ISSN 1819-432X print / ISSN 1993-3495 online
СУЧАСНЕ ПРОМИСЛОВЕ ТА ЦИВІЛЬНЕ БУДІВНИЦТВО
СОВРЕМЕННОЕ ПРОМЫШЛЕННОЕ И ГРАЖДАНСКОЕ СТРОИТЕЛЬСТВО
MODERN INDUSTRIAL AND CIVIL CONSTRUCTION
2013, ТОМ 9, НОМЕР 4, 203–211
УДК 697.13:693.69.001.5

НАТУРНІ ДОСЛІДЖЕННЯ ТЕПЛОФІЗИЧНИХ ХАРАКТЕРИСТИК ЗОВНІШНІХ СТІН З ВЕНТИЛЬОВАНИМИ ФАСАДНИМИ СИСТЕМАМИ

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Отримана 24 вересня 2013; прийнята 22 листопада 2013.

Анотація. Проаналізовано сучасні теорії фізичних процесів, що визначають теплотехнічні характеристики повітряного прошарку в будинках з використанням вентильованої фасадної системи. Наведено результати натурних спостережень. Розглядалася мінімальна товщина повітряного прошарку 15 мм на прикладі вентильованої фасадної системи «Марморок». Дослідження проводилися в термомодернізованому п'ятиповерховому будинку на рівні 1-го , 3-го і 5-го поверхів при просвітності стартового профілю 0, 30 і 100 %. На підставі експериментальних досліджень і теоретичних розрахунків визначені швидкості руху, температура і вологість повітря в повітряному прошарку в розрахункових умовах. Побудовані залежності швидкості руху повітря в прошарку від температури зовнішнього повітря. Зафіксовані зміни вологості в прошарку залежно від ступеня відкритості стартового профілю, а також виявлено характер зміни температури по висоті повітряного прошарку при негативних температурах зовнішнього повітря.

Ключові слова: вентильований повітряний прошарок, температура, вологість, швидкість руху повітря, термомодернізація.

НАТУРНЫЕ ИССЛЕДОВАНИЯ ТЕПЛОФИЗИЧЕСКИХ ХАРАКТЕРИСТИК НАРУЖНЫХ СТЕН С ВЕНТИЛИРУЕМЫМИ ФАСАДНЫМИ СИСТЕМАМИ

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Получена 24 сентября 2013; принята 22 ноября 2013.

Аннотация. Проанализированы современные теории физических процессов, определяющих теплотехнические характеристики воздушной прослойки в зданиях с использованием вентилируемой фасадной системы. Приведены результаты натурных наблюдений. Рассматривалась минимальная толщина воздушной прослойки 15 мм на примере вентилируемой фасадной системы «Марморок». Исследования проводились в термомодернизированном пятиэтажном здании на уровне 1-го, 3-го и 5-го этажей при просветности стартового профиля 0, 30 и 100 %. На основании экспериментальных исследований и теоретических расчетов определены скорости движения, температура и влажность воздуха в воздушном зазоре в расчетных условиях. Построены зависимости скорости движения воздуха в прослойке от температуры наружного воздуха. Зафиксированы изменения влажности в прослойке в зависимости от степени открытости стартового профиля, а также выявлен характер изменения температуры по высоте воздушной прослойки при отрицательных температурах наружного воздуха.

Ключевые слова: вентилируемая воздушная прослойка, температура, влажность, скорость движения воздуха, термомодернизация.

FIELD INVESTIGATIONS OF THE THERMO AND PHYSICAL CHARACTERISTICS OF THE EXTERIOR WALLS WITH VENTILATED FACADE SYSTEMS

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Received 24 September 2013; accepted 22 November 2013.

Abstract. The contemporary theories of physical processes that determine thermo and technical characteristics of the air gap in the buildings with ventilated facade systems have been analyzed. The results of field observations have been given. The minimum thickness of 15 mm air gap on the example of ventilated facade system «Marmorok». Have been considered Research was conducted in term modernized five story building at the 1st, 3rd and 5th floors with luminal starting profile of 0, 30 and 100 %. On the basis of experimental studies and theoretical calculation the air speed, air temperature and humidity in the air gap in the design conditions have been determined. The dependences of the air speed in the layer on the outside temperature have been done. The changes in humidity in the layer depending on the degree of openness of the starting profile have been found, and also it has been found out that the nature of temperature change of the gap at subzero temperatures of the outdoor air.

Keywords: ventilated air layer, temperature, humidity, air speed, thermomodernization.

Subject actuality

Ventilated facade systems (VFS) have been widely used in modern construction. Application of a ventilated facade system during thermo-modernization of building is the most promising method to provide the required energy efficiency. This system increases thermal insulation quality of the existing external walls of buildings. For the smooth movement VFS it is necessary to ensure a steady stream of air in the air gap with the values of the speeds with in values contributing drainage of moisture from the layer and prevent condensation on the inner surfaces of the lining or the outer surface of the insulation. Normative documents of Ukraine, taking into account international experience of VFS operation, recommend the optimal thickness of the ventilated layer not less than 40 mm as suitable to perform the abovementioned tasks. Separately specifications DSTU B V.2.6-35:2008 [1] shows that at lower thickness it is desirable to use additional theoretical calculations. As there are no valid engineering calculated methods yet, at in practice ventilated layer thickness structurally is allowed to be from 15 to 25 mm, there may be problems in the operation of VFS. First of all, the speed and air flow rate may be insufficient to meet the basic function of VFS – remove moisture from the insulation. Therefore, there are doubts about the adequacy of specified thickness for the proper functioning of VFS. In connection with the above mentioned considerations field observations are relevant for thermo and technical characteristics in the air gap VFS of minimal thickness to estimate their performance and insertion in the theoretical design.

Tasks

Information on field observations of this kind is contained in the VFS works of scientists of the Russian Federation: V. Gagarin [2] and N. Umnyakova [3, 4]. In the former papers for the first time there is the dependence of the air speed in the layer from the action of the wind. But in reality thickness of the air gap was 40 mm. In the publications of foreign authors, for example H. Künzel [5–7] B. Schwarz, E. Mayer, D. Hoffman, A. Silberstein, C. Langlais, K. Kiebl, which are summarized in the paper of K. Sedlbauer, H. Künzel [8] there is an information for the long period of observation from 1973 till 1998 and the cord itself was introduced VFS. These works are characterized by the fact that at layer thickness of 40 mm was fixed small in signification of air speed of 0,25 to 0,60 m/s. With an average wind (up to 2,5 m/s) was observed even decrease of the air speed in the layer. Strong wind according to the data of scientists increases speed in the interlayer up to 40–60 %. In the papers of

H. Künzel, E. Mayer [5] they are dealing dealing with thickness of the interlayer 10 and 20 mm, but the overall results are given together with a layer of 40 mm. Thus to estimate the situation in the interlayer of the minimum sizes unfortunately is not possible.

The practical application analysis of VFS at the construction of the new buildings e. g. in Donetsk shows that VFS has got the most widespread were the thickness of the air gap by technical means was equal to 15 mm. This is connected with sufficiently considerable weight of facing (nearly 40 kg/m^2) and possible increasing of metal volume of under facing mounting elements and making of deeper thickness. The investigators of the system is the Swedish company «Marmorok» pointing out to possibility of its application in the buildings with height up to 75 m, but there are also recommendations of other supplier up to 100 m.

The main drawback of the application of «Marmorok» system has appeared of air disturbance through the starting profile, peculiar used for these purposes and theoretically provided. It happens either on the demand of fire services, controlling the design and operating the work if there are gas tubes outside application or if some number of holes are drilled by hand after the assembly in the solid starting profile.

In this connexion it is required to clarify the influence of other factors on the air movement in the interlayer. First of all it refers to the above mentioned influence of the wind. Next air permeability of the screen should be taken in to account. Theoretical investigations (studies) of V. V. Kozlov, S. V. Guvernyuk, A. A. Sinyavin [9–10] are devoted to this question. In the investigations [11] it is pointed out that at closed (start and finish) profiles due to air permeability occurs convective air movement in the interlayer and the maximum speed should be expected by mid-height layer.

For the first stage of the experimental investigation was chosen the standard (series 164-80-1) five-storey large-block building facades of which were overhauled with use of ventilated facade system «Marmorok», installed were windows of PVC profiles, glassed loggias and balconies. This building is a hostel (dormitory) № 5 of music school in Donetsk in. Popovich street 37B. In this building successfully were used space-planning decisions, allowing unimplemented conduct surveillance in hallways and rooms designed for the auxiliary functions and having microclimatic characteristics which are related to living rooms solved was the problem of fixing the speed of movement (V_{vp}, m/s), temperature (t_{vp}, °C) and relative humidity (φ, %) in the layer at the luminal of starting profile of 0, 30 and 100 %. Translucent 0 % refers to the fully closed starting profile and 100 % – respectively to the fully open.

The research was conducted on the basis of the methodology of field observations according to the specifications B V.2.6-101:2010 [14]. Studies have been performed on the same vertical line (Fig. 1) at levels 1, 3 and 5th floors.

Solution of the problem

To perform observations on the outside wall tiles of facing were made holes of the required diameter. In holes there were inserted sensors. With the help of a special limiter ending air speed sensor was located in the middle of the air gap, and the temperature and humidity sensor did not prevent the movement of air in the interlayer.

Observations were carried out with the usage of measuring devices – anemometer Testo 425 (Fig. 2), humidity and temperature sensor DTV – 302ts which was connected to a digital meter I2 DTV.

As to the central vertical axis in the layer of facing stone there is a hole to measure air speed and relative humidity measurement sensor is shifted to the right to a sufficient distance so as not to influence the movement of air in the interlayer.

Measurements were carried out within 6 days at outdoor temperatures 4.4 subzero to 4,0 °C above-zero. Number of measurements ranged from 10 to 18 and they were carried out with 30 minutes interval. Carried out were simultaneous measurements of temperature and humidity in the premises at the appropriate levels. Also recorded were: temperature, pressure and humidity of the outdoor air, the wind speed at a distance from the building (V_o) and at the plane of the facade (V_{out}) at levels of observation points (Fig. 1).

The example of the results of field measurements of temperature (t_{ag}) and air speed (V_{ag}) in the layer is shown in Table 1.

Presented in Table 1 values of speed indicates about the negligible air speed in the layer with the

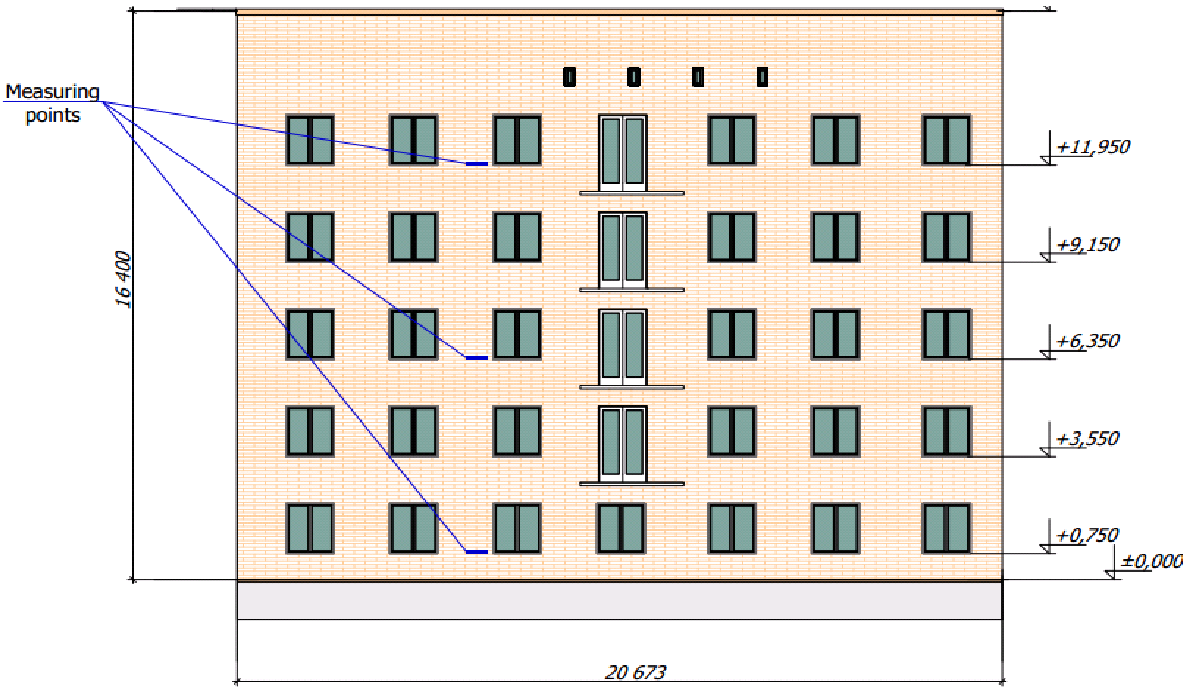

Figure1. Observation object – layout of measuring points.

closed (up to 30 % of luminal – options 1 and 2) starting profile. In general, the air speed adjustment layer increased by only 0,03 m/s. For central layer (third floor level), the maximum air speed is not fixed as it is theoretically predicted in [11]. In option 3 (translucent is 100 %) at the start and finish profiles was observed speed increase with the increase of altitude.

According to the results of observation there were plotted the dependences of air speed in the layer on the outdoor temperature. Figure 3 shows such curves of dependence for 1, 3 and 5 floors. In the resulting mathematical dependences was substituted the value of temperature (–22 °C), which corresponds to the calculated climatic conditions of the 1-st temperature zone of Ukraine. The resulting calculated value of speed at the fifth floor level was about 0,25 m/s. Such a small value can be explained, first by small thickness of the interlayer, secondly by a significant hydraulic resistance of the channel through which the air moving.

Separately was investigated the dependence of the air speed in the layer on the wind speed. Speed is approximated by dependence of general view $V_i = aV_f^b$. Coefficient for the 1st floor is 0,0644, the third – 0,076 and the fifth – 0,1005. Exponents for each floor have different values. Table 2 shows the design formulas according to the results of field observations.

Figure 4 shows the average speed on the ground floor – fifth floor.

Nature of the obtained results coincides with experimental observations N. P. Umnyakova [3, 4] in terms of the law of speed change. Air speed in the layer increases with the increase of the speed of the wind flow and decreases with decrease in the number of storeys.

An important step of observations was to identify the nature of temperature change as to the height of

Figure 2. Use measuring devices – anemometer Testo 425.

Table 1. The results of field observations of thermal and technical characteristics in the air gap

№ opt.	Luminal of starting profile, %	The floor	Air temperature, °C			Speed of movement, m/s	
			out side, t_{out}	average in the gap, t_{avag}	in the gap, t_{ag}	vind, V_{out}	air in the gap, V_{ag}
1	0	1	3,3	4,1	3.1	1.7	0.07
		3			3.6	2.1	0.08
		5			5.1	2.6	0.1
2	30	1	3,4	4,4	3.8	1.72	0.08
		3			3.7	2.2	0.087
		5			5.0	2.7	0.084
3	100	1	3,3	3,8	3.0	1.69	0.08
		3			3.5	2.1	0.11
		5			4.9	2.65	0.14

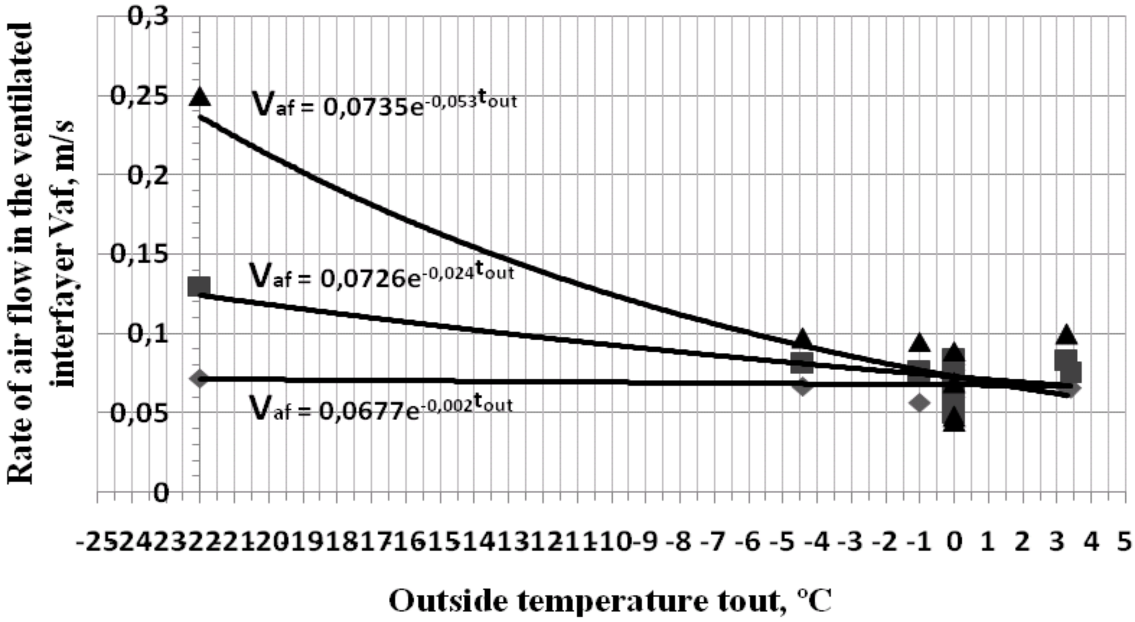

Figure 3. Dependence of the rate of air flow in the layer on the outdoor temperature: ♦ – Vag on the ground floor; ■ – Vag on the third floor; ▲ – Vag on the fifth floor.

Table 2. Calculated dependence accordingto the results of field observations

The floor	Field observations	
	V_{if}, м/с	V_{ifav}, м/с
1	$0{,}0644V_f^{0{,}052}$	$0{,}0895V_f^{0{,}1321}$
3	$0{,}076V_f^{0{,}0325}$	
5	$0{,}1005V_f^{0{,}1831}$	

the air gap. Due to corrective air flow and constant heat input with increasing altitude from the premises, the temperature in the layer must increase. Fig. 5 shows the temperature change in the air gap, depending on the outdoor temperature. Traced are two physical states of air.

The first, when the outdoor air temperature is zero. Here in two cases is observed an inverse

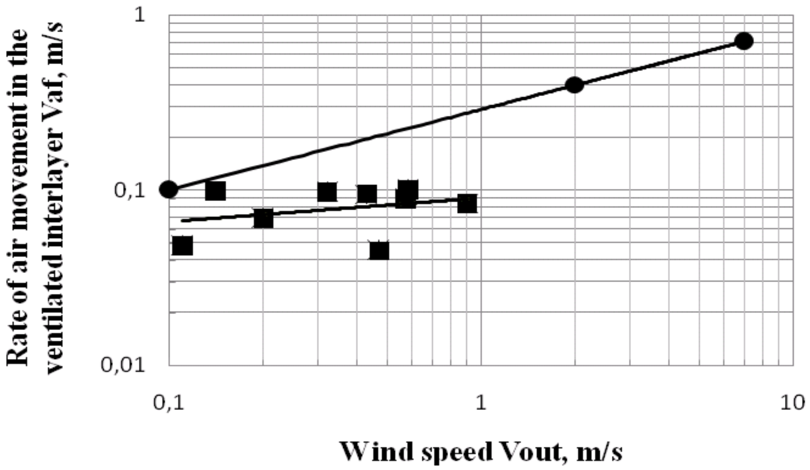

Figure 4. Air speed distribution in a ventilated interlayer depending on floor height and wind speed. In the graphs shown schematically are: ■ – averaged dependence between the first and the fifth floor; ● – according to N. P. Umnyakova [3,4].

relationship of temperature instead of increasing as to the height – it decreases. Reduction is (0,65 – 0,38) = 0,27 °C and (3,38 – 3,35) = 0,48 °C. In one case the relationship is positive and the difference is (1,89 – 1,32) = 0,63 °C. Such uneven temperature distribution is related, probably, to instability of the ambient temperature change when is observed change of temperature from the negative to positive values and vice versa. The second-with outside subzero temperature values. Observed was temperature increase as to the height by (3,35 – 1,55) = 1,8 °C and (1,96 – 0,65) = 1,31 °C. Also at the temperature above-zero increase is (5,1 – 3,1) = 2,0 °C. Increase of values is larger than in the conventional theory [12, 13].

Figure 6 demonstrates changes of interlayer moisture content depending on the degree of openness.

So, with closed bottom starting profile has been observed a steady decrease of humidity at ground level (by 10–35 %) with a further increase at the fifth floor level by (2–8 %). This case testifies about the considerable vapor resistance of exterior sheathing.

When the starting profile is opened (30 % and more of transmissive) humidity on the ground and fifth floors is unstable and varies slightly in comparison with the outdoor air humidity. That is, in-field observations (at the height of building 15 m) conditions of condensation in the air gap are not fixed.

Conclusions

1. According to the results of observations at closed starting and finishing profiles with up to 30 % of luminal in the air gap of ventilated facade systems with air space of minimum thickness was recorded minimum air flow speed in the range from 0,07–0,10 m/s.
2. Reduction of speed to 0 m/s in the low and upper parts of the air gap, as well as the maximum speed at mid-height of the building were not detected.
3. When the starting profiles are opened on the base of experimental investigations was predicted the movement of air in the calculated climatic conditions at a speed of 0,25 m/s, which provides prevention of condensation in the air gap. Evidently height of the air gap at the level of 15–20 m can be adopted for placement of crosscuts as to height.
4. The air temperature in the layer has a steady increase as to height at the temperatures of the outdoor air above and below zero. At a temperature of about 0 °C is observed an unstable temperature state in the layer with the increase or decrease of the temperature as to height.
5. There was fixed air humidity change in the layer depending on its degree of openness. So, with a closed bottom starting profile is observed a steady decline of humidity at ground level by (10–35 %) with a further increase at the fifth floor level (2–8 %). This case testifies

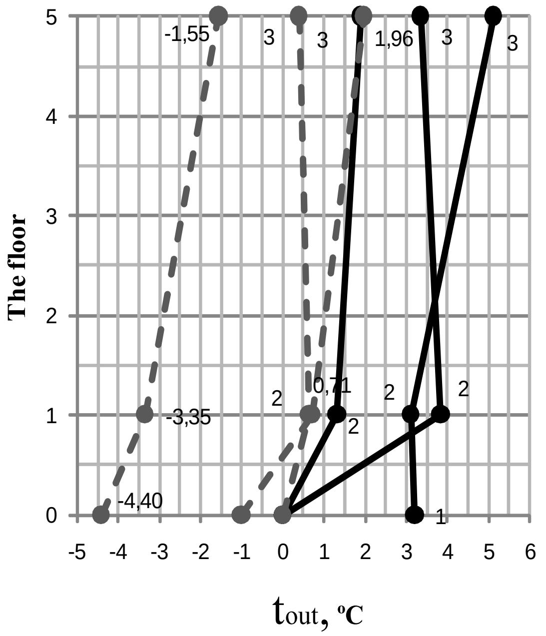

Figure 5. The temperature distribution in a ventilated interlayer depending on floor height and outdoor temperature. The graph shows schematically: – closed starting profile, ---- open starter profile.

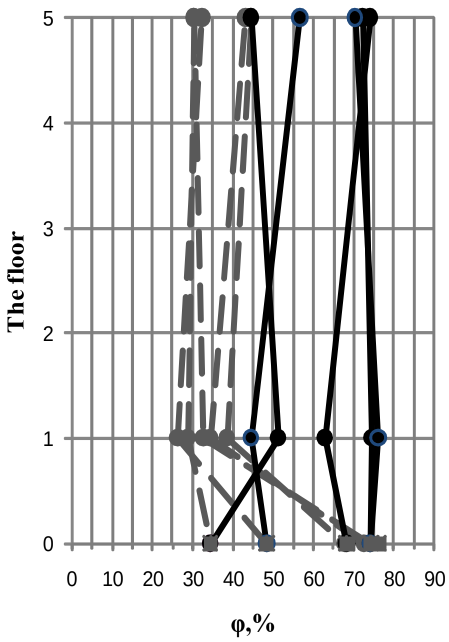

Figure 6. Moisture distribution in a ventilated interlayer depending on floor height and external moisture: ■ – outdoor moisture $φ_f$; ---- $φ_{ag}$ with closed profile; – $φ_{ag}$ at opened starting profile.

about the considerable vapor resistance of facing. When the starting profile is opened (more than 30 % of luminal) humidity, on the ground and fifth floors is unstable and varies slightly in comparison with humidity of the outdoor air. That is, in field observations were not fixed the conditions of condensation in the air gap.

6. Field observations have proved the necessity to take in to account the effects of wind and air permeability of the facing in the theory of air motion in the air gap.

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