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NIGHT RADIATION EFFECT ON ENERGY PERFORMANCE OF VENTILATED FAÇADES

BY

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Abstract. Ventilated façades systems are more and more used for thermal rehabilitation of existing buildings. Their energy performance depends on many parameters, whose influence can be quantified by numerical and analytical models. When designing ventilated façades, the cooling effect of the night sky cannot be neglected because of increased thermal losses through the exterior walls. In the current paper, the influence of wind velocity, ground and outer cladding emissivity is analysed numerically for an insulated brick wall with an exterior wood cladding. Heat gains and losses are compared to a reference value and some results are shown. The computation was based on the steady-state approach of the physical phenomena during the warm season.

Key words: ventilated façades; numerical model; radiation; energy performance.

1. Introduction

The design of the natural ventilated systems requires determination of the heat fluxes and convective air flow. Numerical and analytical methods based on steady-state approach have increasingly been used as a tool to compute heat transfer considering the heat balance on the surfaces of the elements and inside the ventilated channel.

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Detailed radiation models that count for thermal exchange between the exterior surface and the surroundings are necessary to calculate energy balance on the exterior surface of the building. Exterior surface temperatures cannot be calculated accurately if the long-wave radiation effects are not considered (Kehrer & Schmidt, 2008). These values are also needed in order to estimate the risk of condensation and of algae growth if the temperatures decreases below the dew point.

During night time, the exterior envelope exchanges long wave radiation with the sky, ground and surrounding elements. Usually the energy balance is negative, more heat being lost to the exterior than it is being absorbed. This is balanced by the convective heat transfer that depends on several factors like surface humidity, wind velocity and direction.

Griffith (2006) developed a detailed numerical model for the naturally ventilated cavities of opaque building thermal envelopes, but without considering overall thermal performance of the ventilated system. Aelenei & Henriques (2008) analysed the surface condensation risk considering convective and radiative exchanges on the exterior surface. A very accurate radiation model on exterior surfaces has been developed at the Fraunhofer IBP (Kehrer & Schmidt, 2008). Other studies on the energy performance of ventilated façades, are focused more on the heat transfer inside the ventilated channel (Mesado *et al*., 2010; Balocco, 2001; Seferis *et al.*, 2011).

2. Heat Transfer Mechanism in the Ventilated Façades

2.1. Night Sky Radiation

The downward long-wave radiation of the sky, Q_{sky} , [W/m^2], can be computed with eq.

$$Q_{\text{sky}} = \varepsilon_{\text{sky}} \sigma T_e^4, \tag{1}$$

considering the sky as a grey body with the emissivity ε_{sky} , having the temperature equal to that of the ambient air, T_e, [K].

Night time radiation depends on atmospheric water vapour conditions of the cloud cover and the relative humidity of the environment (eq. (3)). Goforth *et al.* (2002) used a modified Swinbank model to determine the night time thermal radiation function of these parameters

$$Q_{\text{sky}} = (1 + KC^2) 8.78 \times 10^{-13} T_e^{5.852} \text{RH}^{0.07195}, \tag{2}$$

where: K is the coefficient that takes into consideration the cloud height, C – coefficient function of the cloud cover, RH – relative humidity, [%].

Sky emissivity can be approximated function of the dew point temperature, T_{dp} , (Chen *et al.*, 1995), but the usual considered value is about 0.74

$$\begin{cases} \varepsilon_{\text{sky}} = 0.736 + 0.00577T_{dp}, \\ \varepsilon_{\text{sky}} = 0.741 + 0.0062T_{dp}, \\ \varepsilon_{sky} = 0.732 + 0.00635T_{dp}. \end{cases} \quad (3)$$

Because of the zenith angle orientation, vertical surfaces will exchange less long-wave radiation with the sky than horizontal ones (Aelenei & Henriques, 2008).

2.2. Energy Balance at the Exterior Surface

During night time, due to night emissivity, surface temperature on the building envelope is lower than the exterior air temperature. Under steady-state conditions, the radiation heat flux, Q_{rad} , [W/m^2], through the outer layer is balanced by the convective Q_{conv} , [W/m^2], and conductive Q_{cond} , [W/m^2], fluxes

$$Q_{\text{cond}} + Q_{\text{conv}} = Q_{\text{rad}}. \quad (4)$$

The radiative heat flux between the wall and the environment is calculated using the Stefan-Boltzmann's law using the corresponding view factors from the envelope, considering the emitted, $Q_{\text{rad,em}}$, [W/m^2], and absorbed, $Q_{\text{rad,abs}}$, [W/m^2], long wave radiation

$$Q_{\text{rad}} = Q_{\text{rad,em}} - Q_{\text{rad,abs}}. \quad (5)$$

The long wave radiation heat flux emitted by the exterior layer can be performed with the relation

$$Q_{\text{rad,em}} = \varepsilon_w \sigma T_w^4, \quad (6)$$

where: ε_w is the wall emissivity, T_w – wall temperature, [K].

The usual emissivity of non-metallic surfaces varies between 0.8 and 1, therefore typical long-wave emissions are at the order of 300...400 W/m^2.

On the other hand, the façade absorbs part of the long-wave radiation emitted by the surrounding objects (terrestrial counter radiation) and by the sky (atmospheric counter radiation) (Künzel, 2002). The relative contribution of the two sources of long-wave radiation depends on the fractional parts they occupy in the field of view of the façade. In the central European climate conditions and for a typical cloud cover, the medium radiation intensity emitted by the sky can be estimated around 80% of the terrestrial objects intensity.

The total absorbed intensity by the façade is a sum of the long-wave radiation from the ground, Q_g , [W/m^2], sky radiation, Q_{sky} , [W/m^2] and the reflected sky radiation from the ground, $Q_{\text{sky},g}$, [W/m^2], as can be seen in the eq.

$$Q_{\text{rad,abs}} = \varepsilon_w \left[F_{wg} Q_g + F_{ws} Q_{\text{sky}} + (1-\varepsilon_g) F_{wg} Q_{\text{sky},g} \right], \tag{7}$$

where: F_{wg}, F_{ws} are view factors from the building surface to the ground and sky, ε_g – emissivity of the ground and T_g – the ground surface temperature, [K].

Because the building exposure is shared by the sky and ground, a direct relation between the view factors can be written

$$F_{ws} = 1 - F_{wg} \tag{8}$$

The vertical wall is considered a long plane in contact with the ground and therefore the ground view factor can be computed with

$$F_{wg} = \frac{1}{2}\left(1 - \cos\beta\right), \tag{9}$$

and is equal to 0.5 in the case of vertical walls, where: β is the angle between the vertical wall and the ground.

Considering eqs. (5),...,(9), the net radiative heat flux on the building envelope becomes

$$Q_{\text{rad}} = \varepsilon_w \sigma \left[T_w^4 + \varepsilon_{\text{sky}} \left(\frac{1}{2}\varepsilon_g - 1 \right) T_e^4 - \frac{1}{2}\varepsilon_g T_e^4 \right]. \tag{10}$$

The convective heat transfer at the surface of the exterior surface is given by the Newton's law and depends on the value of the convective coeeficient, h_c , [W/m^2.K]. The international standard ISO/FDIS 6946 (2007) approximates its value function of the wind intensity with the relation

$$h_c = 4 + 4v, \tag{11}$$

where v is the wind speed adjacent to the surface, [m/s].

The external surface resistance, R_{se} , varies with the velocity. This variation is done in Table 1,

Table 1
Values of R_{se} for Different Wind Speeds

Wind speed, [m/s]	R_{se}, [m^2.K/W]
1	0.08
2	0.06
3	0.05
4	0.04
5	0.04
7	0.03
10	0.02

2.3. Energy Balance for the Ventilated System

In an opaque ventilated façade all three heat transfer mechanisms are present in or around the cavity walls (Fig. 1).

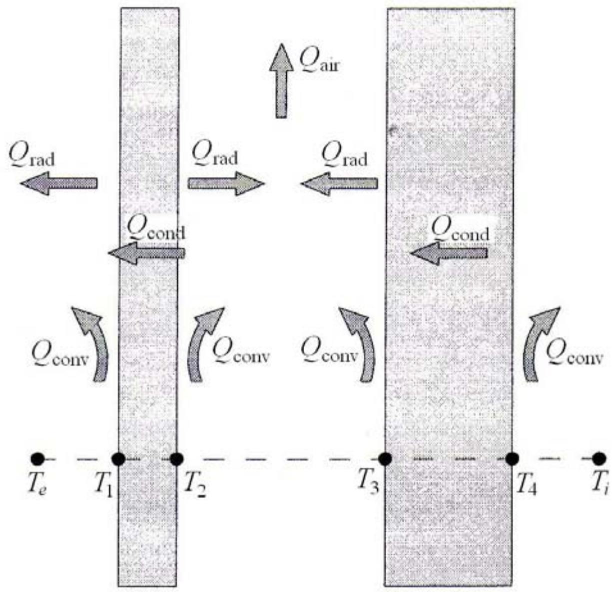

Fig. 1 – Schematic of the ventilated channel with temperatures and heat transfer.

In steady state, thermal eqs. are based on the conservation of conductive, Q_{cond}, convective, Q_{conv}, and radiative, Q_{rad}, fluxes on the outer façade, inner façade, outer wall and inner wall surfaces, respectively,

$$Q_{rad1} - Q_{conv1} = Q_{cond12}\,, \qquad (12)$$

$$Q_{\text{rad}} + h_c (T_e - T_1) = \frac{k_{12}}{d_{12}} (T_2 - T_1), \tag{13}$$

$$Q_{\text{cond12}} = Q_{\text{conv2}} + Q_{\text{rad23}}, \tag{14}$$

$$\frac{k_{12}}{d_{12}} (T_2 - T_1) = h_2 (T_c - T_2) + \varepsilon_r \, \sigma (T_3^4 - T_2^4), \tag{15}$$

$$Q_{\text{rad23}} + Q_{\text{conv3}} = Q_{\text{cond34}}, \tag{16}$$

$$\frac{k_{34}}{d_{34}} (T_4 - T_3) = h_i (T_i - T_4), \tag{17}$$

$$Q_{\text{cond34}} = Q_{\text{conv4}}, \tag{18}$$

$$\frac{k_{34}}{d_{34}} (T_4 - T_3) = h_i (T_i - T_4). \tag{19}$$

Eqs.

$$Q_{\text{conv3}} = Q_{\text{conv2}} + Q_{\text{air}} \tag{20}$$

$$h_3 (T_3 - T_c) = h_2 (T_c - T_2) + \dot{m} c_p (T_c - T_e) \tag{21}$$

represent the correlation between heat transfer by convection inside the channel and heat flow from natural ventilation, Q_{air} , where: T_e ,T_1, T_2, T_3, T_4, T_i are the air and surface temperatures, [K], T_c – the volumetric channel temperature, [K], σ – Stefan-Boltzmann constant (5.67 × × 10^{-8} W/m^2.K^4), ε_r – the modified radiation coefficient for the materials facing the cavity, h_2 and h_3 – the convection coefficients inside the channel, [W/m^2.K], h_e – the exterior heat transfer coefficient, h_i – the interior heat transfer coefficient (8 W/m^2.K), k_{12} and k_{34} – the exterior layer and wall thermal conductivities, [W/m.K], d_{12} and d_{34} – the thicknesses of the outer and inner layers, [m] and c_p – the air specific heat at constant pressure (1,004 J/kg.K).

3. Numerical Modeling Results

In order to analyse the effect of night radiation on thermal fluxes in a ventilated wall, a single layer brick wall (λ = 0.70, d = 0.25) with a 5 cm mineral wool thermal insulation (λ = 0.04, ε = 0.70) was considered. The height of the ventilated channel is of 3 m and the width, of 4 cm. The outer cladding is made of wood boards (λ = 0.18, d = 0.02, ε = 0.9). The schematic of the system can be seen in Fig. 2.

Interior air temperature is considered to be +25ºC while the exterior air temperature varies between +5 and +15ºC. These values are specific for a summer night. When solving the numerical eqs. previously written, the temperature distribution and thermal fluxes values can be found. Temperature drops on the outer cladding can be observed in Fig. 3.

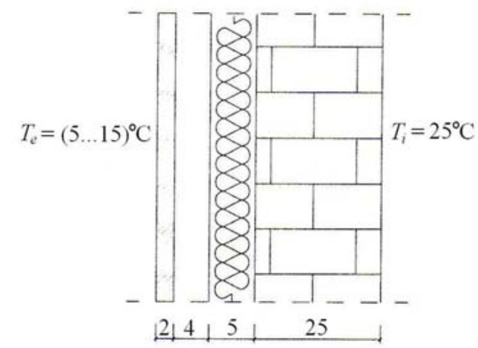

Fig. 2 – Schematic of the analysed system.

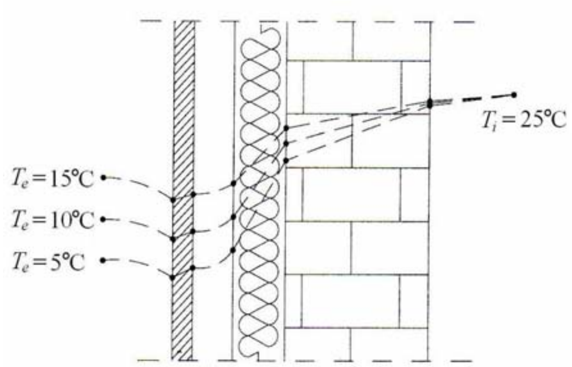

Fig. 3 – Temperature variation in the wall function of the exterior air temperature.

Due to the cooling effect of the night sky and smaller temperature on the exterior layer the heat flux lost through the brick wall increases as it can be observed in Fig. 4.

In order to optimize the ventilated systems in summer night, the influence of different parameters has been analysed by comparing the thermal gains and losses to a reference value. The influence of the outer cladding emissivity on the thermal performance of the system can be observed in Fig. 5, function of the reference value of ε = 0.9, common for many typical building materials.

The emissivity of the terrain influences the thermal efficiency of the system. A greater value for the terrain emissivity will increase the temperature on the outer cladding because the radiation temperature of the ground is equal to the exterior air temperature and will decrease the thermal flux through the wall (Fig. 6). The reference value is of 0.9.

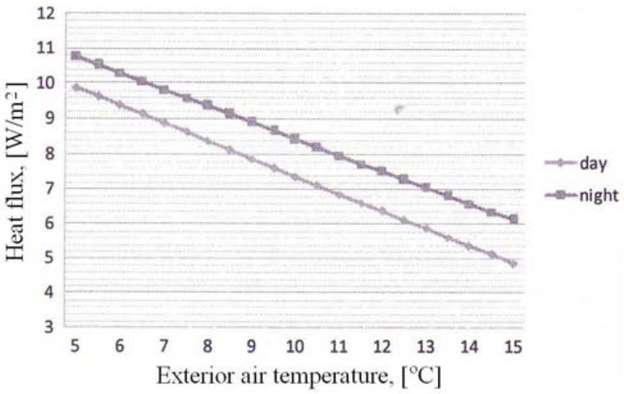

Fig. 4 – Day and night heat fluxes through the exterior walls function of the exterior air temperature.

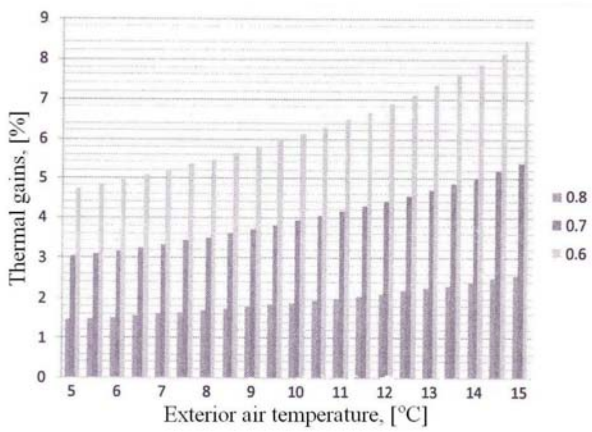

Fig. 5 – Thermal gains for a ventilated system with a decrease of the emissivity of the outer layer.

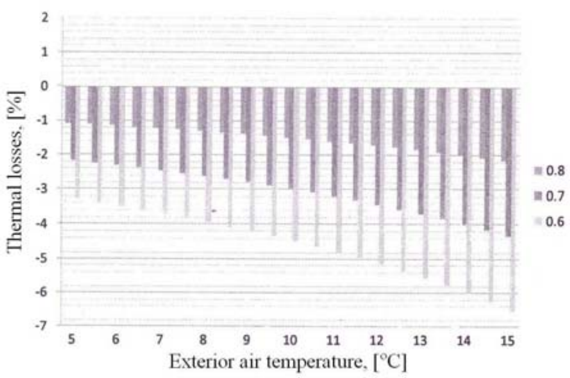

Fig. 6 – Thermal losses for a ventilated system with a decrease of the ground emissivity.

A bigger wind velocity will increase the convection coefficient, thus more heat will be transferred to the outer cladding, increasing the surface temperature and decreasing heat flow to the exterior (Fig. 7).

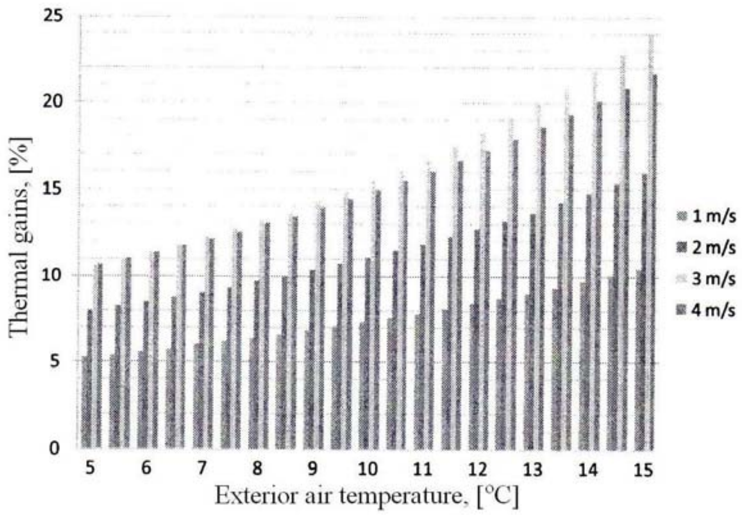

Fig. 7 – Thermal gains for a ventilated system function of the wind velocity.

4. Conclusions

Due to the multitude of constructive systems and influencing parameters of ventilated façades, a universal solution for a given climate has not been realized. Numerical and analytical models are being increasingly used as a tool to analyse thermal efficiency of different ventilated systems.

Sky radiation influence on ventilated system performance has been less studied but the long wave radiative heat transfer cannot be neglected. For the same exterior/interior air temperature difference the heat fluxes during night time have been with 10% higher compared to the one during day time.

Thermal performance during night time as a function of ground emissivity, wind velocity and outer layer emissivity, has been analysed. In the present study the wind velocity has been found to have the biggest influence while the ground emissivity the smallest. Using materials with low emissivity for the outer layer has been found to decrease the heat fluxes with up to 8%.

Further studies are needed to extend the range of studied systems and to determine the energy performance during the cold season.

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EFECTUL RADIAȚIEI ATMOSFERICE ASUPRA PERFORMANȚEI ENERGETICE A FAȚADELOR VENTILATE

(Rezumat)

Sistemele de fațade ventilate sunt utilizate pentru reabilitarea clădirilor existente dar şi ca o strategie pasivă de reducere a consumurilor energetice pentru clădirile noi. Eficiența termică depinde de o serie de parametri a căror influență poate fi cuantificată cu ajutorul modelelor de calcul numeric şi analitic.

Se analizează efectul radiației atmosferice prin compararea fluxurilor termice prin pereții exteriori în timpul sezonului cald. Fluxurile de căldură au fost calculate prin stabilirea bilanțului termic în noduri şi a transportului convectiv de căldură în canalul ventilat.