Determination of buildings sun shields operating parameters for the purpose of durability and sustainability

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ABSTRACT: considers the modern building envelope construction with outside skin used as a sun shields. Such a construction is often used for buildings with low energy consumption. A number of factors besides sun radiation influencing on the performance of facade system in general and every certain parts and elements throughout the entire period of building operation.

Subject: multilayer and double skin building facades and sun screens located on their surfaces. Including, dual-use facades combining functions of the sun screen and sub construction for the placement of photovoltaic cells.

Materials and methods: the main method was an estimation the aerodynamic and air-thermal characteristics of a double skin façade. Was considered a construction with combined function of a sun shield. The method was previously used in evaluation of the air-thermal regime of hinged facade systems of buildings for cold period of a year. The general approach was advanced and verified by the results of full-scale tests of building facades in the warm period of the year.

Results: indicates great influence of air and thermal conditions of air gap in double skin and similar construction facades on performance of façade system in general and on every certain part of it.

Conclusions: the construction of complex facade systems with the use of up to date technologies requires additional study of the air-thermal conditions of the air gap between the main facade of the building and its second skin or sun screen. Ignoring the operational features of active sun shields under extreme loads can lead to a decrease in the equipment functionality and its premature failure.

KEY WORDS: facade systems, sun protection, thermal protection, air-thermal conditions of the air gap, energy efficiency, durability, reliability

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Определение параметров работы элементов солнцезащитных экранов зданий для обеспечения их долговечности и устойчивого функционирования

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АННОТАЦИЯ: рассмотрены основные конструкции солнцезащитных экранов современных зданий с пониженным потреблением энергии в теплый период года, а так же ряд факторов, влияющих на обеспечение работоспособности фасадных систем в целом и отдельных их элементов на протяжении всего периода эксплуатации здания.

Предмет исследования: многослойные наружные ограждающие конструкции зданий и солнцезащитные экраны, размещаемые на их поверхностях. В том числе, экраны двойного применения с совмещенной функцией барьера против потока солнечного излучения и подосновы для размещения фотогальванических элементов.

Материалы и методы: применен метод оценки аэродинамических и аэротепловых характеристик двухслойного фасада, выполняющего совмещенную функцию солнцезащитного экрана на основании методики ранее применявшейся для оценки воздушно-теплого режима навесных фасадных систем зданий. Общий подход дополнен и верифицирован результатами натурных испытаний фасадов зданий в теплый период года.

Результаты: продемонстрировано существенное влияние воздушно-теплого режима воздушной прослойки между основным фасадом здания и навесной экранирующей фасадной системой на особенности работы элементов фасадной системы.

Выводы: устройство конструктивно сложных фасадных систем с применением современных технологий требует дополнительного изучения воздушно-теплого режима воздушной прослойки между основным фасадом здания

и его солнцезащитным экраном. Игнорирование особенностей эксплуатации активных солнцезащитных экранов в условиях экстремальных нагрузок может привести к снижению функциональности используемого оборудования и преждевременному выходу его из строя.

КЛЮЧЕВЫЕ СЛОВА: фасадные системы, солнцезащита, теплозащита, воздушно-тепловой режим вентилируемой прослойки, энергоэффективность, долговечность, надежность

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INTRODUCTION

In modern conditions, when the governments regulate industry and the economy, states have been giving special attention to the issues of saving the natural environment and reducing the consumption of all types of resources. This causes significant changes in city look, types and design features of vehicles, information and communication facilities, as well as in the lifestyle of city inhabitants. Most changes connected with the way of consumption of various services, new demands both in new technologies and in teaching them to use. In the construction industry for many years two opposite development directions have been rising at one time. On the one hand, the construction of the building envelope is improved to reduce energy consumption by dissipating heat to outside space. On the other hand, the industry providing permanent search for new energy sources and developing new kind of devices for its efficient transformation, distribution, transmission and saving.

Multi-layer facades with air gaps, previously called by several authors ventilated, allow designers and architects to achieve a number of useful results. The traditional application of ventilated facades in Russia has always been industrial and public buildings with a wet indoor microclimate. The movement of external cold and dry air in between of the layers allows to maintain the material of the insulation layer in a non-wet condition. The most common type of facade with a ventilated air gap are so-called facades with a hinged facade system. Their wide expansion in practice in recent years was greatly provided by activity of the elemental base of such a facades manufacturers. Most of them were implemented a lot of innovations in practice to improve the structures and reduce their costs, to develop fundamental principles and practical recommendations, standards and finally to promote this product. Another and very representative construction of multi-layer facades is the so-called two-layered facades, made of a frame and two layers of glazing.

Such constructions should not be confused with traditional glazing in paired or separate bindings. Because their main characteristic feature is the integrated

space between layers of glazing with a height equal the number of a floors in a building. This space allows to organize natural or forced air movement along the glazing plate. The third extremely popular type of the double facade is the installation on the outer vertical and horizontal surfaces of so-called solar screens or even PV screens. In this case, screening can be performed both on the entire surface of the facade or fragmentarily in the most vulnerable places. For example, the typical structure of sun screens near windows and traditional solution for southern countries called awnings and fabric canopies. All of them with some admission could be called double facade made of light building structures.

The next important aspect of the application of double-layer facades and various kinds of screening of the building's surfaces is the strong will of architects and designers to combine the different functions of screens. Some examples of such approaches implementation are shown in Fig. 1, 2, 3. The most obvious combination in the design of double facades is the installation of a facade with a ventilated air gap, when the outer shield layer — facing forms a ventilated gap in which an formed upward air flow is ensures drying of the mineral wool insulation located on the outer surface openly or with a coating device windproof membrane. In the cold period of the year [1] moisture from the internal warm air, which has a high capacity for its assimilation under the influence of a variety of partial pressures of water vapor outside and inside the building, is filtered through the wall. This contributes to the accumulation of moisture in the insulation layer, but rising flow of cold dry air formed in the air gap of the facade ensures the removal of moisture from the surface of the insulation layer. An additional effect gives heating of air passing through the air gap as it moves from the bottom to the top. As the temperature rises, the air's ability to assimilate moisture increases. Factors that provide an increase in air temperature can be the presence of heat flow through the enclosing structure from inside the building to its outer surface, and the arrival of heat due to solar radiation. The most significant effect is noticed in that part of the cold period of the year when the

Fig. 1. The modern construction of a sunscreen device for protecting the roof from heating by direct sunlight. The library building in Harbin Polytechnic University (China. A photo from a personal archive of authors)

Fig. 2. The design of a multi-layer facade with a ventilated air gap, longitudinal vertical section (t_B and t_H — respectively, temperature differing from each other outside and inside the building, °C; t_{3a3} — air temperature in the air gap, °C; d — width of the air layer, as a rule expressed in mm)

Fig. 3. An example of a simple sun shield on the outer surface of the wall in a temperate climate (Berlin, Germany. Photography from a personal archive of authors)

Fig. 4. An example of combining the functions of the protective screen and the photovoltaic element (PV) of the power supply system, implemented at the experimental facility of the energy-efficient building by staff and students of the University of Applied Sciences (HTW, Berlin, Germany. Photography from the personal archive of the authors)

angles of the sun above the horizon in clear weather provide almost direct falling rays on a vertical surface. An additional effect can also be given by the dark coloration of the outer shielding parts (facing) of the multilayered facade.

Another characteristic example of functions combining in a multi-layered enclosing structure is the attempts of architects to use the whole surface of the building in a useful way by placing photovoltaic elements of renewable energy systems — solar panels (PV) — on the shielding layer. This extremely obvious solution is fraught with a number of technical difficulties that, when ignored during the design phase, can give an unexpected effect in any period during its operation. This effect can be especially notable when using active shielding panels that are equipped with mechanical devices for changing the position in the space. Thus, in the case of a substantial heating of the screening surface, its deformation can occur. And in combination with its considerable size even small relative temperature elongations can lead to negative consequences. From wedging of moving elements, to their complete destruction with the deposition of panels from the attachment points.

As shown in Fig. 4, even on a relatively small object, a protective screen with a combined function of the photovoltaic element of the power supply system [2] is a product of considerable size and surface area. For a single-storey building, this is characterized by a significant shading of its side surfaces by nearby buildings or elements of planting the territory. Consequently, the fluxes of solar radiation and the resulting heating of the surface of the screen and the air layer behind it will be limited. At the same time, of course, the performance of the solar power supply system will also be reduced. Otherwise, this facade will work at a significant height on the building outside of the dense urban development. At the same time, the height of the facade will also have a significant effect due to the prolonged intensive heating of the air flow along the entire height of the enclosing structure.

LITERATURE REVIEW

A deep and significant influence on the systematization of all data, knowledge's and classification of external walls and building envelope parts was provided by Yu. Granik [3]. The term screened facades was replaced with the abbreviation NFS, which means hinged facade systems. In situation their active use in construction, the frequency of their mention can create the wrong impression that shielded facades are the NSF as they are. However, as we have already shown, the variants of technical solutions can be different and most correct way is to give the generic name of multi-layer facades with a shielding outer layer. In this case, various special cases can be analyzed from different angles of view among different authors. Thus, the other char-

acteristic and extremely common name for this type of facade structures is the term “ventilated facades” [4]. Many authors, for example, Yuriy Tabunshchikov [5] and Vladimir. Kozlov [6], note that only facades can be called ventilated, for which the manufacturer of the elements provides in the very design of the screen openings, slots, holes, perforations or other solutions for air access in the upper and lower parts of the facade. Similarly, the design of the facade can provide for the use of entirely perforated panels on its shielding part. However, it should always be remembered that the sun shield does not need to be located parallel to the protected surface [7–9]. In architecture well known many ways of shading parts of facades for all kinds of fractures in the geometry of surfaces, columns and other often decorative elements.

Figure 5 shows the construction of a sun shield in one of the buildings in northern region [10] (Mikkeli, Finland), made of local materials with a shield placed perpendicular to the protected surface. Thus, following the definitions in [5] and [6], the construction depicted in Figure 5 will also be a ventilated façade. Most experts will disagree with that. Thus, when considering ventilated facades, it is necessary to clarify the definition by using definition detailed with words about existing upward flow of air in the gap between the screen and the supporting subbase.

The screen must be reliably fixed [11] on the supporting sub-base by means of a system of brackets, supports or suspensions, which must have considerable structural strength. Since in a number of cases, their bearing capacity should be sufficient to retain not only the material of the facing, but also the insulation layer, as we have shown before. And in some cases the entire construction and all elements of the photovoltaic cell. Special and still not discussed requirements should be made when placing activated elements [12], i.e. movable screens on the sufficient hinged supports. Nevertheless, the approach proposed in [5] to the classification of ventilated facades can be considered as traditional for experts in Russia [13]. The variety of the multilayered facade with a ventilated gap made in the form of longitudinal vertical canals is well studied and is presented in the work of N. Nizovtseva, V. Belyi and A. Sterligov [14]. Such a construction doesn't fully correspond to the definition of multi-layer shielded facades. The outer facing layer only partly works as a screen in that part of its area that covers the air channels. In addition, a contradiction arises with the definition proposed in [5] и [6]. However, the approach realized in work [14] is applicable also in task of analyzing the parameters of the shielding part of multilayer facades. An effective method for studying the air-thermal conditions of hinged facade systems was demonstrated in [15] by a group of scientists from Spain (Christina Sanjuan, Maria Nuria Sanchez, Ricardo Enriquez, Mariadel Rosario, Heras Celemin). The authors [15] succeeded in carrying out a laboratory experiment on the basis of

Fig. 5. A typical design of a sun screen made of local materials with the arrangement of shielding elements perpendicular to the protected surface (photo from a personal archive of authors)

measuring the velocity of a two-dimensional field of moving particles. As the indicator particles that were to be illuminated by the laser beam, pairs of olive oil evaporating from the open surface located at the bottom of the test bed and drawn into the air stream were used. In the work it was possible to demonstrate clearly that the greatest intensity of air movement in the air layer is achieved in the middle-height part of the facade. In the work of N. Vatin and D. Nemova [16] was shown an approach to the analysis of the air-thermal conditions of the air gap in facade with a detailed analysis of the wind and gravity pressure distribution along the facade surface. Then in [16] was presented the results of calculating the dependence of the air velocity in the air gap, depending on its width. It is characteristic that, with an increase in the cross-section for air movement, its velocity can both increase and decrease. Clearly visible is the boundary when the effect achieved from reducing the resistance of the flow section, begins to be compensated for by the lack of air flow through the slots of the lining and the speed of its movement drops. Under the conditions of our task, this may mean limiting the possibilities for removing excess heat from the lining or sunscreen design. In [16], the authors propose to focus designers' attention on increasing the area and the number of openings through which air can enter the gap as a measure of improving simple hinged facade structures without movable screening elements. Such results in general do not contradict the data and conclusions obtained in other conditions by one of the authors of this publication [17].

MATERIALS AND METHODS

The presence of significant temperature changes on the facing surface of hinged facade systems was noted during the studies of the air-thermal conditions of air gaps, which was carried out in order to predict the state and perspectives of the thermal protection properties of the thermal insulation layer from mineral wool boards as part of a multilayer structure. During the research it was repeatedly noted that air temperature in the inter-layer itself, which varies considerably in height, is of great importance for the air-thermal regime of the air layer of the hinged facade. A significant influence on both the temperature dynamics and its maximum value have the arrival of solar radiation [17], which is taken into account by means of the conditional temperature of the outside air ($t_{\text{н}}^{\text{ycн}}$), determined by the formula 1 [18].

$$t_{\text{н}}^{\text{ycн}} = t_{\text{н}} + \frac{I_{\text{с}} \cdot \rho}{\alpha_{\text{н}}},$$

here $t_{\text{н}}$ is the value of the outside air temperature, °C; ρ — coefficient of absorption of solar radiation, fraction of units; $\alpha_{\text{н}}$ — heat transfer coefficient of the external surface, $W / (m^2 \cdot ^\circ C)$; $I_{\text{с}}$ is the intensity of solar radiation (direct and scattered) on the vertical surface, W/m^2 .

Then was made the assumption that the second component of equation 1 can exert a multiple effect on the resulting conditional temperature of the air layer ($t_{\text{н}}^{\text{ycн}}$) in some periods. Air, in view of its low heat capacity [19], is an inefficient coolant [20] and in the case where the intensity of heat input [21] on the vertical

Fig. 6. *a* — the explored facade; *b* — placement of measuring instruments in the air gap (photos from the personal archive of authors)

surface of the screen is maximal, one does not have to count on effective heat removal from this surface by air moving behind it in the interlayer. To assess the degree of influence of air movement in the air layer and the dynamics of the temperature change of the shielding surface, it was decided to observe the characteristic design of the hinged facade with the registration of a number of parameters and, in particular, the air temperature in the air layer.

On the selected fragment of the facade, the facing panels were temporarily removed as it is shown on Fig. 6, *a*, *b*. Then the temperature meters Testo174H-2 were placed directly on the surface of the mineral wool insulation layer (Fig. 6, *b*). Panels returned to the site and for long periods of time, in different periods from the summer of 2016 to the present days, recorded parameters were saved. Similar devices are also located in other characteristic points of the facade, but the values obtained from them do not affect the conclusions assumed in this paper.

RESULTS

Almost all the data obtained indicated that during periods with a significant intensity of sunlight and

a high temperature of the outside air, the temperature drop at certain points in the air layer may amount to tens of degrees per day, which does not create significant difficulties in the operation of simple facings of hinged facade systems, but cannot be ignored by the installation of moving screens or the placement of photovoltaic cells on the buildings facades. Figure 7 is a graph illustrating the dynamics and amplitude of air temperature daily fluctuations in the air gap during only one week of summer 2018.

Such significant fluctuations in air temperature in the interlayer are caused by the action of solar radiation on the smooth dark vertical surface of the facade on that part of the facade that is located in a relatively shady place. A similar experiment on a high-rise building [22] in its upper part with minimal shading should show an even more expressed result [23].

CONCLUSIONS

The research confirmed the proposed assumption of significant differences in the temperature of the air layer and the facade of the shielding during the operation of the building. Also revealed a significant temperature dependence of the facing elements itself and the space

Fig. 7. Dynamics and amplitude of daily temperature fluctuations in the air gap

behind it from the intensity solar radiation. Taking into account main features of photovoltaic cells and more then all intensive self-heating and dark surface, one should pay attention to the fact that air movement in the air layer can not give the necessary effect on removal of heat from the surface and hinges of the shielding. Negative effect of low heat capacity of air will be intensified

by its high temperature. At summer time, for example. Similarly, it is necessary to pay special attention to the operation mode of various moving shielding elements, since the temperature deformations of large elements of such facades can cause a change in the mobility of hangers and hinged supports.

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