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Review

Solar radiation glazing factors for window panes, glass structures and electrochromic windows in buildings—Measurement and calculation

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ABSTRACT

Window panes, glass structures and electrochromic windows in buildings may be characterised by a number of solar radiation glazing factors, i.e. ultraviolet solar transmittance, visible solar transmittance, solar transmittance, solar material protection factor, solar skin protection factor, external visible solar reflectance, internal visible solar reflectance, solar reflectance, solar absorbance, emissivity, solar factor and colour rendering factor. Comparison of these solar quantities for different glass fabrications enables one to evaluate and thus select the most appropriate glass material or system for the specific buildings and applications. Measurements and calculations were carried out on various glass materials, including three electrochromic window devices, and several two-layer and three-layer window pane configurations.

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1. Introduction

Since early times when man discovered and began utilising the glass material in their buildings, they have had an efficient means to let solar radiation into the buildings and at the same time be protected from harsh weather in the form of rain and wind outside. This has provided mankind with buildings where daylight and solar heat have given comfortable living and working spaces in a protected environment. With the following citation we may go back 4000–6000 years in history [205]:

"Who, when he first saw the sand or ashes ... melted into a metallic form ... would have imagined that, in this shapeless lump, lay concealed so many conveniences of life? ... Yet, by some such fortuitous liquefaction was mankind taught to procure a body ... which might admit the light of the sun, and exclude the violence of the wind ..."

The main component in glass is sand (silica, SiO_2), but to melt silica one has to use temperatures higher than 1700 °C, which is not so practically done. However, adding soda ash (Na_2CO_3) reduces the melting point, e.g. to 800 °C, which is a much more feasible and practical temperature. Unfortunately, this makes the resultant material into sodium silicate (water–glass, $NaSiO_3$), which is soluble in water. To obtain a non-soluble product, a stabiliser, like limestone ($CaCO_3$), is included. A typical glass composition will then consist of 65% sand, 20% soda ash and 15% limestone [51]. The glass structure is amorphous, and is in every respect like a liquid, but with such a high viscosity that at room temperature its fluid properties cannot be measured, i.e. a rigid liquid. As an example a given deformation taking place in glass at 965 °C in 1 s, takes 30 s at 742 °C, 1 min at 660 °C, 1 h at 538 °C, one day at 427 °C, one year at 316 °C, 1000 years at 254 °C and 35×10^9 years at room temperature [51]. Thus, the common misinterpretation that glass is believed to slowly creep at normal temperatures is seen to be wrong, e.g. in churches and cathedrals several centuries old.

As the use of window panes and glass structures in buildings have become more and more widespread and extensive up throughout the years, the construction design and glass material properties have become more important. This is also strengthened by the increasing tendency of often employing rather large glass areas in today's buildings. Glass with material additives and different surface coatings is tailor-made and chosen in order to fulfil the various requirements for the specific buildings. The glass and window properties are selected with respect to several, often contradictory, considerations. Generally, a window is supposed to let in as much daylight as possible, give comfortable luminance conditions, give satisfactory view out of (and often into) buildings, transmit a minimum of heat from the interior to the exterior in order to reduce the heating demand, transmit solar radiation from the exterior to the interior in order to reduce the heating demand (i.e. in winter), shut off solar radiation by reflection which otherwise might cause too much heating, not induce air current problems or give a poor thermal comfort and not induce unacceptable interior or exterior water condensation.