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Impact on the U-value due to airflows behind insulation modules attached to façades of old buildings

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Abstract

The paper analyses the impact of air flow between an existing construction and an attached thermal insulation module. The paper presents general and handy formulas which can be used to determine the degradation of the U-value due to forced and natural induced air flows. The presented formulas accounts for varying insulation degree of the existing wall and the insulating modules, as well as the air flow rates.The estimations of the changed U-value can be used to balance moisture safety of the new construction and the energy performance.

Keywords: Building envelope, retrofitted, façades, heat transfer, convection, U-values

1. Introduction

There is a need of upgrading the old building stock with respect to the thermal insulation of the building envelope and specifically the facades. There is a big building stock from the post second world war that needs to be upgraded. There

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are a number of systems on the market and some are quite new and innovative. In order to bring down the cost some of the systems are based on prefabricated moisture tight insulated units. This means that, in case there is moisture tight barrier on the interior side, two moisture tight barriers surrounds the wall structure. Depending on the leakage of driving rain into the structure, air leakages from the interior, or the status of the existing wall there is sometimes a need for a ventilated gap to have a drying possibility. Also the unevenness of the existing façade air gap might be there anyway.

It is of major importance to evaluate the risk when changing an existing building envelope [1-3]. The risk involves various performances. Securing a better moisture safety might instead influence the energy performance. In this paper the energy efficiency is in focus, and in particular how much the U-value will degrade due to airflows behind the retrofitting insulation modules.

The thermal effect of air flows inside the components of a wall has been studied earlier. Pioneering work can be found in for instance [4,5].

2. Analyzed wall system - Simplifications

The analysis will be based on 2D quasi-steady state analysis, i.e. we will assume that the temperature profile and air flow rates within the wall system can be treated as always being at steady-state condition. This should not be any major simplification as long as we look at average heat flows through the wall during longer periods.

The existing remaining wall, with the height *H* (m) has the U-value *U* (W/m^{2}K) and the additional module attached to the wall has the thermal resistance R (m^{2}K/W). Between the existing wall and the module there is an air gap with the height *h* (m) and length *H* (m). The air flow between the existing wall and the attached module is caused by forced, natural or mixed convection. Here, we will treat it as either forced or natural convection. The air flow rate is denoted q_a (m^3/ms).

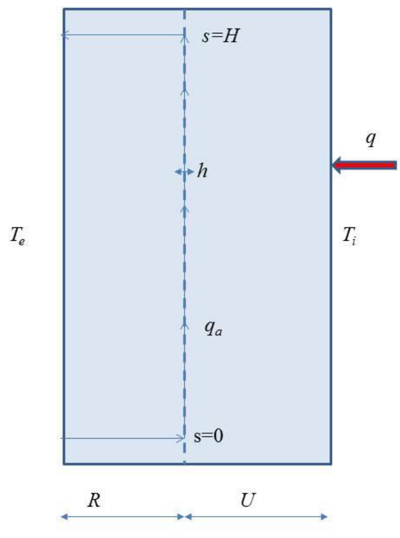

Fig. 1. Wall system to be analyzed.

The external temperature is denoted T_e (°C), the interior one T_i (°C), and q (W/m) is the heat loss in to the interior wall.

We will assume that the inflowing air will reach its equilibrium temperature before it exits to the outside again. Requirement for this is analyzed below, specified on the right in (1). A further simplification introduced is that the air flow resistance in the horizontal air channel segments is neglected as well as their thermal impact.

3. Temperature in the air channel

The temperature in the channel, starting at *s=0* and ends at *s=H*, is:

$$T(s) = T_c + (T_e - T_c) \cdot e^{-s/\ell_c} \qquad \frac{H}{\ell_c} > 3 \tag{1}$$

Here, T_c (°C) is the balance temperature far away from the air entrance and ℓ_c (m) is a declination length. The temperature disturbance by the air flow is assumed to be negligible for distances more than three times this length.

$$\ell_c = \frac{\rho_a c_{pa} \cdot q_a}{U + 1/R} \tag{2}$$

Here $\rho_a c_{pa}$ (J/m^{3}K) (approximately 1,2·1000 J/m^{3}K is assumed in this study) is the volumetric heat capacity of air at constant atmospheric pressure.The balance temperature T_c (°C) becomes:

$$T_c = \frac{U \cdot T_i + T_e / R}{U + 1/R} \qquad (T_c - T_e) = (T_i - T_e)\frac{U}{U + 1/R} \tag{3}$$

4 Air flow rate in the channel, forced convection

Using [6,7] and assuming laminar flow in the vertical air channel, the airflow rate becomes:

$$q_a = \frac{\Delta p}{R_{pc}^0} \qquad \frac{R_{pc}^0}{\eta} = \frac{12 \cdot H}{h^3} + \frac{2 \cdot 1080 \cdot 0.885}{h^2} \tag{4}$$

Here, Δp (Pa) is the pressure difference between the entrance and the exit of the channel induce by the wind, and η is the dynamic viscosity of air, 17.5·10^{-6} Ns/m^2 at 10 °C. The term R_{pc}^0 (Pa/(m^3/ms)) represents the air flow resistance in the channel.

5 Air flow rate in the channel, natural convection

Using [6,7] we have the following formula for the stack effect, i.e. pressure difference over the air channel due to temperature differences.

$$\frac{\Delta p}{g\beta\rho_a} = \int_0^H (T(s) - T_e) ds = \int_0^H T_c + (T_e - T_c) \cdot e^{-s/\ell_c} - T_e ds \approx (T_c - T_e) \cdot (H - \ell_c) \tag{5}$$

Here, we have used the assumption that H/ℓ_c is much greater than one in the exponential term.
The air flow rate becomes:

$$q_a = \frac{\Delta p}{R_{pc}^0} = \frac{g\beta\rho_a}{R_{pc}^0}(T_c - T_e)\cdot(H - \ell_c) \tag{6}$$

Using (2) and (6) we get:

$$\ell_c = \frac{\rho_a^2 c_{pa} g\beta}{R_{pc}^0 (U + 1/R)}(T_c - T_e)\cdot(H - \ell_c) \tag{7}$$

With the solution:

$$\ell_c = \frac{H}{1 + \dfrac{R_{pc}^0 (U + 1/R)}{\rho_a^2 c_{pa} g\beta (T_c - T_e)}} \tag{8}$$

Coupling the formula (2) and (8) gives the air flow rate.

6. Impact on the U-value

The cold air flowing in to the wall construction represents a heat sink that can be superimposed on the linear undisturbed 1D heat flow through the wall.

$$q_s = \rho_a c_{pa} \cdot q_a \cdot (T_c - T_e) \tag{9}$$

From [8] we directly get how the heat sink will take up extra heat from the interior:

$$q_e = q_s \frac{U}{U + 1/R} \tag{10}$$

The change in U-value becomes:

$$\Delta U = \frac{q_e}{H(T_i - T_e)} = \frac{\rho_a c_{pa} \cdot q_a \cdot (T_c - T_e)}{H(T_i - T_e)} \frac{U}{U + 1/R} = \frac{\ell_c}{H} \frac{U^2}{U + 1/R} \tag{11}$$

Here, we have used (2-3) and (6).

7. Example: Forced convection

The following data are assumed:

H=3 m, h=0.005 m, U=0.5 W/m^{2}K, R=2 m^{2}K/W, Δp=2 Pa

$$R_{pc}^{0}=\eta\left(\frac{12\cdot H}{h^{3}}+\frac{2\cdot 1080\cdot 0.885}{h^{2}}\right)=17.5\cdot 10^{-6}\left(\frac{12\cdot 3}{\left(5\cdot 10^{-3}\right)^{3}}+\frac{2\cdot 1080\cdot 0.885}{\left(5\cdot 10^{-3}\right)^{2}}\right)=4978\ \text{Pa/(m}^{3}\text{/ms)} \tag{12}$$

$$\ell_{c}=\frac{\rho_{a}c_{pa}\cdot q_{a}}{U+1/R}=\frac{\rho_{a}c_{pa}}{U+1/R}\frac{\Delta p}{R_{pc}^{0}}=\frac{1200}{0.5+0.5}\frac{2}{4978}=0.48\,\text{m} \tag{13}$$

Our analysis is applicable since the height H is six times greater than the declination length ℓ_c found in (1).

$$\Delta U=\frac{\ell_{c}}{H}\frac{U^{2}}{U+1/R}=\frac{0.48}{3}\frac{(0.5)^{2}}{0.5+0.5}=0.04\quad \text{W/m}^{2}\text{K} \tag{14}$$

This means that instead of reaching a U-value of 0.25 W/m^{2}K the air flow increases it to 0.29 W/m^{2}K.

8. Example: Natural convection

The following data are assumed (same as in last example):

H=3 m, h=0.005 m, U=0.5 W/m^{2}K, R=2 m^{2}K/W, Δp=2 Pa, T_e =0 °C, the interior one T_i =20 °C.

For this case the difference between the balance temperature of the channel and the exterior one is needed to calculate the declination length, (3).

$$T_{c}=\frac{0.5\cdot 20+0/2}{0.5+1/2}=10\,^{\circ}\text{C} \tag{15}$$

The declination length becomes:

$$\ell_{c}=\frac{3}{1+\dfrac{4978\cdot(0.5+1/2)}{1.2^{2}\cdot 1000\cdot 9.81\dfrac{1}{273+10}(10-0)}}=0.273\quad \text{m} \tag{16}$$

The length is a bit shorter than in the last case so the simplified analysis is still valid. The change in U-value becomes:

$$\Delta U=\frac{\ell_{c}}{H}\frac{U^{2}}{U+1/R}=\frac{0.273}{3}\frac{(0.5)^{2}}{0.5+0.5}=0.023\quad \text{W/m}^{2}\text{K} \tag{17}$$

This means that instead of reaching a U-value of 0.25 W/m^{2}K the air flow increase it to 0.27 W/m^{2}K.

9. Conclusions and Discussion

The analysis performed in this paper and the handy formulas for both forced and natural convection shows the impact of air flow between an existing construction and the attached thermally insulation module. This gives a possibility to balance moisture safety of the new construction and the energy performance.

The estimated change in U-value should be considered a conservative one, i.e. an overestimation. This is due to the fact that the exchange of heat to and from the horizontal air flow segments is neglected. We basically assume that the temperature of the air is equal to the external one at the point where it starts flowing in the vertical segment. We also assume that the air exits the wall with the balance temperature T_c. As shown in [6], the change in heat loss for very small air flow rates instead tends to zero. This represents the case when the air temperature along the channel is the same as the wall temperature when the flow rate is equal to zero. For that case the thermal effect by the vertical segment is zero since the temperature of the air is not changing at all along the path. For the horizontal exit paths the uptake of heat and the corresponding release of heat cancel each other's effect for the whole wall. In the wall part where external air is entering there will be a cooling effect and at the exit part there is a corresponding warming up effect.

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