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Minimizing Connected Lighting Power in Office Rooms Equipped with Anidolic Daylighting Systems

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MINIMIZING CONNECTED LIGHTING POWER IN OFFICE ROOMS EQUIPPED WITH ANIDOLIC DAYLIGHTING SYSTEMS

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ABSTRACT

Electric lighting is responsible for up to one third of an office building's electricity needs. Making daylight more available in office buildings can not only contribute to significant energy savings but also enhance the occupants' performance and wellbeing. Anidolic Daylighting Systems (ADS) are one type of very effective façade-integrated daylighting systems. All south-facing office rooms within the LESO solar experimental building in Lausanne (Switzerland) are equipped with a special type of ADS. A recent study has shown that these offices' occupants are highly satisfied with their lighting environment. The most energy-efficient south-facing offices have a lighting power density of less than 5 W/m². The lighting situation within these "best-practice"-offices has been assessed using the RELUX Vision lighting software. Because this lighting situation is very much appreciated by the occupants, it was used as a starting point for developing a yet more energy-efficient office lighting design. Two new lighting designs, leading to lighting power densities of 4 W/m² and 3.1 W/m² respectively, have been suggested and simulated with RELUX Vision. Simulation results have shown that the performance of these new systems can be expected to be comparable to that of the current lighting installation within the "best-practice"-offices or even better.

INTRODUCTION

Rational use of electricity within buildings is a very important topic in times where energy becomes more expensive and excessive energy use is suspected to accelerate climate changes through high emissions of greenhouse gases [1]. Electric lighting is responsible for up to one third of an office building's electricity needs [2, 3]. Daylight generates outdoor illuminances that often exceed the required illuminances for office rooms by several orders of magnitude. Making daylight more available in office buildings can therefore contribute to important energy savings. In addition to that, it can enhance the occupants' performance and wellbeing [4]. Over the last decades, various daylighting technologies have been developed for that purpose [5]. Amongst others, so-called façade-integrated daylighting systems have recently been subject to detailed discussions [2, 6, 7] and have confirmed their energy saving potential.

Anidolic Daylighting Systems (ADS) [5] are one type of very effective façade-integrated daylighting systems. They are designed following the principles of non-imaging optics [8] and allow to collect a maximum of daylight outside the building and to redistribute it internally with a minimum number of reflections. Detailed computer simulations carried out for different sky types and system configurations have shown that such advanced systems can significantly reduce the electric lighting needs of office rooms in various built environments [2, 6]. However, in order to benefit from the daylight provision offered by such systems and to realize effective electricity savings, artificial lighting strategies must be carefully adapted to the daylighting systems. Substantial savings can be achieved by using dimmable electric lighting systems, which automatically reduce the flux of electric light in an office at times where sufficient daylight is available [3]. In addition to dimming, it is very important to ensure the use of highly efficient components and to avoid the installation of over-sized electric lighting systems.

This article presents the lighting situation within selected office rooms of the LESO solar experimental building, located on the campus of the Swiss Federal Institute of Technology in Lausanne (EPFL). Ways to minimize the lighting power density within the LESO offices are then discussed. Two different options for a new, highly energy-efficient electric lighting system are introduced. At the end of this article, these options are compared with the current "best-practice" office lighting solutions within the LESO building: this is done by using the ray tracing software "RELUX Vision" [9].

LIGHTING SITUATION WITHIN THE LESO SOLAR EXPERIMENTAL BUILDING

Most office rooms of the LESO solar experimental building are equipped with a basic type of ADS [10]. This ADS first collects daylight from the sky vault through a zenithal collector. One single anidolic element then redirects the collected daylight to the room's diffuse ceiling from where it is reflected into the room. The system increases the daylight flux to the rear of the room and helps to reduce glare within the office's window section by blocking large amounts of direct sunlight [10, 11].

The connected electric lighting power is not identical for all LESO office rooms. Figure 1 shows the lighting power densities of 15 LESO offices all equipped with an ADS. Various combinations of different ambient and task lighting solutions lead to lighting power densities between 4.5 W/m^2 and 13.7 W/m^2. The average is equal to 9.1 W/m^2. Common values for lighting power densities in Swiss office rooms are normally situated between 10 and 15 W/m^2. Li et al. have recently described a comparable office room with a value of 16.7 W/m^2 [3]. The comparably low average observed within the LESO offices already suggests the large energy saving potential of this type of ADS.

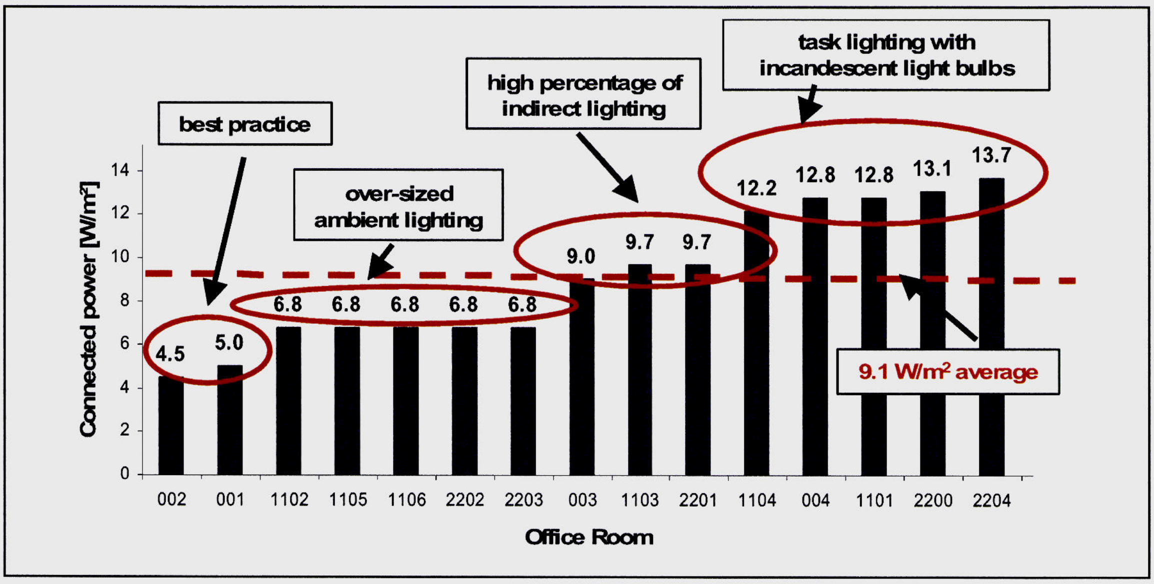

Figure 1: Lighting power densities of 15 LESO office rooms. Use of incandescent light bulbs, excessive indirect lighting and slightly over-sized ambient lighting lead to an average of 9.1 W/m^2. "Best practice"-offices have lighting power densities slightly lower than 5 W/m^2. Additional power consumption due to the electronic gear has not been taken into account.

The differences in lighting power density for the office rooms shown in Figure 1 have three main reasons: use of task lighting solutions with incandescent light bulbs, high percentage of indirect lighting and slightly over-sized ambient lighting. The two "best practice"-offices, with lighting power densities of 4.5 and 5 W/m^2 respectively, are both equipped with two ceiling-mounted luminaires with an optical efficiency of 69% (31% of the light emitted by the source is absorbed by the fixture). Each one of these luminaires is equipped with one single 36W fluorescent tube. Both offices are occupied by two persons; one person uses a desk lamp equipped with an 8W compact fluorescent lamp for individual task lighting.

In order to assess the building occupants' satisfaction with the lighting environment of their offices, a questionnaire with 28 questions was recently distributed and evaluated. Detailed discussions of the survey results are beyond the scope of this article and will be subject to another publication in the very near future. Only a few important findings of this satisfaction assessment are presented here. Figure 2 shows the occupants' agreements to the four following statements:

S 1: "In general, the lighting in my office is comfortable."

S 2: "The electric lighting system in my office is able to supply enough light."

S 3: "The lamps in my office are in the right place."

S 4: "I often have the impression that there is not enough light on my workplane."

S 5: "My office often seems too dim."

Twenty occupants (five of them working or having recently worked in one of the "best practice"-offices) were asked to state their agreement with these statements on a 1 to 4 scale (1 = no = 0%, 2 = rather no = 25%, 3 = rather yes = 75%, 4 = yes = 100%).

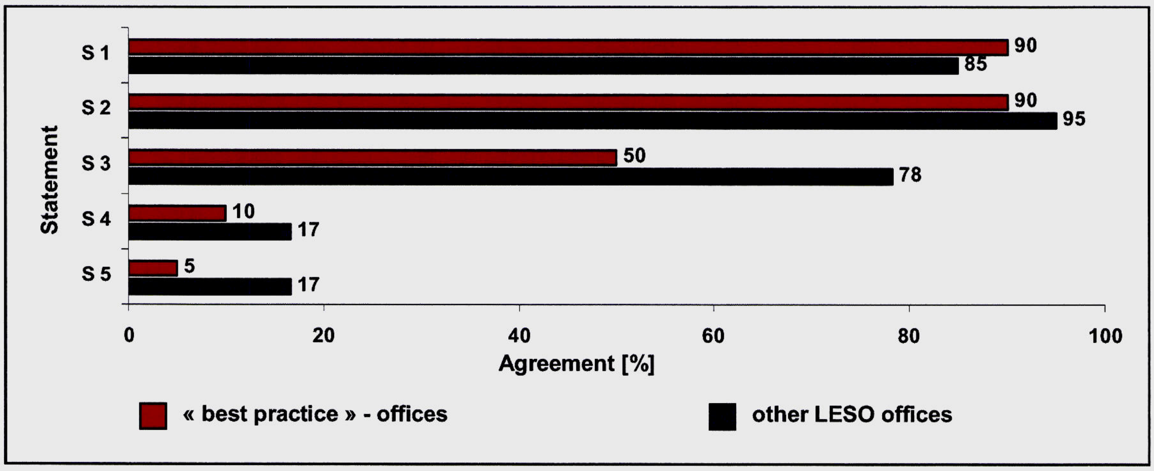

Figure 2: Agreement of LESO building occupants within "best practice" and other office rooms with statements 1 to 5. The occupants are very satisfied with their office lighting, "not enough light"-situations are rare. However, placement of lamps seems to be somewhat of a problem, especially within the "best-practice"-offices.

The average agreement with statement 1 was found to be 90% and 85 % for the "best practice"-offices and the other LESO office rooms, respectively. Recent studies have found that agreement with statement 1 is typically around 70% in the US [12]. If we suppose that the situation in Switzerland is similar, all office rooms within this experimental building can be considered extremely comfortable as far as lighting is concerned. The high percentages of agreement with statement 2 indicate that the electric lighting is appropriate in all offices. The very low agreement levels to statements 4 and 5 indicate that "not enough light"-situations are rare. Agreement values for statement 3 show that lamp positioning within the LESO experimental building is not always ideal, especially in the case of the "best practice"-offices.

In general, these results illustrate that all building occupants are more than satisfied with their office lighting and that this satisfaction does not depend on their offices' lighting power densities. In other words, occupants who work in the two "best practice"-offices are as happy with their office lighting as their colleagues who work in offices with more powerful electric lighting systems.

Figure 3 shows the illuminance distribution within one "best practice"-office for the current electric lighting installation (two 69% efficiency ceiling-mounted luminaires, each equipped with one 36W fluorescent tube): only artificial light has been simulated with RELUX Vision. Five different reference planes (all 75 cm above floor level) have been considered during the simulations: entire office, workplane surroundings, workplane, as well as two individual workspaces. These individual workspaces have a size of 0.6m x 0.6m and are located on those workplane areas where the two office occupants carry out special visual tasks (like writing or reading) that require comparably high illuminances. This is a common choice for designing energy-efficient lighting situations [13]. The simulation result clearly shows an illuminance maximum in the middle of the room, with illuminances ranging from 250 and 300 lux. This is coherent with the occupants' impression that lamps within this office might not be in the right place. It is also important to note that illuminance levels are substantially lower than the values suggested by the corresponding standards [13]. The fact that the office's occupants nevertheless judge the lighting situation to be extremely comfortable might be a hint that current illuminance requirements for office rooms are somewhat too demanding in the case of offices that are equipped with Anidolic Daylighting Systems and that benefit from a lot of daylight. According to Altherr and Gay, daylight factors within the building's offices equipped with ADS have been found to equal 6.5% next to the windows, 5% in the centre of the room (2m from window) and 2% at the rear (4m from window) [11].

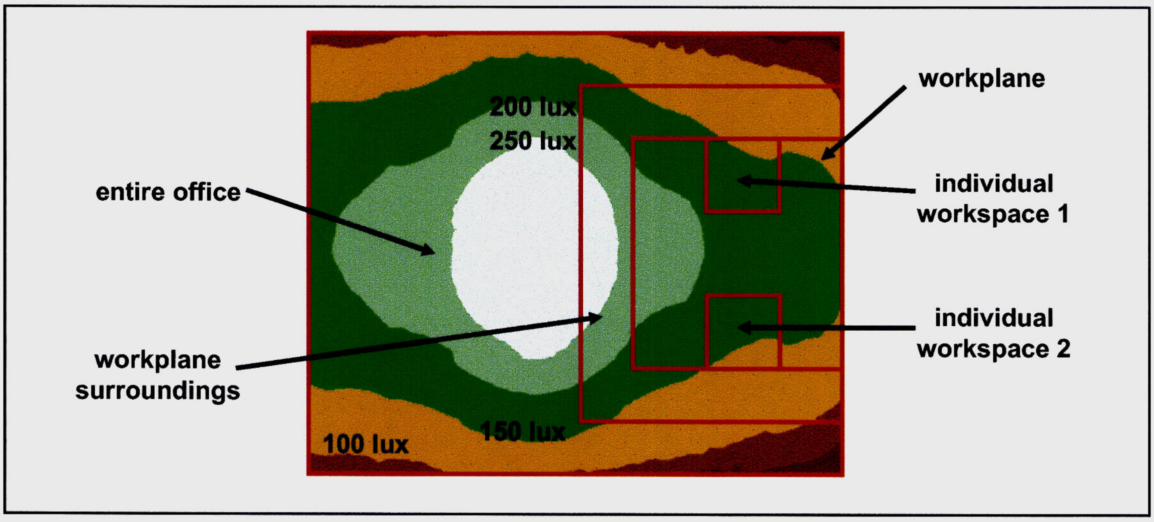

Figure 3: Illuminance distribution within one of the "best practice"-offices (RELUX Vision simulation). Five different reference planes have been defined. The illuminance maximum is situated in the middle of the room instead of on the workplane. This is coherent with the occupants' impression that the luminaires might not be appropriately placed.

MINIMIZING CONNECTED LIGHTING POWER WITHIN THE LESO BUILDING

It has been shown within the previous section that user satisfaction within the "best practice"-offices is comparable to those of the other LESO offices. It is therefore possible to take the situation within these "best practice"-offices as a starting point for developing a more energy-efficient electric lighting system. If this new system creates a lighting situation similar to the one shown in Figure 3, one can assume that user satisfaction with the new system will also be very high. Various designs of electric lighting systems for the "best practice"-offices have therefore been simulated using the RELUX Vision software. Figure 4 shows the illuminance distribution for two of them. In both cases, two ceiling-mounted luminaires with 96% optical efficiency have been chosen. The luminaires leading to the illuminance distribution on the left are each equipped with one 28W fluorescent tube. The lighting power density equals 4 W/m² if the electronic gear's power consumption is taken into account. The simulation represented on the right uses only one 21W fluorescent tube in each luminaire. The resulting lighting power density (electronic gear included) is 3.1 W/m². Compared to the current situation represented in Figure 3, the new luminaires have been slightly displaced to the right. One can observe that the illuminance maximum has therefore also shifted to the right. This leads to higher illuminance levels on the workplane, compared to the rest of the room.

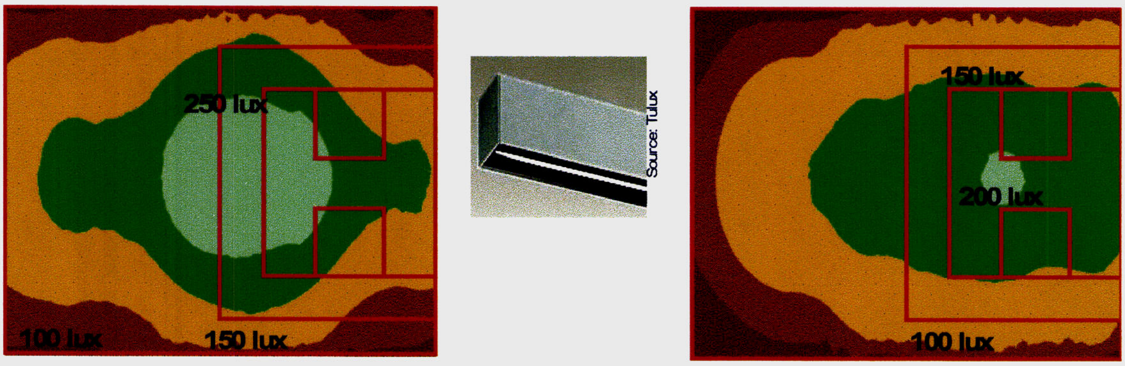

Figure 4: Illuminance distributions for two more energy-efficient electric lighting designs and suggested 96%-efficiency luminaire. The illuminance maxima have shifted from the middle of the room in the direction of the workplane.

Figure 5 compares the current situation with the two new energy-efficient lighting designs.

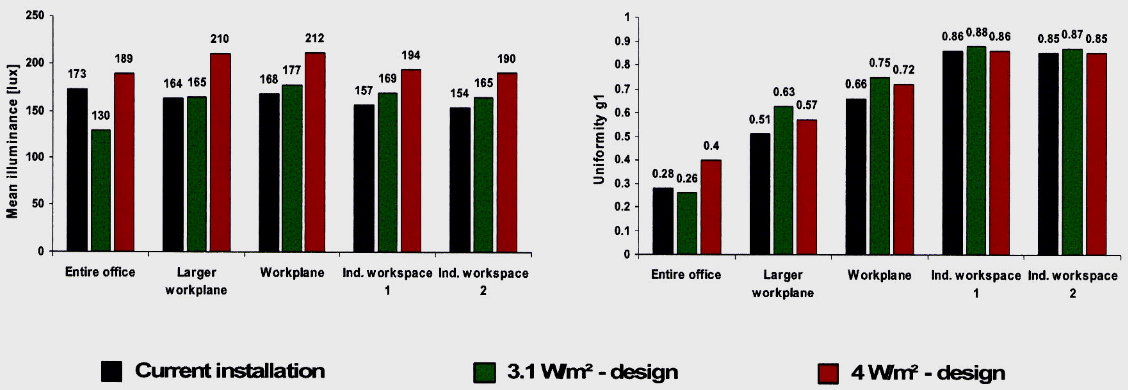

Figure 5: Comparison of the current lighting installation and the two new electric lighting designs for the "best practice"-offices. Performance of the new systems will be similar to that of the current installation.

If we look at the mean illuminances on the different reference planes in Figure 5, it is obvious that the 4 W/m² - solution leads to higher mean illuminances on every reference plane than the current installation. However, the 3.1 W/m²-solution is also valuable: except for the reference plane "entire office", the mean illuminances are slightly higher than those supplied by the current installation. A close look to the uniformity values g1 for the different reference planes (defined as the highest illuminance observed on each plane divided by the corresponding average illuminance) shows that the 3.1 W/m²-solution outperforms the current installation and the 4 W/m² - solution on every reference plane, except for the "entire office" plane.

Conclusion

The simulation results presented in this article show that it would be possible to reduce the lighting power density within the LESO office rooms down to around 3 W/m². This could be achieved by using highly effective luminaires appropriately placed within the offices. The performance of such a new highly energy-efficient artificial lighting design would be comparable to that of the current system, if not better. Because the current situation is highly appreciated by the LESO occupants, we assume that the described new systems would be equally well appreciated. Within the next few months, this hypothesis will be tested within a test-office by setting up the corresponding lighting equipment.

Acknowledgements

The authors would like to thank all occupants of the LESO solar experimental building for answering the questionnaires. Special thanks are due to Natalia Filchakova, Frédéric Haldi, Darren Robinson and Fabien Desponds for their valuable remarks concerning the questionnaires.

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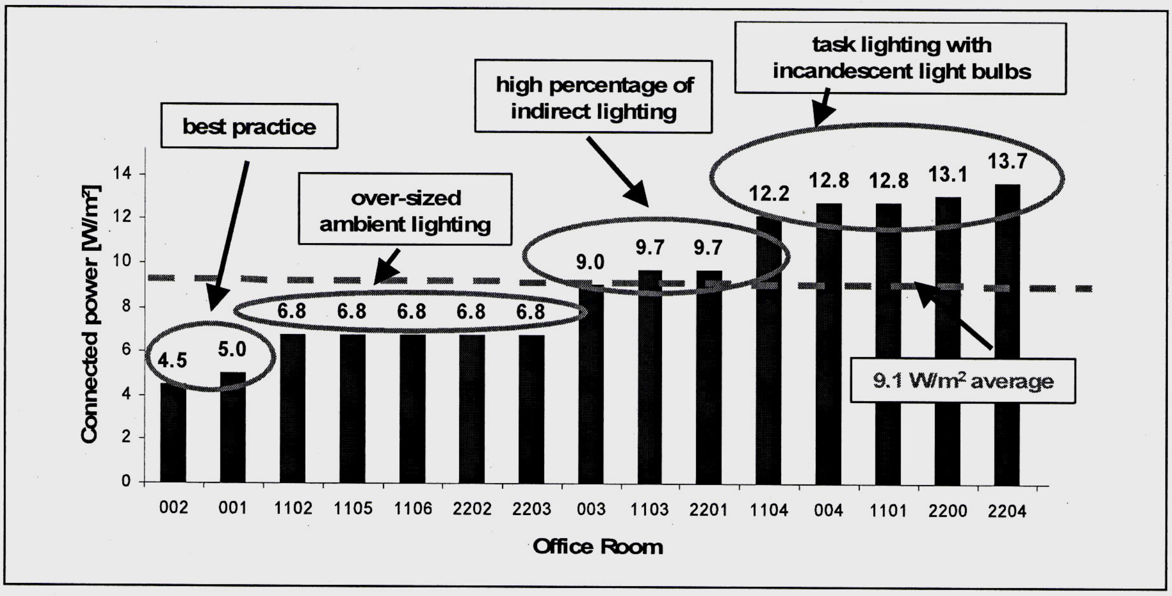

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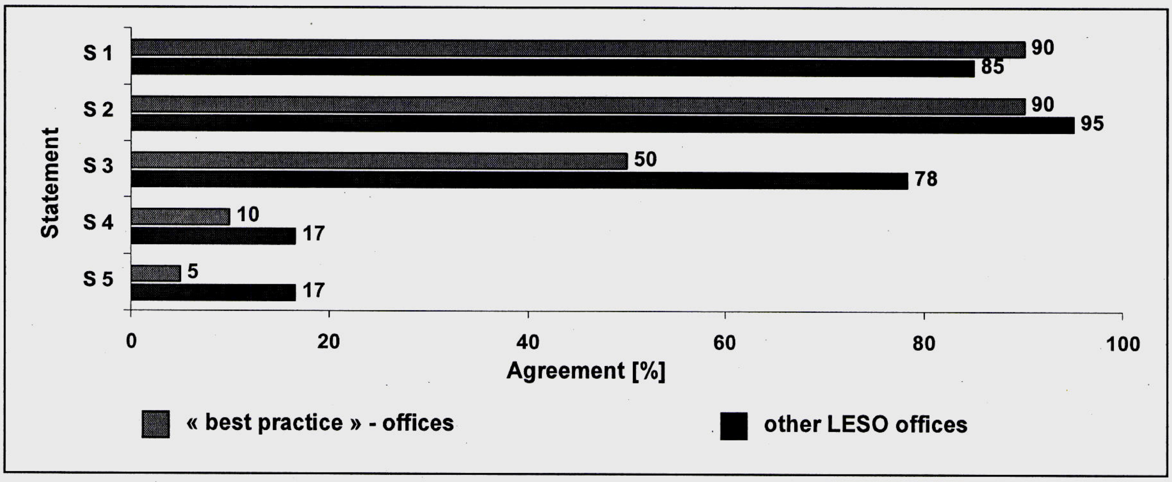

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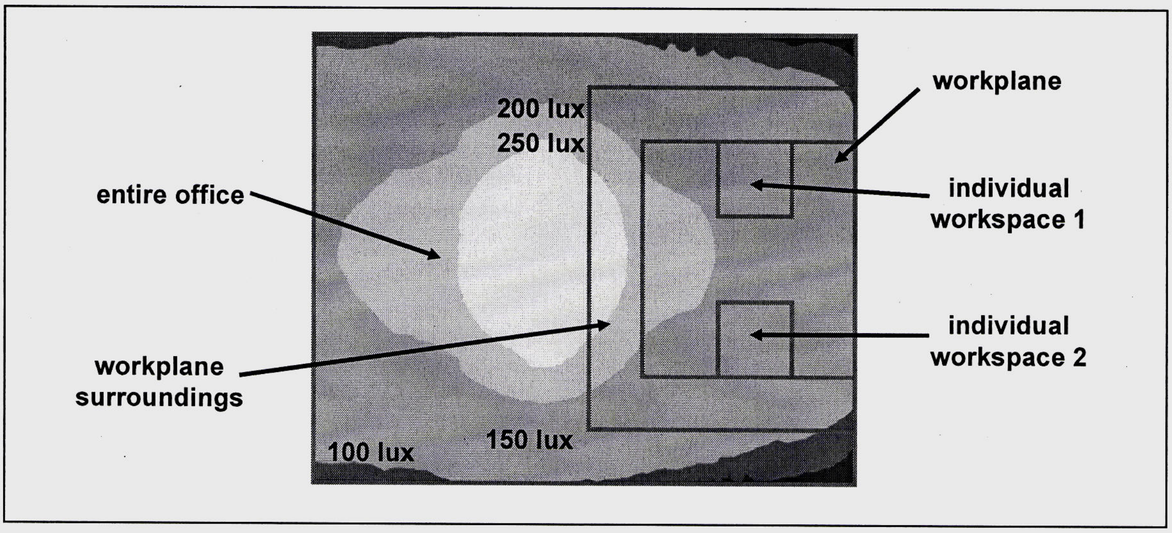

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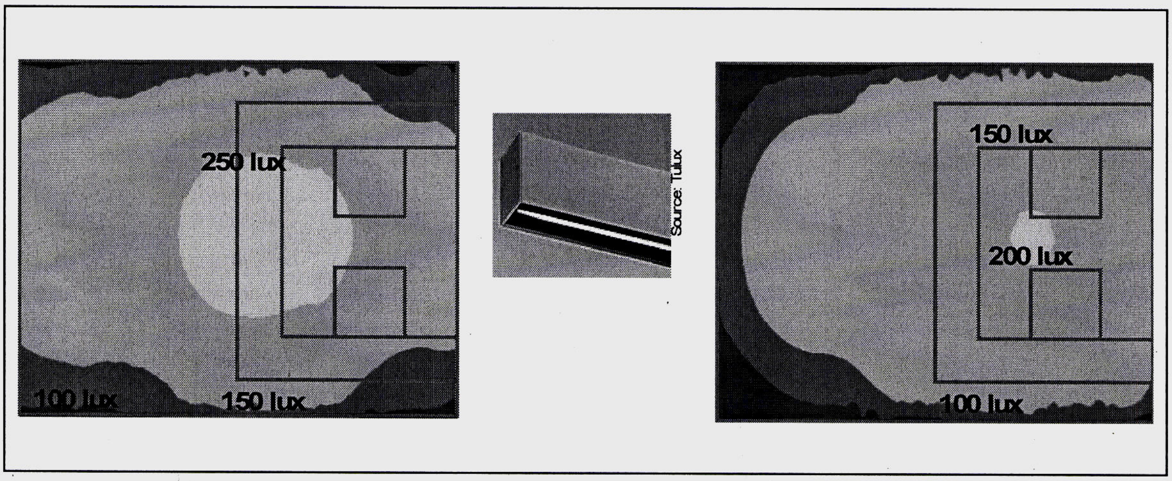

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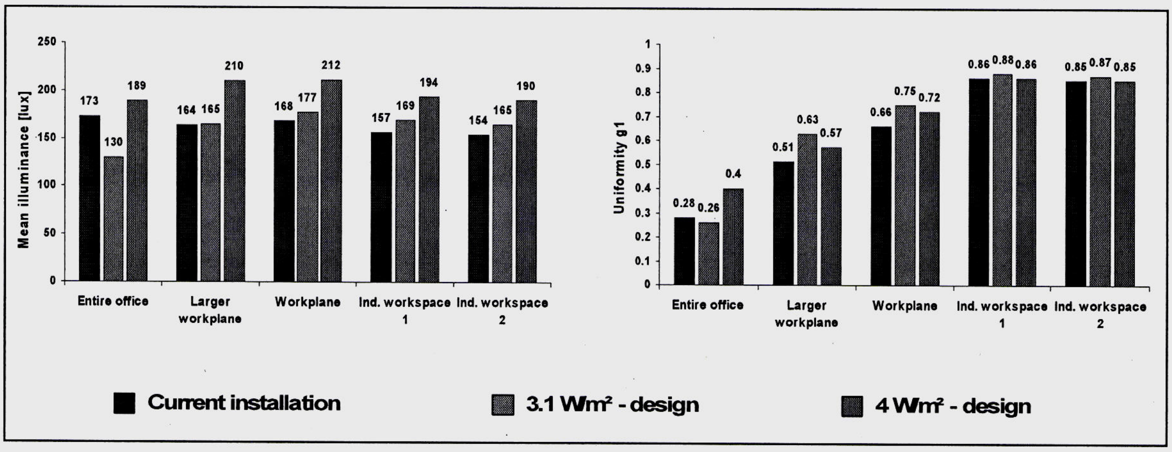

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CONCLUSION

The simulation results presented in this article show that it would be possible to reduce the lighting power density within the LESO office rooms down to around 3 W/m². This could be achieved by using highly effective luminaires appropriately placed within the offices. The performance of such a new highly energy-efficient artificial lighting design would be comparable to that of the current system, if not better. Because the current situation is highly appreciated by the LESO occupants, we assume that the described new systems would be equally well appreciated. Within the next few months, this hypothesis will be tested within a test-office by setting up the corresponding lighting equipment.

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