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Holographic optical elements: various principles for solar control of conservatories and sunrooms

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Abstract

Holographic optical elements (HOE) can be used to reflect the direct (beam) sunlight incident on a window whilst allowing the diffuse light to pass through. This is achieved with a semi-transparent hologram, which enables solar control of a building without reducing the benefit of a window or façade to the occupants. Domestic conservatories represent an interesting potential market for such a product. Conservatories and sunrooms by their very nature have large expanses of glass and so are prone to periods of unacceptably high solar gain during the summer months. Currently, blinds or other opaque shading devices are used to reduce the solar gain but this is at the expense of daylighting. This paper describes the potential application of solar control HOE applied as either a fixed plate or tracked solution. The performance of such systems for the UK climate is predicted using transient thermal analysis simulation of commonly used UK conservatories. The benefit of selective HOE glazing of specific elevations within a conservatory is considered to achieve 'peak clipping' of daytime temperatures to an acceptable level. The simulations predict that reductions of up to 17° are possible with fully tracked HOE applied to all the elevations of a typical conservatory design. Selective use of fixed plate HOE glazing, can achieve a temperature reduction of 6.1° when only 62% of the glazing within a conservatory is replaced.

Keywords: Hologram; Simulation; Conservatory; Sunroom

1. Introduction

High house prices in the UK are forcing an increasing number of homeowners to try and maximise their present living space. Amongst the most common developments is that of a conservatory which can provide an additional space at a reasonable cost, often without the need for planning permission. The UK market for conservatories was estimated to be €1.6 billion for the year 2000 with around 150,000 installations (AMA, 2000). At present, air conditioning is not used in domestic buildings in the UK due to the relatively small number of days per year when it would be of benefit.

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Conservatories and sunrooms by their very nature have large expanses of glass and so are prone to periods of unacceptably high solar gain during the summer. Currently, blinds or other opaque shading devices are commonly used to reduce the solar gain but this is at the expense of daylighting. This paper investigates the use of HOE in such an application and gives an indication of the properties of the devices and summarises the results achieved through simulation. Reflecting HOE applied principally in a fixed glazing mode are described as the solar control glazing solution.

Holographic shading devices can be realised by different principles and types of holograms, i.e. either by reflecting or transmitting holograms (LBNL, 2000). The desired hologram structure is typically recorded onto a thin, dichromated gelatin film using a laser and following processing the developed film is laminated between two sheets of glass to provide structural and environmental protection to the film (Saxby, 1988; Rallison, 1997; Stojanoff et al., 1999). The laminated glass section can be then be used as a building glazing element for light control. Transmission holograms can be tailor made to cause total internal reflection in glass louvers or to concentrate direct solar radiation onto reflectors (Kischkoweit-Lopin and Mueller, 1997; Muller, 1994a,b). A one-axis-tracking system can achieve virtually complete daytime solar control when applied with either reflection or transmission holograms. Reflecting HOE allow diffuse light to be transmitted whilst direct (beam) light is reflected.

Both reflecting and transmitting HOEs are only able to control the direct light over a range of azimuth and zenith angles (Breitenbach and Rosenfeld, 2000). The present 'state-of-the-art' is such that a reflecting HOE film functions for ±25° from a designed angle, α (light incident at Bragg angle). Incident light outside this angle range is not affected by the HOE. The angle tolerance of transmitting holograms is much tighter at ±5° from a designed angle. In reality, the HOE behaviour is not a simple 'on–off' dependence based on angle, but shows a more Gaussian response. A perfectly recorded HOE functions at 100% for light incident at the designed working angle, α, falling to 50% when the angle difference, θ, increases to 25° for a reflecting hologram (Muller, 2003). The Gaussian HOE function behaviour of both reflecting and transmitting HOE is highlighted in Fig. 1. The diffraction efficiency of a hologram is also dependent on the wavelength of the incident radiation (Ludman et al., 1997; Breitenbach and Rosenfeld, 2000).

The simulations undertaken here assume a perfect reflection hologram with a diffraction efficiency of 100% over the entire spectral range. The only reduction in the diffraction efficiency of this perfect hologram is due to the angle, θ, between the incident beam radiation and the working angle of the HOE. If reflecting holograms are applied without solar tracking, the HOE is able to redirect light for between 1.5 and 3 h per day in the UK depending on the time of year and latitude. The solar transmission of the hologram for diffuse light and non-reflected beam radiation is assumed to be 85% based on measured performance of reflecting HOE (Muller, 2003). In reality, the diffraction efficiency of the HOE at the designed working angle may be only 70%, with an associated spectral variation in diffraction efficiency.

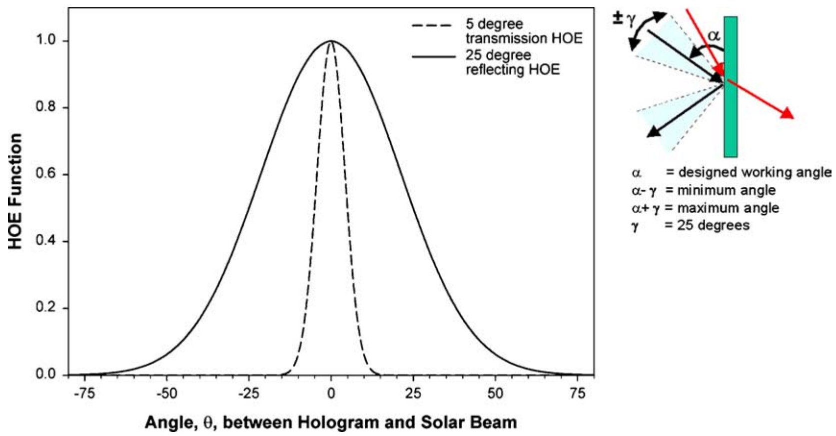

Fig. 1. The operating principle of a reflecting solar control HOE. Incident beam radiation within a certain angle range is reflected. Diffuse radiation passes through the HOE. The angle, θ, between the incident beam radiation and the working angle, α, of the HOE, is due to the combined effect of zenith and azimuth angle changes. The HOE function (diffraction efficiency) as a function of θ is shown. Transmission HOE have a far narrower working angle range (5°) than reflecting HOE (25°) and need to be used in tracked systems. *Source*: Muller (2003) Holographic Optical Elements (HOE) for High Efficiency Illumination: Solar Control and Photovoltaic Power in Buildings, EU Project Report, EC project no. ENK6-CT-2000-00327.