Adaptive Shading System as a Building Heat Load Reduction

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Abstract. This article deals with conceptual design and experimental implementation of active shading system to reduce building heat gains. First, the problem of building overheating in the summer period and the requirement of lighting in the building interior is explained. Then, the concept of the automated shading system is presented as an efficient yet simple solution to this problem. 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 stages of the project along with its significance for the industry are explored.

Research background: The issue of overheating of utility buildings in the summer period and the requirement of sufficient lighting of their interior. Measurements in the respective literature and on-site in industrial buildings.
Purpose of the article: Explaining the conceptual design of an automated shading system as a remedy to the overheating problem and also to raise awareness of this widespread issue.
Methods: Direct measurements of the respective quantities in the industrial sites were conducted. Laboratory experiments along with measurements of several used shading solutions were conducted.
Findings & Value added: Some substances showed promising results in creating a translucent heat barrier for sunlight. Further solutions are planned to be tested.

Keywords: *shading; skylights; heat load; utility buildings; roofs;*

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1 Introduction

By large utility buildings, one big thermodynamic issue occurs on a regular basis. These natural, yet problematic phenomena are heat gains of buildings in the warm period of the year - from April to September in Slovakia. In this period of the year, solar radiation increases by so much that significant heat gains occur in the interior of large buildings. The buildings affected are mostly of industrial nature but other utility buildings, such as warehouses and workshops, are also severely affected. [1] [2]

The resulting overheating of buildings is mostly caused by construction materials and architectonic elements used. These do, unfortunately, allow for extensive penetration of solar heat into the interior of the building. The aforementioned problematic architectonic elements are first and foremost skylights on the roof. Skylights usually take up 10-15 % of the overall roof area yet they contribute at least 60 % to the overall solar heat gains. As for the construction materials, the traditional layout used is ill-suited for thermal insulation.[8] In fact, some of the best heat accumulators are commonly used by roof building, including asphalt and corrugated metal panels [2], [9]. While these provide great protection against the elements of weather, they have a disastrous effect in terms of the heat load reduction of the specific building. While all these facts hold true, it is virtually impossible to omit elements such as skylights when designing an utility building. (In addition to the redesign of existing buildings not being a financially viable option). [1]

The simple reason for the continued inclusion of glass surfaces in the design of buildings is lighting. Natural light and workplace illumination is a key parameter for optimal working conditions and long-term health of the employees. [6] The optimal value of illuminance (measured in lux) in the workplace is between 500 and 2000 [1]. These levels of workplace illumination can only be reached by using artificial lighting or, with much reduced expenses, by using natural lighting, e.g. from skylights. With skylights and other glass surfaces being the source of the vast majority of the heat gains in the warm months, the real challenge lies in designing a system that would allow for absorbing or reflecting the heat-bearing part of the solar radiation spectrum, the infrared radiation, while letting enough visible light into the interior of the building [11]. [3]

2 Adaptive shading system

Automated adaptive shading system, the layout and experimental design of which is the subject of the Institute of Energy Machinery at Faculty of Mechanical Engineering research team’s work. Its purpose is to ensure the reduction of heat gains generated through glass surfaces of buildings, specifically skylights. This effect will be achieved through an effective combination of a specific physical principle, a simple design and an electronic automating system.

The operating principle will be based on creating a layer of fluid on the transparent surface, with an appropriate additive, that would ensure the filtering of the infrared spectrum of solar radiation while allowing for maximum permeability of visible light [7]. A liquid layer of only water cannot be used as its IR filtration capacity is severely limited (as shown in figure 1). While several approaches were considered, such as opaque fluid “strips” with variable width or using a specialized chemical compound in a very specific range of concentrations, eventually the most suitable approach was chosen - water-based shading solution with variable concentration of the additive.

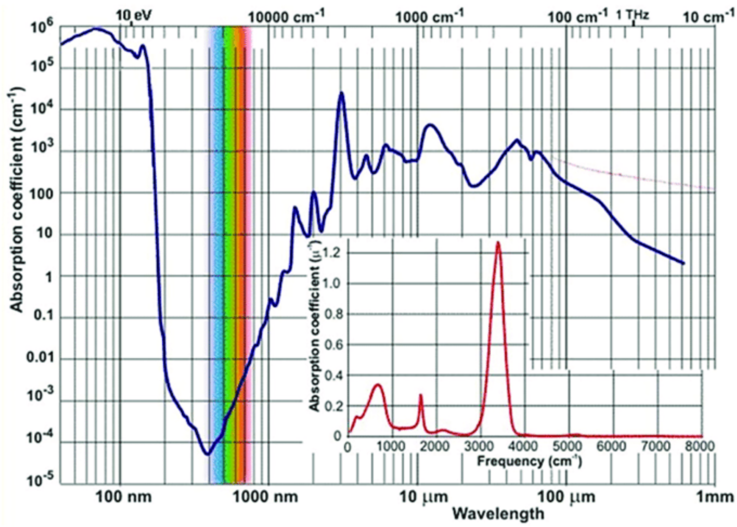

Fig. 1. Absorption of wavelengths in water [12].

2.1 System limitations

Before describing the experimental implementation of the aforementioned system, let us have a look at the practical limitations, in the realm of which the system must function in order for its usage to be financially and technically viable. There are three conditions that define how the system should operate.

The first is the requirement of simplicity and minimal maintenance. The reason for this is the capability to replace standard exterior shading systems - mostly electromechanical systems. [5] Next, a sufficient IR shading/visible transparency efficiency is required. In order for the adaptive shading system to be able to compete with hi-tech systems, such as active-layer windows [4], it has to be able to reach at least intermediate levels of performance. Finally, the system has to be innovative and resource-efficient. [4] For the shading system to be appealing to potential users, it has to have some element of technological innovation, traditionally coupled with optimal use of resources [8]. This requirement will be fulfilled by the electronic automation part of the system.

2.2 Experimental design and testing

In order to determine the appropriate additive to create an effective shading solution, several experiments with various chemical compounds and coloring agents were conducted. The chosen concept of the system was for it to use a sufficiently available additive in a water-based solution with variable concentration. Due to this, commercially accessible dyes and other coloring chemical compounds were used and tested on the prototype system. It is important to distinguish between variable concentration of the additive as a function of the shading system (electronically controlled, using separate tanks and pumps) and varying concentrations of the additive by the experiments (added manually and their effects being observed).

The experiments were conducted on a large, 130 cm x 160 cm window and on a smaller, 52 cm x 50 cm glass plate. During the winter months, a 65 W IR lamp and a regular 60 W table lamp were used as light sources for measurements. From March onwards, measurements were made on direct sunlight, as it was already available. In the case of each additive, solar irradiance E_e [W/m^2] and illuminance E_v [lux] were measured - at first without the added chemical compound, then with it. 3D model of the testing stand is shown on figure 2.

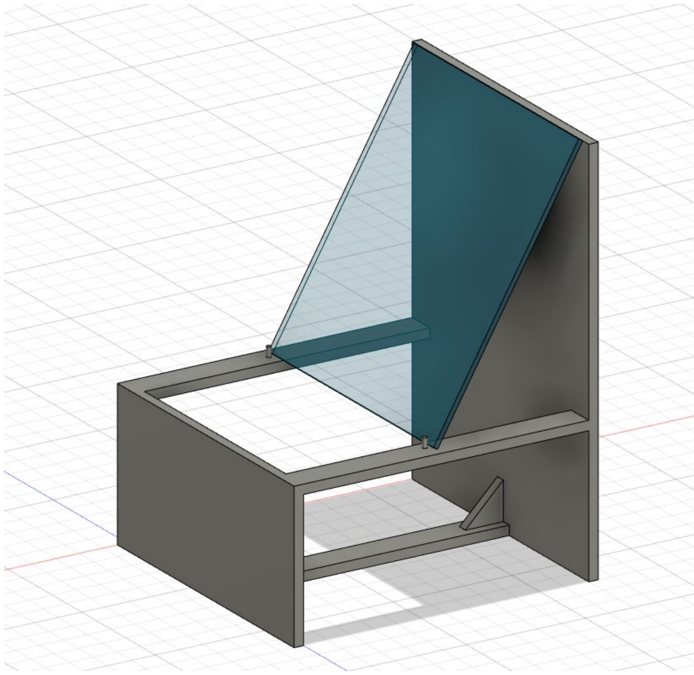

Fig. 2. 3D model of experimental stand.

2.2.1 Tested additives

Silver Paint

The first tested chemical compound added to the water solution was silver paint. The rationale behind its use was the presence of aluminum particles on which the paint is based. Similar to other metals, aluminum has high reflectivity in the IR spectrum [3] and having its particles in a jellied form was suitable for creating a water solution. Various concentrations were tested and the results are shown in table 1.

Table 1. Silver paint tests.

Substance	**Irradiance E_e [W/m²]**	**Illuminance E_e [lux]**
Water 20 l	96	144
Silver paint 190 g	76	123
Silver paint 290 g	66	104
Silver paint 390 g	51	93

In general, the silver paint has reached satisfying efficiency in filtration of IR radiation. However, its use presented a whole set of other issues, which made it unsuitable to be used. The first being its toxicity - this trait makes it unsuitable due to health and environmental concerns. Next, it left a notable residue after use, even after washing the system with clean water, which is a significant technological obstacle.

Liquid Foil

The next tested substance added to the water solution was a specific type of paint "liquid foil". This substance was originally intended to be used as paint, applied in several layers. Experiments were conducted with both a painted dried glass surface as well as a surface with a liquid layer being poured onto it. Although the manufacturer did not state the exact formula of the substance, it was a playmaker-based compound that was non-toxic and soluble in water. Results of the measurements are shown in table 2.

Table 2. Liquid foil test.

Substance	Irradiance E_e [W/m²]	Illuminance E_e [lux]
Water 3l	498	4350
Liquid foil 20g	315	2603

After the initial experiment, the water solution with this additive was deemed unsuitable for general use. This was due to extensive residue that was hardly removable just a few minutes after the shutdown of the system. On the other hand, the painted surface, which was used as a comparison, did show notable improvement in filtering IR radiation and was kept as an efficiency benchmark.

Acrylic paint

Acrylic paint was chosen as an inexpensive and widely available alternative to other tested additives. Experiments were conducted with black, white, metallic orange and metallic yellow acrylic paints. Several concentrations were tested, while in some cases - for example after a very weak performance, it was redundant to continue the process with lower concentrations and the testing did not continue. Test results of acrylic paints are shown in table 3.

Table 3. Acrylic paints tests.

Substance	Irradiance E_e [W/m²]	Illuminance E_e [lux]
Water 3 l	114	129
Black acrylic 13 g	47	26
White acrylic 50 g	86	105
Substance	**Irradiance E_e [W/m²]**	**Illuminance E_e [lux]**
Water 3 l	152	210
Orange acrylic 60 g	134	191
Yellow acrylic 50 g	146	196

The measured shading efficiency of acrylic paints was mixed. It was heavily dependent on the color shade used. The metallic colors had the poorest results and were deemed unsuitable due to very weak performance. On the other hand, white acrylic paint yielded significantly better results, though a higher volume was needed. Finally, black acrylic paint yielded the best results, reaching the performance of white paint while requiring ⅓ of its volume. Black acrylic paint was deemed effective and its performance and effects will be further tested in future experiments.

3 Conclusions and further project continuation

Of the conducted experiments, a clear conclusion can be drawn - there is a potential for a recycled liquid-based shading system that will use simple yet effective water solution in order to provide shading of glass surfaces of buildings, without reducing the input of visible light. It is important to note, that the aforementioned experimental project is in its initial phase and the second round of experiments is being conducted.

Of the tested additives and the resulting water solutions, some have been shown to have little suitability and value for the project, mostly due to their poor performance or the capability to filter visible light instead of IR light - a property inverse to the desired one. On the other hand, by some substances it was demonstrated that they have a satisfying capacity to achieve the desired IR filtration without significantly reducing the illuminance of the building interior.

As was mentioned in the description of the designed system, its significant part is an automation and control system that would ensure its innovative 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.

The potential of the concept and its capacity to supplement or replace existing exterior shading systems are vast [7], to say at least. With the extensive use and fast-paced implementation of automation coupled with an increased focus on environmentalism and energy-efficient systems [10], projects such as these are becoming the center of attention of business and scientific communities alike.

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