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Construction of the air gap with variable width in the double-skin facades

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ABSTRACT

It is hard to imagine the modern market of enclosing structures without the double-skin facades (DSF). Double-skin facades have established themselves as a multifunctional system capable to improve the energy efficiency of buildings. The air gap under the facing is responsible for allocating the moisture from the construction. In the design of modern buildings, special solutions for enclosing structures can be applied. For example, the combined facades which includes DSF and a glass curtain wall. As a result, the air gap with variable width is formed. The purpose of this work is hydraulic calculation of the structure of the vertical air gap with variable width. It was proved that loss-reducing effect in air gap with variable width fails when building has large height and insufficient length of cantilevers. It was also proved that in the small gap free-convective flow is impossible. The results of this work may be found as practical application in the design of similar buildings and analysis of free-convection flow in the air gap of DSF.

Contents

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1. Introduction

There is an increase of volume of industrial and civil constructions on the territory of the Russian Federation. Therefore, issues of new technologies' realization that allows to use the energy resources efficiently and minimize costs exist are broached. Improving the buildings' energy efficiency is one of the most important and relevant aspects of modern construction. System of double-skin facades (DSF) can solve the problem of energy efficiency.

In modern construction, double-skin facades are becoming more common and widespread. This fact is explained by the versatility of these systems. Double-skin facades protect the building against external influences and effectively perform heat-shielding function. DSF allow to give the building an architectural expressiveness and individuality. All thermal characteristics depend on the facade ventilated air gap, so its organization is an important practical task.

Insufficient interchange of air into the vertical gap causes icing up of facing layer in winter and structural elements that are included in the air gap. Insufficient interchange of air is also a reason of the overall reduction of heat-shielding functions of the structure. The condensation and moisture accumulation in the enclosing structure are possible during the exploitation. There are common construction solutions of removal the moisture throughout updraft, which moves in flat channels of enclosing structures. These solutions, for example, are used in double-skin facades.

When combined facades with DSF and a glass curtain wall are used, there is the air gap with variable width. The study of free-convective flow of the air in such gap allows us to estimate the effect of reducing heat loss of enclosing structures.

2. Overview

Air movement in the vertical air gap can be described as a free-convective. Free convection is one of the most economical and practical methods for removing moisture from the air gap [1].

If the surface temperature is higher than the environmental temperature, the stream of air which flows over the surface is heated. It becomes lighter and starts to float. In this case, the dense adjacent air layers replace a rising one. This principle of the layer's substitution is used in designing of the air gaps in the double-skin facades [1].

Great contribution to the study of the characteristics of free-convective flow was made by Russian and foreign researchers. Many scientists were engaged to research thermophysical properties of the ventilated air gap and their effect on temperature and humidity conditions of enclosing structures. For example, M.A. Mikheev, E.R. Eckert, G.Z. Gershuni, Y.A. Sokovishin, O.G. Martynenko, E.I. Idelchik, V.L. Shifrinson, E.M. Zhukhovitskii, G.A. Ostroumov, U.S. Chumakov, S.B. Koleshko, V.D. Machinsky, K.F. Fokin, H.Wang, V.N. Bogoslovskii, Y.A. Tabunshchikov, V.G. Gagarin, V.V. Kozlov, E.Y. Tsykanovskii and others studied this subjects [4-22]. There are well-known works of hydrodynamics and heat and mass transfer at free-convective flow in structures [23-37].

In [2] the economic benefits of using DSF as enclosing structures were assessed. According to the resulting output, the cost savings achieved on the structures with minimum height of 50÷60 m. Optimum hydraulic characteristics of the gap also were obtained. In the article [3] the optimal distance from the screen to the wall in a vertical air gap was determined

However, in the above articles the movement of air in gap with variable width was not discussed. Thus, the purpose of the work is hydraulic calculation of the structure of vertical ventilated gap, providing the maximum intensity of the free-convective air flow. The construction of double-skin facades is being developed for the educational project of public and business center, which is used to certain some parameters of the building. Objectives of the research:

- determination of the optimal ratio of the width of the air gap in a double-skin facade to the width of the air gap in the stained glass;
- study of free-convective flow in the air gap with variable width.

3. Description of the research object

Combined facade is used for the educational project of social and business center in the bachelor thesis. The main architectural and constructive solutions of designed center are shown below.

The object of major construction is a 21-storey public and business center with underground parking.

The social and business center includes offices, hotel rooms and a restaurant. In accordance with the preliminary specifications there are planning concept of entrance hall, typical floors and landscaping elements.

For this article, the decisions on the protective structures are particularly interesting. Combined facade consists of a glass curtain wall and double-skin facades, which includes gas-concrete blocks, heat retainer, air gap and facing layer in the form of ceramic granite tile. Connection of glass curtain wall to the DSF is shown in Figure 1.

Light steel thin-walled structures may be used as load-bearing structural elements (guiding profile) [38]. Methods of calculation of guiding profiles of double-skin facade`s construction, including numerical, are described in [39] and [40,42]. Consideration of termoperforation that allows avoiding "cold joints" is described in [41].

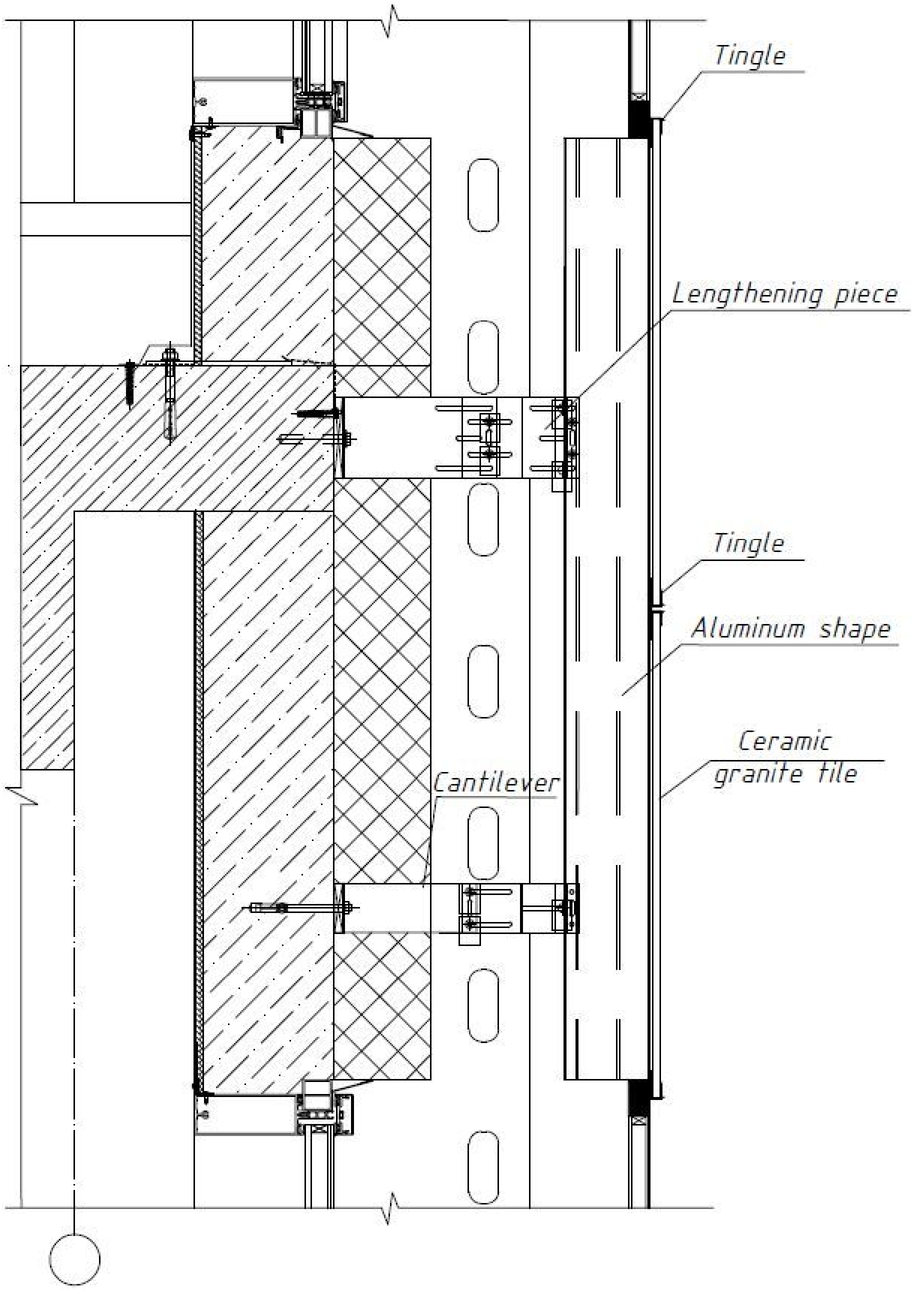

Figure 1. Connection of glass curtain wall to the DSF

4. *Calculation of structure*

The analytical model is a substructure with a length L and variable width of gap. Analytical model is presented at Figure 2.

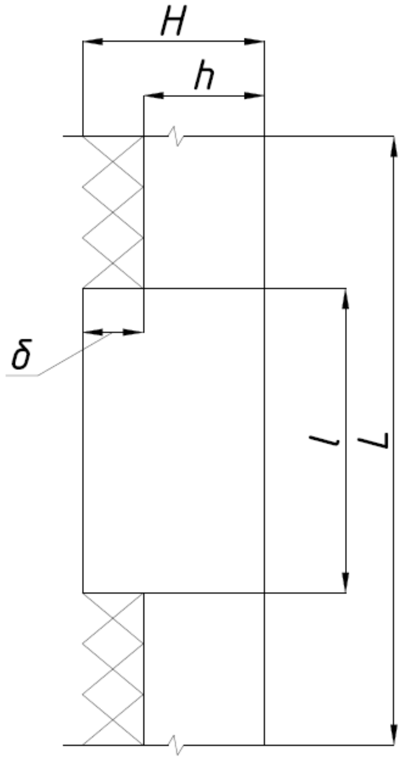

Figure 2. Analytical model of enclosing substructure

The following designations are used to carry out calculations:

H – width of air gap in a glass certain wall, m;

h – width of air gap in double-skin facade, m;

δ – difference between width of air gap in a glass certain wall and width of air gap in double-skin facade, m:

$$\delta = H - h. \quad (1)$$

L – length of all substructure, m;

l – length of a part of substructure which corresponds to the glass certain wall, m.

Architectural concept determines values L and l:

$L = 5$ m, $l = 2{,}5$ m.

Designation of unknown value:

m – ratio of difference between width of air gap in the glass curtain wall and width of air gap in double-skin facade to width of gap in DSF:

$$m = \frac{\delta}{h} \quad (2)$$

Thus, it is necessary to find such a value of m, that will ensure maximum transfer of heat in a variable width air gap.

The problem is considered from the point of view of structure`s geometry. Optimum value m corresponds to the case when the minimum volume of the air gap can provide a fixed heated perimeter. This condition in mathematical form:

$$\begin{cases} A = h \cdot L + \dfrac{\delta \cdot L}{2} \to min \\ P = L + 2 \cdot \delta \to fix \end{cases} \quad (3)$$

According to the duality principle, this condition is equivalent to the condition that under a given volume of air gap the maximum heated perimeter will be produced:

$$\begin{cases} A = h \cdot L + \dfrac{\delta \cdot L}{2} \to fix \\ P = L + 2 \cdot \delta \to max \end{cases} \quad (4)$$

To solve this problem the extremum of the function f must be found:

$$f = h \cdot L + \frac{\delta \cdot L}{2} + \lambda \cdot (L + 2 \cdot \delta) \to extr \quad (5)$$

To find the extremum of the function f partial derivatives on L and δ must be found:

$$\begin{cases} \dfrac{df}{dL} = h + \dfrac{\delta}{2} + \lambda = 0 \\ \dfrac{df}{d\delta} = \dfrac{L}{2} + 2 \cdot \lambda = 0 \end{cases} \quad (6)$$

$$\begin{cases} \lambda = -(h + \dfrac{\delta}{2}) \\ L = 4 \cdot \lambda \end{cases} \quad (7)$$

Doing system of equations (7) it can be received, that:

$$L = 4 \cdot \left(h + \frac{\delta}{2}\right) = 4 \cdot h + 2 \cdot \delta \quad (8)$$

Using relation (2), there are following equations:

$$\delta = m \cdot h \quad (9)$$

From two last equations it can be received, that:

$$L = 4 \cdot h + 2 \cdot m \cdot h \quad (10)$$

$$\frac{L}{h} = 4 + 2 \cdot m \quad (11)$$

The height of the designed building is accepted as following: $H = 65$ m.

Then, the quantity of substructures with length L, which are a part of the facade, will be equal to:

$$n = 13$$

Thus, whole height of the building composes $(n \cdot L)$.

From article [2] it is known that the «optimal» air gap with maximum capacity is described by the formula:

$$\frac{H}{h} = \frac{1}{\lambda_{eq}} \quad (12)$$

where H – height of building, m;

λ_{eq} – equivalent pipe friction number.

$$\frac{n \cdot L}{h} = \frac{1}{\lambda_{eq}} \quad (13)$$

$$\frac{n \cdot L}{h} = n \cdot (4 + 2 \cdot m) \quad (14)$$

Head loss coefficient in complex gap is determined by formula:

$$\zeta_f = \lambda_{eq} \cdot \frac{L}{h} \quad (15)$$

Keeping in mind the geometry of our gap, there is the following expression:

$$\zeta_f = \lambda_0 \cdot \left(\frac{L - l}{h} + \frac{l}{H}\right) \quad (16)$$

where $\left(\lambda_0 \cdot \frac{L-l}{h}\right)$ – loss of pressure head in narrow part of air gap;

$\left(\lambda_0 \cdot \frac{l}{H}\right)$ – loss of pressure head in wide part of air gap.

After equalization the right part of the last two equations, the following equation can be received:

$$\lambda_{eq} \cdot \frac{L}{h} = \lambda_0 \cdot \left(\frac{L - l}{h} + \frac{l}{H}\right) \quad (17)$$

$$\lambda_{eq} = \lambda_0 \cdot \left(\frac{1}{2} + \frac{h}{2 \cdot H}\right) \quad (18)$$

Consequence from formulas (1) and (2):

$$m = \frac{\delta}{h} = \frac{H - h}{h} = \frac{H}{h} - 1 \quad (19)$$

$$\frac{H}{h} = m + 1 \quad (20)$$

Equations (18) and (20) allow to get following relation:

$$\lambda_{eq} = \lambda_0 \cdot \left(\frac{1}{2} + \frac{1}{2 \cdot (m + 1)}\right) \quad (21)$$

Using equations (13) and ratio for λ_{eq} there are following equations:

$$\frac{n \cdot L}{h} = \frac{1}{\lambda_0 \cdot \left(\frac{1}{2} + \frac{1}{2 \cdot (m + 1)}\right)} \quad (22)$$

$$\frac{n \cdot L}{h} = \frac{2 \cdot (m+1)}{\lambda_0 \cdot (m+2)} \tag{23}$$

After equalization the right part of equations (14) and (23), there are ensuing equations:

$$\frac{2 \cdot (m+1)}{\lambda_0 \cdot (m+2)} = n \cdot (4 + 2 \cdot m) \tag{24}$$

There is second-degree equation:

$$m^2 + \left(4 - \frac{1}{n \cdot \lambda_0}\right) \cdot m + \left(4 - \frac{1}{n \cdot \lambda_0}\right) = 0 \tag{25}$$

The condition of real roots` existence of this equation looks like:

$$\frac{1}{4 \cdot (n \cdot \lambda_0)^2} - \frac{1}{n \cdot \lambda_0} \geq 0 \tag{26}$$

$$n \cdot \lambda_0 \leq \frac{1}{4} \tag{27}$$

When $n \cdot \lambda_0 = \frac{1}{4}$ there is one equation root $m = 0$, then $\frac{\delta}{h} = 0$. This ratio does not satisfy us because in this case air gap does not have variable width.

Equation roots:

$$m_{1,2} = -2 + \frac{1}{2 \cdot n \cdot \lambda_0} \pm \sqrt{\frac{1}{4 \cdot n^2 \cdot \lambda_0^2} - \frac{1}{n \cdot \lambda_0}} \tag{28}$$

To estimate the received results two dependency diagrams were constructed:

1. $m = f(n)$ with $Gr_h = fix$;
2. $m = f(Gr_h)$ with $n = fix$.

Comments to figures 3 and 4: our calculations are in the range of low Reynolds numbers, therefore:

$$\lambda_0 = \frac{64}{\sqrt{Gr_h}} \tag{29}$$

where Gr_h – Grashoff number:

$$Gr_h = \frac{g \cdot h^3}{\nu^2} \tag{30}$$

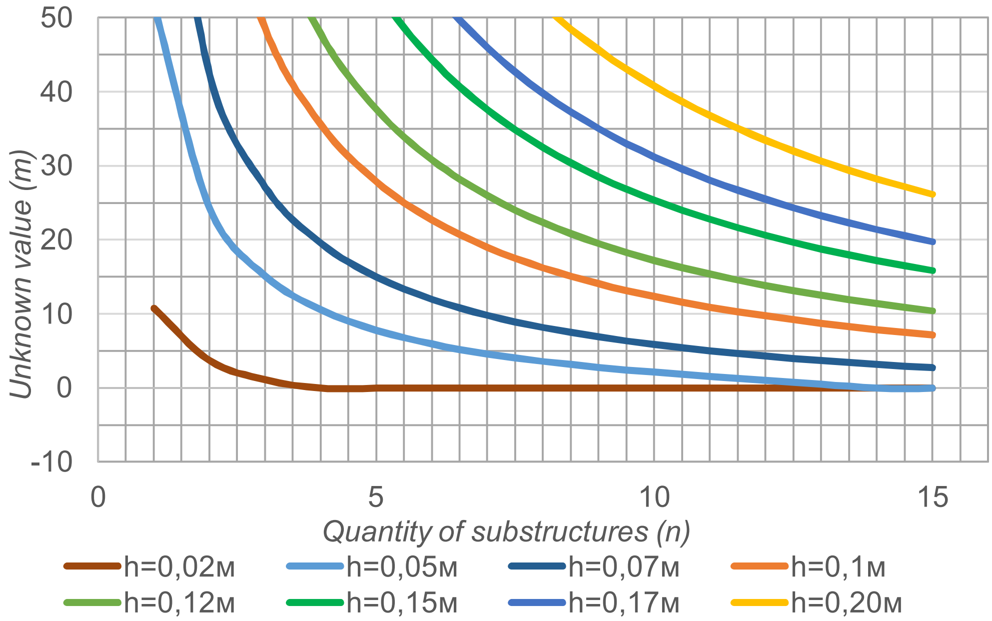

Figure 3. Dependency diagram m from n

Inference for Figure 3:

The value of m asymptotically approaches to one when the number of substructures n is rising. Thus, loss-reducing effect in air gap with variable width fails when building has large height and insufficient length of cantilevers. When using the long cantilevers loss reducing effect is significant. In low-rise building for any length of cantilevers creating of air gap with variable width can give results.

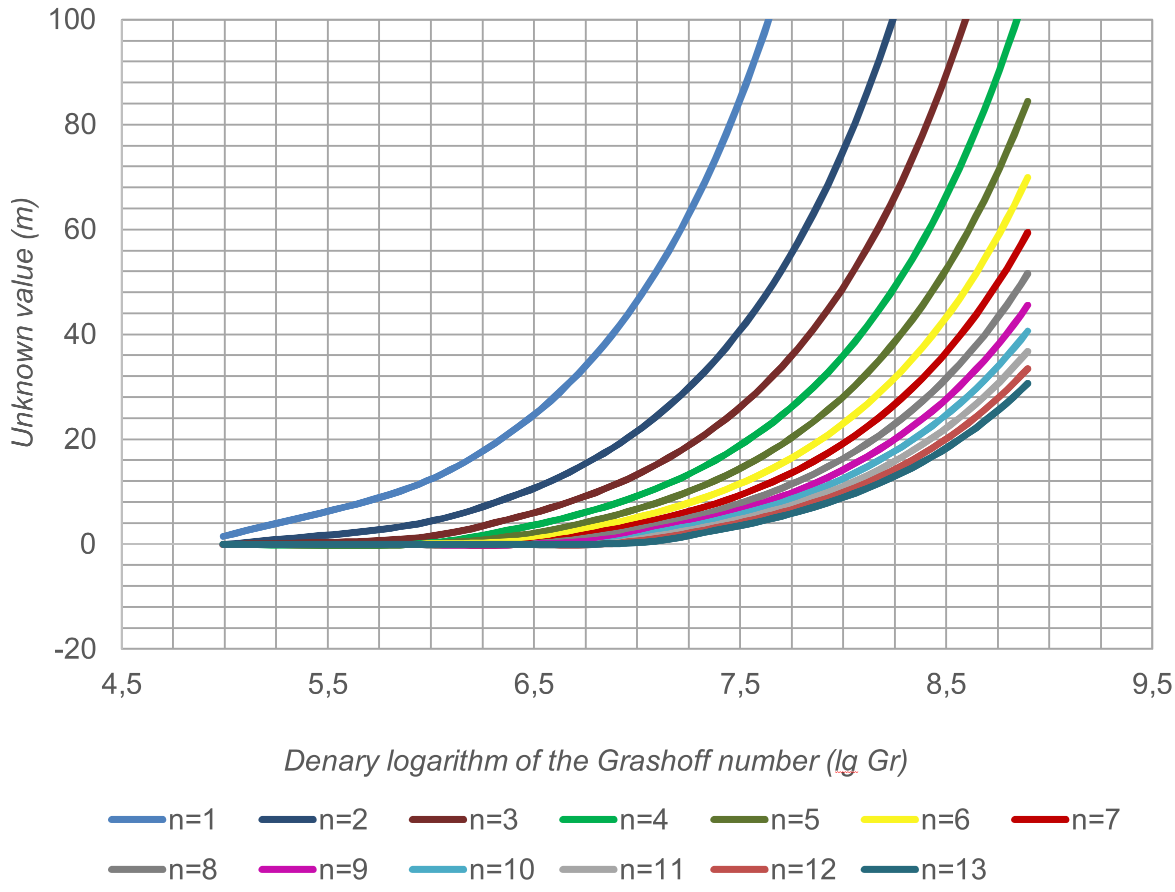

Figure 4. Dependency diagram m from $lgGr$

Inference for Figure 4:

It is proved that in real range of low Reynolds numbers free-convective flow is possible for some $h > h_0$. Grashoff number is limited below the value of $\sim 10^5$.

It is also clear that in the small gap there is no free-convective flow.

5. Conclusion

The work has been dedicated to the hydraulic calculation of the construction of vertical air gap with variable width in the double-skin facades for the design of public and business center. In the calculations, the following tasks have been solved:

1. Vertical air gap with variable width in the combined facades has been constructed. It`s been proved that loss-reducing effect in air gap with variable width fails when building has large height and insufficient length of cantilevers. When using the long cantilevers loss reducing effect is significant.
2. After the necessary calculations and construction of the corresponding dependency diagrams, the main conclusion has been received: there is no free-convective flow in the small gap.

Having analyzed the results it can be approved that the energy efficiency of buildings with double-skin facades needs to pay special attention to the construction of the air gap, which depends on the geometric and thermal characteristics of the building, as well as its location.

Hydraulic calculation of ventilated gap is an inalienable part of the design and calculation of enclosing structures in the case, when double-skin facades are used.

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Конструкция переменного по ширине вентилируемого зазора в навесных вентилируемых фасадах

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УДК 692.232.45	Подана в редакцию 29 января 2016	гидравлика; навесной вентилируемый фасад; свободно-конвективное течение; вертикальный вентилируемый зазор; переменная ширина зазора;

АННОТАЦИЯ

Современный рынок ограждающих конструкций трудно представить без навесных вентилируемых фасадов (НВФ). НВФ зарекомендовали себя как многофункциональные системы, способные повысить энергоэффективность зданий. Воздушный зазор, находящийся под облицовкой, отвечает за отведение влаги из конструкции. При проектировании современных зданий возможны случаи использования в качестве ограждающий конструкций нестандартных решений. Например, комбинированные фасады, включающие в себя не только НВФ, но и витражное остекление. В результате образуется переменный по ширине воздушный зазор. Цель данной работы – гидравлический расчет конструкции переменного по ширине вертикального вентилируемого зазора. В ходе работы было доказано, что при большой высоте здания и малой длины кронштейнов эффект снижения потерь в переменном по ширине вентилируемом зазоре не дает результатов. Также доказано, что в малом по ширине воздушном зазоре свободно-конвективное течение невозможно. Полученные результаты могут найти практическое применение при проектировании аналогичных зданий и анализе свободно-конвективного течения воздуха в воздушном зазоре НФВ.

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