive, intelligent light regulation in one single closed room.



Different aspects of open loop regulation

5 Potential Impact

5.1 Economic potential and exploitation

The research carried out in the framework of the Project is expected to lead to new product developments and innovative improvements of existing product portfolios which might be translated into commercial success as well as patents. Consequently, prior estimation of potential market will be done by industry partners (Lighting Industry).

5.2 Dissemination

The academic partners will concentrate on disseminating the results of their research to the scientific community and thus contribute to the body of knowledge in human-computer interaction, architecture, ethics and related fields. This comprises publications in refereed scientific journals.

5.3 Solving societal problems

Given recent demographic developments the percentage of older adults will grow significantly in virtually every country. Technologies to help people compensate for the physical and sensory deficits that may accompany ageing therefore have become a "hot" topic. An increasing number of conferences and workshops organised by artificial intelligence is devoted to assistive technologies. Most studies show that the majority of people (>90%) want to go on living in their home as long as possible. At the same time, people's ability to look after themselves decreases with age and they often need care or support. Therefore, interest in intelligent assistive technology for older adults is growing rapidly. By enhancing the wellbeing and fitness of older adults ALADIN will contribute.

5.4 Contribution to policy developments

The Project is in line with several policy initiatives at regional, national and EU level that aim at integrating older people as well as people with disabilities into the information society.

5.5 Participation in international or national activities

All of our consortium partners are involved in R&D activities at national and international level and are therefore in a position to take into account developments relevant to the research in this Project.

The exchange of knowledge on the most up-to-date research on circadian rhythms is ensured by the participation of one of our partners in the EUClock, an Integrated Project in FP6 (www.euclock.org). This IP is actually coordinated by the Institute of Medical Psychology of Ludwig-Maximilans-Universität München (LMU-MUENCHEN), which is also the umbrella of the Generation Research Program. EUClock aims at identifying new genetic components and interactions that control the circadian clock and its entrainment.

5.6 Contributions to standards

The pre-normative research carried out within the framework of this Project will advance our under-standing of human needs and requirements about the impact of light in an indoor environment.

The most recent research in the field of hormone control by light (e.g. melatonin, circadian rhythms) will be extended and supplemented to be used as a basis for more ambitious standards. At present, there is no single standard for multimodal interfaces, which is why research concerning multimodal interfaces has to consider a multitude of standards, for instance, for input and output signals in different configurations, for image processing, for the exchange of physiological and behavioral data.

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