

Advanced Lighting Control Technologies for User Satisfaction and Energy Efficiency

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ABSTRACT

In the past various lighting control strategies have been used to save energy in lighting. Individual manual switching, light sensor based "constant light systems", daylight linked switching, time based switching or dimming and occupancy detector base switching can all reduce the energy consumption of a lighting installation. In reality many of these systems have got negative feedback from the end users.

Initial studies gave large variations in user preferences with regards to the overall lighting scene in office work. Similar findings were also published by other research teams. It was quite clear that the idea of "constant light" at work did not correlate with what the users wanted. Unexpected switching has also reportedly a negative effect on user satisfaction. These studies show that the visual requirements of human beings are a much more complex issue than what is covered by present lighting requirements. From a visual point of view it can also be argued that the present lighting solutions are using unnecessary high levels of energy. These studies have resulted in some basic ideas about new control parameters and algorithms for lighting control systems.

There are two main types of energy saving lighting control systems on the market. One system is a combination of luminaire with direct light level feed back of the space. The other is a system based on outdoor light sensors, space profiles and user input from which the system calculates the light levels of luminaires.

These studies are leaning in a direction of the use of adaptive system technologies and new sensing elements to generate the relevant control parameters. It is also shown, that to have the highest light control, it is necessary to use

multi sensor and multi channel systems in almost every case.

BACKGROUND

In the past various lighting control strategies have been used to save energy in lighting. Individual manual switching, light sensor based "constant light systems", daylight linked switching, time based switching or dimming and occupancy detector base switching can all reduce the energy consumption of a lighting installation. In reality many of these systems have got negative feedback from the end users. In the early 1990's Helvar, together with the Helsinki University of Technology (HUT), decided to study what could be done to overcome this resistance. The results of this work gave a good basis for a larger research. In 1996 a project started called IDAS. This project is mainly funded by the European Commission within the JOULE program and is coordinated by Helvar.

In the IDAS project the main objective of the research is on control systems and daylight utilisation. To find out control strategies and algorithms to gain real savings in lighting energy without reducing visual comfort and performance.

HUT has built a rotating test cell for lighting tests. The test cell can be used in lighting component, system testing, lighting evaluations and comfort tests. Dimensions of the test room are: the length 5,00 m, the width 2,75 m and the height 2,75 m (Fig. 1).

The whole test cell is placed on a 4 wheel rotating base equipped with a servo motor. The direction angle of the cell can be controlled either manually or automatically by software so that the window wall is following, for exam-

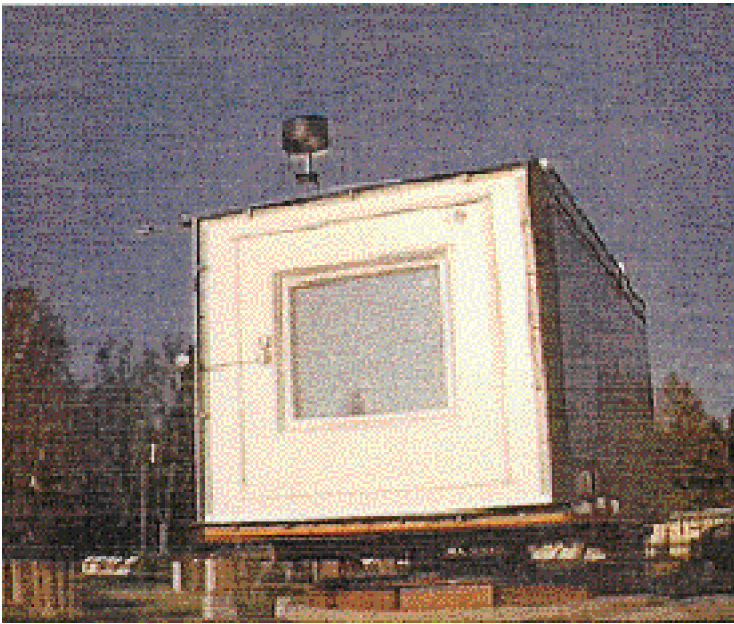


Fig. 1: Rotating test cell

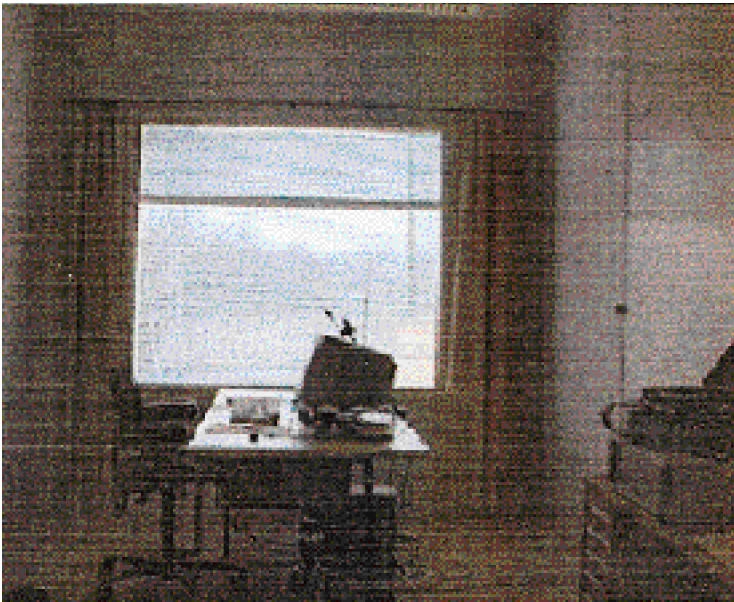


Fig. 2: A view of test cell

ple, the solar azimuth. The great advantage of the cell is that for example it is possible to carry out glare evaluation tests in various daylight conditions with short intervals.

VISUAL REQUIREMENTS

Initial studies gave large variations in user preferences with regards to the overall lighting scene in office work. Similar findings were also published by other research teams. It was quite clear that the idea of "constant light" at work did not correlate with what the users wanted.

The difficulty of maintaining the light levels as constant as possible has been usually considered as the main problem in daylight integration. However, the continuously changing amount of daylight and thus the changing lighting level in the working area doesn't seem to have any neg-

ative influence on user satisfaction. On the contrary, the lively lighting is considered refreshing compared to the constant artificial lighting. As the main problem should thus be considered as maintaining sufficient minimum illuminance level in changing daylight conditions and reducing the luminance differences between different parts of the room.

The contrast levels and the size of printed material are at present in office work usually in the range where changes in task luminances do not have noticeable effects on visual performance. The increase in luminance levels has a positive effect on the visual performance only in low contrasts and low luminance levels (15...40 cd/m²). In illuminance levels between 400...2400 lx, that are the usual levels in working spaces, there are no differences in visual acuity.

The attitudes towards the use of daylight are mainly positive. Daylight is considered to be of better quality, and the colour of the light is more comfortable compared to artificial light. Even if the colour temperature is very high, the users feel the daylight being "warmer" than the artificial light. This is caused by the continuous spectral composition of daylight, the colours seem natural, which also increases the comfort. The changes in illumination in the office caused by changing daylight are not taken as a disturbance, because of the changing nature of daylight.

An advantage of daylighting is the visual connection with outdoors. It is assumed that the importance of the window in the work space depends only partly on the availability of daylight. At least as important is the view out, the possibility to see and what's happening outside.

The windows and the use of daylight may cause disadvantages, too. The most important of them are lack of privacy, the glare and the heat caused by solar radiation.

The incoming daylight may radically change the luminance distribution of the visual field and the effects of daylight on vertical luminance values may become noticeable. When daylight is used in interior lighting, special care has to be taken to maintain the quality of lighting. Especially in offices where VDU's are used, the use of daylight must be carefully considered. Daylight may cause strong cast-shadows depending on the room geometry, window size and surface reflectances. The windows may also become a source of discomfort glare in uncontrolled daylight conditions.

As the adjustment of lighting is done with dimming controls and Venetian blinds, the user satisfaction in their use is an important question. Important facts are that the user should be able to control the lighting from the work place and the automatic control should be as imperceptible as possible.

Unexpected switching has also reportedly a negative effect on user satisfaction. These studies show that the visual requirements of human beings are a much more complex issue than what is covered by present lighting requirements. From a visual point of view it can also be argued that the present lighting solutions are using unnecessary high levels of energy. These studies have resulted in some basic ideas about new control parameters and algorithms for lighting control systems.

Satisfaction toward the lighting

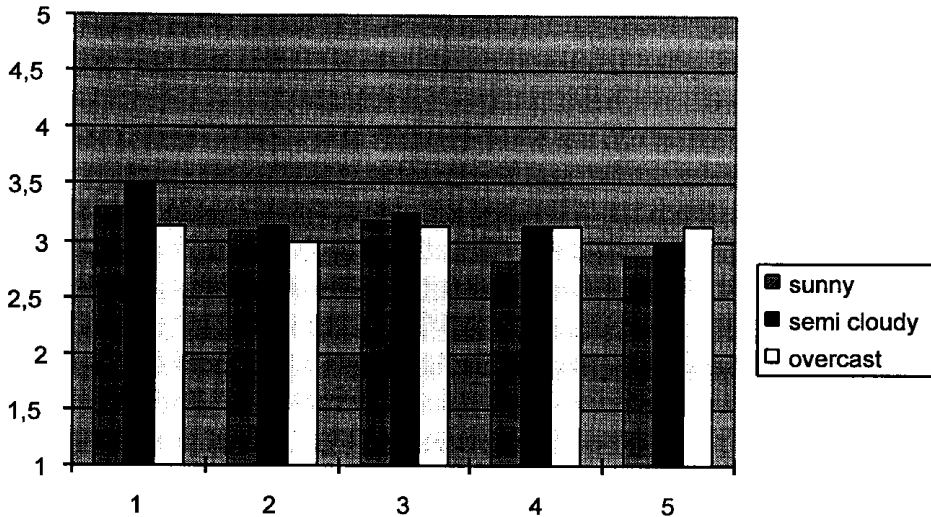


Fig. 3: Satisfaction toward the lighting in the test room. Numbers 1 to 5 refer to: 1 = amount of light, 2 = adequacy of light, 3 = evenness of the light on the desk, 4 = evenness of the light in the room, 5 = evenness between the desk and the room. On the Y-axis the numbers 1 to 5 refer to: 1 = too poor/even, 5 = too high/-uneven.

Glare in the test room 1= no glare at all, 5= glare intolerable

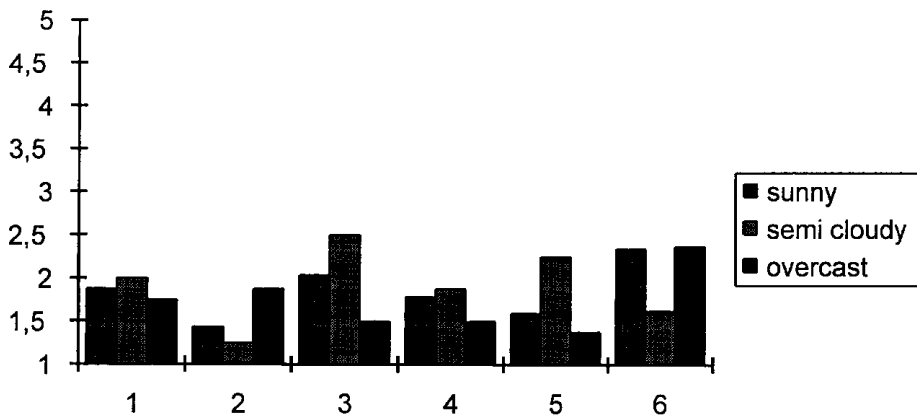


Fig. 4: Experienced glare in the test situation caused by different sources. Numbers 1 to 6 refer to sources: 1 = general assessment, 2 = luminaries, 3 = window, 4 = reflected daylight, 5 = direct sunlight, 6 = reflections on the screen. On the Y-axis the numbers 1 to 5 refer to: 1 = no glare at all, 5 = glare intolerable.

MIMO 20 and MIMO 2: Constant Light Sensor automatically controls the artificial light level complementing the amount of natural light in the room by measuring the natural light level and adjusting the control level of EL-HFC and EL-CC ballasts. MIMO 2 is designed to be installed in luminaires.

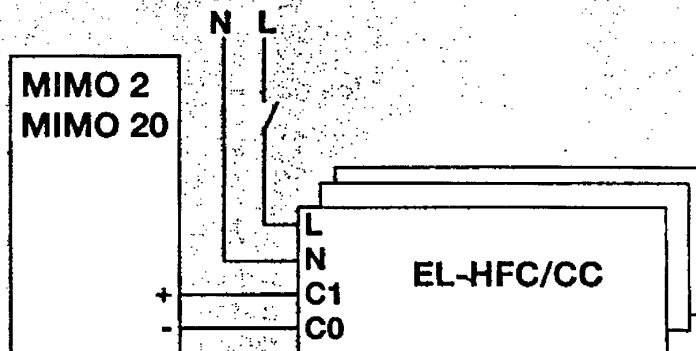


Fig. 5: MIMO 2/20: Constant Light Sensor

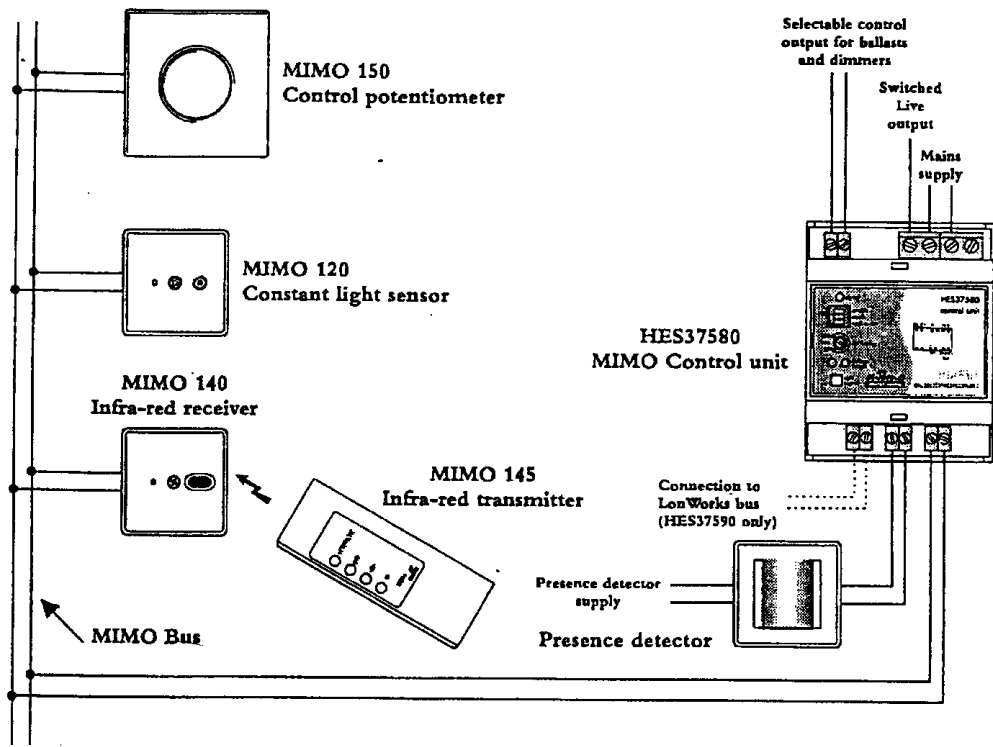


Fig. 6: MIMO 101 system

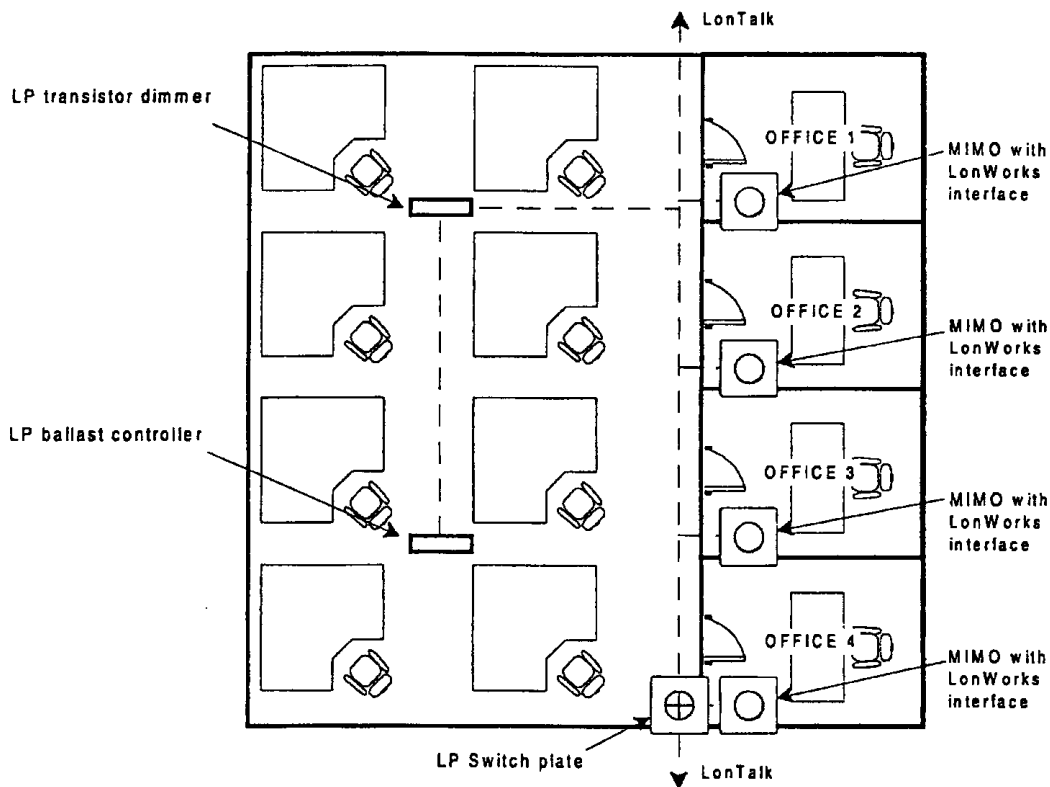


Fig. 7: MIMO 101 and LonWorks™ interface

In a study made in HUT the user satisfaction to the integrated daylight was researched in a rotating test room, that rotates according to the sun so that the sun is always shining inside the room (Fig. 2). The subjects adjusted the

lighting using the dimming controls and the venetian blinds and afterwards filled in the questionnaire. The questions concerned the glare, amount of light, distribution of light and the controls. The questions were to be answered

CONFERENCE CENTRE

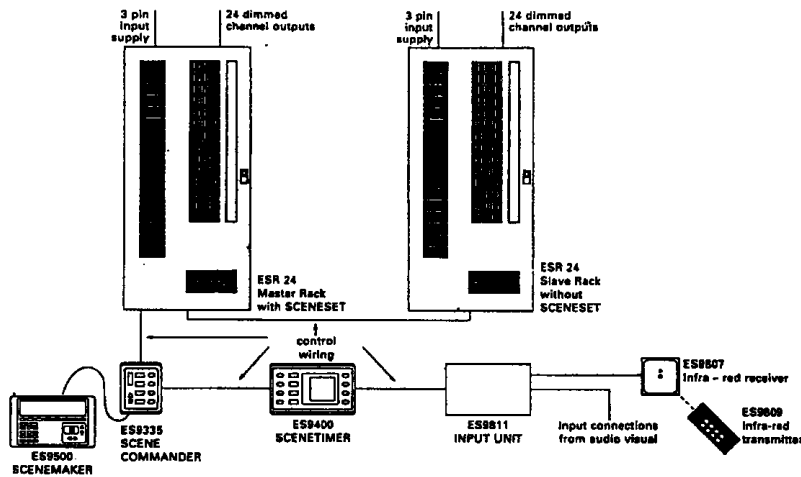


Fig. 8: IMAGINE system

in a numerical scale from 1 to 5. The open questions were used to define the numerical answers and to get answers not directed by the alternatives.

In Figure 3 are the answers to the questions about the satisfaction to the lighting.

It can be seen that the lighting is considered good (=3) in different weather situations and from different points of view. The amount of light is rather too high than too poor, especially on semi cloudy days, when the artificial lighting must be sufficient to provide adequate lighting level also when the sun isn't shining. Adequacy of lighting for reading is good or little higher in all weather conditions. Evenness of the light distribution was considered good in average, even if some of the subjects didn't understand the concept "too even". However, the light distribution was considered rather too even than too uneven, that is, most subjects seem to prefer different luminance levels in different parts of the room.

In figure 4 are the results from the glare evaluation in the test room. Even though the test room is plain with glossy white walls, the glare was not considered too disturbing. Noticeable is that glare was most noticed on semi cloudy days, when the lighting had to be adjusted to the level of cloudy weather but the moments that the sun was shining the illumination levels increased high and glare was experienced more.

Among other things this study shows that glare is not experienced very much even in sunny daylight conditions. The people's attitudes towards daylight are so positive, that glare is tolerated if it is caused by daylight instead of artificial light.

AVAILABLE TECHNOLOGIES

There are two main types of energy saving lighting control systems on the market. One system is a combination of luminaire with direct light level feed back of the space. The other is a system based on outdoor light sensors, space profiles and user input from which the system calculates the light levels of luminaires.

The most popular application is a light sensor connected directly to the luminaire. The idea is to keep the light level in the room as constant as possible, but more or less

the unit keeps light flow to sensor constant. If there are more daylight, the sensor will reduce the artificial light. As an example of constant light system is Helvars MIMO 20¹⁾ light sensor connected to luminaire equipped with dimmable electronic ballast (fig. 5).

This kind of system is the most economic way to save energy and still giving moderate or good lighting comfort. In coming days also the so called intelligent luminaries are taking market. In those, light sensor is already integrated in to the luminaire, but the control system is basically the same. These types of luminaries may also have integrated infra red (IR) remote control and/or presence detector. The main advantage of these is easy and cheap installation, but those are best in rooms where there are no other constant light systems. Two or more, on feedback based systems, may interfere to each other and the total space light level control does not work.

In cases, where there are need of direct control by a person, Helvar has a product called MIMO 100. With this product you can override the automatic control with manual potentiometers, infrared remote control. Also utilising presence detectors automatically to start or shut down lights, when you are coming or leaving the room. In latest model MIMO 101 it is also possible control two separate light channels so that one luminaire will have higher light output than the other one (fig. 6). This is very practical in rooms where the rear side is more dark than the window side, for example in sunlight conditions. There the control system helps to minimise glare and to make the light more even.

In buildings which are equipped with building management system, MIMO 101 offers a general and open LonWorks^{TM2)} interface to it (fig. 7). With MIMO 101 status and light level may also be supervised by building control system and the energy savings will be maximised.

If there are needs for even more advanced control we must have systems equipped with outside sensors. Those sensors measure the outside light level and are used to control the light level of luminaires. Because this type of system does not have any direct feedback the lighting dynamics and the control curve have to be programmed to

the system. This way the system will get theoretically best light control quality, if the parameter adjustments are done well enough. To carry out this procedure is quite time consuming and it will mean high costs. Therefore this kind of systems are mainly used only in very critical applications. In those systems it is possible to connect also world time clocks to calculate the place of sun to get even more accurate control. An example of this type system is Helvars IMAGINE³⁾ system (fig. 8). In IMAGINE system time scheduler and light sensors triggers pre-programmed light scenes, depending on the time, sun position, clouds etc. Also system settings are very often selected to the different purpose of this space. This will add the number of combination of light status. Occupation of the space is informed to the system by computer interface or push buttons.

FUTURE POSSIBILITIES

Adaptivity

To achieve all demands, especially in section 2 described, economically there are a few possibilities. It is quite well shown in this study, that to have highest light control, it is necessary to use multi sensor and multi channel system almost in every case. To achieve maximum energy savings without compromising the lighting environment also the control of curtains and blinds have to be a integral part of the system. The hardware of multi channel system is already available but to determine the lighting control functions of the space to every case will generate enormous measuring work. This work and then the system parameter setting work will generate the major and sometimes unacceptable costs. To avoid that the system should do it itself, the keyword to solve this is adaptivity.

The sensor (light and presence) is used as feedback to the system, also the optimising priorities like energy saving or lighting control quality have to be told to the system. Direct response from users through for example push buttons is the most valuable way to determine the control function operation. In systems, which normally do not have any user interface (wall switches etc.) temporal interfaces have to be done to get the response for adaptive functions. In adaptive system the function of push buttons may be less/more contrast or glare instead of less/more light. All control commands and sensor signals, carry out asked changes, they are used also as feedback to a adaptive control "engines". In cases where the system has collected enough feedback it should know how to work in each situation and in the ideal world the temporal push buttons are unused. In practical cases we all know, situations will vary and new adaptive control parameter adjusting is always needed. The system will the whole time be more close to optimal operation until user needs changes and this optimising process will be repeated. Adaptive functions always are much more complicated than fixed ones. In the complexity level of the above described system the development work for them will be enormous with conventional tools. Similar type of problems are solved with good success by tools based on fuzzy logic technology (ref. washing machines). This will be much more close to the human language and the "translation" work of response for the adaptive control engine is much less.

Hardware demands

The evolution that manual work seems to become more expensive, will continue. The hardware has also to be as easy and quick to install as possible. Earlier we stated that a high level system needs several sensors to get the best results, but this will mean more installation work. By integrating the sensors we can reduce the installation work. For the presence sensor and especially for the light sensor it means new construction.

Applying CCD (Charge Coupled Device) chips, normally used in video camera, as a matrix light sensor we will have a real multi light sensor unit in one mechanical case. The effectiveness of that type of sensors is already proven, there will be light cameras based on this technology designed for high accuracy light measurements. The cost of sensor chips is already low enough for commercial light sensor. The complexity of embedded control program for multi light sensor use of CCD element seems to slow down this type of components coming to the market. Theoretically the same sensors may be utilised as movement detector. In near future the size of needed image recognition software is too big for sensor electronics but as we all have seen the evolution of electronics is unbelievable quick. ●

ENDNOTES

- 1) MIMO is a trademark of Oy Helvar
- 2) LonWorks is a trademark of the Echelon Corporation registered in the United States and other countries.
- 3) IMAGINE is a trade mark of Electrosonic