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Optical properties of a liquid paraffin-filled double glazing unit

Dong Li*, Yumeng Zheng, Zaiwu Li, Hanbing Qi

School of Architecture and Civil Engineering, Northeast Petroleum University, Fazhan Lu Street, Daqing 163318, China

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ABSTRACT

Based on the transmittance spectra modeling, spectroscopic methods were developed to determine the optical properties of a liquid paraffin-filled double glazing unit, including reflectance and absorptance. The transmittance spectrograms of paraffin-filled double glazing units at normal incidence with different thicknesses in the wavelength 240–900 nm were measured by a TU-19 FTIR spectrometer. These values were introduced into spectroscopic methods to calculate the reflectance and absorptance of paraffin-filled double glazing units. The results showed the transmittances of glazing unit that are filled with paraffin in most area are enhanced compared with the empty glazing unit. The absorption and reflectance profiles with different paraffin thicknesses are very similar in shape and are relevantly affected by the paraffin thickness.

1. Introduction

Nowadays, energy and environment are the two keys in the development of human beings. The energy production from coal and fossil fuel is the preponderant factors for CO_2 emission into the atmosphere, which is widely believed to be contributing to global warming [1]. Building is one of the leading sectors of the energy consumption, and especially about 40% of total fossil energy per each year in China was consumed in building sector in the last five years [2,3]. Furthermore, the energy consumption of buildings is still increasing with the developing demand for the life style and the living standards, which will be estimated about 20×10^{12} MJ in 2020 in China [4]. During recent years, developing the novel technology to promote energy efficiency and conservation in buildings has been one of the major issues of governments and societies, whose aim is reducing the energy consumption without affecting the level of thermal comfort in a wide range of weather conditions.

The energy performance of a building is depending on the thermal mass of building envelope specially the window. In most buildings with large window areas, the thermal mass of the building envelope is much lower than conventional building walls. The effectiveness of thermal mass is based on its ability to absorb and store heat, and dampen the temperature fluctuations within a space. It is widely accepted that thermal mass is beneficial to buildings with respect to increasing thermal comfort and reducing energy consumption. For example, the thermal loss of building envelope is the leading sector of the total heat loss of building due to directly solar radiation [5–7], and the heat loss through the window envelope accounted for 30% of the energy consumption of the building envelope [8,9]. An alternative practice to enhance thermal mass is to increase its thermal storage capacity, which offers improved heat transfer control, which results in energy use and energy demand reductions, enhanced occupant comfort, and increased equipment operating life. An effective approach to increase the thermal mass of window is to incorporate phase change materials (PCM) in the window structure, for example double glazing unit filled with paraffin material [10]. PCM refer to materials with enhanced heat storage capabilities in a specific temperature range through the utilization of their latent heat capacity. The latent energy is obtained due to changes in the molecular structure of the material as it changes phase. In the case of solid–liquid PCM, the melting process is endothermic, while freezing is exothermic. This extra energy that can be stored or released by the material during phase change can improve the energy storage potential of the overall window structure, and therefore enhance thermal mass. The aim of the paraffin-filled double glazing unit concept is thus to absorb part of the solar radiation for thermal energy storage, while letting visible radiation enter the indoor environment for daylighting. The double glazing unit filled with paraffin material can smoothen the indoor temperature fluctuations as the external temperature changes, increase thermal inertia of the glazed building envelop, improve the thermal comfort of the indoor environment [11–13].

To create a building envelope component with a high heat capacity and transparency in the visible spectrum, the process of solar radiation and thermal heat transfer in double glazing unit firstly needs to be quantified, and the optical properties of

* Corresponding author.
E-mail address: Lidonglvyan@126.com (D. Li).

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Nomenclature

A	absorptance of paraffin-filled glazing unit
c	calculating parameter
er	relative error
I	incident (baseline) intensities
I_0	transmitted intensities
k	average extinction coefficient of liquid paraffin-filled glazing unit
L	thickness of liquid paraffin layer, m
L_1	thickness of liquid paraffin layer, m
n	average refractive index of liquid paraffin-filled glazing unit
L_2	thickness of liquid paraffin layer, m
R	reflectance of paraffin-filled glazing unit
T	transmittance of paraffin-filled glazing unit
T_{cal}	simulated transmittance
T_{exp}	experimental transmittance
T_1	transmittance of glazing unit with liquid paraffin layer thickness L_1
T_2	transmittance of glazing unit with liquid paraffin layer thickness L_2

Greek letters

ρ	interface reflectance for surface between air and glazing unit
λ	wavelength, m

Subscript

cal,	simulated value
exp	experimental value

paraffin-filled double glazing unit play an important role in this investigation as the basic optical parameters. Although a lot of researchers investigated the thermal properties of double glazing units filled with PCM [8–19], there are a limited references about optical properties of paraffin-filled double glazing units [17–19].

The recent studies of Goia et al. [17,18] and Gowreesunker et al. [19] contributed a lot to the fundamental aspect of optical properties of paraffin-filled double glazing units. Goia et al. [17] measured the spectral transmission, reflection and absorption coefficients of the paraffin-filled glazing system between 400 and 2000 nm, in which the maximum relative error is 4%. The measurements of spectral transmission were performed at the incidence angles 0, 30, 45°. The reflectance with 8° angle of incidence was measured. The measurements of spectral absorption were performed at the incidence angles 8, 30, 45°. Goia et al. [18] also investigated the spectral and angular behavior of different PCM glazing samples by means of commercial spectrophotometer and a dedicated optical test bed that includes a large integrating sphere with a diameter of 0.75 m. However, the spectral transmission, reflection and absorption coefficients were measured with different conditions [17,18].

Gowreesunker et al. [19] investigated gray transmittance performance of RT27 PCM-filled glazing unit with different environment temperatures using spectrophotometry principles, and calculated the gray reflectance and absorptance of RT27 material. The radiation heat flux transmitted through the glazed surface test specimens was measured by a Kipp & Zonen CMA-6® pyranometer, and the light source was a 150 W metal halide lamp with a spectrum ranging mainly from 350 to 850 nm. The gray transmittance of the PCM, which is the basic parameter to calculate the reflectance and absorptance, was obtained by the radio between transmitted radiation intensity of PCM-filled and empty glazed unit. The authors indicated that the refractive indices of glass and PCM are relatively small (<1.5), and the effects of internal reflections within the glazed systems are of minimal consequence. Hence the transmittance observed in the experiments was solely attributed to the overall radiation attenuation effects of the media and the constant overall reflection at the primary air/glass boundary for the two systems. However, a lot of researching work shows that the effect of refractive indices of glass material on the experimental inversion of optical properties of liquid material that is filled in the glass cavity is important [20–24].

In this work, a new inverse method of optical properties of a liquid paraffin-filled double glazing unit based on the transmittance spectra modeling is proposed. The transmittance spectrograms at normal incidence were measured for the prepared liquid paraffin-filled double glazing units. Reflectance and absorptance spectrograms of the liquid paraffin-filled double glazing units were deducted by the inverse method. This is the first inversion study of the reflectance and absorptance spectrograms of a liquid paraffin-filled double glazing unit based on the transmittance spectra of glazing unit filled with liquid paraffin, to the authors' knowledge.

2. Methods

2.1. Spectral measurement

Spectrophotometric measurements at normal incidence were made using a U-19 FTIR spectrometer with a wavelength range from 240 to 900 nm. Light from the FTIR's internal light source was focused through an iris, collimated, and passed into a Michelson interferometer that caused each wavelength to be modulated. This modulated beam was then passed through glass slabs and focused onto a detector. The detector signal was analyzed with the manufacture's software, which uses Mertz phase correction and boxcar apodization without zero filling to provide spectrally resolved transmitted intensity.

For each measurement, the transmittance is as a function of the transmitted and incident intensity as follows [24]:

$$T = \frac{I}{I_0} \tag{1}$$

where I and I_0 are the incident (baseline) and transmitted intensities, respectively. The incident intensity was measured with the paraffin-filled glazing unit removed from the beam's path. The transmitted intensity was measured with the paraffin-filled glazing unit placed in the optical path. Measurements were made with a resolution of 4 cm^{-1} in air and at room temperature 26 °C. The liquid paraffin-filled glazing unit is a sandwich system as shown in Fig. 1, which consists of two clear glass slabs and a liquid paraffin material layer.

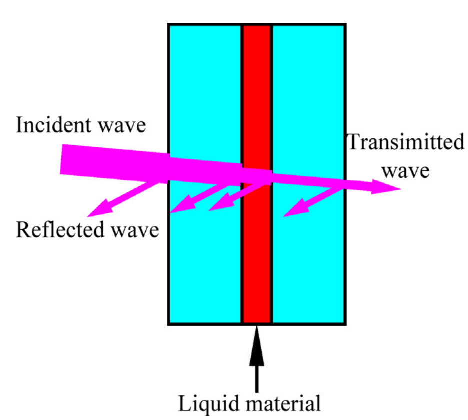

Fig. 1. Liquid paraffin-filled glazing unit.