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ACTIVE SHADING SYSTEM AS A REDUCTION OF BUILDING COOLING REQUIREMENTS

Michal Masaryk jr.[(a)], Michal Masaryk[(a)]

[(a)] Slovak University of Technology, Faculty of Mechanical Engineering
Bratislava, 81231, Slovakia, michal.masaryk@stuba.sk

ABSTRACT

This article deals with conceptual design and implementation of active shading system to reduce building cooling requirements. First, the problem of building overheating in the warm period of the year and the requirement of lighting in the building interior are explained. Then, the concept of automated shading system is presented as an efficient yet simple solution to this issue. Along with that, the initial phase of experimental verification, namely the design and additives used, is described. In conclusion, the results of the initial phase are discussed and the future application of the project along with its significance for civil engineering are explored.

Keywords: Shading, Automation, Skylights, Buildings, Industry

INTRODUCTION

A significant thermodynamic challenge arises frequently in large utility structures. This natural yet troublesome occurrence involves excessive heat gains within these buildings during the warmer months, specifically from April to September in Slovakia. During this season, the increase in solar radiation leads to substantial heat accumulation inside large structures. While industrial facilities are most commonly impacted, other types of utility buildings like warehouses and workshops also experience severe effects.

The overheating of buildings primarily stems from the construction materials and architectural features employed. Regrettably, these elements facilitate significant solar heat penetration into the building interiors. Among the problematic architectural elements, skylights on roofs stand out. Despite occupying only 10-15% of the total roof area, skylights account for at least 60% of the total solar heat gains. Regarding construction materials, the conventional layouts are poorly suited for thermal insulation. Certain materials, notably asphalt and corrugated metal panels, are known to be excellent heat accumulators, often used in roofing. Although these materials offer robust protection against weather conditions, they significantly hinder the reduction of the building's heat load. Despite these challenges, it remains practically unfeasible to exclude elements like skylights from the design of utility buildings, especially considering the high costs associated with redesigning existing structures.

The primary justification for incorporating glass surfaces into building designs is the provision of lighting. Natural light and adequate workplace illumination are crucial for maintaining optimal working conditions and ensuring the long-term well-being of employees. The ideal illuminance level, measured in lux, for workplaces ranges between 500 and 2000. Achieving these illumination standards can be accomplished through artificial lighting or, more cost-effectively, by utilizing natural lighting sources such as skylights. Given that skylights and other glass surfaces are responsible for the majority of heat gains during warmer months, the main challenge is to design a system capable of absorbing or reflecting the heat-carrying portion of the solar radiation spectrum (infrared radiation) while still allowing sufficient visible light to enter the building's interior.

ACTIVE SHADING SYSTEM

The research team from the Institute of Energy Machinery at the Faculty of Mechanical Engineering is focusing on the development of an automated adaptive shading system. The goal of this system is to minimize heat gains that occur through the glass surfaces of buildings, with a particular emphasis on skylights. This objective will be realized through a combination of a specific physical principle, a straightforward design, and an electronic automation system.

The operating mechanism of the system will involve forming a fluid layer on the transparent surface, enhanced with an appropriate additive. This layer is designed to filter out the infrared spectrum of solar radiation while maximizing the transmission of visible light. It's important to note that a pure water layer is insufficient due to its limited ability to filter infrared radiation (as shown in figure 1). Various strategies were explored, including the use of opaque fluid "strips" with adjustable widths or employing a specialized chemical compound at precise concentrations. Ultimately, the most effective solution was identified as a water-based shading system with a variable concentration of the additive.

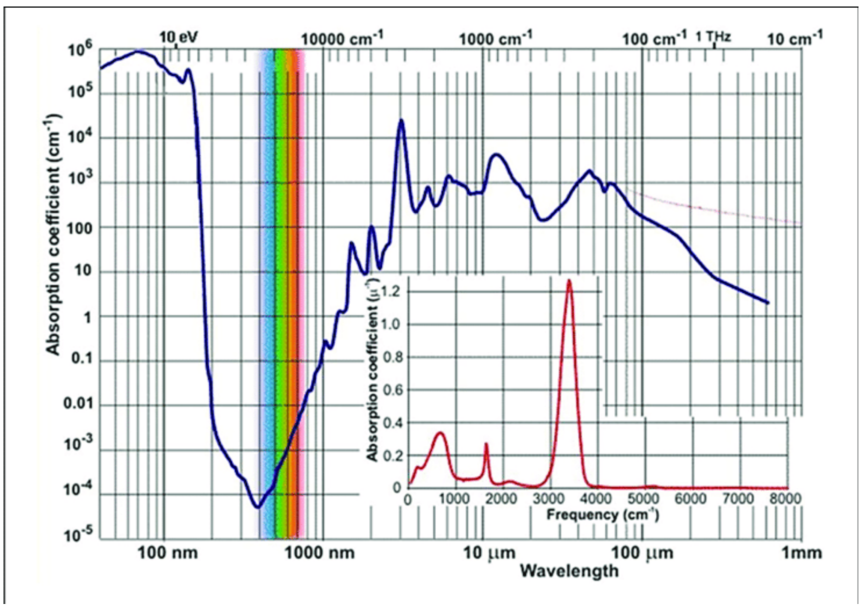

Figure 1: Radiation spectrum absorption for water

1.1. Practical Limitations

Before delving into the experimental setup of the system described, it's essential to consider the practical constraints within which the system must operate to ensure both financial and technical feasibility. Three key conditions outline how the system should function.

The first condition is the need for simplicity and low maintenance requirements. This is crucial because the system aims to replace conventional exterior shading systems, which are typically electromechanical. Secondly, the system must achieve adequate IR shading and visible transparency efficiency. To compete with advanced systems like active-layer windows, the adaptive shading system needs to meet at least intermediate performance levels. Lastly, the system must be innovative and resource-efficient. For the shading system to attract potential users, it must incorporate technological innovation and efficiently utilize resources, which will be addressed by the electronic automation component of the system.

1.2. Experiments and Testing

To identify the suitable additive for an effective shading solution, numerous experiments were carried out with different chemical compounds and coloring agents. The system concept envisioned the use of a readily available additive in a water-based solution with a variable concentration. Consequently, commercially available dyes and other coloring chemical compounds were utilized and tested on the prototype system. It's crucial to differentiate between the variable concentration of the additive as a function of the shading system (electronically controlled, involving separate tanks and pumps) and the varying concentrations of the additive used in experiments (manually added, with effects observed).

Experiments were performed on a small greenhouse model made of polyacrylic material, with dimensions of 600 cm x 250 cm x 200 cm (rounded top). The experiments were conducted from September 1st to September 12th 2023. For each additive tested, solar irradiance (E_e in W/m²), illuminance (E_v in lux) and temperature difference inside and outside the model were measured. Testing greenhouse model is shown on figure 2.

Figure 2: Testing model

1.3. Tested Additives

Acrylic Black Paint

Acrylic paint was chosen as an inexpensive and widely available alternative to other tested additives. Black color has previously shown the potential to be a good IR radiation absorbant. The results of testing did show impressive capabilities for blocking IR radiation (more than 80% of IR radiation blocked), however the drawback was definitely the relative amount of visible light transmittance which was very low (about 10% transmittance).

Carbon Gel Black Paint

Specific by its near-zero environmental impact due to being used as a grocery colorant, the carbon particles-based black gel paint was chosen as the next testing substance. Carbon particles, and the consequent black color, were also promising as an IR-absorbing agent. The result of testing the carbon black paint were relatively satisfying, with IR absorption exceeding 60% and visible light transmittance nearly reaching 40%. This additive was the best one tested up until this point.

Titanium White Paint

As the third testing substance white paint containing titanium particles was chosen. The rationale behind its use was the presence of metal particles. Similar to other metals, titanium has higher reflectivity in the IR spectrum [3] and having its particles in a jellied form was suitable for creating a water solution. Unfortunately, similarly to the acrylic paint, the titanium white paint has shown good IR-blocking properties (excess of 70% IR radiation blocked) but with only limited visible light transmittance (less than 20%).

Summary

To sum up, many of the tested additives did not fulfill the basic requirement of sufficient visible light transmittance in spite of showing significant potential in terms of IR radiation blocking (mostly absorbance). The most promising of the testing group was the carbon black gel paint. The results of its testing in tabular and graphical form are shown in table 1, figure 3 and figure 4.

Table1. IR radiation and visible light values inside/outside the model for carbon gel paint.

Time od day:	IR radiation outside (W/m^2)	IR radiation inside (W/m^2)	Vis. light outside (Lux)	Vis. light inside (Lux)
14:15	846	432	77680	31820
14:25	802	382	77320	30560
14:35	775	402	72850	29440
14:45	775	382	70180	26460
14:55	763	376	69660	25240

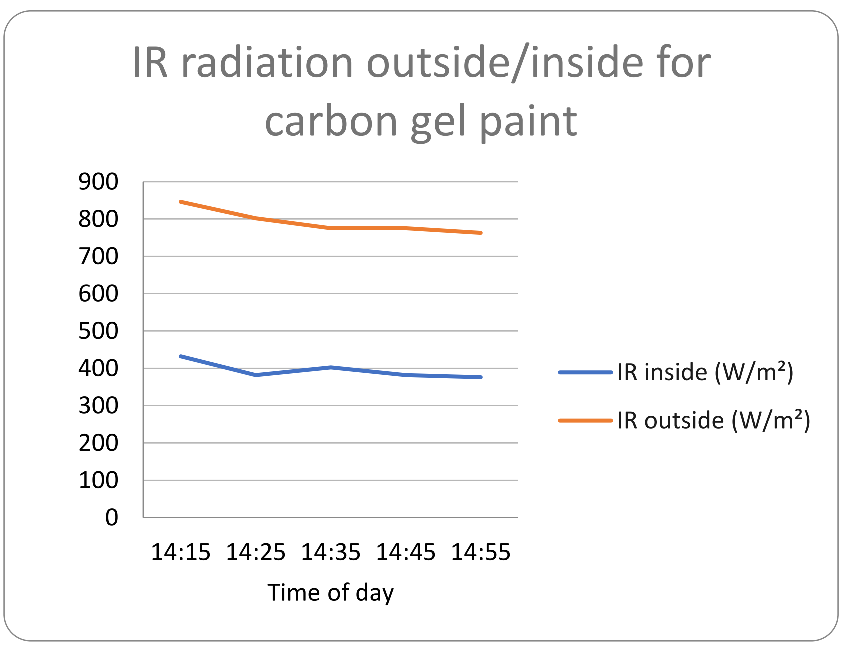

Figure 3: IR radiation values for carbon gel paint

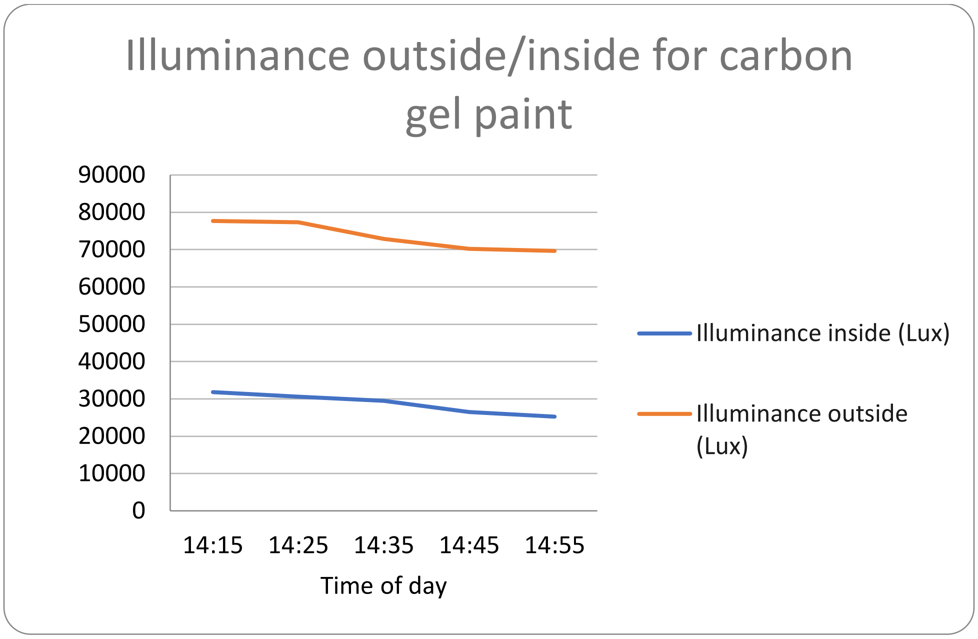

Figure 4: Illuminance values for carbon gel paint

CONCLUSIONS

Of the conducted experiments, a clear conclusion can be drawn - there is a potential for a liquid-based shading system that will use simple yet effective water solution in order to provide shading on glass surfaces of buildings, while allowing sufficient transmittance of visible light.

The reduction of thermal load penetrating the roof skylights is achieved by IR filtering water films with suitable additives. These water films are flowing on and covering the surface of the skylights, creating a coherent layer 1 - 1.5 mm thick. Reduction of transmitted IR solar radiation reaches approximately 65% with best additives. Another positive effect is a direct convective cooling of skylights by relatively cold water which reaches about 150 - 200 W_{cool} per m^2 of surface.

As a result, this unconventional shading system reduces the needed power outputs of cooling machinery, particularly in compressor-based air-conditioning systems.

As was mentioned in the description of the designed system, its significant part is an automation and control system that would ensure its continuous and effective function. This electronic automation part is yet to be designed and its function and specifics yet to be determined. However, just like the underlying operating principle of the shading system - simplicity, the automation system is likewise projected to be built on an existing widely available control platform, such as Arduino.

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