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Thermal resistance of the ventilated air-spaces behind external claddings; theoretical definition and a parametric study

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Abstract. The presence of a ventilated air cavity between the external cladding and the wall core of a wall assembly can have a varying contribution to the thermal performance of the building envelope. In particular, the thermal resistance of a ventilated air-space is a dynamic parameter that is influenced by various thermo-physical parameters. In this study, a theoretical definition of the thermal resistance of a ventilated air-space behind an external cladding is introduced, employing a non-linear network of thermal resistances in the air-space. A numerical code is developed for the steady-state condition and verified with data from hot box tests available in the literature. Thereafter, a parametric analysis is performed based on the air change rate in the cavity (0 to 1000 1/h), type of the external cladding (brick and vinyl siding), seasonal variation (summer and winter conditions), and presence of the reflective insulation. The results are compared with a closed cavity to see the efficiency of the ventilation in the air-space. The results confirm that the theoretical thermal resistance of the ventilated air-space is a function of multiple factors, and its magnitude varies under different conditions.

1. Theoretical background

The thermal energy losses through the building envelope are responsible for about 50% of all building energy use [1]. The energy use in buildings can be reduced by analyzing the thermal characteristics of the layers used in the building envelope. The presence of an air-space within the wall structure can affect the thermal performance of the entire wall assembly [2]. This study aims to provide the theoretical definition of the thermal resistance of a ventilated cavity and compare the results obtained with the sealed cavity at certain conditions. In contrast to the thermal resistance of a sealed cavity defined based on the linear summation of convective and radiative heat transfer correlations in the cavity [3], the theoretical definition of the thermal resistance of a ventilated cavity in this study is defined using a non-linear network of thermal resistances in the air-space, as a function of convective heat transfer correlations of the left and right surfaces bounding the air gap, and the radiative heat transfer correlation between the cavity walls (equation (1)). A detailed explanation of this definition is provided by Rahiminejad and Khovalyg [4].

$$R_{\text{ventilated cav}} = \frac{\left(\frac{1}{h_{\text{cav, conv, left}}} + \frac{1}{h_{\text{cav, conv, right}}} \right) \cdot \frac{1}{h_{\text{cav, rad}}}}{\left(\frac{1}{h_{\text{cav, conv, left}}} + \frac{1}{h_{\text{cav, conv, right}}} \right) + \frac{1}{h_{\text{cav, rad}}}} \quad (1)$$

Based on the analytical solution using the energy balance in the ventilated wall assembly at a steady-state condition, a MATLAB[®] code is developed to calculate temperatures and heat flow across the wall



structure. To validate the analytical solution, computed temperatures of surfaces are compared with the results of hot-box tests [4]. It should be noted that some assumptions, such as ignoring the effect of the thermal mass of the solid materials, are considered in the calculation procedure.

In the following section, the results of the parametric analysis of the theoretical thermal resistance in the ventilated cavity are provided by varying the effective factors that are listed in Table 1. The results of the ventilated air gap are also compared with the closed cavity.

Table 1. Input parameters.

Parameter	Unit	Value	
		Brick cladding	Vinyl Siding
Thickness of the cladding	m	0.12	0.012
Conductivity of the cladding	W/(m · K)	0.43	0.19
Thickness of the wall core	m	0.16	0.16
Conductivity of the wall core	W/(m · K)	0.03, 0.06, 0.18	
Thickness of the air-space	m	0.025	0.009
Air change rate per hour	1/h	0.1, 10, 300, 500, 800, 1000	
Outdoor air temperature	°C	0 (winter), 35 (summer)	
Solar radiation	W/m ²	0, 500, 1000	
Emissivity of the left cavity wall	-	0.9	
Emissivity of the right cavity wall	-	0.9 and 0.05	

2. Results and Discussion

2.1. Impact of effective factors

The variation of the thermal resistance at different conditions is shown in Figure 1. Based on the results, the external cladding type has no significant effect on the theoretical thermal resistance of the cavity.

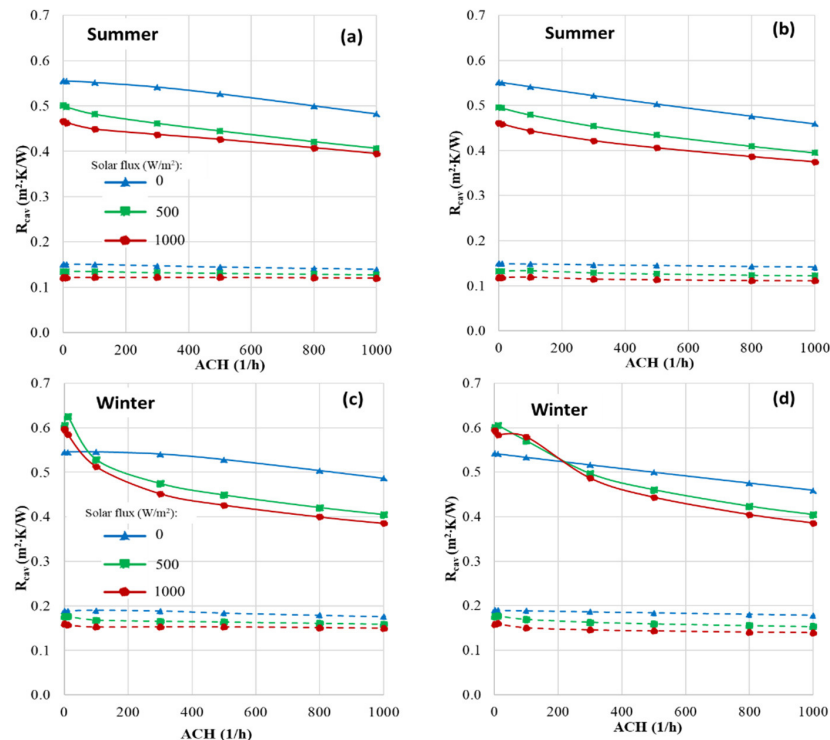


Figure 1. Thermal resistance of the ventilated cavity behind brick (a & c) and vinyl siding (b & d) (dashed lines: $\varepsilon_1 = \varepsilon_2 = 0.9$; solid lines: $\varepsilon_1 = 0.9$ & $\varepsilon_2 = 0.05$).

Moreover, an increase in ACH results in the reduction of the theoretical thermal resistance of the air-space due to the effect of the higher mean velocity on the convective heat transfer coefficient inside the

cavity. The presence of reflective insulation on the cavity wall adjacent to the wall core affects the radiation between cavity walls and consequently increases the thermal resistance of the air gap. At higher solar fluxes, the buoyancy effect causes higher airflow in the air gap, and the convective heat transfer coefficient will be increased; therefore, the total thermal resistance of the cavity decreases. For both types of external claddings, the thermal resistance of the air in the cavity in winter conditions is greater than in summer if we compare two points at the same ACH and the fixed case of reflective insulation. This is due to the higher outdoor temperature that makes the temperatures of the cavity surfaces higher.

2.2. Comparison with the closed cavity

In this subsection, the efficiency of the ventilated air cavity is evaluated as the ratio of the theoretical thermal resistance of the ventilated air gap to the thermal resistance of the enclosed cavity. We will refer to the ratio as Effective Thermal Resistance Ratio (ETRR) in the discussion. Two formulas are used to specify the cavity surface temperatures [3]:

$$T_m = \frac{T_{left} + T_{right}}{2} \quad (2)$$

$$\Delta T = T_{left} - T_{right} \quad (3)$$

Based on the values of the thermal resistances of the closed cavity reported in [3], three different scenarios for the above temperatures are considered. The values of the ETRR are compared in Table 2 for two air change rates (0.1 and 300 1/h), two thicknesses of the cavity (13 and 20 mm), and two emissivity values (0.05 and 0.82) for the cavity surface adjacent to the wall core.

Table 2. Thermal resistance of the closed cavity and the corresponding ETRR values.

Scenario	Emissivity	Cavity thickness (m)					
		0.013			0.020		
		R-value of the closed cavity	ETRR 0.1 1/h	ETRR 300 1/h	R-value of the closed cavity	ETRR 0.1 1/h	ETRR 300 1/h
$T_m = 32.2\text{ }^\circ\text{C}, \Delta T = 5.6\text{ }^\circ\text{C}$	0.05	0.41	1.18	1.10	0.57	0.85	0.79
	0.82	0.14	1.00	0.99	0.15	0.96	0.94
$T_m = 10\text{ }^\circ\text{C}, \Delta T = 16.7\text{ }^\circ\text{C}$	0.05	0.43	0.97	0.92	0.49	0.85	0.80
	0.82	0.16	0.98	0.96	0.17	0.92	0.90
$T_m = 10\text{ }^\circ\text{C}, \Delta T = 5.6\text{ }^\circ\text{C}$	0.05	0.45	1.11	1.04	0.61	0.82	0.77
	0.82	0.16	1.04	1.02	0.18	0.93	0.91

As shown in the above table, an increase in ACH results in the decrease of ETRR values in all cases due to the higher convective heat transfer coefficient inside the cavity at higher mean air velocities. The values of ETRR are less than unity in all cases in the wider air gap, which can be inferred as lower thermal resistance of the ventilated air-space compared to the closed cavity. In the case of the smaller air gap, however, when the mean temperature is 10°C and the temperature difference is 5.6°C, the thermal resistance of the ventilated cavity is higher compared to the enclosed cavity. In contrast to the smaller cavity where the presence of reflective insulation could increase the value of ETRR, the presence of the reflective insulation in the wider cavity results in a lower ETRR compared to the air gap without the reflective insulation.

3. Conclusion

A theoretical thermal resistance for a ventilated air gap was introduced in this study. The results showed that the air change rate in the cavity and the presence of reflective insulation have a noticeable impact on the thermal resistance of the ventilated air-space. Moreover, the ventilated cavity could have higher thermal resistance compared to the enclosed cavity at particular conditions.

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