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In situ measurement of thermal transmittance and thermal resistance of hollow reinforced precast concrete walls

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ABSTRACT

A study was conducted to determine the in situ thermal transmittance and thermal resistance of two exterior reinforced precast concrete walls of a building constructed with hollow panels. The results indicate that the North and East facing walls have a mean thermal transmittance (air to air) of 1.459 and 1.803 W/m^2 K, respectively. The mean thermal resistance value (surface to surface) of the North and East walls is 0.355 and 0.352 m^2 K/W, respectively. While the thermal transmittance depends on the wall orientation and the outside weather conditions, the thermal resistance is independent of the wall orientation. The results also indicate that a monitoring period of six days is sufficient to ascertain the in situ thermal transmittance and thermal resistance of reinforced precast concrete walls.

1. Introduction

Buildings are major users of electrical energy which consume about 75% of the total electricity generated [1], and the design of energy efficient buildings are of high priority for energy conservation. As air-conditioning accounts for about 73% of the electricity consumed in residential buildings in hot and arid regions [2], in order to conserve electricity, building systems efficient in energy conservation should be developed. As the conservation of energy in buildings is location-dependent, the local climate is an important consideration in the selection of the appropriate building technology. In a cooling-dominated climate where hot weather conditions prevail, investigations involving the thermal performance of the building envelope and systems can aid in the conservation of energy in buildings. Aging of buildings is another important aspect that significantly increases the power consumption for cooling purposes. The elements of a building envelope or the so called "protective skin" include the walls (exterior), windows, roof, and the underground slabs and foundations. The three factors which determine the heat flow across a building envelope include the temperature differential, area of the building exposed, and the heat transmission value of the exposed area. Thus, the use of a suitable thermal mass and thermal insulation is very important for controlling the heat flow and energy conservation in buildings. The components of a building envelope respond "dynamically" to changing ambient conditions.

Desogus et al. [3] compared the various approaches available for the in situ measurement of the thermal resistance (*R*-value) of the components of a building envelope in a test chamber in Cagliari, Italy. Both non-destructive and destructive methods were used to determine the *R*-value of a test wall and the *R*-values measured by the non-destructive methods and those calculated using the destructive method obeyed the compatibility of measurement principle. Courville and Beck [4] compared and described the four techniques available for the in situ determination of thermal resistance of rigid board insulation installed in conventional low-sloped roofs. The measured temperature distribution and heat flux were used to evaluate the four techniques and it was found that the steady-state least-squares technique, the absolute value technique, and a computer code for determination of thermal conductivity from in-situ data PROPOR gave very nearly the same results. Flanders [5] established the convergence criteria for the calculation of in situ thermal resistance and highlighted the effects of low-frequency temperature inputs on the calculation of the *R*-value. According to Flanders, mathematical simulations allow discrimination between conditions that cause a lack of convergence and those that represent a long-term *R*-value.

Cabeza et al. [6] evaluated the thermal performance of three insulation materials, namely, polyurethane, polystyrene, and mineral wool in situ by constructing house-like cubicles and comparing

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Nomenclature

C	thermal conductance, W m^{-2} K^{-1}
CR_n	convergence factor, %
CV	coefficient of variation, %
d	wall thickness, m
k_{eqv}	equivalent thermal conductivity, W m^{-1} K^{-1}
q	heat flux, W m^{-2}
R	thermal resistance, m^2 KW^{-1}
R_{si}	inside surface air film resistance, m^2 K W^{-1}
R_{so}	outside surface air film resistance, m^2 K W^{-1}
R_T	total thermal resistance, m^2 K W^{-1}
T_o	outside air temperature,°C or K
T_i	inside air temperature,°C or K
T_{so}	outside surface temperature,°C or K
T_{si}	inside surface temperature,°C or K
U	thermal transmittance, W m^{-2} K^{-1}

Subscripts

i	inside
n	number of hours
o	outside
s	surface

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j	individual measurements
m	total number of measurements

the in situ thermal transmittance values with the theoretical values. They found that the average difference between the experimental and theoretical transmittance values were in the range of 12–14%. Peng and Wu [7] determined the in situ thermal resistance of building construction materials in a test chamber. In addition to the conventional method of measuring the in situ thermal resistance, the authors introduced the frequency response method where indoor and outdoor temperatures and the average inside surface temperature of the building envelope components were measured to compute the in situ thermal resistance. This method does not depend on the measurement of the heat flow rate through the building envelope.

Studies have been conducted to measure the thermal conductivity of insulation materials [8–10]; Abdelrahman et al. [11], Al-Hadhrami and Ahmad [12], and Ahmad and Al-Hadhrami [13] measured the thermal conductivity of some of the commonly used bricks using a guarded hot plate. The drawback of the guarded hot plate technique is that large wall samples or panels cannot be tested, and to overcome this problem either a guarded hot box or in situ measurements are required to evaluate the thermal performance of building envelope components. However, studies have not been conducted so far on the in situ measurement of the thermal performance of building components, including the measurement under hot weather conditions.

In this study, in situ measurements were conducted to evaluate the thermal performance of two exterior walls of a building made of reinforced precast concrete panels. The standard procedures specified in international standards were adopted for the in situ measurement of the thermal transmittance and thermal resistance of the walls. The work involved the in situ measurement of thermal parameters, such as inside and outside air temperature, inside and outside surface temperature of exterior walls, and the heat flux through the exterior wall surfaces.

Fig. 1. Outside view of the instrumented walls of the building.

Fig. 2. Inside view of the instrumented walls of the test room.

2. Test procedure

Thermal performance of two exterior walls of a building constructed with hollow reinforced precast concrete panels was determined in situ. The instrumented building and the test room walls are shown in Figs. 1 and 2.

The exterior walls of the test room, facing the North and the East, were instrumented using heat flux sensors, air temperature sensors, and thermocouples. Each exterior wall was instrumented with thermocouples on the inside and outside surfaces and three heat flux sensors on the inside surface. In addition, air temperature sensors were also installed on the inside and outside sides of the walls. The locations for placement of heat flux sensors were determined using an infrared thermographic camera to avoid the areas with thermal leakage. The air temperature inside the room was controlled by installing a split type air-conditioner. The set point of the air-conditioner was 22 °C.

The North and East facing exterior walls of the test room were painted on the inside and outside by the cream colored paint. The walls of the test rooms were made of 150 cm wide, 320 cm high, and 30 cm thick reinforced precast concrete wall panels with a hollow air space of 16 cm thickness as shown in Fig. 3.

2.1. Parameters measured and instrumentation

The parameters measured and instruments used for the thermal performance evaluation of the reinforced concrete walls are listed in Table 1. All the sensors listed in Table 1 were connected to a Campbell Scientific Inc. data acquisition system consisting of