Thermochromic Glazing for "Zero Net Energy" House

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Keywords

1 = Dynamic control of solar energy 2 = "Smart window" 3 = Thermochromic laminated glass
4 = Heat transfer modelling

Abstract

Thermochromic laminated glazing (TLG) enables to regulate daylight automatically adapting dynamically to the continuously changing climatic conditions, aids in reducing the energy needs of a building and providing thermal comfort. Neither electrical power nor driving unit are required. The polymeric interlayer of TLG is doped with complexes of transition metals, which change their coordination and transmission or colour of the film under influence of light and heat fluxes. Now we have neutral colour conversions from light to dark (grey or brown) and coloured ones from rosy or yellow to blue and green at our disposal.

In combination with Low-E glass, TLG makes possible to create regulated cover heating for "zero net energy" houses ("intelligent facades"). Energy modelling of the heat-transfer in ventilated facades has shown that TLG can provide decrease of 15-30% in the building energy consumption during the winter heating time in climatic conditions of some regions in Russia. During summer time the reduction of solar energy gain reaches 30-40% and it is enough to get rid of air-conditioning at all.

Introduction

Glazing with changing optical and thermal properties called as "Variable Transmission Windows" has been desired for many years. Such product offering the best balance between heat loss and solar energy gain is the most appropriate. "Intelligent facades" with "smart glazing" should be dynamic and flexible to exterior environment and occupant needs and desires and also be able to reduce energy requirements.

So far, glass technology aiming to reduce the energy needs of a building has largely used passive materials (tinted glass), whose properties do not change with climatic conditions. Their chief disadvantages are that they become warm themselves and visibly coloured. In regions such as Northern Europe where high visible light transmission is favoured it is undesirable because of unattractiveness of tinted glass in winter low light conditions. Besides, tinted glazed buildings have drawbacks of heat losses in winter and overheating in summer even in Northern European climates.

It is well known that half of the energy consumed throughout the developed world is used to heat, cool and light buildings. Power supply sector is not only the primary source of electrical and thermal energy but the main source of greenhouse gases – caused principally by the burning of fossil fuels as well. In Russia fuel and energy complex emits about 70 per cent of the total volume of greenhouse gases.

Use of "smart windows" in building constructions can significantly reduce energy consumption and carbon dioxide (the main contributor to the greenhouse effect) emissions, retain energy in building. The ecological goal of "smart window" is to exploit solar energy resources to meet the energy needs of a building.

"Smart" glazing can be divided into some major categories: non-electrically activated (photochromic and thermochromic) and electrically activated types. The most popular and most complicated is electrochromic. The electrically activated devices have the advantage of automatic control. For the electronically switchable technologies, costs are probably in the range of several hundreds US$/m^2. As to photochromic glass it is not presently produced in sufficient sizes or at low enough cost (about 500 US$/m^2) to allow its use in buildings or cars.

Thermochromic laminated glazing (TLG) developed in TUPP is a "smart" glazing that regulates the entry of light on a programmable and automatic basis. No electrical power, or other power is needed to operate the thermochromic system. Use of thermochromic material allows the creation of "intelligent" windows and facades. These techniques allow building, with extensive glazing, to adapt dynamically and continuously to ever changing climatic conditions - and thereby minimize energy requirements. Thermochromic materials are affordable and have a service life of over dozen years. Cost of TLG can be estimated at 50 US$/m^2. In combination with Low-E glass, TLG makes possible to create regulated cover heating for "zero net energy" houses ("intelligent facades"). "Zero net energy" (ZNE) homes provide most of their own energy, so the economic benefit to owners is free energy provided by the ZNE design and thermochromic technologies.
It is possible to design a ZNE home to support several types of cottage industry, so the homes help the owners generate income.

So TLG can solve the problem concerned creation of energy conserving glass whose properties and activity are affected by external stimuli.

Dynamic solar control and effectiveness of TLG

Materials and technology

New developed thermochromic laminated glass "glass-pane – thermochromic interlayer – glass-pane" (TLG) with variable transmission includes polymeric interlayer, which is doped with complexes of transition metals (Fe, Cu, Cr, Co etc.).

The change of the complexes coordination occurs under influence of light or heat fluxes, that results in reversible change of transmission and/ or colour of TLG. At present we have conversions from light grey or brown to dark grey or brown and coloured ones from rosy or yellow to blue or green at our disposal.

Thermochromic interlayer is synthesized on the water-soluble polymer base at 90^{0}C. The hot polymeric melt is extruded through the draw plate onto unadhereable underlying material or directly on the glass. The drying process is controlled over with spectroscopy. Thickness of the film is within 0.3-1 mm. The value of adhesion can be varied within the interval 1-20 kg/cm.

Water-soluble thermochromic interlayer must be protected against exposure to the atmosphere. For this purpose earlier we developed "glass-pane – thermochromic interlayer – curable resin – glass-pane" type of TLG from resin laminating technology. However, flat TLG can be produced more cheaply using the autoclave process than a resin laminating process requiring additional materials and equipment (a filling table, a curing area, an uniform source of UV radiation). Now we have worked out the technology of thermochromic films autoclaving under heat and pressure, similar to known one for PVB foil. We have achieved higher level of interlayer thermoplasticity using plasticizers that in turn lets us laminate TLG at reduced and readily available temperatures (<100^{0}C).

Daylight Regulation and Advantages of TLG

TLG enables to regulate daylight automatically, adapting dynamically to the continuously changing climatic conditions, aids in reducing the energy needs of a building and providing thermal comfort. Neither electrical power nor driving units are required. TLG can be also used in exterior and interior design as a vitrage consisted of elements with changing colour.

One of the major trends expected in the area of "Smart windows" was the development of colour-neutral products. At present we have conversions from slightly grey or slightly green to dark grey, from lightly brown to dark brown, from pink to blue, and from yellow to green at our disposal.

The energy-efficient glass market is currently driven by U-value decreasing. As it is known it is necessary to decrease the solar gain in the South latitude to avoid overheating of the room. But local building codes of some cities (San Francisco, Calgary, Singapore etc.) limits the visible reflectivity to less than 20% or lower. This leads to inevitable warming up of the window and that is the best condition for TLG operating with high efficiency because TLG absorbs visible and near infrared rays and then reradiates energy in far infrared region.

In winter in regions such as Northern Europe it is desirable to increase the total solar heat transmittance of the window for the purpose of decreasing "effective U-value". In the same place in summer more expensive air conditioning will induce to increase solar control. Considering that our TLG is responsive to both the temperature and light flux this contradiction can be resolved. In winter because of the low temperature (T<20^{0}C) outside TLG will constantly have the maximum light transmittance, and in summer (T>20^{0}C) TLG will normally regulate transmittance, protecting from overheating.

In combination with Low-e coating TLG can serve for "zero net energy" houses ("Intelligent facades"). In winter solar energy through clear TLG will heat a wall and the energy accumulated by the wall remains inside owing to Low-e. In summer time TLG transforms the solar energy into heat, which will be reflected by Low-e in far infrared region without blinding effect.

This product is toxic-free. Service life of TLG is several dozen of years. Thermochromic dyes consumption ranges from 2 to 20 g/m^2. Cost of TLG can be evaluated at 50 US$/m^2. As a contrast to available "smart glazing" on photochromic and electrochromic base TLG is produced significantly more cheaply. Contrary to photochromic glazing TLG is manufactured using lower temperatures and more cheaply raw materials. Compared to electrochromic glazing, TLG is characterized by simple design, feasibility of large glass area production and having no regulatory imperative.

Chief advantages of TLG are the following: daylight regulation adapted on a programmable and automatic basis without using of any electrical power or driving unit, no blinding effect; simple design, cheap laminating technology and raw materials, feasibility of large glazing area production, high material UV-stability established by UV-testing, cyclic recurrence unlimited in number, storage in a wide range from –50^{0}C to +80^{0}C.

Calculations of TLG effectiveness

From properties of thermochromic material described above it is clear that the energy efficiency of a glazing system can be improved by using of TLG unit as an outdoor pane of IG-unit. Estimation for energy saving was performed based on reduction of total energy admittance from glazing system before and after the TLG was installed. The parameters needed were shading coefficient and U factors, daily average solar radiation data of the location, room and outdoor temperatures, solar exposure hours.

The course of the temperature from the outside (t_{out}) to the inside (t_{in}) across an IG-unit is shown in Fig.1. The basic equation of the total heat admission through IG-unit for estimation of daily power consumption saving by TLG is:

$$Q = T(t_{TLG}, s) \cdot I + U \cdot (t_{TLG} - t_{in}) \qquad (1)$$

where $T(t_{TLG},s)$ is total solar heat transmittance as a function of TLG temperature t_{TLG} (see Fig.2) and an angle s of incidence of the sun rays. I is local solar radiation at specific orientation, obtained from meteorological service. U is a total heat transfer coefficient depending on the temperature of different parts of IG-unit in a complicated way. t_{TLG}, t_{in} are TLG and indoor temperatures. Energy modelling of the heat-transfer throw this type of IG-unit was carried out under condition air-mass 2. It was shown that the temperature of external pane rises from 45 to 60^{0}C under increasing of outside air temperature in the interval 25-35^{0}C.

The calculation suggests 33-42% air conditioning power can be saved by the IG-unit supplied with TLG in the climatic conditions of the middle latitudes (55^0) in Russia in summer time.

As a contrast to tinted or coated glass products TLG has non linear glazing square dependence of thermochromic efficiency (fig.3.). The same value of illuminance inside of the room realised with different squares of glazing will be reduced (as solar radiation increases) to a greater extent for greater square of glazing. So the more square the glazing the more effective the TLG operating work.

Another implications for window glass design

Another area of application is a design of stained glass panels. The picture of the stained glass panel assembled out of coloured thermochromic laminated glasses will change its image during a day.

It is shown that complexes of transition metals providing TLG properties can be used as dyes for photo-curable resins, for example, for colouring resins such as "Naftolan UV11" of Chemetall GmbH, "PK-P1"

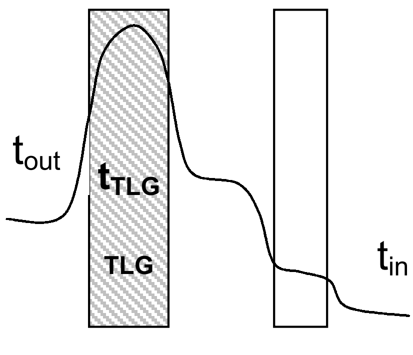
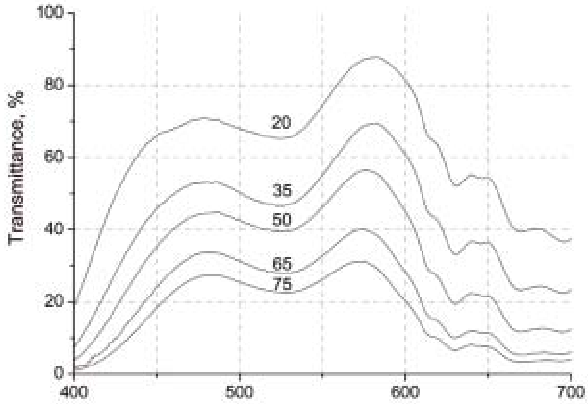


Figure 1.

Illustration of heat transmittance calculation. t_{out}, t_{in}, t_{TLG} are outdoor, indoor, and TLG temperature.

Fig.2.

Temperature dependent visible spectra of TLG interlayer of neutral type in the wavelength range 400-700 nm. The temperature (t, ^{0}C) is given on each curve.



of AOZT Bikos and some others in pink, rosy, brown, yellow-green, blue, and their combinations. Dye consumption ranges from 2 to 20 g/m^2 depending on intensity of the colour. Cost of these tinted laminated glass is estimated at 30 US$/m^2.

Conclusions

A new type of variable transmittance window for automatic regulation of lighting is proposed. TLG is a laminated glass or glasspackage in which the inner polymer layer has the property of reversibly change light transmittance under influence of light or heat radiation. The colour of TLG may vary from slightly grey or slightly green to dark grey, from lightly brown to dark brown, from pink to blue, and from yellow to green and some others.
The picture of the stained glass panel assembled out of TLG will change its image during the day.

In combination with Low-E glass, TLG makes possible to create regulated cover heating for "zero net energy" houses ("intelligent facades"). Energy modelling of the heat-transfer in IG-units with TLG has shown that during summer time the reduction of solar energy gain reaches 30-40% and it is enough to get rid of air-conditioning at all.

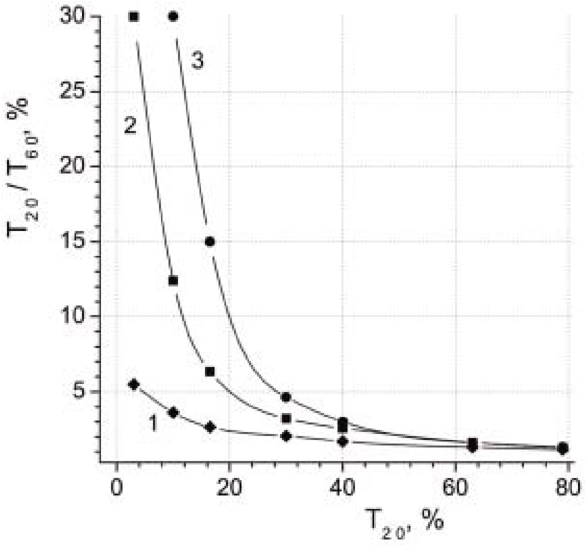


Fig.3.

Reduction of integral transmittance ($T_{20 C}$ / $T_{60 C}$) under influence of light or heat radiation as a function of initial light transmittance. (1) - TLG of brown type, (2) - TLG of grey type, (3) - TLG of rosy-blue type.