

# Investigation of the Dynamics of Solid Particles Motion Into the Ventilated Air Gap of the Cladding Façade Systems

N Umnyakova<sup>1</sup>

<sup>1</sup>Research Institute of Building Physics (NIISF), 21, Lokomotivnij pr., Moscow, 127238, Russia

E-mail: n.umniakova@mail.ru

**Abstract.** All articles must contain atmospheric air in cities contains a large number of pollutants in the form of solid particles and dust. One of the most dangerous not only for humans, but also for building structures, are the particles smaller than 10 microns. They penetrate into the structures of cladding façade systems, fall and settle on the surface of a insulation made of mineral wool, as well as on metal elements of the façade cladding system, faced into the ventilated air layer. The author carried out a large number of experimental studies of structures of façade cladding systems, which made it possible to choose the following parameters and characteristics when performing this work. The article deals with the dynamics of the motion of dust particles with a size from 1 to 5 microns in the air interlayer of the cladding façade system with the Reynolds number  $Re \leq 1$ . An equation is obtained for calculating the velocity of dust particles in a size of 10-50  $\mu\text{m}$  in the air stream at its rate of 0.1-0.0, 8 m/s at various outside air temperatures, as well as the conditions under which dust particles "levitate" in the air gap are determined. At the same time, "levitating" dust particles settle on the surface of a mineral wool insulation from a stone fiber and penetrate into the thickness of the fibrous insulation, causing a change in its thermal and sorption characteristics.

## 1. Introduction

The growth of the city and its infrastructure contributes to an increase of the content of pollutions in the air [1,2,3]. Injuries chemicals and waste gases from industrial facilities and transport change the atmospheric air, worsening its composition. The concentration of pollutants often approaches a biologically dangerous limit not only for people, animals, plants, but also for building structures [3,4,5]. In the production of building materials a large number of pollutants are also released (Table 1). At the same time, various pollutants  $\text{SO}_2$ ,  $\text{CO}$ ,  $\text{NO}_2$ ,  $\text{H}_2\text{S}$ , heavy metal particles (Pb, Zn, Ni, Co), as well as particles from the road surface including asphalt or asphalt concrete, and road transport - rubber are present in the ambient air [6]. They in the form of aerosols (dust) under the influence of aerodynamic flows rise up and flow around the facades of buildings [7,8], including the design of cladding facades.

## 2. Basics for creating a model

To solve the problem, we will consider a complex model of the dynamics of the movement of air flow with dust particles from the surface of the urban environment till its penetration and winding in the ventilated air layer of the cladding facade system.



The movement of aerosols under the influence of wind flow from the surface of the pavement (asphalt) and its air-flow on the windward side of the facade with pollution particles ( $C_1 + C_2 + \dots + C_n$ ), which have the summation of the action.

**Table 1.** Disperse composition of dusts formed in certain technological processes

Technological equipment	Particle material	Dustiness of gases, g/m <sup>3</sup>	Diameter of material particle $d_m$ , μm
Rotary kiln	Magnesite	100-120	43
	Dolomite	35-45	28
Shaft Mill	Magnesite	1200	72
	Clinker	40	11
Rotary cement kiln (dry method of production)	A mixture of slag and quail	20	20
	Aluminum oxides	1	20
Electrolyzer of aluminum (lateral current lead)	Clinker	25-30	23
		9-9,6	9,5
Furnace for firing clinker (wet method of production)	Clinker	28,5	14
		18,5	8
Cement mill	Double superphosphate»	45	17
		3-5	80
Spray dryer	Double superphosphate»	12-16	35
		17	41
Drum dryer	Ash	27	29
		Limestone	
Incinerator			
Fluidized bed furnace			

Based on Bernoulli's equation in connection with the speed of the air flow along the surfaces of the  $v_{s, \text{fac}}$  and the wind speed  $v_{\text{wind}}$ , the equation (1) is derived. This equation allows one to describe the dynamics of particle movement in the form of aerosols and dust particles with their partial penetration through the gaps between the facing tiles in the ventilated air interlayer of façade cladding system

$$K_{45} (C'_1 + C'_2 + \dots + C'_n) v_{s, \text{fac}}^2 = (C_1 + C_2 + \dots + C_n) v_{\text{wind}}^2 \quad (1)$$

где  $(C_1 + C_2 + \dots + C_n)$  и  $(C'_1 + C'_2 + \dots + C'_n)$  – concentration of pollutants, determined experimentally, mg / m<sup>3</sup>;  $K_{45}$  - aerodynamic coefficient, proposed by E.Retter [9], which takes into account the influence of wind at an angle of 45° on the windward surface of the facade, which has holes;  $v_{s, \text{fac}}$  - speed of air flow at the surface of the ventilated facade, m/s;  $v_{\text{wind}}$  - wind speed is wind speed, m/s.

The airflow blows around the building, enters the ventilated air interlayer through the gaps between the cladding tiles into the inlet openings and is removed through the exhaust openings. Under the influence of wind and gravity pressure there will be a natural circulation of air flow [10] with particles of dust in the ventilated air interlayer of the cladding façade system.

### 3. The solution of the problem

Let us determine the velocity of dust particles moving upward with the air flow into the ventilated air layer. To do this, let us take into consideration the dust particles with dimensions  $d_{d,p}$  from 10 to 50

$\mu\text{m}$  [11]. In calculations based on the results of investigations of the authors [11,12,13,14,15] we take the spherical shape of the dust particle. The Reynolds number for these dust particles in these conditions is in the range  $0 \leq \text{Re} \leq 1$ . The movement of dust particles in the air stream will depend on the density of the dust particles  $\rho_d$  and the air flow density  $\rho_{\text{air.flow}}$ , as well as the velocities  $v_d$  and  $v_{\text{air.flow}}$ , which is caused by the action of the frontal force  $R_x$ . This dependence can be written in the form

$$R_x = C' \cdot \frac{\pi d_{4d}^2}{4} \cdot \rho_{\text{air.flow}} \frac{(v_{\text{air.flow}} - v_d)^2}{2} \quad (2)$$

where  $C'$  — coefficient of aerodynamic resistance is characterized by the Reynolds number

$$\text{Re} = \frac{(v_{\text{air.flow}} - v_d) d_{4d}}{\nu}$$

For the dust particles under consideration with the Reynolds number  $0 < \text{Re} \leq 1$ , we express  $C'$  in accordance with the well-known Stokes formula

$$C' = \frac{24}{\text{Re}} = \frac{24\nu}{(v_{\text{air.flow}} - v_d) \delta_d} \quad (3)$$

When solving the problem of the movement of dust particles upwards for a vertical air flow, let us dwell on the equation proposed by N.S.Sorokin and V.N.Taliev [13], when a particle of dust with a weight  $mg$  rises upwards with an airflow at a speed  $v_{\text{air.flow}}$

$$R_x - mg = m \frac{dv_d}{d\theta} \quad (4)$$

where  $g$  - the acceleration of free fall,  $\text{m/s}^2$ ;  $\theta$ - time, s.

However, the solution of equation (4) is not given in the works of the authors [15]. In addition, it does not take into account the air density  $\rho_{\text{air.flow}}$  and the density of dust particles  $\rho_d$ . In this regard, the final equation to determine the speed of the upward movement of the air flow with dust particles was obtained by the author in the following form

$$v_d = v_{\text{air.flow}} - \frac{gd_d^2 \rho_d}{18\nu \rho_{\text{air.flow}}} \quad (5)$$

where  $v_{\text{air.flow}}$  - air velocity in the ventilated air layer,  $\text{m/s}$ ;  $g$  - acceleration of free fall  $\text{m/s}^2$ ;  $d_d$ - the diameter of the dust particle,  $\mu\text{m}$ ;  $\nu$  -the kinematic viscosity of air,  $\text{m}^2/\text{s}$ ;  $\rho_d$ - density of a particle of a dust,  $\text{kg/m}^3$  and ;  $\rho_{\text{air.flow}}$  - density of an air stream,  $\text{kg/m}^3$ .

The obtained equation (5) allows to calculate the speed of dust particles moving upward in the air flow into the ventilated layer, depending on the diameter of dust particles, their density and air flow density at different altitudes of the ventilated facade. In addition, equation (5) differs from the equations of other authors [12-16]. These consider the conditions when the dust particles fall down.

The analysis results of the calculation according to equation (5) for the conditions of  $0 < \text{Re} \leq 1$  has allowed to establish the following regularity. The dust particle, trapped together with the outside air through supply opening in a ventilated air layer under the action of gravity and wind pressure rise upwards. Into the air interlayer together with the air stream the movement of dust particles with a

diameter of 10 to 50 microns takes place. It has been established that the velocity of the air flow  $v_{air.flow}$  and the speed of the dust particles  $v_d$  within the considered limits are practically the same. This pattern is seen at air temperature in a ventilated air layer  $t_{ext} = -20^\circ\text{C}$ ,  $t_{ext} = 0^\circ\text{C}$  and  $t_{ext} = 20^\circ\text{C}$ .

To determine the speed of air movement in a ventilated air layer, special experimental thermal engineering studies were performed in the cladding facade structures with air gap in the buildings located in the center of Moscow [17,18]. In the facing plates of the cladding facade system, holes were drilled into which special sensors were inserted to measure the speed of air movement in a ventilated air gap. At the same time, the velocities of the wind flow were measured. The obtained dependences between the velocities of the wind flow and the speed of air movement in the ventilated air layer made it possible to obtain the following empirical equation

$$v_{air.flow} = 0,327 v_{wind}^{0,46} \quad (6)$$

It should be noted that the scope of equation (6) is limited to numerical values, when the wind speed is not higher than 8 m/s.

After substituting (6) into equation (5), we obtain formula (7), which allows us to determine the velocity of dust particles in the air layer as a function of the wind flow

$$v_d = 0,327 v_{wind}^{0,46} - \frac{gd_d^2 P_d}{18v_{air.flow} \rho} \quad (7)$$

The results of the calculation using formula (7) are given in Table 2.

**Table 2.** The velocity of dust particles, depending on the speed of the wind flow and air flow in a ventilated interlayer ventilated.

Wind speed, m/s	Air speed, m/s	Diameter of dust particles $d_d$ , $\mu\text{m}$				
		10	20	30	40	50
At an outside temperature $t_{ext} = -20^\circ\text{C}$						
0,1	0,1	0,099	0,098	0,097	0,097	0,096
0,35	0,2	0,199	0,197	0,197	0,197	0,196
0,8	0,3	0,298	0,298	0,298	0,297	0,297
1,5	0,4	0,399	0,398	0,397	0,397	0,397
2,5	0,5	0,498	0,497	0,498	0,498	0,497
3,7	0,6	0,599	0,598	0,597	0,598	0,597
5,2	0,7	0,698	0,698	0,698	0,698	0,697
7,0	0,8	0,799	0,798	0,798	0,797	0,797

The analysis of the motion of dust particles with diameter from 10 to 50  $\mu\text{m}$  at the speed of air flow from 0.1 to 0.8 m/s, showed that these particles have practically equal velocities in the air layer of the cladding facade system.

#### 4. Conclusion

Thus, the complex theoretical and experimental studies carried out have made it possible to develop a method for calculating the velocity of dust particles with a size of 10  $\mu\text{m}$  to 50  $\mu\text{m}$  in a ventilated air interlayer of the ventilated facade, with the wind flow on the windward side of the building.

#### References

- [1] Lokoshchenko M, Elansky N, Trifanova A 2014 *Influence of meteorological conditions on air pollution in Moscow*, Bulletin of the Russian Academy of Natural Sciences vol 14(1) p 64

- [2] Elanskii N, Lokoshchenko M, Trifanova A, Belikov I, Skorokhod A 2015 *On the content of small gas impurities in the surface layer of the atmosphere above Moscow*, Izvestiya of the Russian Academy of Sciences. Physics of the Atmosphere and Ocean vol 51(1) p 39
- [3] Elanskii N, Lokoshchenko M, Trifanova A, Belikov I, Skorokhod A 2016 *On the limiting levels of air pollution in Moscow*, Bulletin of Moscow University vol 5(4)
- [4] State report 2013 *On the state and on the protection of the environment of the Russian Federation in 2012* (Moscow: The Ministry of Natural Resources of Russia) p 483
- [5] Umnyakova N 2011 *Influence of air pollution of the city on the design of ventilated facades* Bulletin of the Moscow State University of Building Engineers vol 3 p 221
- [6] Pavlushkina Yu, Pavlushkin M 2016 *Cladding ventilated facade and its characteristics*, Young scientist vol 28 p 136
- [7] Timofeev G 2017 *Environmental safety in the system of national Security of the Russian Federation* . Power vol 2 p 69
- [8] Elantseva E, Kostarev S, Sereda T 2015 *Estimation of the background content of priority pollutants in the ambient air at the pre-project stage of the construction of the solid waste disposal facility*, Modern problems of science and education vol 2 p 2
- [9] Isaev S, Vatin N, Gouvernyuk S, Gagarin V, Basok B, Zhukova Yu *Reduction of the drag of an energy-efficient high-altitude structure by means of a throttling effect with the selection of wind energy*, Thermophysics of High Temperatures, Publishing House Nauka p 53(6) p 918
- [10] Retter E 1984 *Architectural and construction aerodynamics* (Moscow: Stroyizdat) p 293
- [11] Umnyakova N 2017 *Calculation of air temperature in the ventilated air layer of cladding façade taking into account the wind*, BST vol 6 p 36
- [12] Pirumov A 1974 *Debris from the air* (Moscow: Stroyizdat) p 296
- [13] Green H, Lane N 1972 *Aerosols - dust, smoke and fog* (Moscow: Chemistry) p 482
- [14] Sorokin N, Taliev V 1978 *Aspiration of machines and pneumatic transport in the textile industry* (Moscow: Light industry) p 215
- [15] Istomin V, Kutsenogiy K 2010 *A technique for determining the aerodynamic diameter of aerosol particles of a complex geometric shape in the Reynolds number range from 0.1 to 6.0*, Thermophysics and aerodynamics vol 17(1) p 77
- [16] Fuks N 1961 *Advances in the mechanics of aerosols* (Moscow: Publishing house of the USSR Academy of Sciences) p 161
- [17] Umnyakova N 2011 *Thermal protective properties of cladding operated facade structures*, Housing construction vol 2 p 2
- [18] Umnyakova N 2013 *Sorption of water vapor mineral wool insulation in operated ventilated facades* Housing construction vol 3 p 50