Implementation of Digital Ergonomic Tools during the Flexible Screening of Lighting in the Working Environment

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Abstract **– Light is an integral part of our environment. Its effect on humans is significant - it affects not only their visual performance or well-being but also other extra-visual functions of the body, which affect the quality of their life. Lack of light causes various health problems of physiological or psychological dimensions caused by visual discomfort at the workplace. The presented article describes the possibilities of assessing the visual well-being of the workplace by implementing digital ergonomic tools during the flexible screening of lighting. The introductory part of the article is focused on a theoretical description of the issues in the field and then the tools of digital ergonomics are introduced, through which the experiment is carried out. The main part of the article provides an overview of the achieved results and describes the conclusions based on the analysis. Regarding the achieved results, at the end of the article, there is a description of the possibilities of ensuring rationalization measures and the direction of further research.**

Keywords **– Digital ergonomics, screening, lighting, workplace.**

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1. Introduction

The term working environment can be defined as the current influence of external tangible and intangible factors that affect the worker and the work performed by him. In a broader sense of the term, it is a set of conditions under which the production process takes place through various means and manpower. In a narrower sense of the term, it is an element of the working environment in production, which forms part of the production and in which various types of work are performed by workers [1], [2]. The working environment as a complex system consists of the following parameters [3]:

- Workspace - corresponding to the dimensions of the worker, considering:
  - access or escape in the event of danger;
  - the basic working position and movements at work;
  - the location of direct and indirect sources of information;
  - the types and location of controls;
  - used equipment, working tools and aids;
  - the dimensions and shapes of the equipment with which the workplace is equipped;
  - the distance between individual jobs.
- Handling area – the area folded by the place to which the most frequently performed upper limb working movements relate.
- Pedipulation area - the area translated by the place to which the most frequently performed lower limb working movements relate, which is conditioned by:
  - at the lowest height above the floor;
  - the smallest overall width;
  - at the smallest depth from the edge of the table;
  - the optimum depth of movement space.
- Controllers - a device for controlling events - to achieve the desired changes in the controlled

quantities of the machine (technology) - speed, temperature, etc., designed to control the machine by man.
- Notifiers - indicate the relevant information for the controls.

In the work environment, there are agents (components of physical reality) that expose or may expose the subject to the environment (e.g., heat, sound, light). The agents (Figure 1) often act together and have common effects on the subject (e.g., a complex of heat-humidity and water vapour flows or a vibroacoustic effect). Their effect on humans can also be harmful, and then they are referred to as noxins. Any effect of the agents is functionally dependent on [4]:

- the intensity of the flow of agents exposing the subject;
- the concentration of these agents;
- on the spatial distribution, their uniformity in space;
- on time of exposure and time distribution of agent flows.

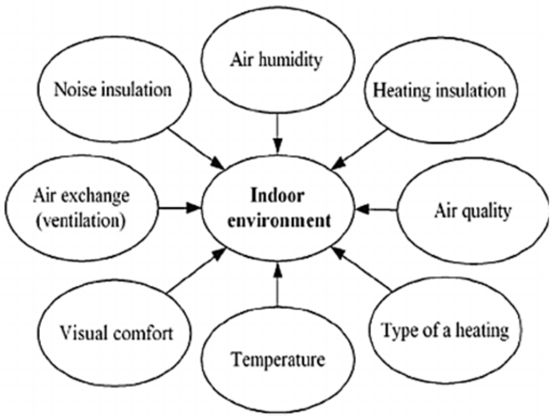

Figure 1. Agens of the indoor working environment [4]

The work environment as a comprehensive system of agents is influenced by several attributes, which include [5]:

- employee performance (productivity, quality of work);
- safety at work;
- morbidity of workers;
- staff turnover, i.e. their satisfaction with the work performed in the given environment;
- the service life of production funds;
- operating costs and possible financial risks.

The undeniable impact of the above attributes in the work environment is determined by one of the primary agents - lighting. [5] Lighting is provided in the work environment by daylight or artificial lighting, or a combination of them, while several characteristics (Figure 2) are considered to ensure light comfort in the workplace, such as light colour, intensity, or glare. [6]

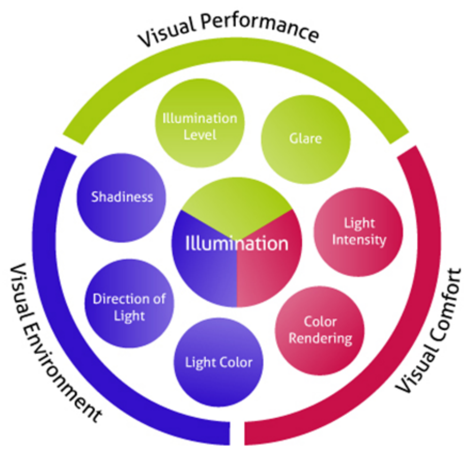

Figure 2. Illumination parameters in the working environment [6]

The importance of lighting is conditioned by the fact that lighting affects the performance of humans and the quality of work, and the occurrence of accidents and incidents. The effect of lighting on performance is manifested by a direct proportion consisting of increasing the intensity of lighting while recording the increase in power (Figure 3). [7], [8] According to various studies, the increase in performance ranges from 4% to 35%. The significance of increasing the intensity of lighting regarding labour productivity is justified up to the level of its increase by 150 - 200 lux. The subsequent increase can no longer be observed in any way to improve the work performance of employees and is also unprofitable. [9]

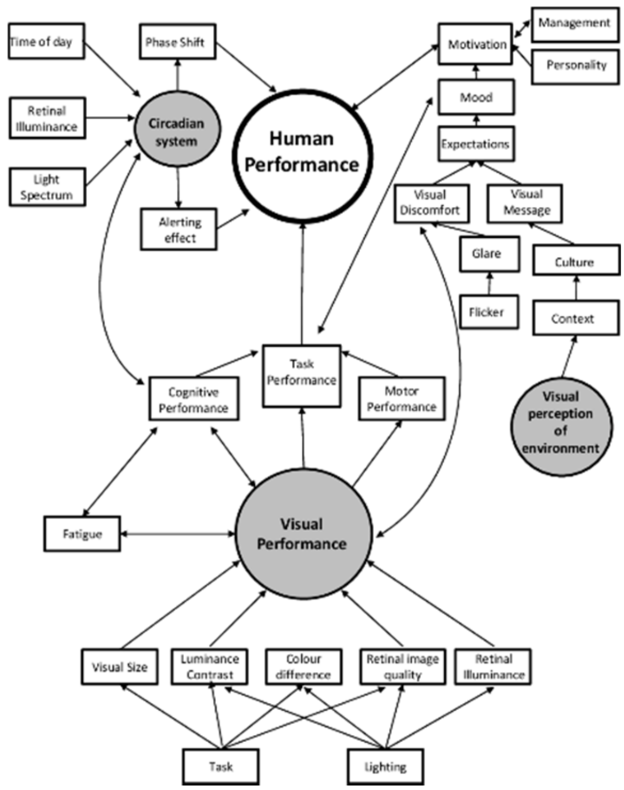

Figure 3. Visual ergonomics and worker's performance [9]

In case of insufficient lighting, visual discomfort arises in the workplace, which is associated with subsequent visual difficulties for workers. The visual load can be divided into 4 groups [10]:

- Ocular - associated with the visual organ - burning eyes, redness of the eyes, tearing of the eyes, carding in the eyes and tics, pressure in the eyes;
- Visually - associated with changes in perception - flickering before the eyes, feeling of reduced sensitivity of the eyes, blurred vision, double vision;
- Non-specific - related to mental well-being - light-headedness, headaches from visual stress, feeling uncomfortable under artificial or insufficient lighting, the need to interrupt work and look at the open space;
- General - visual fatigue, general fatigue, and weariness.

Discomfort at the workplace affected by the lighting system can be caused by the obsolescence of the lighting system and by the non-compliance of the implemented lighting system with the basic lighting requirements, which are set by legislative regulations and technical standards. Due to the frequent ignorance of the required amount of investment and its subsequent return to the rationalization of lighting systems, employers ignore their shortcomings in the workplace, thus indirectly supporting the persistence of economic, environmental, and human discomfort. However, the first step in the realization of rationalization measures is to create a simple technical lighting study that analyzes the current state of lighting systems in the workplace, defines solution options and provides an overview of the profitability and economic efficiency of the proposed solutions.

Rationalization of light distribution in building interiors can be ensured on three levels [8]:

- The preparatory stage - design - design. The first solutions are already in the stage of project elaboration for the zoning decision, then in the stage of project elaboration for the building permit and implementation project. Natural or artificial light is designed by applicable regulations and standards;
- The construction implementation stage - construction of the building according to the project documentation;
- The stage during operation. When using a newly built, or of the reconstructed building, it is necessary to achieve the prescribed lighting parameters, as they were designed and solved in the previous stages.

2. Material and Methods

The basic step for the creation of rationalization measures to eliminate the discomfort of the working environment is to obtain information about the current state of the assessed lighting system, which can be implemented by flexible screening using digital ergonomics tools. In the implemented case study, the current state of the working environment was analyzed using a certified lux meter KIMO LX200 (Figure 4).

Figure 4. Digital lux meter KIMO LX200

Using a digital lux meter, the course of the light intensity over time was recorded as a graphic output of the specialized software LLX200 (Figure 5) intended for the processing of the obtained data.

Figure 5. Software LLX200 for analysis of measured values

In addition to the application of a certified lux meter, digital ergonomics tools were used to obtain information on the current state of the assessed lighting system - the Photometer PRO mobile application developed on the android platform and the Dialux Evo simulation tool for building a digital state of the art.

The Photometer PRO application was chosen to present the fastest possibility of screening the current state of the working environment, while its use also provided information on the accuracy of the obtained data in comparison with a certified calibrated instrument.

In the simulation tool Dialux Evo (Figure 6), a digital model of the current state was created, through which it is possible to subsequently create rationalization solutions and adjustments to the working environment by the currently valid legislative requirements.

Figure 6. The main screen of Dialux Evo lighting software

3. Digital Ergonomics and Flexible Screening of Lighting at the Workplace

For flexible screening of the lighting system, the workplace shown in Figure 7 was chosen - a workplace (measuring point) in an office measuring 7 m x 3 m and a ceiling height of 2.8 m, which is the furthest workplace in the room from the main lighting source. As the picture shows, the walls of the office are white, based on which the light reflection factor was set at 0.80. The reflection factor value for the floor was defined at 0.21.

Figure 7. Analyzed workplace

Data were written to the instrument's internal memory at a frequency of 1 second for 30 minutes via a lux meter. Subsequently, the lighting solution of the collected data was created using the LLX200 software solution, the example of which is interpreted in Figure 8.

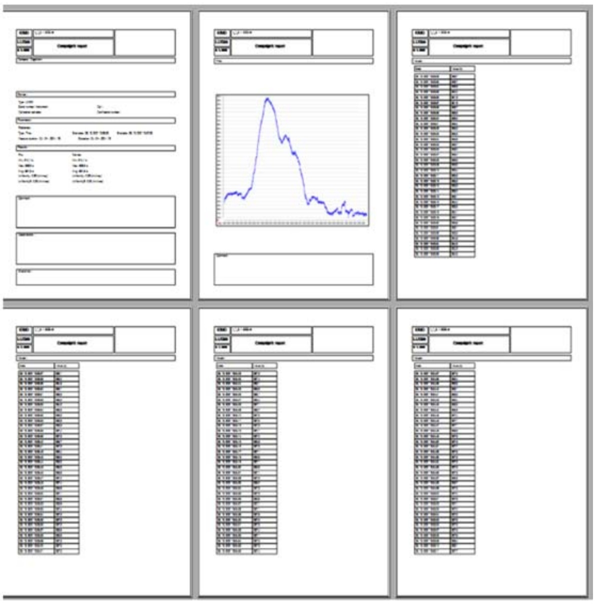

Figure 8. Report of measured values – LLX200 software

The data collected were graphically presented over time using specialized digital lux meter software. Based on the graphical interpretation of the collected values, it is possible to observe the oscillation of the light intensity in the determined working environment in the range from 214 lx to 332 lx. The course of intensity depending on time and a summary of values are presented in Figure 9.

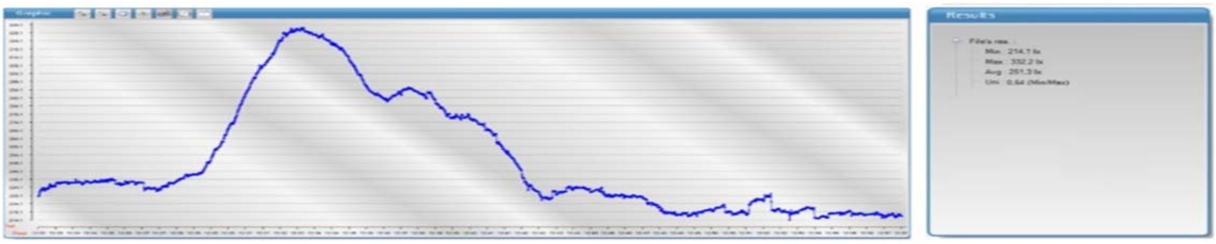

Figure 9. The intensity of illumination of the assessed workplace in time dependence (left) and a summary of obtained values (right) - Software LLX200

The first option for flexible lighting screening realization at the workplace is the digital ergonomic mobile tool. In this case, it was selected the free version of Photometer Pro - a mobile digital tool. Through the modification of the digital ergonomic application focused on the assessment of the lighting of the working environment, 500 measurements were performed in the frequency of 1 second, starting at the same time as the measurement of the lighting intensity with a digital lux meter. Samples from the measurements are shown in Figure 10.

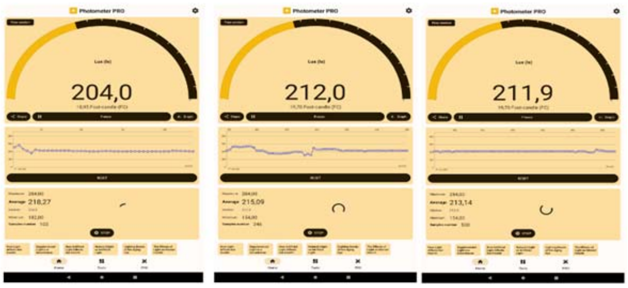

Figure 10. Demonstration of measurements using the digital application Photometer PRO

A video recording was made of the measurements carried out using the free version of the digital mobile tool, as the version does not have data storage or its conversion into any supporting spreadsheet or another editor. The collected data were thus written into a spreadsheet editor and their time course was created (Figure 11).

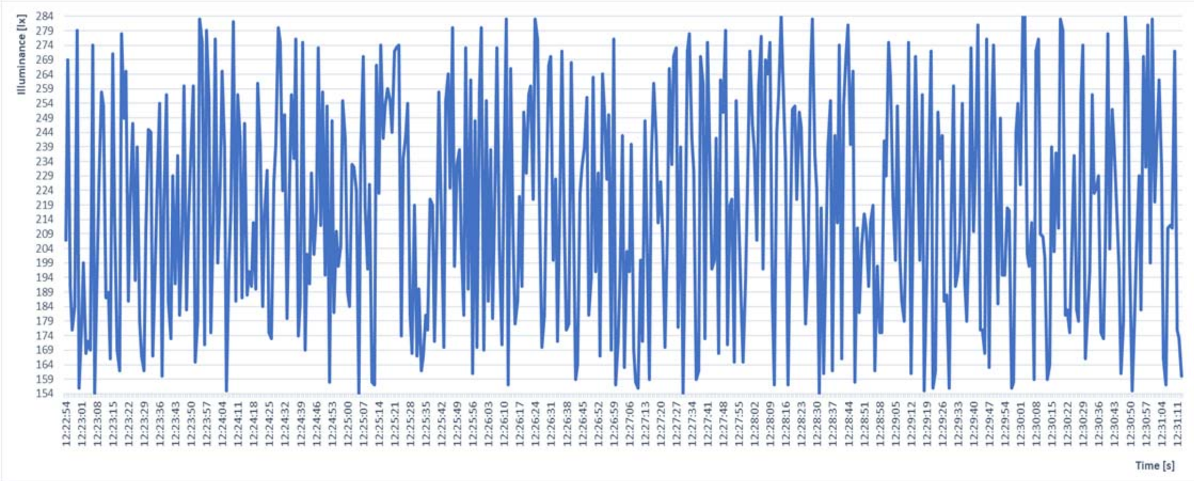

Figure 11. Lighting intensity of the assessed workplace in time dependence - Table editor

The measured values were then compared with the legislative requirements set by the standard STN EN ISO 12 464-1, while insufficient values of light intensity were found at the assessed point.

To create a digital twin of the analyzed work environment (Figure 12), the basic input data were determined:

- Office dimensions (7.20 m x 3.10 m x 2.80 m);
- Lighting-technical parameters of the analyzed lighting system;
- Maintenance factor: 0.80.

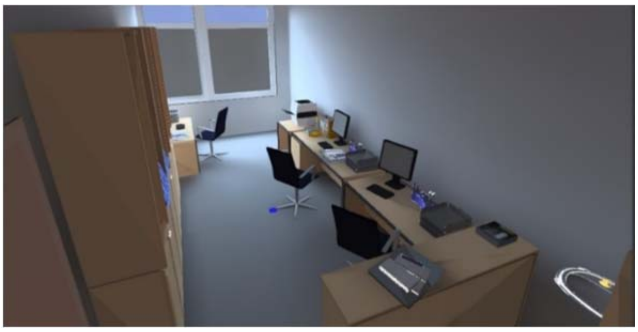

Figure 12. The digital twin of analyzed workplace

After compiling the model of the analyzed workplace and defining the basic input data, a simulation was performed, the overall result of which was a lighting report, the acquired values of which are shown in Figure 13. As a partial graphical output of the achieved values of the realized simulation, the course of the isophots of the lighting of the working environment was selected (Figure 14).

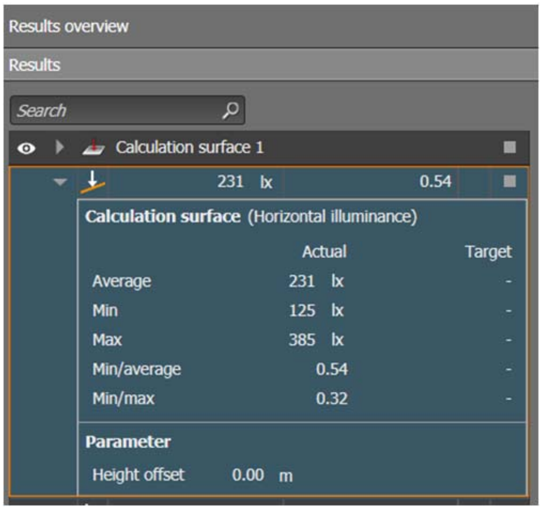

Figure 13. Obtained values of simulation – Dialux Evo

Based on the achieved data from the simulation of the current state of lighting at the workplace, it is also possible to state non-compliance with the minimum legislative requirements for lighting intensity values in the indoor environment of buildings prescribed in the standard STN EN ISO 12 464-1.

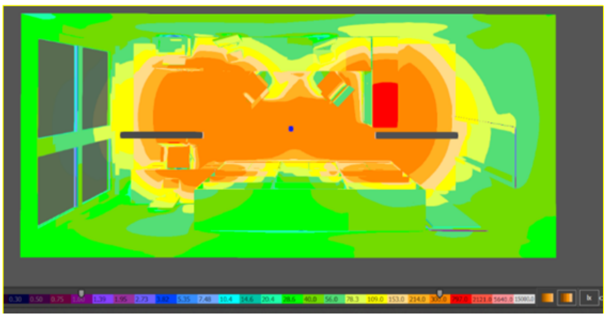

Figure 14. Graphical interpretation of illumination via isophotes in Dialux Evo

After the implementation of flexible screening with all selected tools, a graph was created comparing the accuracy of the achieved results against a calibrated digital lux meter. The results are presented in Figure 15.

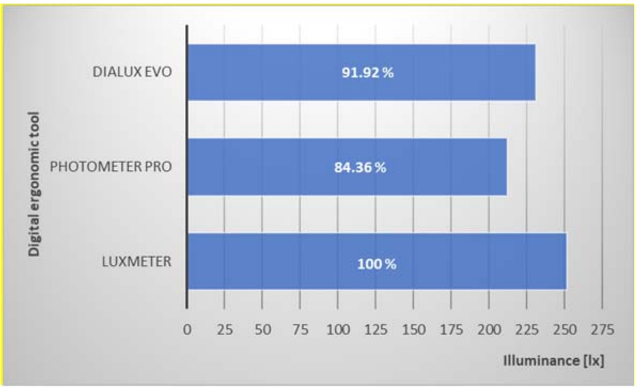

Figure 15. Comparison of achieved results for the used digital tools

From the achieved results it is possible to determine the exact percentage deviations (shown in the inner area of the bar diagrams - Figure 15), while when comparing the obtained values of digital lux meters and mobile Photometer Pro tools, the deviation of the obtained data was set at 15.64% and with the created digital twin the deviation was 8.08%. Based on the results of the comparison and determination of individual deviations, it can be stated that the digital tools in the form of the mobile application Photometer Pro and the simulation tool Dialux Evo are suitable representatives for creating flexible screening of lighting at the workplace.

4. Conclusion

Rapid development in the field of computer technology and especially software support is caused by the constant increase in requirements for the use of simulation tools in every field of practice [11], [12]. The presented article describes the possibilities of implementing digital ergonomics tools in the flexible screening of lighting comfort in the workplace. In the implemented study, unsatisfactory values of light intensity were recorded through all implemented tools. These values need to be rationalized by replacing or adjusting the distribution of light sources, adjusting the layout of the working environment or, for example, adding additional lighting sources. In addition to the many benefits that the digitization of illumination brings, it is also necessary to consider the emerging risks that come with it, while it is possible to focus on other areas of research precisely the risks associated with the digitization of lighting.

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