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DEFINITION OF THE OPERATIONAL EFFICIENCY OF VENTILATED FACADES

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Annotation. ***Formulation of the problem.*** The aim of work is the choice of optimal technological solutions to determine operational efficiency of ventilated facades, while reducing the complexity and cost of operation of the system. Under the operational efficiency of hinged technological insulation systems adopted in the maintenance-free period of operation, its main figure are preserved, which are due to regulations and which are functionality capable. ***Methods.*** To research the influence of technological factors on the design features of the ventilated facade has developed a special technique of laboratory research. For the analysis of research results used in the theory of experimentally-statistical modeling. ***Results.*** Given the way the selection of optimal technology solutions unit of ventilated facades on the basis of experimental and statistical modeling. The main constructional and technological parameters of the display device of ventilated facades and the size of the air gap were determined. It is shown that ensuring operational efficiency of ventilated facades for 27 years is possible with the use of a dense insulation (130 kg/m3).It is possible to significantly reduce the complexity of operating costs and the cost of the device suspended facades. ***Scientific novelty.*** The optimum constructional and technological parameters of ventilated facades that provide operational efficiency. ***Practical significance.*** The total cost of the device and operation of hinged ventilated facade system, term of conditional operation 25 years, the application of insulation density 150 kg/m^3 more than 2 times more economical than a similar facade, but with the density of insulation 80 kg/m^3.

Keywords: *hinged ventilated façades, operational efficiency, mineral wool insulation, experimental and statistical models, fire safety*

ВИЗНАЧЕННЯ ЕКСПЛУАТАЦІЙНОЇ ЕФЕКТИВНОСТІ НАВІСНИХ ВЕНТИЛЬОВАНИХ ФАСАДІВ

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Анотація. ***Постановка проблеми*** – вибір оптимальних технологічних рішень для визначення експлуатаційної ефективності вентильованих фасадів за одночасного зменшення трудомісткості і вартості експлуатації системи. За експлуатаційну ефективність навісних технологічних систем теплоізоляції в роботі прийнято безремонтний період експлуатації, при якому зберігаються її основні показники, зумовлені нормативними документами, що здатні забезпечити функціональне призначення. ***Методика***. Для дослідження впливу технологічних факторів на конструктивні особливості вентильованого фасаду розроблено спеціальну методику лабораторних досліджень. Для аналізу результатів досліджень використано теорію експериментально-статистичного моделювання. ***Результати.*** Наведено шляхи вибору оптимальних технологічних рішень улаштування навісних вентильованих фасадів на основі експериментально-статистичного моделювання. Визначено основні конструкційно-технологічні параметри влаштування екрана навісного вентильованого фасаду та розмір повітряного прошарку. Показано, що забезпечення експлуатаційної ефективності вентильованих фасадів протягом 27 років можливе за умови використання щільного утеплювача (>130 кг/м^3). При цьому можливо значно скоротити трудомісткість експлуатаційних витрат та вартість улаштування навісних фасадів. ***Наукова новизна.*** Визначено оптимальні конструкційно-технологічні параметри навісного вентильованого фасаду, що забезпечують експлуатаційну ефективність. ***Практична цінність.*** Загальна вартість улаштування і експлуатації навісної вентильованої фасадної системи, при терміні експлуатації умовних 25 років, за умови застосування утеплювача щільністю 150 кг/м^3 більш ніж удвічі економніше аналогічного фасаду, але із щільністю утеплювача 80 кг/м^3.

Ключові слова: *навісні вентильовані фасади; експлуатаційна ефективність; мінераловатний утеплювач; експериментально-статистичні моделі; пожежобезпека*

ОПРЕДЕЛЕНИЕ ЭКСПЛУАТАЦИОННОЙ ЭФФЕКТИВНОСТИ НАВЕСНЫХ ВЕНТИЛИРОВАННЫХ ФАСАДОВ

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Аннотация. ***Постановка проблемы*** – является выбор оптимальных технологических решений для определения эксплуатационной эффективности вентилируемых фасадов при одновременном уменьшении трудоемкости и стоимости эксплуатации системы. Под эксплуатационной эффективностью навесных технологических систем теплоизоляции в работе принят безремонтный период эксплуатации, при котором сохраняются ее основные показатели, которые обусловлены нормативными документами, и которые способны обеспечить функциональное назначение. ***Методика.*** Для исследования влияния технологических факторов на конструктивные особенности вентилируемого фасада разработана специальная методика лабораторных исследований. Для анализа результатов исследований использована теория экспериментально-статистического моделирования. ***Результаты.*** Приведены пути выбора оптимальных технологических решений устройства навесных вентилируемых фасадов на основе экспериментально-статистического моделирования. Определены основные конструкционно-технологические параметры устройства экрана навесного вентилируемого фасада и размер воздушной прослойки. Показано, что обеспечение эксплуатационной эффективности вентилируемых фасадов на протяжении 27 лет возможно при использовании плотного утеплителя (>130 кг/м^3). При этом возможно значительно сократить трудоемкость эксплуатационных расходов и стоимость устройства навесных фасадов. ***Научная новизна.*** Определены оптимальные конструкционно-технологические параметры навесного вентилируемого фасада, которые обеспечивают эксплуатационную эффективность. ***Практическая значимость.*** Общая стоимость устройства и эксплуатации навесной вентилируемой фасадной системы, при сроке эксплуатации условных 25 лет, при применении утеплителя плотностью 150 кг/м^3 более чем в 2 раза экономичнее аналогичного фасада, но с плотностью утеплителя 80 кг/м^3.

Ключевые слова: *навесные вентилируемые фасады; эксплуатационная эффективность; минераловатный утеплитель; экспериментально-статистические модели; пожаробезопасность*

Introduction. During the last decades the exterior walls design and facade insulation utilization of industrial elements with a ventilated air layers an outer insulation enclosing structures of residential and public buildings are used in the construction industry in Ukraine. The name of hinged ventilated facades (HVF) is often used in construction practice [10, 12, 13, 15]. It should be noted that the two variants of systems are most widely used for thermal insulation of high-rise buildings. The first variant of ventilated facade construction provides a continuous system, which consists of a facing layer, generally made of composite panels with flammability class of G1, G2 without openings in between, and the air motion speed in substructure space up to 2 m/s [9, 11]. Ceramic granite slabs are often used at the second variant. In such systems, the design provides for the opening between the facing panels. Air speed in the substructure space, depending on the height, can be up to 12 m/s and higher, particularly in the coastal zone [1, 2, 9].

The primary requirement for the construction of facade insulation is to ensure the operational efficiency during the normative period of 25 years [8]. Under the operational efficiency of hinged thermal insulation systems in this study the exploitation without repair is accepted. The efficiency is shown by main parameters, determined due to normative documents, by which a functional purpose can be ensured.

One of the components of construction, which determines period of effective exploitation system of thermal insulation is the mineral wool insulation.

Constructive and technological structure features of the second variant may result in moistening of insulation caused by slanting rain the gaps between the facing plates. Mineral wool insulation is inclined to the destruction due to wind emission of fibers from the surface. It is caused by its fibrous structure.

One way to prevent this process is to find the optimal constructional and technological solutions of arranging the screen and securing the windproof and waterproof membranes on the surface of insulation in the air space. Unfortunately, using of these membranes increases a fire hazard [6, 7, 14]. This is confirmed by many fires on the facades of high-rise buildings, both in our country and beyond its borders, for example in the cities of Odessa, Kiev, Moscow, Istanbul, and others.

The construction and exploitation of ventilated facades are characterized by significant technical and economic expenses due to the use of high cost components.

Thus, itis significant and needed to select optimal technological solutions to ensure the operational efficiency of ventilated facades without a windproof membrane on basis of research of facing layer constructive solutions and optimization of its assembly.

The aim of research is the selection of optimal technological decisions to ensure operational efficiency of ventilated facades while decreasing labor input and operating cost of the thermal insulation system.

Results of research. The research was conducted in three stages. On the first stage of the research the task was to select the constructional and technological solutions in order to reduce the impact of the slanting rain on the mineral wool insulation, specifically the amount of moisture which is trapped in the insulation ($Y_{moisture}$, g).

This is achieved using an experimental statistical modelling (ESM) by optimizing the slits sizes, thickness of facing plates and the size of the air gap. This mathematical method can considerably reduce the amount of experiments. Factors and their varying levels are given:

Factors climatic:

x_1 – intensity of rain (6 ± 4), *mm/min;*

x_2 – rain tilt angle (60 ± 30), *deg*;

Factors structurally-technological:

x_3 – thickness of ventilated gap (100 ± 60), *mm*;

x_4 – size of the clearance between the screen plates (7 ± 3), *mm;*

x_5 – thickness of the facing screen elements (9 ± 3), *mm;*

x_6 – density of mineral wool insulation (80 ± 50), kg/m^3.

The mathematical processing of the experimental results is performed in the program «Compex-2009v1.1». This includes regression analysis, assessment of the importance of the model coefficients and the adequacy of the obtained model [4, 5].The regression dependence of moisture mass change in the mineral wool insulation was obtained after performing these actions. This dependence adequately describes the impact of climate, construction and technological factors on the amount of moisture trapped in the insulation through technological holes (1). The experimental error was (Ts) e = 0.515:

$$
\begin{array}{lllllllll}
Y_{hum.} = 8.55 & +3.95x_1 & & & & & & +1.37x_1^2 & \\
 & +5.21x_2 & * & & & & & +0.93x_2^2 & \\
 & +0.95x_3 & +0.47x_1x_3 & +0.79x_2x_3 & & & & * & \\
 & +3.55x_4 & +0.78x_1x_4 & +0.65x_2x_4 & +0.29x_3x_4 & & & * & (1) \\
 & -1.19x_5 & -0.39x_1x_5 & * & -0.43x_3x_5 & * & & * & \\
 & -0.96x_6 & * & -0.55x_2x_6 & -0.45x_3x_6 & -0.66x_4x_6 & -0.55x_5x_6 & +1.01x_6^2 &
\end{array}
$$

Based on the obtained mathematical model, the following graphs of extreme value function were constructed (Fig. 1).Graphical analysis of the mathematical model is presented in the form of single-factor dependencies. They present there impact of each factor on the amount of moisture trapped in mineral wool insulation on minimum and maximum values of index zones.

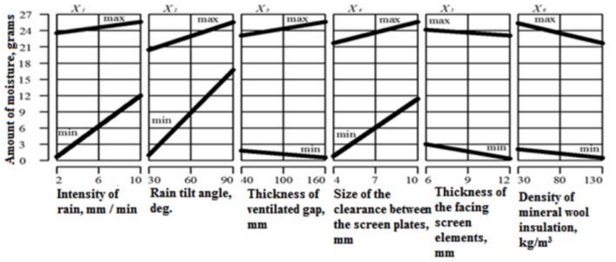

Figure 1. Single-factor depending on influence of studied factors on the amount of moisture which falls to mineral wool insulation

Figure 1 shows that character of influence of all the six factors on studied parameters are different. This is indicated by curve slope angle at each of the graphs. Rain intensity, rain deflection angle, size of ventilated gap and value of deformation clearance provide a directly proportional effect on the amount of moisture that gets on mineral wool insulation at the maximums zone of index (top lines on the graphs). In its turn, the thickness of screen's slabs and the density of the mineral wool insulation are inversely proportional to effect on studied parameters. Index of intensity was negligible in investigation of impact factors on the maximum values of moisture. Each of factors can change its value by 5-10%.

It is necessary to analyze the amount of moisture that penetrated the mineral wool insulation in the zones of minimum values index (it is the lower line on the graph) to be able to choose optimal constructional and technological decisions. First and foremost this analysis of climatic factors x_1 and x_2 has shown that even with insignificant index values, it is possible to get moisture on insulation (1-1,5 gr.). It should be noted, that it is almost impossible to avoid the negative impact of these factors. Therefore, constructional and technological decision factors x_3, x_4, x_5, x_6 are the most important.

In the analysis of these factors, it is needed to observe the following constructional and technological parameters to obtain the minimum values of moisture falling on mineral wool insulation.

Specifically, the distance of the ventilated gap should be 80-100 mm (larger distance increases the weight of construction);size of slits between screen plates - 4-6 mm (in this case complied with enough air permeability, while the rain drops size is not more than this indicator, and due to the surface tension of water cannot penetrate through joints between the slabs of screen), the thickness of the screen's plate – 6-8 mm (sizes that are used often); the density of mineral wool insulation is essentially independent of previous parameters.

On the basis of optimal constructional and technological parameters of hinged screen construction with air gap, some research was conducted to study emission of mineral wool insulation fibers under the influence of aerodynamic loads. The research conducted by authors demonstrated [3] that ventilated facades systems with paneling of ceramic granite slabs are characterized by emission of fiber mineral insulation of different densities, functioning as thermal insulation layer.

We proved that highest indicator by emission of mineral wool insulation fibers is characterized of low density (30-40 kg/m^3), and the lowest if it density is 130-150 kg/m^3.In the second stage conducted a definition of operational efficiency of hinged ventilated facades with different densities of mineral wool insulation are based on research set out in work [3] for fiber emissions.

Table 1

Results of calculating operational efficiency of the hinged ventilated facades technological systems for second climatic zone of Ukraine

Density of mineral wool insulation, kg/m^3	$R_{primary}$ m^2* K/W	Effectiveness effective E_e, m^2*K/W						
		Term of operation, year						
		1	3	5	7	8	9	27
40	3,395	3,187	2,981	2,528	-	-	-	-
80	3,498	3,321	3,142	3,002	2,900	2,836	2,783	-
150	3,470	3,379	3,248	3,163	3,130	3,047	3,046	2,790

After calculating operational efficiencies of facade systems with mineral wool insulation various densities without a windproof membrane according to the constructive-technological scheme of hinged ventilated facades, for the second climatic zone of Ukraine, such data were obtained (Table 1).

The system of thermal insulation, wherein used mineral wool insulation density 40 kg/m^3 without a windproof membrane keeps its properties for almost 4 years, subject to the application of second climate zone of Ukraine (for example, Odessa), as shown in Table 1.

Therefore, usage mineral wool insulation with density 40 kg/m^3 without a windproof membrane is inadvisable. Resistance to the heat transfer becomes less than the required normative after five years of exploitation. For the city of Odessa, it is 2.8 m^2·K/W.

At the same time, our research showed that the mineral wool insulation with a high density of 150 kg/m^3 does not require any windproof membrane.

We define the minimum required thickness of mineral wool insulation according to the heat engineering calculations and the results of research on weathering, with the same composition of the wall (300 mm thick aerated concrete) for the first climatic zone of Ukraine.

Table 2 shows the results of the calculation the operational efficiency of facade systems with single- and double-layer thermal insulation of different densities.

Table 2

Results of calculating operational efficiency of technology hinged ventilated facades systems for first climatic zone of Ukraine

Density of mineral wool insulation, kg/m^3(Thickness)	$R_{primary}$ m^2*K/W	Effectiveness effective E_e, m^2*K/W						
		Conjectural term of operation, year						
		1	3	5	7	8	9	27
80 (70mm)	3,974	3,797	3,618	3,478	3,376	3,312	3,259	-
80(50mm) +150(20mm)	3,946	3,855	3,724	3,639	3,606	3,523	3,502	3,266

The calculation results demonstrated that thermal insulation system with mineral wool insulation of high density, 150 kg/m^3, is characterized by normative value of heat transfer resistance after 25 years of conditional exploitation.

Thus, at this density of mineral wool insulation system, windproof membrane (such as flammable G2 material) is not needed to increase fire safety and reduce the risks of violation of the culture facade production.

When using mineral wool insulation with a density of 80 kg/m^3 in 25 years of exploitation conventional thermal insulation system does not correspond regulatory requirements. And for such a system, regulatory requirements are maintained for 8-9 years of conditional exploitation.

Therefore, such systems can be recommended to make wind and moisture protective membrane, but only of non-flammable materials (class NG) and especially for ventilated facades of high-rise buildings.

At the third stage of the research, given the results shown in Tables 1 and 2, the calculation of economic indexes was conducted only for systems with mineral wool insulation with a density of 80 and 150 kg/m^3. Performing the calculations in a program complex AVK 5 (3.0.0) and analyzing the results, we obtain the following. The estimated cost of installing 100 m^2 of ventilated facades with mineral wool with a density of 150 kg/m^3 without windproof membrane by 3.4% more expensive than mineral wool with a density of 80 kg/m^3, based on compulsory use of windproof membrane.

Expenses for repair associated with partial or complete replacement of mineral wool insulation, almost identical 57.8% and 56.3% of the cost of installing a new system, respectively.

At almost the same cost of the installation of ventilated facade, with a density of mineral wool insulation 80 kg/m^3 with the windproof membrane than the density of mineral wool insulation 150 kg/m^3 without it. Saving expenditures of labor the second variant is 22 man-hours on 100 m^2 of facade installation. This system completely eliminates a fire hazard due to the absence of the flammable windproof membrane.

According to the research results presented in Table 2 and 3, the repair of facade systems with mineral wool insulation density of 80 kg/m^3 should be carried out every 9 years, while the repair time for density of 150 kg/m^3 in 27 years.

By defining term efficient operation of ventilated facades of 25 years, the cost of installing and operating the system with the average density mineral wool insulation 80 kg/m^3 will be conditionally 138.048 thousand, and at 150 kg/m^3 – 67.241 thousand. That is, a total cost of installation and operation hinged ventilated facade system when using mineral wool insulation density of 150 kg/m^3 more than 2 times economical equivalent of facade, but mineral wool insulation with a density of 80 kg/m^3.

The research proves that the use of mineral wool insulation of low density 30-50 kg /m^3 is inappropriate. The substantiation of the need to use windproof membrane with a degree of flammability (NG) when using mineral wool insulation from 80 to 120 kg /m^3 for extending the period exploitation of maintenance-free, is also confirmed by research of other scientists.

In its turn the use of mineral wool insulation of higher density of 150 kg on m3 and higher ensures operational efficiency of ventilated facades at more than 25 years without installing windproof membrane.

Summary

1. It was found that the minimum moisture on the mineral wool insulation when using a screen facing ceramic granite tiles is achieved when the deformation clearance of 4-6 mm, with a maximum thickness of 6.8 mm screen finishing and size of ventilated layer is 80-100 mm.

2. To enhance the fire safety of ventilated facade is possible to arrange them without windproof membrane. The operational efficiency of insulation mineral wool with density of 150 kg/ m^3 is 27 years old, 80 kg/ m^3 – 9 years, 40 kg/m^3 – 4 years.

3. Installation of ventilated facades without a windproof membrane to reduce their labor content by 22.0 man-hours on 100 m^2 of facade compared with traditional technology with the windproof membrane. When using insulation of mineral wool density 150 kg/m^3 labor content operating costs for conventional 25 years is reduced by 486 man-hours on 100 m^2. The total cost of installation and repair for normative operational period, at a density of mineral wool insulation 150 kg/m^3 is more economical variant, in average doubled.

REFERENCES

1. Ahmeto V.K. *Matematicheskoe modelirovanie zakruchennyx techenij v kombinirovannyx vysotnyx sooruzheniyax* [Mathematical modeling of swirling flows in combined high-rise buildings]. *Fundamental'nye nauki v sovremennom stroitel'stve* [Fundamental sciences in modern construction]. Moskovskij gosudarstvennyj stroitel'nyj universitet [Moscow State University of Civil Engineering]. Moskva, 2008, pp. 41–46. (in Russian).
2. Babij I.N., Menejlyuk I.A., Safonova D.M. and Lavri I.Yu. *Issledovaniya vliyaniya aerodinamicheskix vozdejstvij na texnologicheskie sistemy navesnyx ventiliruemyx fasadov* [Investigations of the aerodynamic effects influence on technological systems of ventilated facades]. *Visnyk Odeskoi derzhavnoi akademii budivnictva ta arxitektury* [Bulletin of Odesa State Academy of Construction and Architecture]. Odesa, 2015, iss. 58, pp. 54–59. (in Russian).
3. Babij I.M. and Menejlyuk I.O. *Vyznachennya emisii volokon mineralovatnoho utepliuvacha v ventilovanykh fasadakh* [Determination of fibers emission of the mineral wool insulation in ventilated facades]. *Suchasni tekhnolohii, materialy i konstruktsii v budivnitstvi* [Modern technologies, materials and structures in construction]. Vinnyts. nats. tekhn. un-t [Vinnytsia Ntional Technical University]. Vinnytsia, 2014, no. 2(17), pp. 26–31. (in Ukrainian).
4. Voznesenskij V.A., Lyashenko T.V. and Ogarkov B.L. *Chislennye metody resheniya stroitel'no-texnologicheskix zadach na EVM* [Numerical methods for construction and technological problems solving on a computer]. Kiev: Vishha shk., 1989, 328 p. (in Russian).
5. Voznesenskij V.A. and Koval'chuk A.F. *Prinyatie reshenij po statisticheskim modelyam* [Decisions making on statistical models]. Moskva: Statistika, 1978, 196 p. (in Russian).
6. Gagarin V.G., Kozlov V.V.,. Lushin K.I. and Pastushkov P.P. *O primenenii vetrogidrozashhitnyx membran v navesnyx fasadnyx sistemax s ventiliruemoj vozdushnoj proslojkoj* [About the wind-protective membranes application of hinged facade systems with a ventilated air gap]. *Nauchno-tehnicheskij vestnik Povolzh'ya* [The scientific-technical bulletin of Povolzh'ya]. 2012, no. 5, pp. 128–131. (in Russian).
7. Gagarin V.G., Guvernyuk S.V. and Lushin K.I *Modelirovanie emissii volokon iz mineralovatnogo uteplitelya navesnoj fasadnoj sistemy s ventiliruemoj proslojkoj* [The fiber emission modeling from the mineral wool insulating of non-restraining cladding with ventilated layer]. *Promyshlennoe i grazhdanskoe stroitel'stvo* [Industrial and Civil Construction]. 2013, no. 9, pp. 27–29. (in Russian).
8. M-vo rehion. rozvytku ta bud-va Ukrainy. *Konstruktsii budinkyv i sporud. Konstruktsii zovnishnikh stin z fasadnoiu teploizoliatsieiu ta oporiadzhenniam industrialnymy elementami z ventilovanym povitrianym prosharkom. Zagalni tekhnichni umovy: DSTU B V.2.6-35:2008, chynnyi z 2009.06.01* [Buildings and structures construction. Construction of the external walls with facade insulations and industrial elements with ventilated

layer. General specifications: National Standard of Ukraine B V.2.6-35:2008, dated on: 2009.06.01]. Kyiv: , 2009, 28 p. (in Ukrainian).

9. Tabunshhikov Yu.A. and Shilkin N.V. *Aerodinamika vysotnyx zdanij* [Aerodynamics of high-rise buildings]. AVOK, 2004, no. 8, pp. 25–30. (in Russian).
10. Timofeev N.V. and Vasil'chenko N.V. *Primenenie ventiliruemyx fasadnyx sistem pri rekonstrukcii zhilyx zdanij* [The use of ventilated facade systems in the reconstruction of residential buildings]. *Tezisy Mezhdunarodnoj nauchno-prakticheskoj konferencii "Gradostroitel'stvo, arxitektura, iskusstvo i dizajn"* [Theses of the International Scientific-Practical Conference "Urban planning, architecture, art and design"]. Feder. agentstvo po obrazovaniyu, Juzh. feder. un-t, In-t arxitektury i iskusstv [The Federal Agency for Education, Southern Federal University, Institute of Architecture and Art]. Rostov-na-Donu, 2009, pp. 326–329. (in Russian).
11. Timofeev N.V. and Saxnovskaya S.A. *Proektirovanie teploizolyatsionnoj obolochki zdaniya po maksimal'no dopustimym teplopoteryam zdaniya* [Thermal insulation design of the building envelope on the maximum allowable heat loss of the building]. *Rekonstruktsiia zhytla* [Building reconstruction]. Derzh. n.-d. ta proekt.-vyshukuv. in-t. [The State Scientific- and Design-Research Institute]. Kyiv, 2010, iss. 12, pp. 149–154. (in Russian).
12. Fareniuk H.H. *Teplova nadiinist ohorodzhuvalnikh konstruktsii ta enerhoefektivnist budynkiv pry novomu budivnytstvi ta rekonstruktsii: avtoref. dis. d-ra tekhn. nauk: 05.23.01* [Thermal walling reliability and energy efficiency of buildings in new construction and renovation: Abstract of Dr. Sc. (Tech) Dissertation: 05.23.01]. Poltav. nats. tekhn. un-t im. Juriia Kondratiuka [Poltava National Technical University named after Kondratiuk Yurii]. Poltava, 2009, 36 p. (in Ukrainian).
13. Xomenko V.P. and Farenyuk G.G. *Spravochnik po teplozashhite zdanij* [Buildings thermal protecting directory]. Kiev: Budivelnyk, 1986, 215 p. (in Russian).
14. Ciampi M. Some thermal parameters influence on the energy performance of the ventilated walls / Ciampi M., Leccese F., Tuoni G. // 20th National Heat Transfer Conference – UIT 2002 : proc. nat. conf., Maratea (Italy), 27-29 June 2002. – Pisa : ETS Editions, 2002. – P. 357–362.
15. Lang W., Cremers J., Beck A. and Manara J. *New Envelopes for old Buildings – the Potential of using Membrane Systems for the thermal Retrofitting of existing Buildings.* Life-Cycle and Sustainability of Civil Infrastructure Systems Proceedings of the Third International Symposium on Life-Cycle Civil Engineering (IALCCE'12). Vienna, Austria, October 3-6, 2012. London, 2013, pp. 1737–1744. Available at: http://www.crcnetbase.com/doi/pdfplus/10.1201/b12995-268.

СПИСОК ИСПОЛЬЗОВАННЫХ ИСТОЧНИКОВ

1. Ахметов В. К. Математическое моделирование закрученных течений в комбинированных высотных сооружениях / В. К. Ахметов // Фундаментальные науки в современном строительстве : сб. докл. / Моск. гос. строит.ун-т, Ин-т фундамент. образования МГСУ. – Москва, 2008. – С. 41–46
2. Исследования влияния аэродинамических воздействий на технологические системы навесных вентилируемых фасадов / И. Н. Бабий, И. А. Менейлюк, Д. М. Сафонова, И. Ю. Лаври // Вісник Одеської державної академії будівництва та архітектури : зб. наук. пр. – Одеса, 2015. – Вип. 58. – С. 54–59.
3. Бабій І. М. Визначення емісії волокон мінераловатного утеплювача в вентильованих фасадах / І. М. Бабій, І. О. Менейлюк // Сучасні технології, матеріали і конструкції в будівництві : зб. наук. пр. / Вінниц. нац. техн. ун-т. – Вінниця, 2014. –№ 2(17). – С. 26–31.
4. Вознесенский В. А. Численные методы решения строительно-технологических задач на ЭВМ / В. А. Вознесенский, Т. В. Ляшенко, Б. Л. Огарков. – Киев : Вища шк., 1989. – 328 с.
5. Вознесенский В. А. Принятие решений по статистическим моделям / Вознесенский В. А., Ковальчук А. Ф. – Москва : Статистика, 1978. – 196 с.
6. О применении ветрогидрозащитных мембран в навесных фасадных системах с вентилируемой воздушной прослойкой / В. Г. Гагарин, В. В. Козлов, К. И. Лушин, П. П. Пастушков // Научно-технический вестник Поволжья. – 2012. – № 5 – С. 128–131.
7. Гагарин В. Г. Моделирование эмиссии волокон из минераловатного утеплителя навесной фасадной системы с вентилируемой прослойкой / В. Г. Гагарин, С. В. Гувернюк, К. И. Лушин // Промышленное и гражданское строительство. – 2013. – № 9. – С. 27–29.
8. Конструкції будинків і споруд. Конструкції зовнішніх стін з фасадною теплоізоляцією та опорядженням індустріальними елементами з вентильованим повітряним прошарком. Загальні технічні умови : ДСТУ Б В.2.6-35:2008. – [Чинні з 2009.06.01]. – Київ : М-во регіон. розвитку та буд-ва України, 2009. – 28 с. – (Національний стандарт України).
9. Табунщиков Ю. А. Аэродинамика высотных зданий / Ю. А. Табунщиков, Н. В. Шилкин // АВОК. – 2004. – № 8. – С. 25–30.
10. Тимофеев Н. В. Применение вентилируемых фасадных систем при реконструкции жилых зданий / Н. В. Тимофеев, Г. М. Васильченко // Тезисы Международной научно-практической конференции

"Градостроительство, архитектура, искусство и дизайн", 6-9 октября / Федер. агентство по образованию, Юж. федер. ун-т, Ин-т архитектуры и искусств. – Ростов-на-Дону, 2009. – С. 326–329.

11. Тимофеев Н. В. Проектирование теплоизоляционной оболочки здания по максимально допустимым теплопотерям здания / Н. В. Тимофеев, С. А. Сахновская // Реконструкція житла : зб. наук. пр. / Держ. н.-д. та проект.-вишукув. ін-т. – Київ, 2010. – Вип. 12. – С. 149–154.
12. Фаренюк Г. Г. Теплова надійність огороджувальних конструкцій та енергоефективність будинків при новому будівництві та реконструкції : автореф. дис. д-ра техн. наук : 05.23.01 / Фаренюк Геннадій Григорович ; Полтав. нац. техн. ун-т ім. Юрія Кондратюка. – Полтава, 2009. – 36 с.
13. Хоменко В. П. Справочник по теплозащите зданий / В. П. Хоменко, Г. Г. Фаренюк. – Киев : Будівельник, 1986. – 215 с.
14. Ciampi M. Some thermal parameters influence on the energy performance of the ventilated walls / Ciampi M., Leccese F., Tuoni G. // 20th National Heat Transfer Conference – UIT 2002 : proc. nat. conf., Maratea (Italy), 27-29 June 2002. – Pisa : ETS Editions, 2002. – P. 357–362.
15. New Envelopes for old Buildings – the Potential of using Membrane Systems for the thermal Retrofitting of existing Buildings. / Lang W., Cremers J., Beck A., Manara J. // Life-Cycle and Sustainability of Civil Infrastructure Systems Proceedings of the Third International Symposium on Life-Cycle Civil Engineering (IALCCE'12), Vienna, Austria, October 3-6, 2012 / edited by A. Strauss, D. M. Frangopol, K. Bergmeister. – London, 2013. – P. 1737–1744. – Available at: http://www.crcnetbase.com/doi/pdfplus/10.1201/b12995-268.

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