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REGULATION OF RADIATION TRANSMITTANCE THROUGH ELECTRO-OPTIC TECHNOLOGIES

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There are three fundamental mode of heat transfer: diffusion, convection and radiation. Although our modern windows are really good at blocking heat transferred from diffusion and convection, a lot of energy is able to pass through them in the form of electro-magnetic waves, mostly in the visible and infrared spectrum. It has been proven that even transparent curtains will afford adequate protection from optical radiation in the ultraviolet region, but that all of them will transmit high percentages of infrared radiation, while the solar irradiance is high in the infrared spectrum. Using a system of polarizers active specifically for the range of the IR spectrum with the highest irradiance and a liquid crystal cell (LCC) we can alter the energy transmittance of windows without blocking visible light. This way, using less energy than usual conditioning systems we can control the temperature of the environment, without rendering our windows opaque in the visible spectrum. This is achieved by using a system of combined Kerr and Pockels cells, with high electro-optic constant, low energy expenses and longitudinal applied voltage.
Keywords: radiation transmittance, diffusion, convection, radiation, polarizer.

Există trei moduri fundamentale ale transferului de căldură: difuzie, convecţie şi radiaţie. Deşi ferestrele noastre moderne sunt foarte bune pentru blocarea căldurii transferate de la difuzie și convecție, o mare energie este capabilă sa treacă prin ele în formă de unde electromagnetice, mai ales în spectrul vizibil şi infraroşu. S-a dovedit că, chiar dacă perdele transparente vor permite o protecție adecvată împotriva radiațiilor optice în regiunea ultravioletă, cu toate acestea ele vor transmite un procent ridicat de radiații infraroșii, întrucît iradierea solară este mare în spectrul infraroşu. Folosind un sistem de polarizatoare, active, în mod special, pentru gama de spectrul infraroşu cu cea mai mare iradiere, și o celulă de cristal lichid (CCL) putem modifica transmisia de energie prin ferestre fără a bloca lumina vizibilă. Astfel, folosind mai puțină energie decît pentru sistemele obișnuite de condiționare putem controla temperatura mediului, fără a face ferestrele noastre opace în spectrul vizibil. Acest lucru este realizat prin utilizarea unui sistem de celule combinate Kerr și Pockels, cu constante electro-optice înalte, cheltuieli mici de energie și tensiuni joase aplicate longitudinal.
Cuvinte-cheie: transparenţa radiaţiei, difuzie, convecţie, radiaţie, polarizator.

THE PROBLEM

As noticed before, air conditionings are a good countermeasure for over-heated rooms but a bad one for ecology.

For instance, let's analyze the thermal equilibrium of a sky-crapper. Almost all the outer surface of a sky-crapper is covered in windows. If there were no air conditioningsystems the temperature would easily reach 40 ^{o}C. This means that a major amount of energy is lost to cool down the building.

The problem is that these air conditioning systems are fighting the heat that is already inside a closed room. Even though they are cooling down the air using the air convection effect, they are not able to combat the most important source of heat, Infrared radiation.

But, what would happen if we stopped the heat before it had entered the room?

HYPOTHESIS

We propose to decrease by half the amount of energy spent on air conditioning of the buildings with big surface of windows such as sky-crappers. We would do that by placing on the windows an additional heat-filtering layer. Also, we purpose a method that will automatically adjust the amount of filtered heat, such that the temperature inside would be constant.

GOALS AND EXPECTED OUTCOMES

The primary goals of this project are:

1) Creating an optical device (additional window layer) that can regulate the amount of

radiation which passes through the optical device.
2) Proving the fact that it is possible to control the amount of radiation which passes through the optical device using a variable AC source.
3) Finding the theoretical dependence between the voltage applied on the optical device and the energetic transmittance of the device.
4) Applying this additional layer on a regular window, in order to control the radiation passed through the window as a function of the voltage applying on the device.
5) Creating a program that can control the voltage applied on the additional layer as a function of the temperature inside the room. In this way, if the temperature inside increases, the voltage on the device is also increased and as a result, the amount of heat that passes through the window will be decreased and the temperature will be automatically

RESEARCH METHODS

The first step was analyzing the fundamental methods of heat transfer: diffusion, convection and radiation. Although our modern windows are really good at blocking heat transferred from diffusion and convection, a lot of energy is able to pass through them in the form of electro-magnetic waves, mostly in the visible and infrared spectrum.

The stages of our research:
1) Assembling a liquid crystal cell by placing a liquid crystal cell with variable birefringence between two polarizers, thus creating an optical device with a variable transmittance.
2) Then, we assembled an installation suitable for visible light that proved our theory. As the light source we used a red laser with the wavelength of 700 nm.
3) After gathering and analyzing the data, we plotted the dependence of the optical device transmittance as a function of the voltage applied on it. We noticed that the phase shift of the light passed through the liquid crystal cell is a power dependence of the voltage applied on the cell.

$$\Delta\varphi = c \cdot U^{\beta} \tag{1}$$

4) After analyzing the graphs we determined the parameters of our installation, like the value of β, which is β =1.85. Finally we deduced a theoretical dependence of the transmittance of our device as a function of voltage applied on it.
5) After obtaining a working optical device (for visible spectrum), we set our goal to create a similar device which would work in the same manner but this time with infrared light (800-1500 nm).
6) The final step was creating software that regulates the voltage applied on the liquid crystal cell as a function of the temperature inside the room. Which means that if the temperature inside raises, the voltage on the liquid crystal cell rises, and as a result the temperature decreases.
7) Explaining the way we can use the technology and assemble a smart window.

DETAILED EXPLANATION OF EACH STEP

We assembled a liquid crystal cell, which is a component of our optical device.

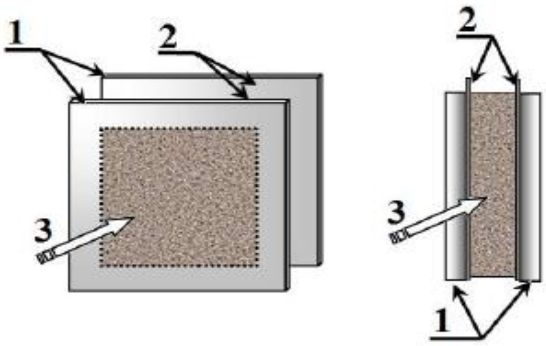

Fig. 1. Two thin polycarbonate protective layers (1), inner surface of the cell which is covered with zinc oxide doped with aluminum (which is used as a transparent conductor) (2), saturated KH_2PO_4 solution (3)

The cell is made up of two polycarbonate protective layers that are covered on the inner side with a transparent conductive material (zinc oxide doped with aluminum). And inside a saturated KH_2PO_4 solution is found.

We chose specifically the KH_2PO_4 solution because after analyzing many solutions that have a variable birefringence like nitrobenzene, Lithium Niobate and others, we came to the conclusion that the solution not only has an optimal electro-optical constant, but is also cheap and available.

EXPERIMENT

The experimental installation sketch is shown in fig. 2.

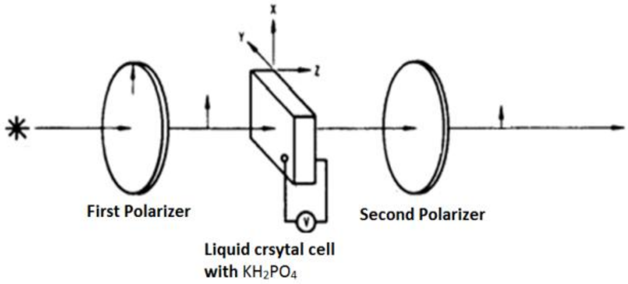

Fig. 2. Experimental installation sketch

The main goal of this experiment is to prove that radiation transmittance is a function of the voltage applied on the device. Our optical device represented as 3 independent layers (2, 3, 4) are shown in the fig. 3.

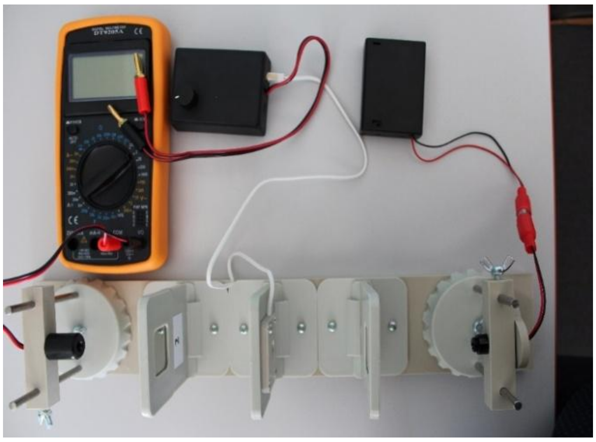

Fig. 3. Optical device

In the photo (from left to right):

1) Photoreceptor that gives voltage output;
2) Polarizer 2;
3) Liquid crystal cell;
4) Polarizer 1;
5) A red light source (700 nm).

Also we have a multi-meter for calculating the voltage on the photoreceptor, and also a variable AC source for the liquid crystal cell.

First and second polarizers have parallel polarization planes.

Then we start our experiment:

- Initially the voltage on the cell was zero, so the light passes without meeting any obstacles.
- Then we start to apply voltage on the cell and we notice that the voltage on the photoreceptor decreases.
- We measure with the voltmeter the dependence of the voltage on photodetector as a function of the voltage applied on the liquid crystal cell, and then we plot the data.

To determine the intensity of the light that emerges out of our optical device we used the following formulas, which we deducted from Malus law:

$$I_{emerged} = I_o/2 \cdot sin^2(\Delta\varphi/2) \quad (2)$$

We also know that I~U, thus we obtain:

$$(\Delta\varphi) = arcsin\sqrt{\frac{U}{Umax}} \quad (3)$$

where $\Delta\varphi$ is the phase shift created in the infrared wave after it passed through the birefringent medium.

In order to find the theoretical formula for $I_{emerged}$ as a function of voltage applied on the optical device, we analyze the graph of the voltage applied at the liquid crystal cell as a function of the voltage on the photoreceptor. Then we plot the graph (fig. 4).

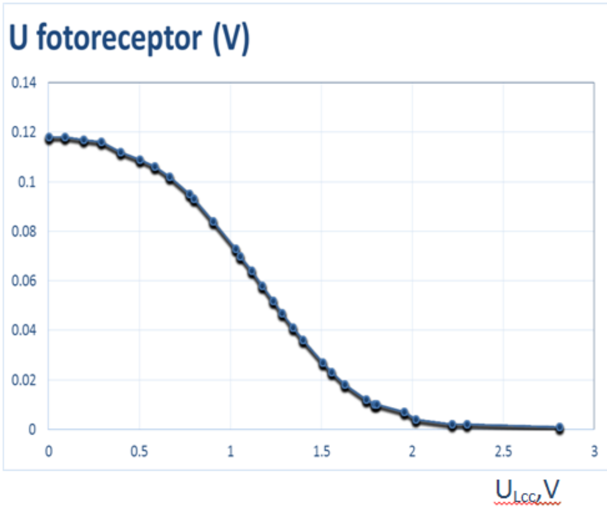

Fig. 4. Graph of the voltage applied at the liquid crystal cell as a function of the voltage on the photoreceptor

Then we supposed that the phase shift is a power function of the voltage applied on the liquid crystal cell (formula (1)).

Then in order to determine the β constant, we plot the graph of ln($\Delta\varphi$) function of ln(U_{Lcc}) (fig. 5).

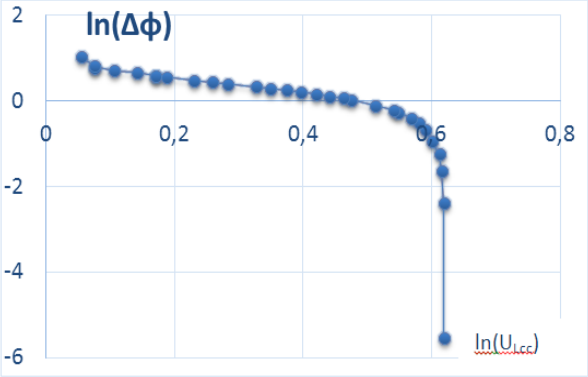

Fig. 5. Dependence ln($\Delta\varphi$) function of ln(U_{Lcc})

So, from the graph above we find that the tangent of the line isβ, and its value is β=1.85. It's a quite interesting result, because using a solution of KH_2PO_4 and applying transversal voltage, we created a cell, similar to a Pockels one, but in which the difference of refractive indexes depends on the voltage applied as roughly U^2 which is similar to a Kerr cell.

The final formula we obtained, which defines the Intensity of the light that emerges from the optical device as a function of the voltage applied on the liquid crystal cell.

$$I_{emerged} = I_0/2 \cdot \sin\left(\frac{c * U^{\wedge}1.85}{2}\right)^2 \quad (4)$$

After obtaining the final formula, we now know the dependence and we created a similar device, but whose aim is to block specific wavelengths, infrared wavelengths (750-1500 nm). This is important because many building are heated not only because of convection or conduction, but also due to the radiation. In fig. 6 the red zone is occupied by radiation which passes the atmosphere and thus can reach the windows. A significant surface of the “red zone” is in the infrared spectrum which means that by regulating this radiation, we could adjust the temperature of buildings.

We propose software which would relate the voltage applied on the electro-optic cell and the desired temperature inside the room. Also, the software has a temperature regulating function; that would mean that if you set a desired temperature, for example 25 °C, the window will be auto-regulating the voltage on the optic device in such a way, that the amount of infrared radiation passed through the window will be able to heat the room maximum to 25 °C.

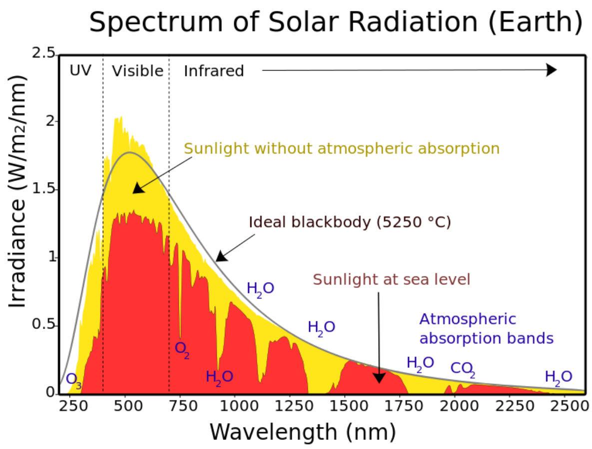

Fig. 6. Spectrum of solar radiation at the Earth

This is how it works:

The temperature inside the room is read by a device namedthermos-copper, which works on the Seebeck effect. Temperature is represented as a voltage. Our software has one input and one output. For the input we have the voltage from the thermo-copper. The output is the voltage on the optical device. We then set the device to execute one simple command, to keep the ratio:

$$\frac{Voltage\ from\ the\ thermo-copper}{Voltage\ on\ the\ optical\ device} = constant \quad (5)$$

The whole idea is that when the temperature inside a building is higher than the desired one, the system varies the applied voltage such that the transmittance of the infrared radiation decreases and therefore the temperature decreases.

Explaining the way we assemble a smart window.

To revise: a smart window will be composed of a regular window with an additional layer that we created. The layer will be made up of small and thin “optical devices” connected in parallel such that the voltage would be the same on every “optical device”.

The efficiency of this product is much higher than the efficiency of the air conditionings, because it is working at small voltages (1-5 volts) and don`t require big amounts of energy.

Take for examplea large 12,000 BTU air conditioner, running six hours each day will consume 270 kWh, at a cost of $36.26 per month. However, our Smart window will consume the maximum amount of 15$.

RISKS AND SAFETY

The system will operate on a maximum value of 10 Volts (AC). The created electric field inside the windows will be of 10 to the 6^{th} magnitude. Although the intensity is high, it will act only on a small interval of 10 microns, which is unreachable for humans. On the other hand, the electric field intensity outside the window will be 0, so will pose no threat for the user. Also in case of a leakage, the substances used in the windows are non-toxic and can be easily be cleaned.

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