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Effect of rustication joints on air mode in ventilated facade

Влияние рустов на воздушный режим в вентилируемом фасаде

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Key words: ventilated facade; enclosing structure; heat-gravitational motion; average velocity; ventilated air gap; energy efficiency

Ключевые слова: вентилируемый фасад; ограждающие конструкции; термогравитационное движение воздуха; средняя скорость; воздушный зазор; энергоэффективность

Abstract. Ventilated facade is a contemporary facade system that is popular due to its energy efficiency. There are different configurations of the façade systems, among other things, various spacing between rustication joints. Cold air penetrates through them, thereby, influences air circulation. In this paper, theoretical estimate of air flow data is carried out by applying Boussinesq's hydrostatic model. Research of an impact of rustication joints interval on air flow data via physical simulation is performed for different façade configurations. Based on the results obtained, the most optimal solution is the design of a ventilated facade without rustication joints, or with the largest joints interval value.

Аннотация. Двойные вентилируемые фасады – это современные фасадные системы, ставшие популярными благодаря своей энергоэффективности. Существуют различные конфигурации данных систем, в том числе могут варьироваться расстояния между рустами. Проникая через них, холодный воздух оказывает влияние на циркуляцию воздуха. В статье представлен теоретический расчет парамаетров воздушного потока с помощью гидростатической модели Буссинеска. Также для различных конфигураций фасада проведено физическое моделирование для оценки влияния расстояния между рустами на параметры воздушного потока. Основываясь на полученных результатах, можно сказать, что оптимальным конструктивным решением вентилируемого фасада является отсутствие рустов, либо максимальное расстояние между ними.

Introduction

Nowadays ventilated facades (VF) are widely used due to their energy efficiency excellence in comparison with other enclosing structures. VF is a multilayer structure, consisted of wall itself, insulation layer, air gap and cladding, bonded with metal framing. This structure diminishes heat loss of the building, therefore increasing its energy efficiency. One of the basic work principle of the ventilated facades is excess moisture removal from the insulation. This effect occurs due to air gap, where heated air along the hot surface come to the output of the structure.

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There are openings between tiles of the cladding in real structures of the VF – rustication joints. Cold air penetrates through these openings. Nowadays impact of rustication joints on air mode is under investigated, in spite of the fact that presence of rustication joints may cause air circulation change.

Analysis of ventilated facades has started recently. Fundamental understanding of the work's principles is of importance for proper operation of the façade and energy efficiency maximizing. Thereby, a lot of scientists research these constructions [2–3, 6, 15–18]. Several researches are focused on the influence of various factors on the operation of ventilated facades [7–8; 19–20]. Also, since ventilated facades are an energy-efficient design, they had been used in smart buildings [10–14].

Feasibility study on a usage of numerical model for analyzing the performance of VF was carried out by F. Peci Lópeza, R.L. Jensenb, P. Heiselbergb, M. Ruiz de Adana Santiagoa [1]. They have performed numerical and physical simulation of natural ventilation inside the façade and approved usage of numerical model subject to certain parameters.

Nizovtsev M.I., Belyi V.T., Sterlygov A.N. [5] have carried out a numerical simulation of thermal resistances of heat-insulating panels. Basing on calculations, they suggested facades, thermally insulated with ventilated channels, for providing low moisture content and good heat-insulating properties of the walls.

In modern construction using of ventilated facades as an enclosure structure has increased. This type of systems is characterized by high heat-shielding properties in comparison with other popular types of walling. Consequently, the question of the optimal ventilated facades construction becomes relevant.

The aim of this study is an experimental evaluation of the impact of rustication joints interval on velocity in the air gap of ventilated façade. To accomplish this aim, such challenges should be figured out:

1. To perform theoretical estimate of airflow data in the vertical channel.
2. To perform physical simulation of heat-gravitational motion in the air gap in different cases of rustication joints interval value.
3. To suggest recommendations for choosing the appropriate spacing between rustication joints.

Theoretical estimate

There are different cladding types of the ventilated facades:

- porcelain stoneware;
- composite tiles;
- aluminum tiles;
- fiber cement tiles;
- terracotta tiles and others.

Most commonly, spacing (rustication joints) between tiles take place in every type of cladding. Firstly, rustication joints are necessary for reasons of design – for thermal distortion compensation. It helps to prevent crack initiation at the façade. However, rustication joints can markedly affect on airflow data in the vertical channel.

The most significant flow characteristic for determination of façade's energy efficiency is an average velocity. In case of heat-gravitational air mode average velocity can be estimated by applying Boussinesq's hydrostatic model [4]:

$$v = \varphi \sqrt{\frac{T_h - T_c}{T_h}} \sqrt{2gL}\,, \qquad (1)$$

where: φ – velocity coefficient,

T_h – temperature of the heated surface,

T_c – temperature of the cold surface,

L – length of the air gap.

$$\varphi = \frac{1}{\sqrt{1 + \lambda \frac{L}{h} + \zeta}}, \qquad (2)$$

where: λ – pipe friction number,

ζ – coefficient of local head loss.

For the narrow channels: h – width of the air gap.

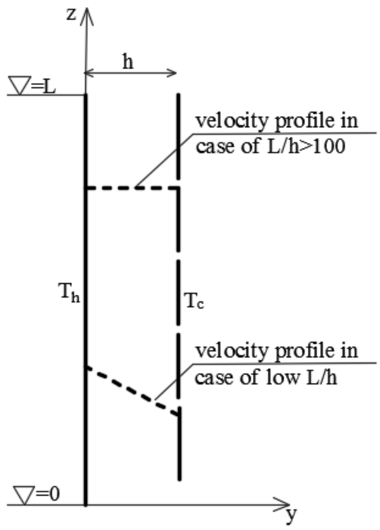

Figure 1. Spacing parameters and velocity

Wide channels perform as a vertical plane in unlimited space. That is why for calculation of the head loss it is relevant to substitute h with the boundary layer thickness of buoyant force δ. Channel is considered to be narrow if h/δ=O(1). In case of h>>δ, channel is wide, and boundary layer does not fulfill the width of the channel.

Basing on Eckert's theory:

$$\delta = \sqrt[4]{\frac{4\nu^2 z}{g}} \le \sqrt[4]{\frac{4\nu^2 L}{g}}, \qquad (3)$$

where: ν – gas viscosity,

z –vertical coordinate, z≤L

Therefore, φ can be calculated by the following formula:

$$\varphi = \frac{1}{\sqrt{1 + \lambda \frac{L}{\delta} + \zeta}}, \qquad (4)$$

For the air gap with rustication joints, open input and output in case of low value of L/h velocity attains its maximum alongside the hot surface. Approximating to the cold surface, velocity value decreases (Fig.1.) In case of L/h>100 velocity profile straightens over the width of the channel.

Physical simulation

Heat-gravitational motion can be simulated on the physical model of the vertical air gap, that is represented an installation with height of 2050 mm and width of 600 mm, and air gap varying from 20 to 300 mm. One of the sides of the installation is fixed, faced with the aluminum sheets and has 3 heat sources (3 heating elements, with 1 kW of power per unit) for imitation of uniformly heated building's wall. Second side is simulating cladding, and it is unheated and movable. It allows varying the width of air gap.

This side consists of wooden sheets with the height of 300 mm, divided by the spacing of 5 mm, simulating rustication joints.

To change spacing between rustication joints, some of them are sealed. Air access from beneath can be modified via special attachments, air outlet from the top is free. Visual appearance of the installation is presented below (Fig.2).

Figure 2. Installation for physical simulation

Series of experiments for studying impact of rustication joints interval on airflow data was carried out in different configurations:

1. Absence of rustication joints – all joints are sealed (imitation of the ideal channel);
2. Value of the interval is equal to 0.6 m – some rustication joints are sealed;
3. Value of the interval is equal to 0.3 m – all rustication joints are opened for air access.

Installation diagram is shown. (Fig.3.)

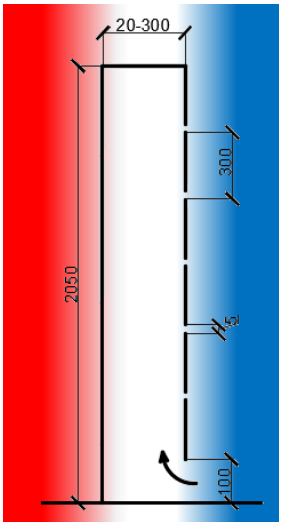

Figure 3. Installation diagram

In the first case width of the gap was constant and was equal to 100 mm for every configuration. Velocity was measured at different height marks.

In the second case air gap width was varying from 20 to 300 mm and all measures were taken at one height mark.

For all cases:

- Height of the air layer was constant and equal to 2050 mm;
- Fixed side was uniformly heated over the length;

- Air access from beneath is provided by the gap of 100 mm – open input.

All experiment were carried out with the use of thermal anemometer (Fig.4). Thermal anemometer is designed for measurement of temperature and velocity of an air flow. Operation principle is based upon the measurement of characteristics of platinum actuators.

Figure 4. Thermal anemometer

Device's minimum velocity in the range of measurement is equal to 0.1 m/s, instrumental uncertainty: for velocity ± 5 %, for temperature ± 0.2 °C.

Temperature in the lab was equal 21.9 °C, temperature of the heated surface was equal to 43.6 °C.

Average velocity of the air flow was measured in the vertical channel for every case and configuration of the installation, and was in the range of 0–0.5 m/s.

Variables for data processing were:

- Vertical coordinate Z and average velocity v;
- The ratio L/h and Froude number $v/(gL)^{0,5}$.

By means of calculated dependences, that were presented above, it is possible to calculate velocity φ and local head loss ξ coefficients. Pipe friction coefficient λ for the ideal channel was also calculated.

Results

Obtained results for the first case are presented in the Figure 5, for the second case – in the Figures 6–10.

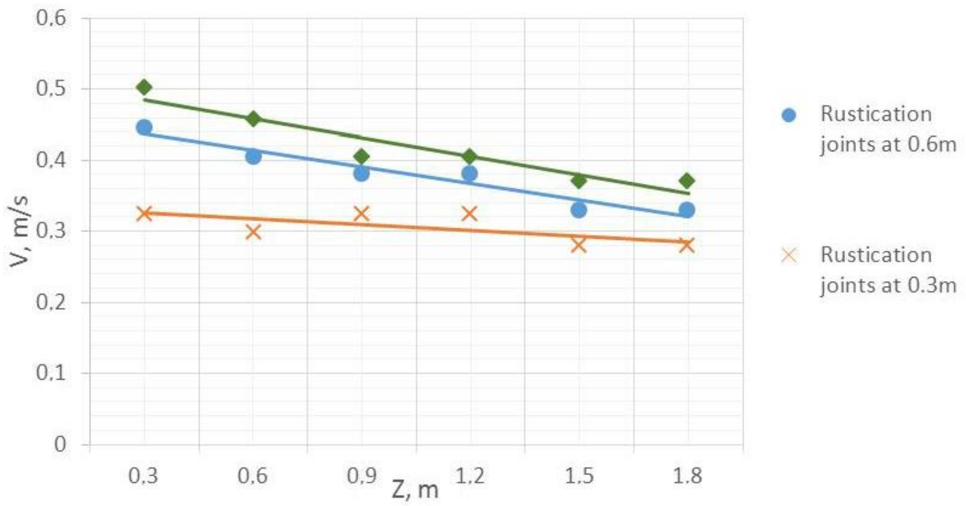

Figure 5. Velocity distribution on vertical coordinate Z

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In Figure 5 it can be seen that velocity of the air flow attains its maximum in the ideal channel, whose movable side is continuous (absence of rustication joints). In case of presented rustication joints with the interval value equal to 0.6 m air velocity decreases in average at 9 %. Rustication joints at 0.3 m diminish velocity at 19 % more. Velocity contrast is well demonstrated at low height marks.

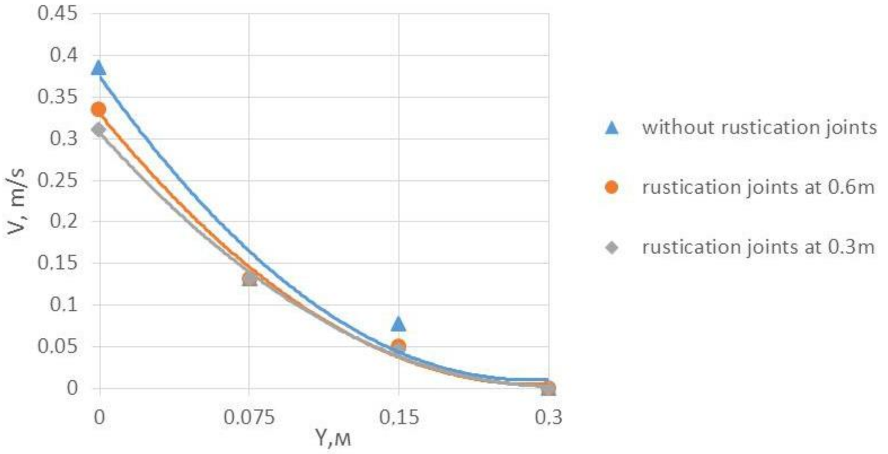

Figure 6. Velocity profile across the width of the air gap at 0.3 m

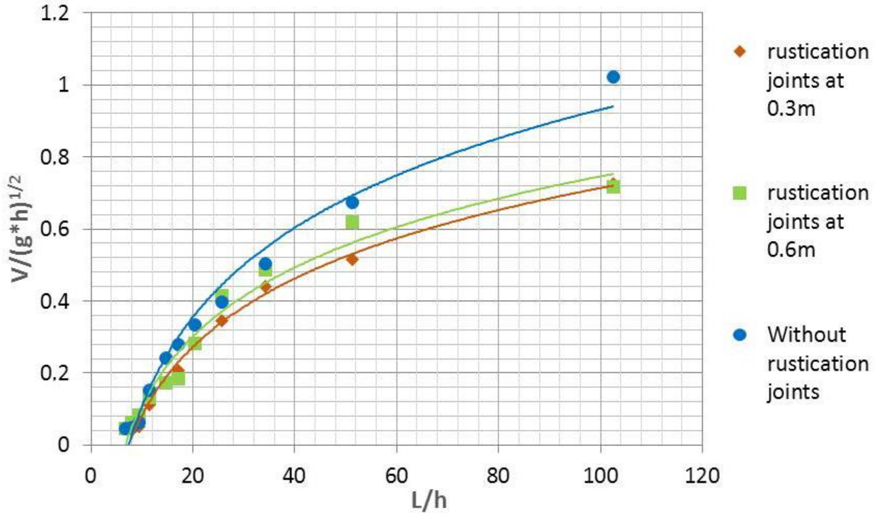

Figure 7. Dependence of Froude number on geometric parameters of the air gap

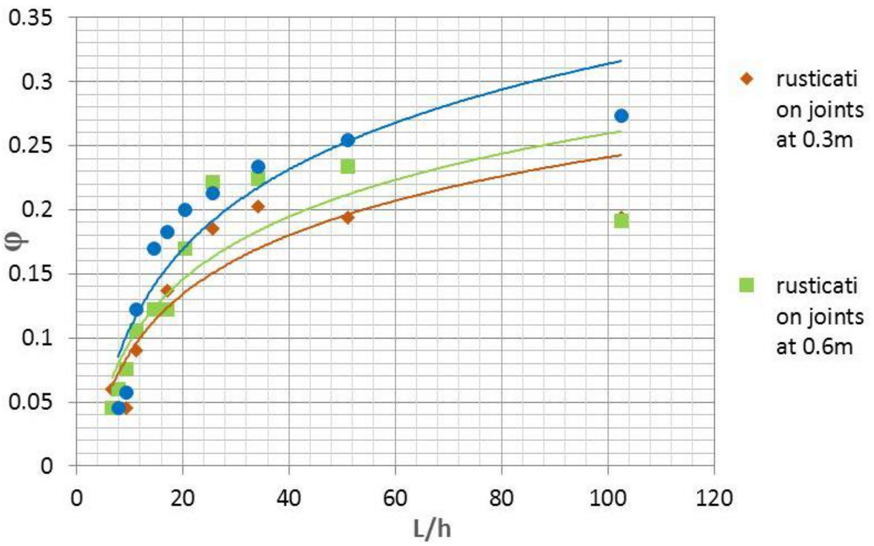

Figure 8. Dependence of velocity coefficient φ on geometric parameters of the air gap

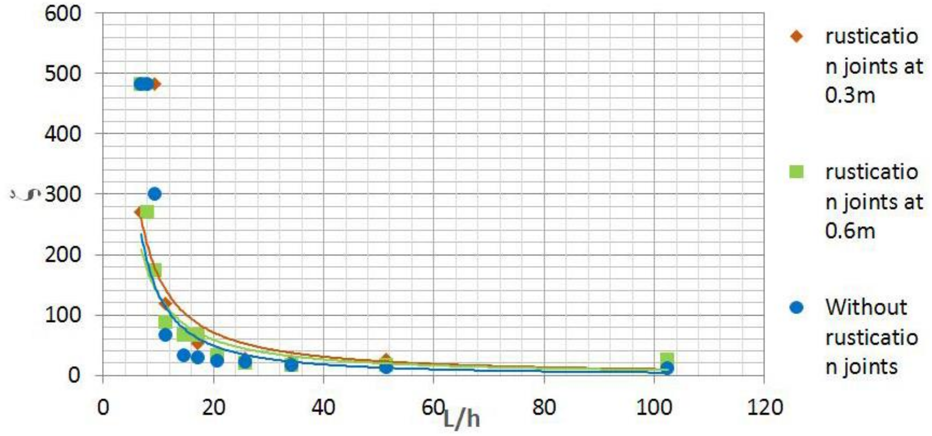

Figure 9. Dependence of local head loss coefficient ζ on geometric parameters of the air gap

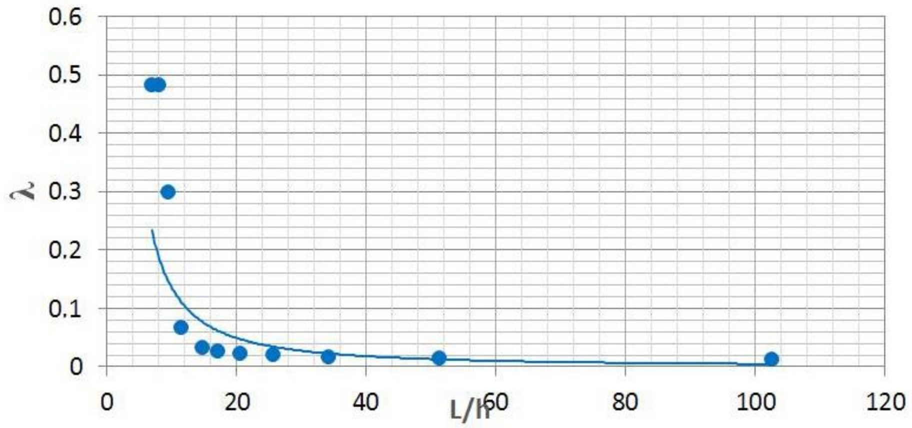

Figure 10. Dependence of pipe friction coefficient λ on geometric parameters of the air gap without rustication joints

In these dependences for the second case it can be seen that:

1. Velocity attaints its maximum alongside the hot surface, and there is no air circulation along the cold surface. Besides, for the width of the gap of 0.3 m impact of rustication joints interval on velocity value is precious little (Fig. 6). When the width of the air gap satisfies a condition $h \geq 0.22$ m, then velocity goes below 0.1 m/s, that is lower than instrumental uncertainty. In this case, experimental results are unreliable.
2. Aside from the width of air gap (h), average velocity, as in the first case, is lower at frequent rustication joints (Fig. 7).
3. Frequently pitched rustication joints diminish velocity coefficient (Fig. 8) and increase local hydraulic resistance (Fig. 9).

Discussion

In this study, we have performed physical simulation of heat-gravitational motion inside of the air gap at different spacing between rustication joints.

Research of the influence of outlet geometry on the airflow and temperatures in the ventilated façade was carried out by E. Šagát, L. Matějka, J. Pěnčík in their paper [16]. This experiment was performed for open joint ventilated façade. A. Fallahi, F. Haghighat, H. Elsadi suggested design approach [6], that involves the integration of passive thermal mass technique. These researches were carried out for the ventilated façade without considering interval value. In our study, we have ascertained, that different spacing between rustication joints also influences ventilated façade performance.

All-in-all results suggest, that interval influences on airflow data. Frequently pitched rustication joints diminish velocity coefficient and increase local hydraulic resistance regardless of width of the air gap. Apparently, cold air penetrates through them, afterwards it descends, thereby decreasing average velocity.

It should be noted, that all measurements were taken without weather impact. Impact of rustication joints on airflow data will increase, in case of wind correction.

Conclusions

1. Average velocity of the air flow depends on spacing between rustication joints and on air gap width.
2. Obtained results show, that velocity attains its maximum in the ideal channel without rustication joints. As the interval is reduced, average velocity decreases because of cold air penetrating. It leads to heat-gravitational motion inversion.
3. The most appropriate design is the façade without rustication joints, or facade with the maximal spacing between them. In comparison with current configurations, the most appropriate interval is equal to 0.6 m.

References

1. Peci López F., Jensen R.L., Heiselberg P., Ruiz de Adana Santiago M. Experimental analysis and model validation of an opaque ventilated façade. *Building and Environment.* 2012. Vol. 56. Pp. 265–275.
2. Patania F., Gagliano A., Nocera F., Ferlito A., Galesi A. Thermofluid-dynamic analysis of ventilated facades. *Energy and Buildings.* 2010. Vol. 42. Pp. 1148–1155.
3. Suareza C., Joubertb P., Molinaa J.L., Sánchez F.J. Heat transfer and mass flow correlations for ventilated facades. *Energy and Buildings.* 2011. Vol. 43. Pp. 3696–3703.
4. Borovkov, V.M., Zysin, L.V., Sergeev, V.V. Itogi i nauchno-tekhnicheskiye problemy ispol'zovaniya rastitel'noy biomassy i organosoderzhashchikh otkhodov v energetike [The totals and technological problems of usage of vegetative biomass and organic waste in power engineering]. *Izvestiya Akademii Nauk. Energetika.* 2002. No. (6). Pp. 13–24 (rus)
5. Nizovtsev M.I., Belyi V.T., Sterlygov A.N. The facade system with ventilated channels for thermal insulation of newly constructed and renovated buildings. *Energy and Buildings.* 2014. Vol. 75. Pp. 60–69.
6. Fallahi A., Haghighat F., Elsadi H. Energy performance assessment of double-skin facade with thermal mass. *Energy and Buildings.* 2010. Vol. 42. Pp. 1499–1509.
7. Borodinecs A., Nazarova J., Zajacs A., Malyshev A., Pronin V. Specifics of building envelope air leakage problems and airtightness measurements. *MATEC Web of Conferences.* 2016. Vol. 73. 02020.
8. Gaujena B., Borodinecs A., Zemitis J., Prozuments A. Influence of building envelope thermal mass on heating design temperature. *Materials Science and Engineering*. 2015. Vol. 96. 012031.
9. Sergeev V.V., Aleshina A.S. Gas-generator combined-cycle plant equipped with a high-head heat-recovery boiler. *Thermal Engineering.* 2011. No. 58(3). Pp. 268–270.
10. Zajacs A., Zemitis J., Tihomirova K., Borodinecs A. Concept of smart city: first experience from city of Riga. *Journal of Sustainable architecture and Civil Engineering.* 2014. No. 2(7). Pp. 54–59.
11. Kaklauskas A. Passive House Model for Quantitative and Qualitative Analyses and Its Intelligent System. *Energy and Buildings.* 2012. Vol. 50. Pp. 7–18.
12. Gamayunova O., Vatin N. The role of the state and citizens to improve energy efficiency. *Applied Mechanics and Materials.* 2015. Vols. 725–726. Pp. 1493–1498.
13. Perlova E., Karpova S., Rakova X.M., Bondarenko E., Platonova M., Gorshkov A. The architectural concept of the building with low energy consumption. *Applied*

Литература

1. Peci López F., Jensen R.L., Heiselberg P., Ruiz de Adana Santiago M. Experimental analysis and model validation of an opaque ventilated facade // Building and Environment. 2012. Vol. 56. Pp. 265–275.
2. Patania F., Gagliano A., Nocera F., Ferlito A., Galesi A. Thermofluid-dynamic analysis of ventilated facades // Energy and Buildings. 2010. Vol. 42. Pp. 1148–1155.
3. Suareza C., Joubertb P., Molinaa J.L., Sánchez F.J. Heat transfer and mass flow correlations for ventilated facades // Energy and Buildings. 2011. Vol. 43. Pp. 3696–3703.
4. Боровков В.М., Зысин Л.В., Сергеев В.В. Итоги и научно-технические проблемы использования растительной биомассы и органосодержащих отходов в энергетике // Известия АН. Энергетика. 2002. № 6. С. 13–24.
5. Nizovtsev M.I., Belyi V.T., Sterlygov A.N. The facade system with ventilated channels for thermal insulation of newly constructed and renovated buildings // Energy and Buildings. 2014. Vol. 75. Pp. 60–69.
6. Fallahi A., Haghighat F., Elsadi H. Energy performance assessment of double-skin facade with thermal mass // Energy and Buildings. 2010. Vol. 42. Pp. 1499–1509.
7. Borodinecs A., Nazarova J., Zajacs A., Malyshev A., Pronin V. Specifics of building envelope air leakage problems and airtightness measurements // MATEC Web of Conferences. 2016. Vol. 73. 02020.
8. Gaujena B., Borodinecs A., Zemitis J., Prozuments A. Influence of building envelope thermal mass on heating design temperature // Materials Science and Engineering. 2015. Vol. 96. 012031.
9. Sergeev V.V., Aleshina A.S. Gas-generator combined-cycle plant equipped with a high-head heat-recovery boiler // Thermal Engineering. 2011. № 58(3). Pp. 268–270.
10. Zajacs A., Zemitis J., Tihomirova K., Borodinecs A. Concept of smart city: first experience from city of Riga // Journal of Sustainable Architecture and Civil Engineering. 2014. № 2(7). Pp. 54–59.
11. Kaklauskas A. Passive house model for quantitative and qualitative analyses and its intelligent system // Energy and Buildings. 2012. Vol. 50. Pp. 7–18.
12. Gamayunova O., Vatin N. The role of the state and citizens to improve energy efficiency // Applied Mechanics and Materials. 2015. Vols. 725–726. Pp. 1493–1498.
13. Perlova E., Karpova S., Rakova X.M., Bondarenko E., Platonova M., Gorshkov A. The architectural concept of the building with low energy consumption // Applied Mechanics and Materials. 2015. Vols. 725–726. Pp 1580–1588.
14. Harmati N., Jakšić Ž., Vatin N. Heat balance method

Mechanics and Materials. 2015 Vols. 725–726. Pp. 1580–1588.
14. Harmati N., Jakšić Ž., Vatin N., Heat balance method application in building energy performance simulation. *Applied Mechanics and Materials.* 2015. Vols. 725–726. Pp. 1572–1579.
15. Šagát E., Matějka L. Experimental assessment of the influence of wind speed on the airflow and temperatures in the open joint ventilated façade cavity. *Applied Mechanics and Materials.* 2016. Vol. 835. Pp. 444–449.
16. Šagát E., Matějka L., Pěnčík J. Experimental assessment of the influence of outlet geometry on the airflow and temperatures in the ventilated façade cavity. *Applied Mechanics and Materials.* 2016. Vol. 824. Pp. 641–648.
17. Saari J., Sermyagina E., Kaikko J., Vakkilainen E., Sergeev V. Integration of hydrothermal carbonization and a CHP plant: Part 2 – operational and economic analysis. *Energy.* 2016. No. 113. Pp. 574–585.
18. Ryabukhina S., Simankina T., Koshkarova M., Sokolovskii N., Ryzhkov O. Combined thermal insulating module of mounted vented facades. *MATEC Web of Conferences*. 2016. Vol. 73. 02005.
19. Kornienko S.V. Testing of calculation method of the enclosing structures temperature-humidity conditions on results of indoor climate in-situ measurements. *Magazine of Civil Engineering.* 2012. No. 2. Pp. 18–23. (rus)
20. Grinfeldi G.I., Gorshkov A.S., Vatin N.I. Tests results strength and thermophysical properties of aerated concrete block wall samples with the use of polyurethane adhesive. *Advanced Materials Research.* 2014. Vols. 941–944. Pp. 786–790.

application in building energy performance simulation // Applied Mechanics and Materials. 2015. Vols. 725–726. Pp. 1572–1579.
15. Šagát E., Matějka L. Experimental assessment of the influence of wind speed on the airflow and temperatures in the open joint ventilated façade cavity // Applied Mechanics and Materials. 2016. Vol. 835. Pp. 444–449.
16. Šagát E., Matějka L., Pěnčík J. Experimental assessment of the influence of outlet geometry on the airflow and temperatures in the ventilated façade cavity // Applied Mechanics and Materials. 2016. Vol. 824. Pp. 641–648.
17. Saari J., Sermyagina E., Kaikko J., Vakkilainen E., Sergeev, V. Integration of hydrothermal carbonization and a CHP plant: Part 2 – operational and economic analysis // Energy. 2016. № 113. Pp. 574–585
18. Ryabukhina S., Simankina T., Koshkarova M., Sokolovskii N., Ryzhkov O. Combined thermal insulating module of mounted vented facades // MATEC Web of Conferences. 2016. Vol. 73. 02005.
19. Корниенко С.В. Тестирование метода расчета температурно-влажностного режима ограждающих конструкций на результатах натурных измерений параметров микроклимата помещений // Инженерно-строительный журнал. 2012. № 2(28). С. 18–23.
20. Grinfeldi G.I., Gorshkov A.S., Vatin N.I. Tests results strength and thermophysical properties of aerated concrete block wall samples with the use of polyurethane adhesive. Advanced Materials Research. 2014. Vols. 941–944. Pp. 786–790.

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