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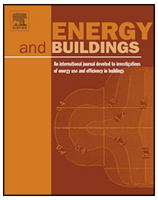

Assessing the thermal performance of insulating glass units with infrared thermography: Potential and limitations

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ABSTRACT

The use of insulating glass units (IGU) is standard practice to reach a high thermal performance of the building envelope. Infrared thermography (IRT) offers a quick, non-destructive method to evaluate their thermal performance in situ. By visualizing surface temperatures, the thermal resistance of IGU's may be estimated. Due to the low thermal mass, a situation close to steady state conditions can be obtained quickly under stable weather conditions. However, the specular reflectance of glass and its relatively low emissivity (0.837) may result in unreliable infrared images. In spite of these obstacles, the use of IRT could address a practical need from the building industry as other inspection tools often render inadequate.

This paper investigates the potential of IRT for thermal performance estimation of IGU's. Firstly, a sensitivity analysis on the boundary conditions was conducted using numerical simulations. Subsequently, quantitative IR-measurements were conducted on different glass types, in the lab and in-situ. Results show that specular reflection should be avoided to obtain reliable measurements. Finally, the thermal resistance of IGU's was calculated with the measured surface temperature, both in the lab and in situ. This showed that the use of inaccurate outside and inside heat transfer coefficients and non-representative inside and outside temperatures renders inadequate thermal resistances, even if IRT was executed in cloudy windless weather and with a temperature difference over 15 °C across the IGU. In these conditions, only single glazing, IGU's without low-e and IGU's with low-e coating are distinguishable. This undermines the practical implementation of IRT as assessment tool for IGU's.

1. Introduction

1.1. Context

The installation of insulating glass units (IGU's) in building envelopes is standard practice in most countries. A measurement tool to assess their thermal performance in-situ would be interesting both for newly installed windows as for renovation purposes. Several techniques are available that allow to check the gas concentration in IGU's, but the applicability is limited. One of the techniques implies the use of a spectrometer to check the concentration of argon or krypton in the cavity. The device launches a high voltage spark that causes the argon or krypton atoms to emit light. This light is measured by the spectrometer, by which a percentage of the gas concentration is generated. The voltage spark needs to be strong enough to reach the cavity through the first layer of glass. By consequence, this method is not reliable when used on IGU's with laminated glass, triple glazing or with a low-e coating on the glass pane closest to the device. On the other hand, a low-e coating on the other glass pane helps to ground the spark back to the spectrometer. Next to that, the method is more reliable for gas concentrations over 80% in the cavity. Argon and krypton are better conductors than air for the voltage spark and the light signal is stronger with higher argon concentrations [1]. Recently, laser technology has been adopted for IGU inspection. Here, the gas concentration in the cavity is measured by means of the oxygen concentration [2]. There are also devices available that detect the presence of a low-e coating and its location in the IGU. These devices function on single, double, laminated and triple glazed units [3].

Infrared thermography (IRT) can offer a quick and non-destructive method to evaluate the thermal performance of IGU's at once. By visualizing the surface temperatures, the thermal performance may perhaps be estimated. Until now, IRT is mainly used in a qualitative way, e.g. to detect thermal bridges and air leakages in building envelopes. The potential of IRT to evaluate the thermal performance of opaque building components was recently examined

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Nomenclature

IGU	Insulating glass unit
CHTC	Convective heat transfer coefficient
IRT	Infrared thermography

Symbols

U	Thermal transmittance [W/m^2 K]
R	Thermal resistance [m^2 K/W]
q	Heat flux [W/m^2]
ε	Emissivity [−]
θ	Temperature [°C]
Δ	Measurement accuracy [%]
V_x	Wind velocity [m/s] at x m above ground level

Subscripts

EN673	According to EN 673
ts	Derived from the temperature sensor
irt	Derived from thermographic measurements
flux	Derived from heat flux measurements
i	Internal, in the heated test box
e	External
refl	Reflected
c	Convection
r	Radiation
g	Gas
se	External surface
si	Internal surface

by several authors [4–9]. In general, the necessity for strict boundary conditions is emphasized for obtaining reliable quantitative IR-measurements. Weather conditions like solar irradiance, clear sky radiation, wind, air temperature and precipitation constantly influence the surface temperatures of a building component. Quasi steady-state behavior is thus virtually nonexistent. The transient response to long-term and short-term changes in boundary conditions will be dominated by the thermal mass of the component and the thermal effusivity of the surface respectively. For massive masonry walls, waiting times up to 30 h under cloudy and windless conditions are expected before reliable IR-measurements are feasible [4]. In Ref. [5], a deviance of 25% to 35% was obtained between the theoretical U-values and the U-values based on in situ IRT measurements of opaque building components. However, the deviance increased to 80% when wind velocities larger than 1 m/s were considered, because the higher external CHTC caused a larger dispersion in the data [5]. In Ref. [6], a deviation of 10–20% was found between U-values derived from IRT and the theoretical U-value. The largest deviations occurred in summer when IRT was conducted on rooftops and glass surfaces. The authors performed only inside IR-measurements and respected a waiting time of 4 h after sun radiance for both heavy building components (20 cm brick wall) and light components (glazing). There was thus no precaution in the boundary conditions towards the difference in thermal mass between walls and glazing. According to the authors, the large deviations of the roofs and glass surfaces were due to an uncontrollable thermal inertia effect. However, glass panels show a low thermal mass and therefore, the deviation caused by the thermal inertia of the building component should be smaller than for brick walls. Lastly, the internal CHTC was a fixed value of 2.5 W/m^2K as found in EN ISO 6946 [6]. A low CHTC results in a smaller dispersion among the thermal transmittance calculated with IR-measurements.

Despite these strict boundary conditions for opaque components, IRT-measurements on glass may perhaps have more potential. After all, glass is opaque in the long-wave infrared field (4–14 μm) [10] and IGU's typically have a low thermal mass reducing the phase shift. Consequently, the time frame in which ideal weather conditions should be maintained to obtain quasi steady-state conditions is significantly smaller compared to most opaque building components. On the other hand, glass shows specular reflection and its emissivity in the field of long-wave infrared radiation is lower than most opaque building materials. Building materials such as brick or wood have an emissivity of 0.90 whereas glass has a total hemispherical emissivity of 0.837 [11]. This implies that IR-images on glass are more affected by radiation sources in the environment compared to IR-images of e.g. masonry façades.

1.2. State-of-the-art of thermography on glazing

In the past decades, several authors have illustrated through lab experiments that IRT can be used to measure accurately surface temperatures on glazing. In Ref. [12], surface temperature measurements with IRT were performed on a double glazed pane with air cavity and low-e coating installed in a hot-box. After comparison with the temperature sensor readings in the middle of the glass surface, IRT proved to be an accurate tool to determine surface temperatures. The measurement deviance in the middle of the surface varied from 0 °C to 0.75 °C. The authors attributed the differences between IR and the temperature sensor readings to the improper installation of the temperature sensors on the glass surface and the temperature sensor wires that were located in the optical path of the IR camera. Furthermore, some temperature sensors installed close to the glass edge were affected by the spacer bar of the IGU and showed a larger deviation of max. 1.75 °C. At these points, the surface temperatures obtained with IRT were higher than the surface temperatures measured with temperature sensors, due to additional radiation exchange with the window frame.

Some researchers also tackled typical problems associated with IRT on glazing. In Ref. [13], two error sources were mentioned: the specular reflection of surrounding objects and the inadequate estimation of the sky temperature. The authors proposed a correction method for this kind of reflection errors by subtracting the radiance of an external object that is specularly reflected on the glass. By doing this, the corrected temperatures of the surface affected by specular reflection were derived. This methodology was used for the thermographic inspection of solar devices [13]. In Ref. [14], a reference emitter with known temperature and emissivity was positioned near the glass in the frame of the IR-image. With this measure, a measurement accuracy of ±0.5 °C was obtained for IRT in laboratory conditions. Note that the absolute error of most IR-cameras is ±2 °C. In Ref. [15], correction equations were developed to estimate the reflectance of specular materials for different incidence angles. By taking an IR-picture of the glass surface and of the radiant heat source, the specular reflectance and the corresponding error were obtained with the correction equations. At last, in Ref. [16] it was recommended to perform IR-measurements of glass surfaces at the inside. By doing this, specular reflection of the clear sky or surrounding buildings is avoided. In Ref. [16], it was also suggested that it is possible to assess the gas concentration of IGU's in the glazing. However, there was no information given about the boundary conditions (temperature difference inside-outside, cloudiness...) during this measurement.

Concluding, literature on IRT analysis of building components suggests that IR-measurements representing the thermal resistance may be possible under strict boundary conditions. However, as discussed above, one can question the adopted research methods and analyses of the papers that claim reliable quantitative assessments. To the knowledge of the authors, the technique has not been applied to IGU's in a well-documented and structured way with a consistent analysis and clear conclusions.