Journal of Physics: Conference Series

PAPER • OPEN ACCESS

In-situ measurements of the U-value of a ventilated wall assembly

To cite this article: M Rahiminejad and D Khovalyg 2021 *J. Phys.: Conf. Ser.* **2069** 012212

In-situ measurements of the U-value of a ventilated wall assembly

M Rahiminejad and D Khovalyg

Thermal Engineering for the Built Environment Laboratory (TEBEL), École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland

E-mail: mohammad.rahiminejad@epfl.ch

Abstract. The walls in a building envelope have the largest contact area with the exterior environment, and, therefore, a considerable portion of the thermal energy can be lost through the walls compared to the other parts of the building envelope. For energy-saving purposes, the thermal transmittance of walls is typically limited by building energy performance standards at the national level. However, the presence of a ventilated air-space behind the external cladding, which has variable hydro-dynamic behavior, can differently affect the total thermal transmittance of the entire structure. This paper aims to provide an experimental analysis of the total U-value of a ventilated wall assembly measured in a building prototype following the average and dynamic methods defined by ISO 9869-1. Differences between the calculated theoretical U-value and the measured U-value are compared. The contribution of the thermal resistance of the ventilated air-space in the total thermal transmittance of the wall assembly is also analyzed. The results show that the air movement and the enthalpy change in the ventilated cavity can affect the thermal performance of the wall structure to a certain extent.

1. Methodology

The thermal performance of a building envelope can be characterized by the thermal transmittance of the components used in the structure. The external claddings in a wall assembly can be separated from the framed wall using a ventilated air-space that can potentially reduce energy use and boost the thermal efficiency of the building [1]. The actual thermal transmittance of a ventilated wall assembly in a building prototype is measured in this study, and the results are compared using two methods, the average method and the dynamic method, defined by ISO 9869-1:2014 [2] and the theoretical method specified in ISO 6946:2007 [3]. The thermal resistance of the air-space was defined based on the recommendation provided in [3] for a well-ventilated air layer. The procedures elaborated by [4] and [5] were employed to determine the U-values based on each method. The criteria established by [2] were satisfied for the average method. To check the quality of the results in the dynamic method, a confidence interval smaller than 5% of the thermal transmittance is adopted as recommended by [5].

2. Experimental setup

A building prototype in Smart Living Lab in Fribourg, Switzerland, was considered as a test building. The external wooden facade is separated from the wall core with horizontal and vertical battens that create ventilated air-space behind the cladding. The thermal and geometrical properties of the layers in the building envelope are summarized in Table 1.

Table 1. Properties of the building prototype [6].

Material (Exterior to interior)	Thickness (m)	Thermal conductivity (W/m·K)	Specific heat capacity (J/kg·K)
Wooden cladding	0.024	0.15	1800
Air-space	0.070	-	-
Insulation polyurethane	0.180	0.03	1404
Wooden covering	0.140	0.13	1600
Earth brick	0.050	0.79	1100
Jute coating	0.015	0.80	1450

The heat flow meter method described by [2] was used to measure the in-situ thermal transmittance of the opaque ventilated wall structure of the test building. To measure the heat flow, a heat flux meter plate (HFP01, Hukseflux) with an accuracy of ±5% and a sensitivity of 60.89 µV/(W/m^2) was used. Following the guidelines of ISO 9869-1:2014, the heat flux sensor was installed directly on the internal part of the wall that had a more stable temperature. Thermocouples (T-type) were used for measuring indoor and outdoor surface and air temperatures. All sensors were connected to a centralized data acquisition system (34972A, Keysight) with 0.1℃ of resolution and ±1℃ accuracy for temperature measurements. The external surface and air temperature sensors were mounted aligned with the internal heat flux sensor and thermocouples (Figure 1a). The outdoor air temperature sensor was shielded against solar radiation. A weather station on the facade monitored outdoor conditions using an air temperature sensor (S-THB-M002, Onset), Davis® wind speed and direction sensor (S-WCF-M003, Onset), and silicon pyranometer for global horizontal irradiance (S-LIB-M003, Onset). All sensors were connected to a micro station data logger (H21-USB, Onset). The experimental campaign was performed continuously under real weather conditions from the 23rd of December 2020 to the 10th of January 2021 (Figure 1b). The data loggers were configured to record data at 1-minute intervals.

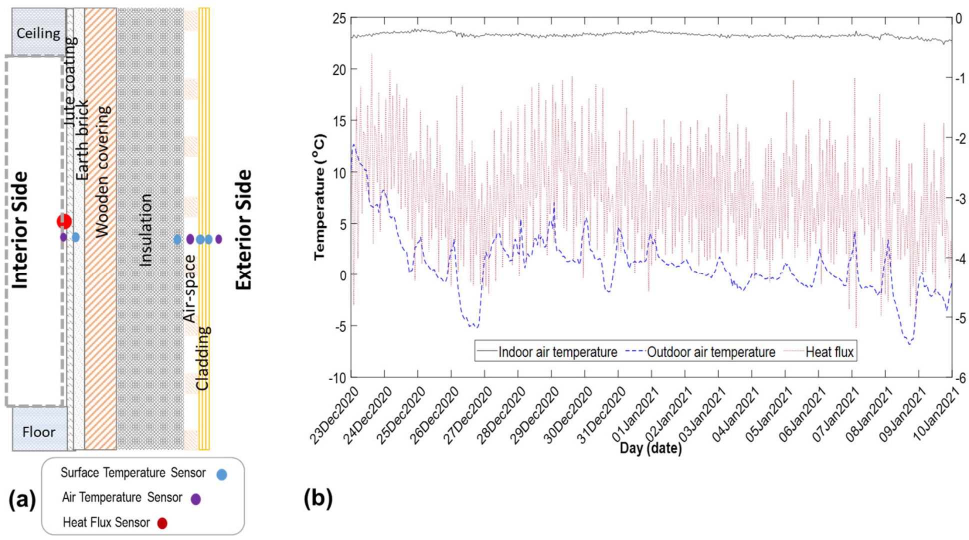

Figure 1. (a) Schematic of the wall assembly and position of the sensors, (b) Data measured in the period of monitoring campaign.

3. Results and Discussion

The results obtained for the U-value of the ventilated wall assembly at the end of the measuring period are shown in Table 2. The combined standard uncertainty of measurements ($\sigma_{95\%}$) is calculated for the U-value obtained using the average method [4]. To evaluate the quality of results in the dynamic method, uncertainty ($I_{95\%}$) is calculated according to the equation proposed by [5]. The relative differences between the theoretical U-value and the measured U-value using the average and the dynamic methods at the end of the measuring period were calculated using the following equation [4,5]:

$$\text{Difference} = \frac{U_{Theoretical} - U_{Average\ or\ Dynamic}}{U_{Theoretical}} \times 100 \tag{1}$$

Table 2. U-value measured using the average and dynamic methods, & percentage of contribution of the thermal resistance of the ventilated cavity to the total thermal resistance.

Days	Thermal Transmittance (W/m²·K)		Percentage of contribution (%)	
	$U_{Average} \pm \sigma_{95\%}$	$U_{Dynamic} \pm I_{95\%}$	Average method	Dynamic method
3	0.140±0.019	0.178±0.004	2.00	29.85
6	0.136±0.017	0.133±0.003	0.79	2.98
9	0.135±0.019	0.118±0.002	1.52	13.92
12	0.132±0.011	0.116±0.002	3.71	15.38
15	0.133±0.011	0.123±0.002	2.98	10.27
18	0.133±0.015	0.123±0.001	2.98	10.27

According to the results, the U-value converges to 0.12 after 9 days for the dynamic method, and it converges to 0.13 after 12 days for the average method. The theoretical U-value is 0.140 which is 5.00% and 12.14% higher than the average and dynamic methods respectively. The difference can be attributed to the uncertainty due to measurement errors, the influence of thermal bridges within the wall structure, the uncertainty of the properties used for the materials in the wall assembly, and the presence of the ventilated cavity. To address the latter, a definition provided by [7] for the effective thermal resistance of the ventilated cavity was used (equation (2)) and a comparison was made to analyze the percentage of contribution of the thermal resistance of the ventilated air-space to the total thermal resistance per each method (equation (3)).

$$R_{\text{cavity,effective}} = \frac{1}{U} - (R_{\text{cladding}} + R_{\text{wall core}} + R_{\text{surface,interior}} + R_{\text{surface,exterior}}) \tag{2}$$

$$\text{Percentage of contribution} = \frac{R_{\text{cavity,effective}}}{R_{\text{total}}} \times 100 = \frac{R_{\text{cavity,effective}}}{(1/U)} \times 100 \tag{3}$$

where the thermal resistances of the solid materials and surface resistances are calculated based on the recommendations provided by [3]. As can be seen in the above table, the presence of the ventilated cavity can contribute to the total thermal resistance of the wall structure up to 10.27% when the results are converged in the dynamic method. This value is lower in the average method that can be attributed to the steady-state assumption made in that method. This assumption neglects the effect of airflow and enthalpy change in the air-space, which is quite dynamic behavior. The percentage of this contribution is 2.00% in the theoretical method that was expectable due to disregarding the air layer in the calculations [3].

4. Conclusion

The in-situ measurement of the U-value of a ventilated wall assembly was investigated in this study. Different standardized methods, including theoretical calculations, average, and dynamic methods were employed to analyze the U-value measured. The results showed that the values obtained from different methods are in the same range. Moreover, the presence of the ventilated air-space was shown to have various contributions to the total thermal resistance of the wall structure. The effect of the unsteady flow in the cavity on the thermal resistance of the building envelope needs more analysis in future studies.

References

[1] Rahiminejad M and Khovalyg D 2021 *Build. Environ.* **190** (107538)
[2] ISO Standard 9869-1, Geneva, 2014
[3] ISO Standard 6946, Geneva, 2007
[4] Gaspar K, Casals M and Gangolells M 2016 *Energy Build.* **130**:592–9
[5] Gasi K, Milovanovic B and Gumbarevic S 2019 *Buildings* 9050132
[6] Brambilla A and Jusselme T 2017 *Energy Build.* **156**:281–92
[7] Rahiminejad M and Khovalyg D 2021 *Sci. Technol. Built. Environ.* **27**:788-805