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Measurement of the environmental temperature using the sol-air thermometer

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Abstract

Heat flow measurement with a heat flow meter is a standardized method (ISO 9869-1) to estimate thermal transmittance (U-value) of a building element. The heat flow meter is a thin plate mounted on top of the surface of the element, and measures the heat flux q through the plate. The measured q is the product of the difference in temperatures between exterior and interior environment, and the U-value. The heat transferred from the element is based on the radiant and the convective heat transfer.

ISO 9869-1 specifies that the environment temperature T_e “is a notional temperature" and it "cannot be measured directly” (section A.3.1). The air temperature T_a is proposed as a reasonable approximation for the indoor environment, while overcast conditions and absence of significant solar radiation are specified conditions for replacing T_e with T_a for the exterior environment.

The sol-air thermometer (SAT) measures the sol-air temperature T_{sa}, i.e. the equivalent temperature of the convective and the radiative environment. In the absence of solar radiation, $T_e = T_{sa}$. SAT is a sensor consisting of a thin flat solid plate, of high thermal conductivity. The front side of the sensor is exposed to the environment, whose T_{sa} is to be measured, and the backside is thermally insulated. The temperature of the SAT-plate equals T_{sa}.

In this work we propose introduction of the measured T_e in the existing standard (ISO 9869-1). The method for measurement of T_{sa}, using the SAT, has been demonstrated experimentally for different periods, without solar radiation present and under stable climatic conditions.

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Keywords: Environmental temperature; Sol-air thermometer; Heat transfer coefficient; Thermal transmittance

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1. Introduction

The standard ISO 9869-1:2014 describes a heat flow methodology for measurement of the thermal transmission properties of plane building components [1]. The standard defines the thermal transmittance U-value of a building element as

$$U = q/(T_i - T_e) \tag{1}$$

, where q is the heat flux through the element, and T_i and T_e are the interior and exterior environmental temperatures, respectively. According to ISO 9869, the environmental temperature T_e of a building surface is properly defined by (cf. Eq. (A.3) in [1]; [2])

$$T_e = (h_r T_r + h_c T_a)/(h_r + h_c) \tag{2}$$

, where T_r is the mean radiant temperature (infrared radiation), T_a is the air temperature, and h_r and h_c are the radiative and convective heat transfer coefficients, respectively. Here we included the surface emissivity ε in the definition: $h_r = 4\varepsilon\sigma T_m^3$, where $T_m = (T_r + T_s)/2$, T_s is the surface temperature, and σ is the Stefan-Boltzmann constant.

The ISO 9869 states that T_e, as defined in Eq. (2), "is a notional temperature" and it "cannot be measured directly" (§A.3.1 in [1]). Our objective with this study was to falsify this statement. For this purpose, we performed direct measurements experimentally. The experimental results and the calculated T_e, which was obtained from Eq. (2), were compared.

Nomenclature

h_c	convective heat transfer coefficient ($Wm^{-2}K^{-1}$)
h_o	heat transfer coefficient ($Wm^{-2}K^{-1}$)
h_r	radiative heat transfer coefficient ($Wm^{-2}K^{-1}$)
I_s	total solar irradiation (Wm^{-2})
q	heat flux (Wm^{-2})
T_a	air temperature (K)
T_e	(exterior) environmental temperature (K)
T_i	interior environmental temperature (K)
T_m	mean temperature, used in h_r
T_r	mean radiant temperature (K)
T_s	surface temperature
T_{sa}	sol-air temperature (K), i.e., the equivalent temperature of the convective and radiative environment
U	thermal transmittance ($Wm^{-2}K^{-1}$)
α	absorptivity of solar radiation (unit-less)
ε	emissivity (unit-less)
σ	Stefan-Boltzmann constant = $5.67 \cdot 10^{-8}$ ($Wm^{-2}K^{-4}$)
w	wind speed (m/s)

2. Experimental

2.1. Sol-air thermometer

The concept of the sol-air temperature T_{sa}, was introduced as the equivalent temperature of convective and radiative environment for a surface. This definition includes solar radiation [3, 4]. T_{sa} is often expressed, according to [4, 5], as