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Visual comfort and light transmission control using window with polymer dispersed liquid crystal layer in the textile industry to ensure occupational safety

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ABSTRACT

Adequate workplace lighting is crucial for employee well-being, productivity and energy efficiency. Yet many industrial settings, such as textile factories, have inadequate, non-adaptive lighting. In the presented article, the author focused on the problem of inadequate lighting conditions in the workplace. Driven by the need for ergonomic workspaces and sustainable energy practices, this research used advanced materials PDLC science to address these challenges. It proposed a solution in the form of an automatic system for regulating the lighting intensity by automatic regulation of light transmittance through window including a PDLC film. Such an active window system is called Smart Window. The control of light transmittance into the knitting factory hall is performed by (control of the voltage of the active film layer) which is an integral part of the entire window surface. A smart window will reduce the overall transmission of solar energy, which will help avoid overheating. Total solar factor is the percentage of solar energy that actually penetrates a room through blinds and windows. Smart Window will also provide visual comfort by optimizing the amount of light reaching the surface near the window and avoiding glare as well as the inconvenience caused by direct sunlight. Visible light transmittance determines the total percentage of daylight that is transmitted into the room through the window with a wavelength from 380 to 780 nm (visible spectrum). The main results demonstrate a strong correlation between the applied voltage and the light transmittance of the film, enabling precise control over the visible light transmittance (VLT). The implemented control model successfully maintained optimal illuminance levels, reducing glare and preventing solar overheating by dynamically adjusting the window opacity. From a methodological point of view, one of the most important issues in designing a lighting intensity control system is choosing the type of sensor and its location in the production hall. This can significantly affect control efficiency. This topic is discussed in this article, which briefly covers good industrial design practices. This approach to lighting requirements is supported by legal requirements, as well as an ergonomic approach to the design of workplaces. The control system was made as a PID controller in the mode of controlling the entire surface of the electrochromic film (control of the light transmittance of the film). This key contributions of this work are the development of a validated PDLC control model for lighting applications, and demonstrating its dual benefit of ensuring visual comfort in accordance with ergonomic and legal standards while promoting energy savings. Implementing lighting control systems in textile factories is a strategic step towards digital transformation and sustainability which is in line with the Responsible Consumption and Production strategy.

Keywords: PDLC materials, control strategy, measurement, modelling.

INTRODUCTION

The basic legal act of the European Union, introducing the obligation to improve the working environment conditions and to apply appropriate preventive measures as a result thereof, is the Council Directive of 12 June 1989 on the introduction of the measures to improve health and safety at work, adopted on the basis of Article 118A of the Treaty of Rome. The requirements of the directive are reflected in the regulations of the EU countries.[1] According to this directive, the employer must ensure safety and strive to improve the safety of employees in the workplace in all aspects related to work, taking into account the following principles regarding the organization of workstations in terms of proper lighting: assess the values that pose a threat to safety and health; avoid occupational risks related to insufficient lighting of the workplace; improve and optimise lighting conditions in workplaces; use new technical solutions where windows play a huge role in today's buildings, allowing for outside view and providing occupants with daylight [2]; adapt the workplace and working conditions to human capabilities; inform employees about hazards[3]. Comfort and safety at the workplace as well as the required legal regulations can be ensured by means of lighting that meets the PN-EN 12464-1:2012 standard [4]. This standard is so convenient that it does not limit the use of new or innovative forms, techniques or lighting devices, nor does it impose specific solutions related to lighting. The regulation above refers to the lighting inside the building, omitting aspects such as emergency lighting, external workplaces or underground lighting. This standard refers to daylight, artificial lighting and a combination of these 2 sources. Therefore, an interesting solution, especially in the countries with high sunlight exposure, may be the solution of self-darkening window areas operating in automatic mode [5]. Such a system will allow avoiding too great differences in the level of lighting of the workstation and its surroundings [6, 7]. However, these often provide incomplete or reactive control, struggling to simultaneously optimise energy use and occupant comfort in real-time. The emergence of smart materials offers a paradigm shift towards truly responsive building envelopes [8].

Great differences in the brightness of lighting in individual work rooms should also be eliminated. Long-term work under the conditions of insufficient uniformity of lighting can accelerate the occurrence of permanent weakening of eyesight, reduce visual acuity and lead to myopia. In addition, it can accelerate the occurrence of general fatigue. In the rooms where knitting machines are operated in the production hall, the recommended light intensity should be over 500 Ix [4]. In the rooms where long-term proofreading and drawing work takes place, the light intensity should be 500–1000 Ix. For medium-difficult and medium-long writing or reading, the required intensity should be 300–750 lx. The required light intensity in office workers' rooms is set at 300 lx (excluding work with computers). This value increases significantly when the rooms are intended for the work of IT specialists. In these cases, the light intensity is assumed to be above 500 up to 1000 lx. Corridors and staircases require a light intensity below 200 lx [4, 9].

When selecting lighting conditions, it is important to remember glare prevention. Glare occurs when eyesight is moved to a surface with much greater brightness [10]. Glare causes visual discomfort and reduces the ability to recognise objects. After a large amount of light enters the eye, the retina in the fundus of the eye is periodically affected. Large glare is rarely encountered at work. However, micro-glare often occurs, acting long-term and systematically. It occurs when only local lighting is used at the workstation, without using general lighting. In addition, local lighting lamps are not shielded. They emit direct light, which can reflect from metallic or bright surfaces located at a short distance, and then reach the eye in a narrow beam. In order to prevent glare in such situations, deep lampshades for electric local lighting must be used. The glare from natural light occurs when an employee sits opposite a light source, especially when the window faces south. Natural light then dazzles the eyes, causing micro-glare [11, 12]

Natural lighting systems are the most common solutions [13]. They can be implemented using roof skylights. This provides the greatest uniformity of lighting. The only requirement is for the windows to be tight and for the room to be air-conditioned when exposed to high levels of sunlight - a beneficial solution, but not always possible to implement. Motivated by the need for a sophisticated ergonomic and sustainable solution, this research investigated a smart window system. This paper focused on the modelling and application of polymer dispersed liquid crystal (PDLC) film for dynamic lighting control in an industrial setting.

A side lighting system, using windows placed in the walls, preferably at the level of the workstation (if the workspaces are small, then with good sunlight, such a lighting system is completely sufficient), if a lot of written or precise work is performed, the workstation should be set in such a way that the hand does not block the light cast on the workspace, and the top-side lighting system should have a window at a height of at least 1.5 m above the floor. A mixed lighting system is also used (a combination of the above systems) [4, 14] Contemporary research on smart windows and electrochromic coatings focuses on multifunctionality as well as integration of different technologies to improve building energy efficiency and occupant comfort. The article by Zhang et al. [15] presented a smart electrochromic film that combines passive radiative cooling with dynamic sunlight regulation, which allows for better thermal as well as lighting control in windows and displays. The research by Zhang et al. [16] introduces a multifunctional window that not only modulates light but also provides microwave shielding, which may be useful in the buildings requiring protection against electromagnetic radiation. The review papers [17, [8] highlight the importance of innovative materials, such as thermochromic and electrochromic coatings, as well as their role in creating energy-efficient solutions for smart cities. Taken together, these works show that the future of smart windows lies in the systems combining light regulation, thermal management [19] and additional functions (e.g. EMI protection), which can significantly impact sustainable construction [20] and smart technologies [21].

In addition to the presented solutions, the key contributions are the development of a validated PDLC control model for lighting applications and demonstrating its dual benefit of ensuring visual comfort in accordance with ergonomic and legal standards while promoting energy savings. This study highlighted the importance of smart window technology in enabling digital transformation and sustainable production, which is in line with the goal of responsible consumption and production.

MATERIALS AND METHODS

Intelligent Textile Factory is a modern production facility in the textile industry, using advanced technologies such as artificial intelligence (AI), Internet of Things (IoT), automation and data analysis to increase efficiency, quality and sustainability [22] In the design of the intelligent system to control light intensity in a textile factory, electrochromic materials are used [23]. They change their optical properties, such as colour or transparency under the influence of an electric current flow. In addition, their heat transfer property changes are also used [24] To build smart windows, changes of the transparency are usually used [25]. Electrochromic materials are made in the form of thin layers [26] and used for modulating the transparency of visible lights as well as solar energy in smart windows. The same technology can be used for energy efficient daylighting based on the notion of balancing the light from the windows and from light-guides to obtain an even illumination level in extended spaces [25], [27, 28]. The sets of thin layers often contain of tin-doped indium oxide also known as indium tin oxide (ITO) which acts as a transparent, electrically conductive connective layer [12, 27]. The arrangement diagram of the active layers is shown in Figure 1.

Control strategy of light and thermal comfort is often based on a different kind of controller. Its design is sometimes performed using MATLAB Fuzzy Logic Toolbox [29]. Using the fuzzy theory, the membership function is defined for the input and output variables and control rules resulting from the applied control strategy. In the presented solution, conventional PID controllers were chosen. To construct the control system, the wireless sensor networks can be used in order to optimise the process and minimise the energy consumption [25]. This allows the use of a variety of external light sources for additional energy savings. In the research, the authors decided to use an L-50 Luxmeter commercial light intensity sensor (Sonopan Sp. z o.o. Poland with Spectral range according to DIN 5032-7). Flexible PDLC (Polymer Dispersed Liquid Crystals) electrochromic film is the control

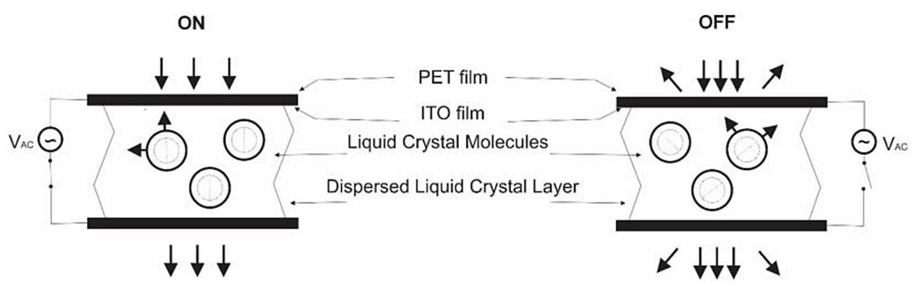

Figure 1. PDLC film structure, polymer dispersed liquid crystals [30]

object in Smart Window system, which changes its transparency under the influence of the AC current. The structure of this film is shown in Figure 1. Its basic data are presented in Table 1.

The research work presents a unique approach to controlling the lighting intensity because the film is divided into 12 horizontal lamellas connected to the control electronic system, which is supposed to be located in a special cassette attached to the window frame. The cassette with the electronic system was connected to the window using special electrical connectors, as shown in the diagram in Figure 2A. The presented prototype uses commercial window components such as a Pilkington [31] glass unit and a Petecki [32] window frame as well as PDLC layer. In the work on optimal lighting conditions in the factory, three lighting control strategies were proposed: control of variable transmittance of 12 lamellas at the same time, control of individual lamella of the on/off type control, individual dimming of individual lamellas. The project is not a commercial product, but only a working prototype. Therefore, it is difficult to estimate the real costs associated with the integration and implementation of the sales system. Due to the large number of conclusions and information, the author decided to separate these systems. The first of them is described in this work.

Designing a system for regulating visual comfort requires the knowledge on the essence of the

Table 1. Characteristics of the PDLC film, provided by the manufacturer (Zhuhai Shuifa Singyes New Materials Technology Co,Ltd.)[30]

Optical features	Voltage	ON	~100 V AC
	Transmittance	ON	~80%
		OFF	~5%
	View angle	ON	>150
	Response time	OFF → ON	<20 ms
		ON → OFF	<200 ms
Physical features	Storage temperature	OFF	-20~80 C
		ON	-10~70 C
	ON/OFF cycles	ON	$>30 \cdot 10^6$ times
	Life time	ON	$>5 \cdot 10^4$ h
Size	Length		50 m
	width		1.2–1.5 m

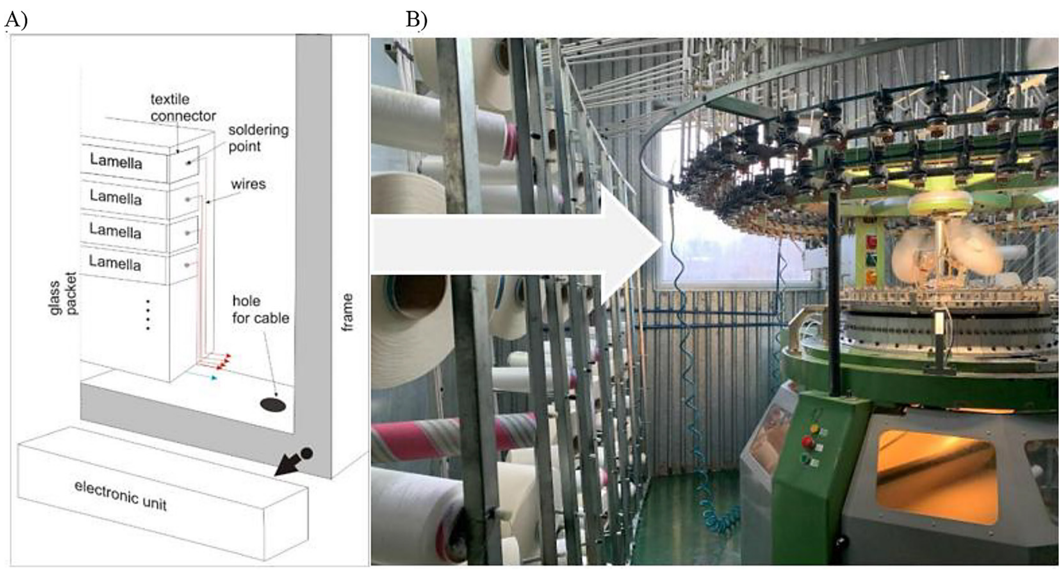

Figure 2. (a) General concept of connecting the PDLC foil with the electronics and window frame; (b) the realisation in building structures, under the textile factory conditions

phenomenon. Control of light transmission through the lamella is possible after determination of the static and dynamic properties of lamellas. A very important problem from the point of view of the methodology of designing a lighting intensity control system is the choice of the type of sensor/sensors and its location in the production hall space. This can significantly affect the control efficiency. Discussion on this topic is the basis of good industrial design practices, which was briefly discussed in this article. The work focused primarily on the construction of the control system using PDLC film segments (lamellas), which is an interesting topic on the subject of smart windows. From the point of view of design ergonomics, lighting standards and norms apply. These standards include, for example, (PN-EN 12464-1:2021 – Light and lighting. Lighting of workplaces. Part 1: Indoor workplaces.; PN-EN 12464-2:2014 – Lighting of workplaces. Part 2: Outdoor workplaces.) According to them, the minimum lighting intensity in the workplace depends on the type of workstation and the nature of the work performed, e.g. warehouses require 200 lx, and office work 500 lx. They also indicate the methodology for measuring lighting intensity, usually 0.75–0.85 m above the floor, on the work surface and measuring equipment with a measurement class of at least C. However, they do not provide information on how to design automatic lighting control systems. This is the domain of automation engineers as well as the associated calibration and tuning of automation systems individually for each workstation. In this work, a general strategy of controlling the active layer of the window was adopted, which depends on the leading value of the intensity expressed in Lx, the so-called SET point. The comparison of the ranges of the two tested lighting intensity regulation intervals Ein = (150 ÷ 250) Lx and Ein = (300 ÷ 500) Lx is presented in Figure 3. On the basis of the research by A. Hemaida at all [30], artificial lighting was omitted in the model assumptions. Diagram of the quality model of light intensity measurements in the room model, presented in Figure 3.

The next step of the research was to place the light intensity sensor in the feedback loop of the control system. For this purpose, a network of 27 sensors was made in the production hall to determine the most effective control space. The scheme of the sensor layout in the hall is shown in Figure 4. The SOL-1000-24A27 floodlight was used in the measurements to avoid interference and to perform measurements of the distribution of lighting intensity under stable and repeatable conditions.

This will enable the identification of zones in the production room for proper lighting regulation, see Figure 5A. On this basis, a control zone with lighting intensity Ein was determined, in which a sensor responsible for regulating of the shading of the smart windows lamellas was placed, Figure 5 B.

The next stage of the research involved studying the different types of illumination sensor placed in the control area. Three types of sensors were examined: 1) photodetector, TEMT6200FX01 ; 2) glare sensor; 3) light meter model L-100. The first sensor used was a typical semiconductor, photoresistor made by Vishay Ltd company. As a glare

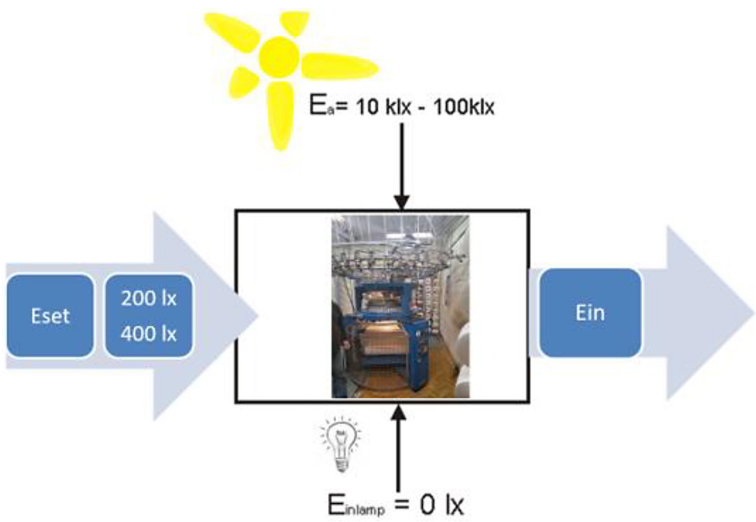

Figure 3. Quality model of light intensity measurements, Eset - set light value, Ein – control value, Ein – indoor light intensity, lx (artificial light), Ea – ambient light intensity, lx

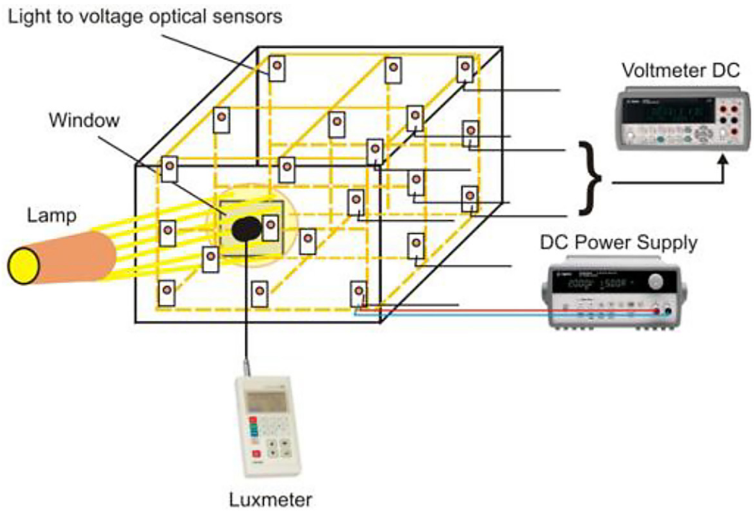

Figure 4. Diagram of the sensor network layout in the production hall

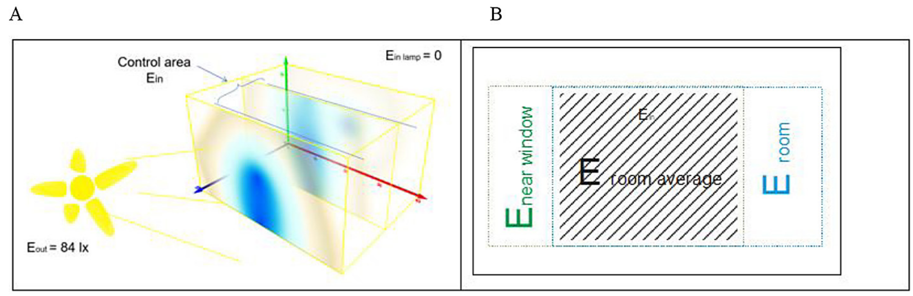

Figure 5. (a) Light distribution in room model without internal light-measurements results; (b) the divided scheme of light control area Ein

sensor uses light sensor, 24 V DC SERVODAN company, capable of measuring in different ranges: 3...300 lux; 30...3.000 lux; 300...30.000 lux; - 600...60.000 lux. L-100 it was used as a reference sensor. During the study a disturbing feature of the glare sensor was observed. When the intensity of light in the room dropped below 380 lx, the sensor saturated. The same situation appeared in the case of larger values of light intensity above 20 klx. This is probably due to the lack of limitations on the size of the boundary (input) value in processing algorithm of sensor. Another observed feature of the test glare sensor was a little change of the output voltage. The output voltage of the sensor is changed only in the range of a few mV. Changing the light intensity in the testing room by 82% caused a change of the output voltage of the glare sensor by 4.6% (overcast day with sparse sunshine). Moreover, it was observed that the temporary changes light intensity did not cause changes in the output voltage of glare sensor. The output voltage of the glare sensor does not exceed 2 V (declared voltage range at the output of the sensor is 0–10 V). This is disadvantageous for the automatic system of the lamellas, because the automation system is not sensitive to small changes in sensor value. Therefore, it was decided to use the first type of sensors in the automatic lighting intensity control system.

Devices used in research:

- Artificial sunlight illumination– SOL-1000-24A27, TSUBOSAKA ELECTRIC CO., LT Japan.
- L-50 Luxmeter, Sonopan Sp. z o.o. Poand with Spectral range according to DIN 5032-7.
- L-100 Luxmeter, Sonopan Sp. z o.o. Poand with Spectral range according to DIN 5032-7.
- Glare sensor 24VDC/0-10V 4 ranges 3..60K, NIKO-SERVODAN Company, Belgium.
- TEMT6200FX01, Vishay Ltd., Queens Square NR17 AFAttleborough, Norfolk, United Kingdom.
- AXIOMET Digital multimeter AX-594,Transfer Multisort Elektronik sp. z o.o. Poland.

- Oscilloscope, USB Pico 3406D MSO PP936 and a PC computer with measurement PicoSDK software, Pico Technology Limited, England.
- Laboratory Power Supplies Matrix, MPS-3005L-3, ShenZhen Matrix Technology Inc, ShenZhen, China.
- NI USB 6009 card, National Instrument, 11500 N Mopac Expwy Austin, USA.
- Matlab & Simulink software, MathWorks, 1 Apple Hill Drive Natick, MA 01760-2098, USA.
- VEVOR TDGC2-2000VA, Vevor Corp. to 1172 Murphy Av Ste 237, San Jose, CA 95131, USA.

RESEARCH

Identification of the static properties of lamellas

Determination of the static properties was necessary for the design of the system supply of lamellas. Static properties of lamellas are set using the control characteristic and impedance parameters, impedance, current and power. The static properties of lamellas were determined by the measuring system are shown in (Figure 6). Lamellas were feed with an alternating voltage from a VEVOR TDGC2-2000 VA autotransformer, 50 Hz. They are powered by the electronics commutator, which was controlled using a measuring card connected to a computer (Figure 7). The commutator switching on particular lamella.

lamellas in alternating current circuit characterised by parallel impedance connection, resistance and capacitance RC. Equivalent circuit of each lamellas is shown in Figure. 4. Substitute Impedance of 12 Lamellas with the film active film is determined by Equation 1.

$$Z_f = \frac{1}{12\sqrt{\left(\frac{1}{R_f}\right)^2 + \left(\frac{1}{X_{fC}}\right)^2}} \tag{1}$$

where: Z_f – impedance of lamella, R_f – leakage resistance of lamella, X_{fc} – reactance of lamella.

The research was carried out by supplying film by sinusoidal voltage from 10 V to 100 V, 50 Hz, (Figure 7) voltage was varied by autotransformer. RMS voltage and current, were

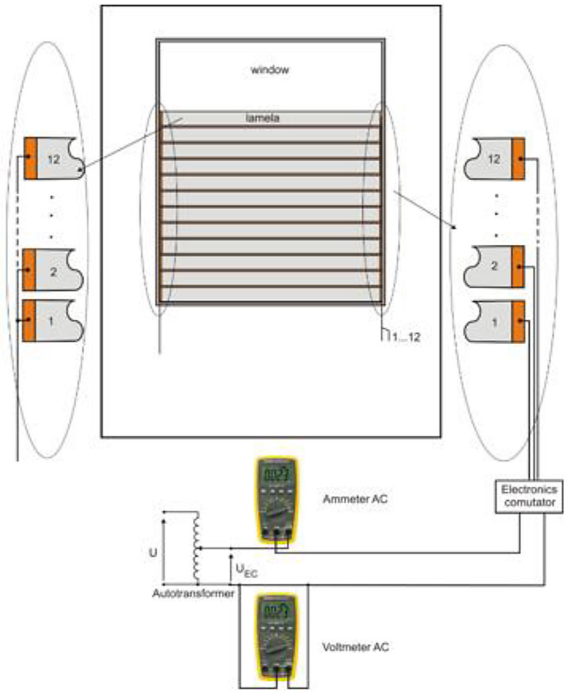

Figure 6. Equivalent measurement scheme

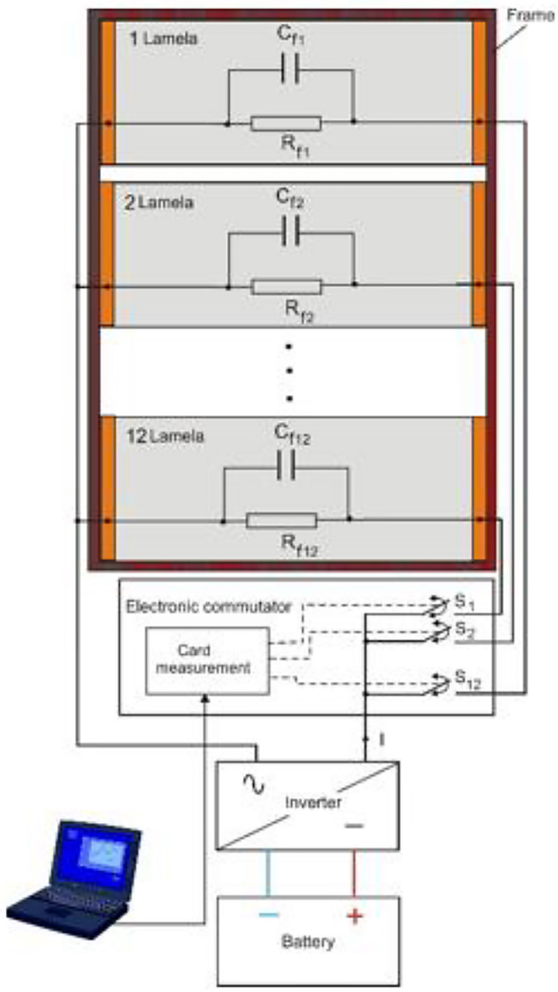

Figure 7. Substitute scheme of circuit with lamellas

measured. The measurements results are presented in Figures 8–13.

The study consisted in determining the impedance, current, apparent power and light inside the room for the selected lamellas depending on modulation voltage supply. Lamella number 4 was placed in the axis perpendicular to the floodlight. The measuring scheme is shown in Figure 14. The measurements results are presented in Figures 15–18.

Identification of the dynamic properties of the lamella with the active film

Designing a Smart Window control system requires also determination of dynamic properties of the active film. The dynamic properties of the active film are defined by the transfer function. The step function was fed to the input of the lamella and the response was intensity of light passing through the lamella. On the basis of the

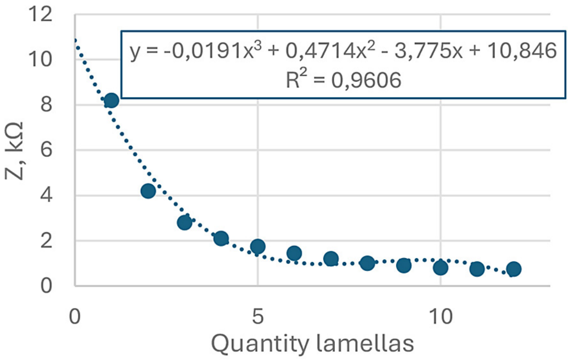

Figure 8. Substitute impedance (Z) lamellas

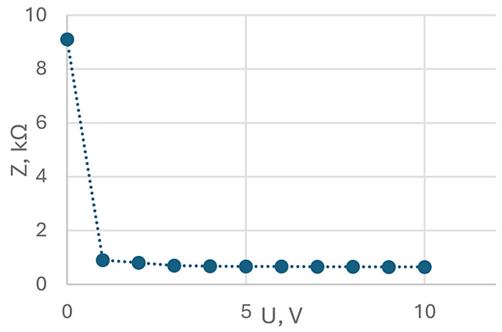

Figure 11. Lamella impedance (Z) depending on the supply voltage (U)

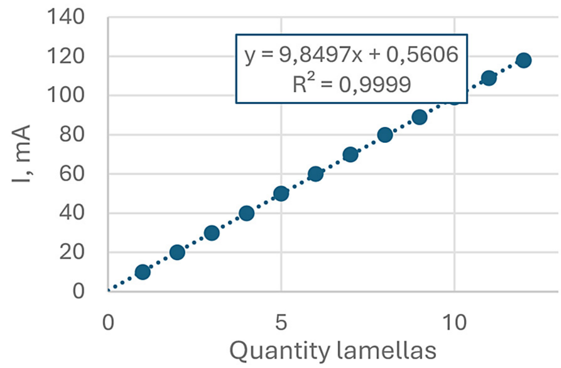

Figure 9. Current (I) of lamellas

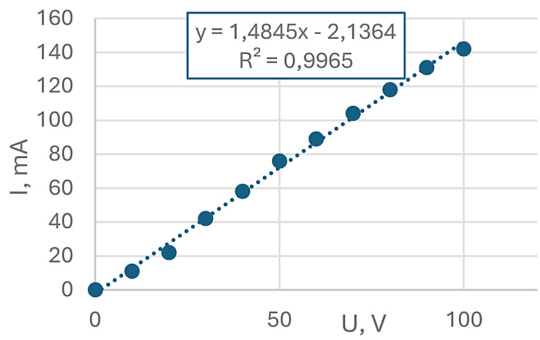

Figure 12. The current (I) flowing through the 12 lamellas depending on the supply voltage (U)

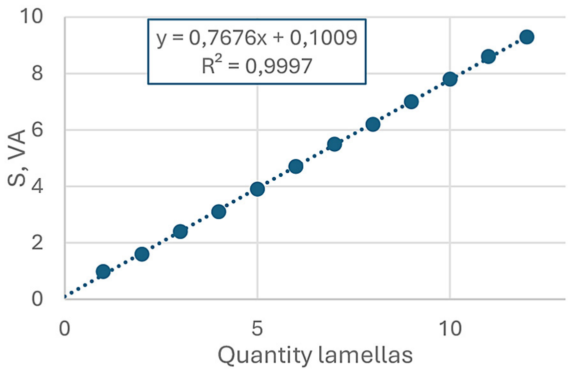

Figure 10. Complex power (S) of lamellas

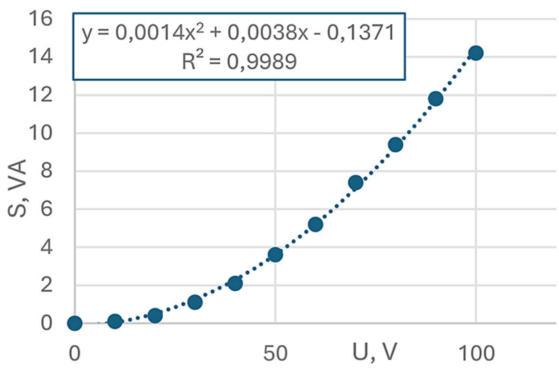

Figure 13. Complex power (S) of 12 lamellas

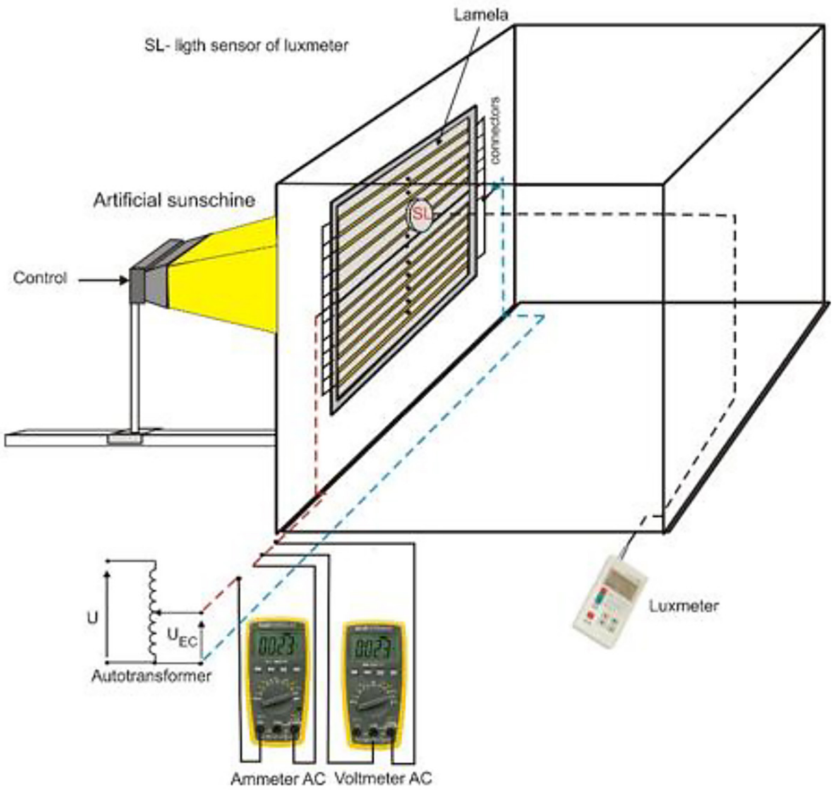

Figure 14. Scheme of the measurement stand

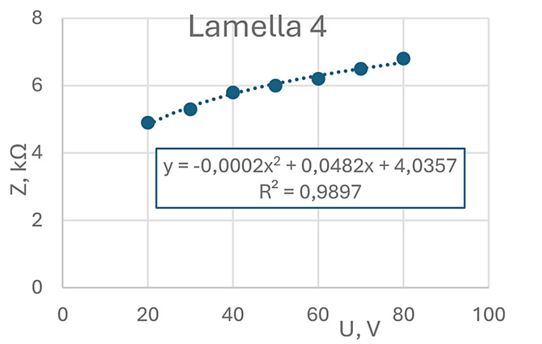

Figure 15. Lamella impedance (Z) depending on the lamella depending on the supply voltage (U)

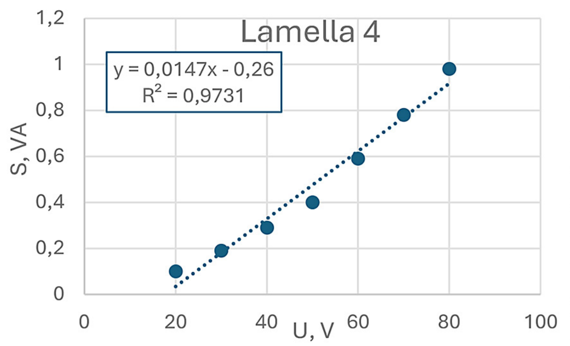

Figure 17. Complex power (S) of one lamella

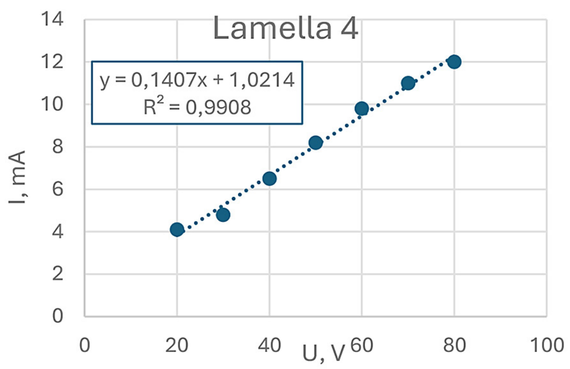

Figure 16. Current (I) of one on the supply voltage (U)

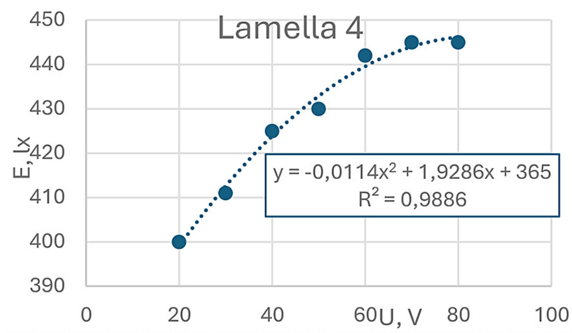

Figure 18. Light intensity (E) in room depending on the supply voltage (U) of lamellas

course of light intensity stated in the Figure 18, the transfer function of a control object is set and it is expressed by the relation (2). The transmittance consists of real different and proportional units.

$$G(s)=\frac{\Delta E(s)}{\Delta U(s)}=\frac{ks}{1+sT}+k_f \qquad (2)$$

where: $\Delta U(s)$ – voltage input function Laplace transform, $\Delta E_{in}(s)$ – light intensity response Laplace transform, k – gain coefficient, k_f – gain coefficient, T – time constant.

The dynamic properties were determined by using the DC voltage step power of lamella. During this time, the current waveform, light intensity and voltage shifts were recorded. The identification was performed for different values of supply voltage (20–80) V. The light intensity recorded by the sensor SL. The voltage from sensor scaled using a luxmeter. The measurement stand is shown in Figure 19. The selected for voltage input function 80 V measurements results are presented in Figures 20–22.

For example, the maximum current is 18 µA for 12 lamellas at a supply voltage of 80 V, and the apparent power is 9.30 VA.

Visual comfort strategy

The study concerns the tests carried out on a real object, which consists of a window with built-in blinds, an electronic system and a software controller. Various types of control strategies were tested in order to obtain optimal visual comfort. First, the visual comfort control system was developed in the Matlab/Simulink program. The results of the tests using the Matlab program were used to create a digital PID controller in C language implemented in a microcontroller system, which will not be presented in this article. The controller system was made in two variants: as a PID controller in the mode of controlling the entire surface of the electrochromic film (control of

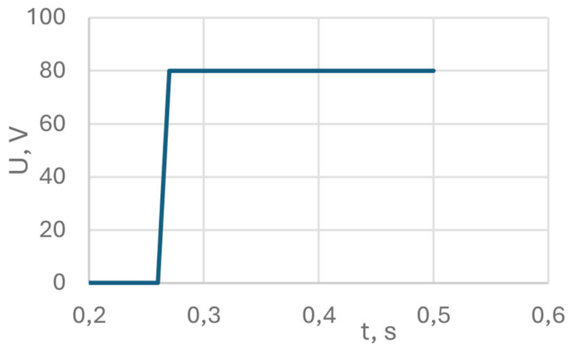

Figure 20. Voltage (U) step function for lamella

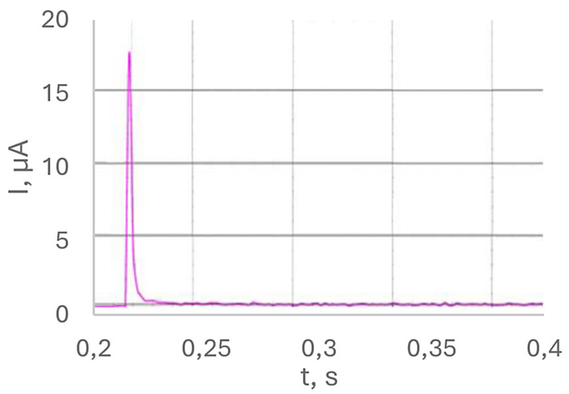

Figure 21. Lamella current (I) response function in time (t)

A) B)

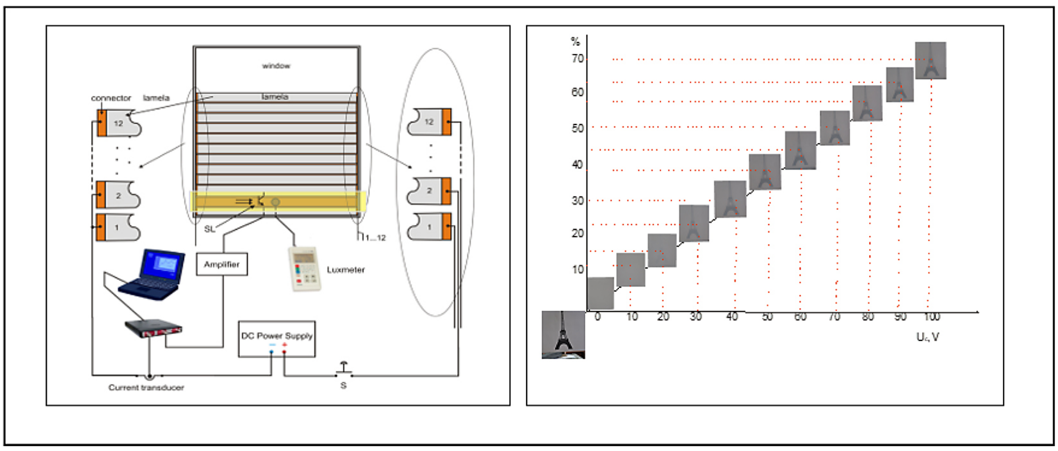

Figure 19. (a) Measurement scheme of dynamic properties; (b) The voltage (V) value vs % of transparency

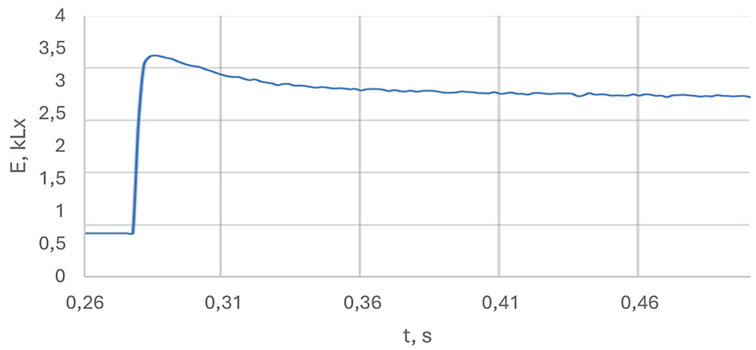

Figure 22. Light intensity (E) response time (t) function to a voltage step, change in lamella

the light transmittance of the film) and a particular lamellas control mode, i.e. switching the lamella of window on/off (maximum light transmittance/ low transmittance). The results of the first case were presented in this article. The block diagram of the control system is presented in Figure 23.

The block diagram of the control system, the connection of the lamellas with the software controller in Matlab is shown in Figure 24. Simulink libraries were used to build the controller. In order to physically connect the lamellas to the software controller, it is necessary to use analog card and software. Simulink function blocks (Analog output and input) allow collecting signals data and function blocks that convert analog signals to digital signals (Discrete Transfer FCN) and digital signals to analog signals (Discrete Transfer FCN2).

RESULTS

The first stage of testing was to conduct a simulation in the Matlab Simulink environment. The results are shown in Figure 26. The

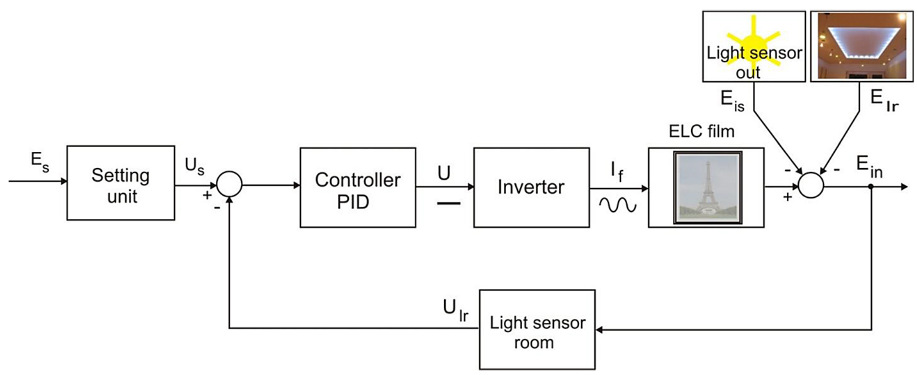

Figure 23. Block diagram of the control system

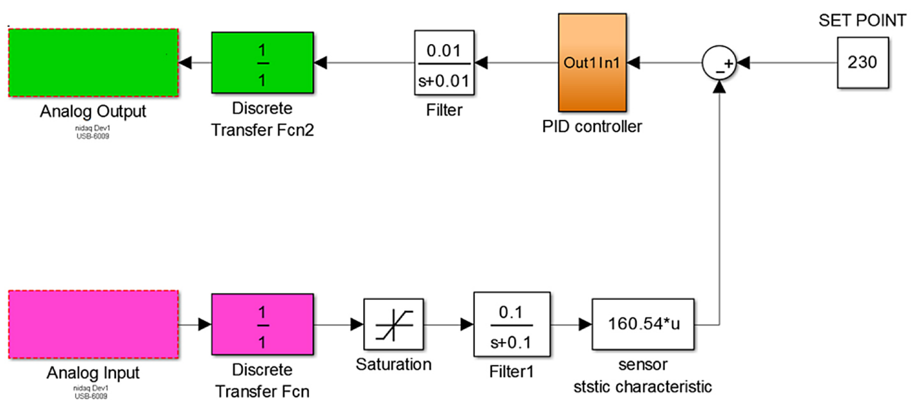

Figure 24. Control system diagram in Matlab/Simulink with output to analog-digital card NI USB 6009

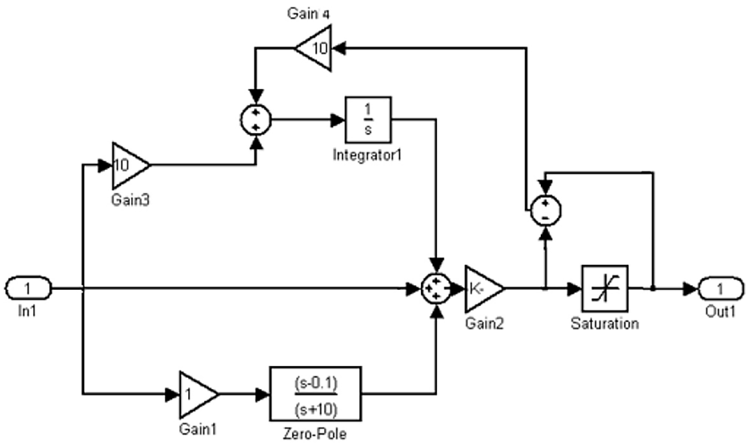

Figure 25. Schematic diagram of the PID controller for controlling the transmittance of the entire surface of the active film

simulation consisted of checking the response of the control system for a given set point value, with assumed external lighting conditions. Additionally, a simulated lighting distribution at a distance of 1.5 m was presented, which is to correspond to the lighting conditions at the knitting machine (Figure 27). The next stage of the work was research in real conditions. Set point values were changed in the range of 200–400 lx. The intensity changes in the production hall was

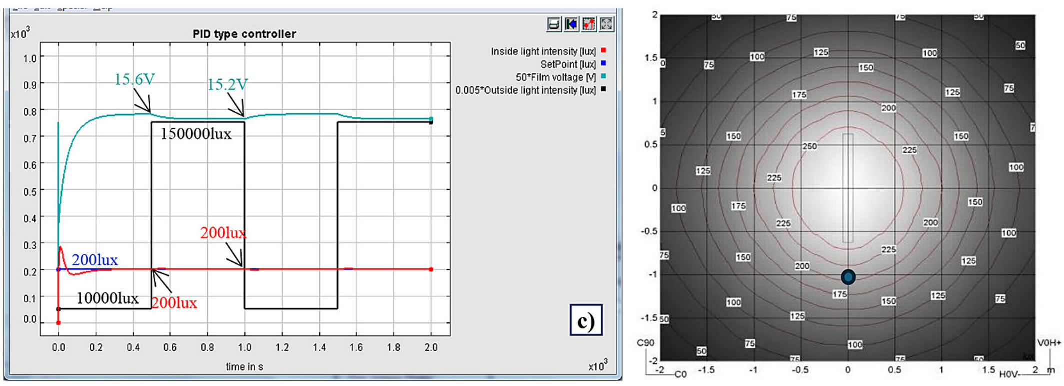

Figure 26. Responses of smart window process control model for the setpoint value equal to 200 lux PID type controller and light distribution in machines area

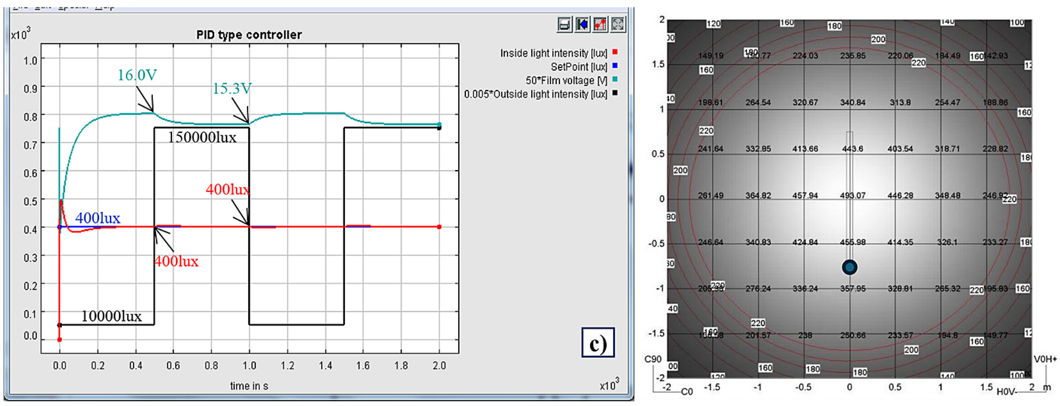

Figure 27. Responses of smart window process control model for the setpoint value equal to 400 lux PID type controller and light distribution in machines area

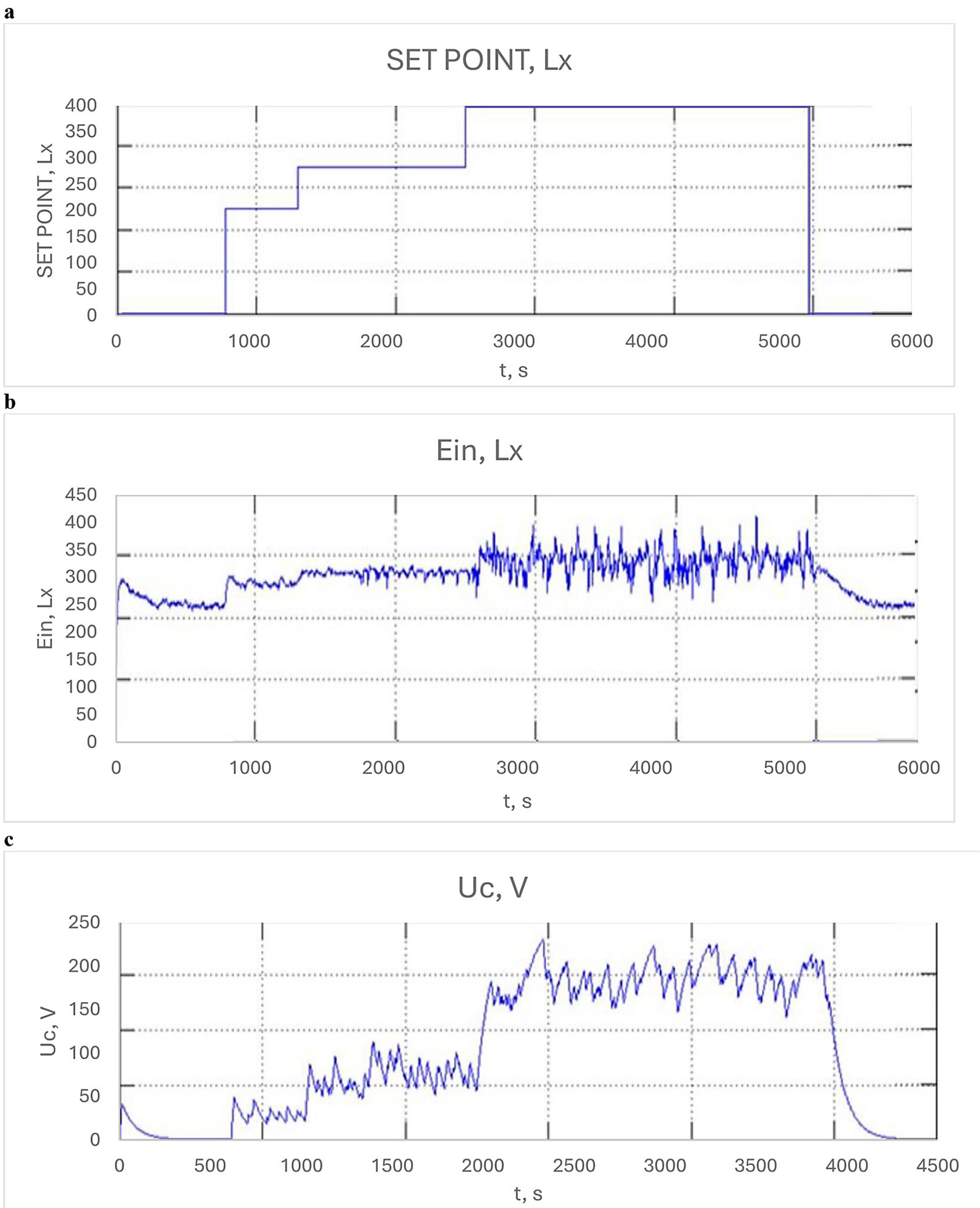

Figure 28. Experiment results, measurements of changes in lighting intensity in the test production hall, time chart (t) in sec. A) change of the set point value 200–400 lx; B) change of lighting intensity in the production hall-measurement with a lighting intensity sensor, lx; C) change of voltage controlling the operation of the lamellas V

also recorded. The research results are shown in Figure 28 a-c. Figure 28b shows a change in the light intensity in the machine surroundings caused by a change in the reference value shown in Figure 28a. This change is caused by the operation of the lamellas system in the window. Figure 24c shows the change in the voltage controlling of the lamellas. The voltage changes confirm the correct operation of the automatic window control system.

DISCUSSION AND CONCLUSIONS

Implementing more complex intelligent lighting control systems in textile factories is a strategic step towards digital transformation and sustainability. Following examples such as Adidas and Siemens [33], manufacturers can achieve significant cost savings, better working conditions and a smaller environmental footprint, which is in line with the global sustainability trends (Responsible

Consumption and Production -SDG 12). As technology advances, further integration with artificial intelligence and smart grids will enable even greater efficiency, strengthening the transition of the textile industry towards a smarter and greener future.

The static properties of the PDLC film were determined by measuring the impedance of the lamella. This impedance affects the intensifying current flowing through the lamella, depending on the supply voltage. Additionally, the apparent power of the lamella was determined depending on the voltage. This information is necessary for designing the power system to supply the lamellas. For example, the maximum current is 117 mA for 12 lamellas with a supply voltage of 80 V and an apparent power of 9.30 VA. The dynamic properties of the control object were determined experimentally in a room with a window.

The response functions were applied using the step voltage method. When analysing the response in terms of current and light in the room, it was concluded that the control object is a real derivative part containing a constant component. The derivative part mapped the transition state resulting from the parallel leakage resistance (R) and capacitance (C) of the active film. The fixed component results from the transmittance of light through the PDLC film lamella. The transmission parameters were verified by a simulation model, the course of which was similar to the registered illuminance.

Research illuminance distribution in the room showed its nonuniform distribution. There is a need to optimise the control system to ensure uniform visual comfort, e.g. by combining the control system with local artificial lighting. Simulation studies should take into account the interference that is visible during real measurements. Fluctuations in light intensity in a room may indicate that the slats are working at a specific frequency which, although not detected by the human eye, may affect the health and well-being of people staying in the room. The static characteristics of the film is nonlinear and it should be linearized in a range of operating point. The dynamic properties of PDLC film were determined experimentally. Transfer function (transmittance) of PDLC film has a form of real derivative unit. The main problem take into account automation process to visual comfort is quantity and placement of light sensors in the room or only in Smart Window. Optimisation of the light intensity sensor placement should be performed individually for each room, so-called system tuning. The developed variant of light transmittance control of the entire surface of the PDLC film allows for the regulation of visual comfort, which was confirmed experimentally and by simulations. It was also found that such systems require individual calibration and optimisation. An important issue from the point of view of the system operation is also the choice of the lighting sensor. The behaviour of the system with different types of sensors results from their static and dynamic properties. Therefore, in each case the controller settings must be selected individually to optimise the control system. The results of the research conducted in the Matlab/Simulink program were used to develop a digital PID controller in the C language, which was implemented in the microcontroller of the electronic control system. This controller allows for precise control of light transmittance, both for the entire film surface and for individual lamellas.

The conclusions indicate the need for further research and optimisation of the system, especially in the field of linearization of static characteristics and improvement of control dynamics, in order to achieve optimal visual comfort under various lighting conditions. It seems interesting to link such system with artificial lighting control in the production hall. There are many benefits that this system can bring. Primarily, it will be a reduction in costs related to air conditioning, it will increase comfort and safety of work, and this aspect is priceless.

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