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Numerical Comparison of Thermal Behaviour Between Ventilated Facades

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Abstract: Increasingly high demands on environmental protection are intensifying the development of sustainable construction. Ventilated facades can provide an energy-efficient alternative to standard facades, that is, external thermal insulation composite systems (ETICS). The article compares standard facades, which was a reference, to ventilated facades in two variants: closed joints and open joints. The comparison was made by means of numerical simulations of computational fluid dynamic (CFD), under conditions of high outside temperature and high sunshine. The results showed great benefits of using ventilated facades in such external climate conditions. It was also observed that the selection of the variant of ventilated facade in the system of close or open joints has minimal influence on thermal efficiency of the whole partition.

Keywords: ventilated facade, heat transfer, CFD, numerical simulation, Energy-efficient facade

1 Introduction

As the environment changes more and more, most global organisations are trying to reduce energy consumption. On the basis of the Eurostat data from 2016 [13], in the case of Europe, the energy consumption in the building sector is 24.8% and the service sector is 13.5% of the total energy consumption in the European Union. In total, this gives 39.2% of the overall energy consumption in the European Union per sector related to the use of buildings, as shown in Figure 1 [13]. For the purpose of sustainable construction assessment, various systems of multi-criteria building assessment have been developed, including BREEAM (Building Research Establishment Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design). The certification of these organisations concerns the design, execution and use of buildings. In Figure 2 [13], the timeline shows the total energy consumption. In this figure, it can be seen that despite the continuous development of countries in the European Union, the level of energy consumption in the construction sector varies within a few percentage points. This is due, amongst other things, to the greater popularity of sustainable construction promoted by investors and customers.

Building facades are a very important element of sustainable construction. These are the elements that have the largest area of 'contact' with the environment and should protect the building against low and high temperatures, sunshine, rainfall and wind. A very beneficial form of facade, providing protection against environmental impacts, is elevations using air cavity

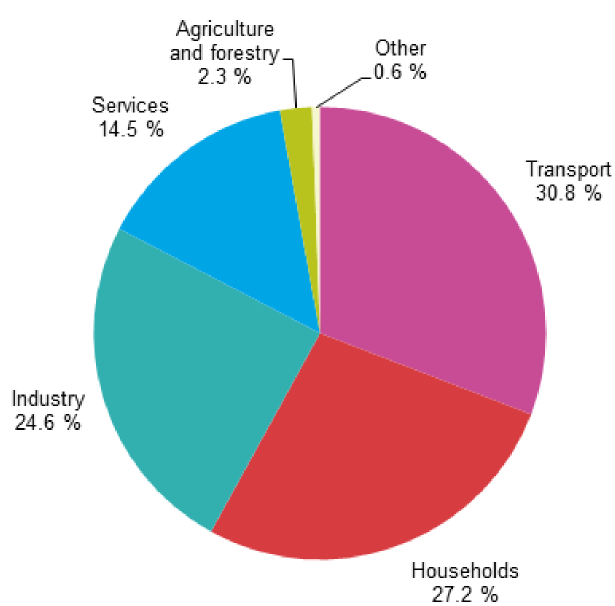

Figure 1: Final energy consumption by sectors (%) [13].

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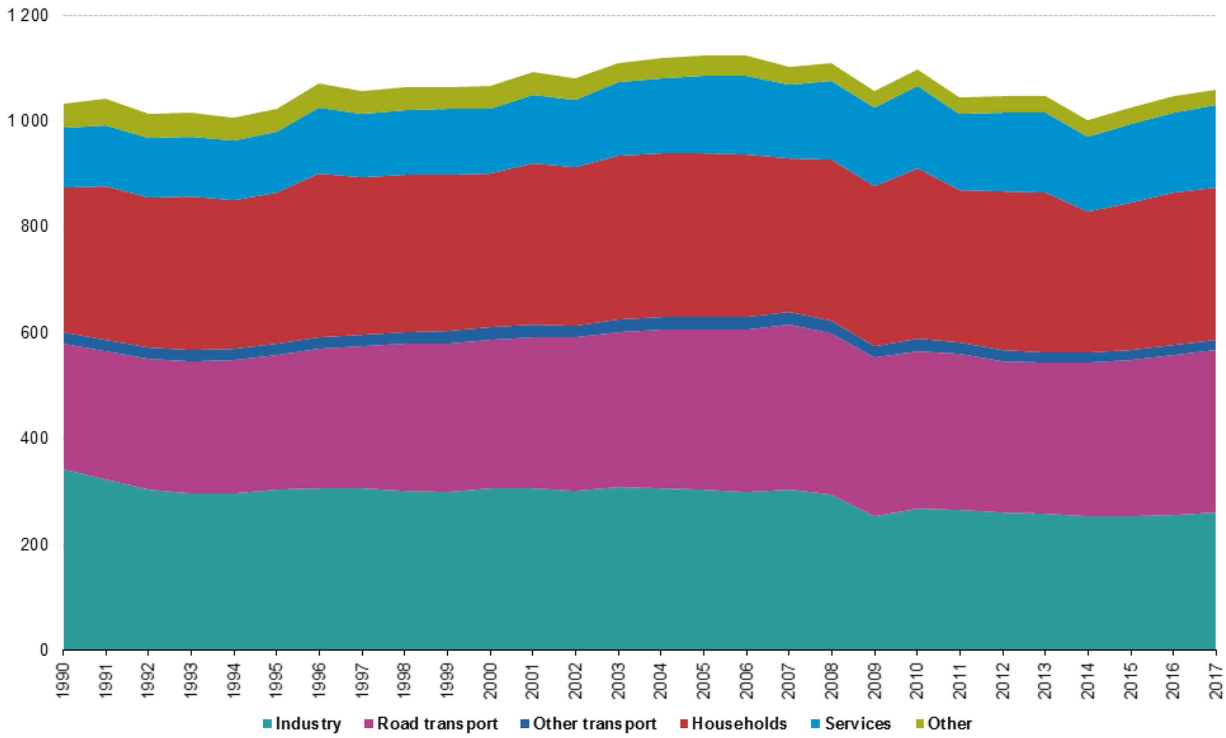

Figure 2: Final energy consumption by sector (million tonnes of oil equivalent) [13].

between the external and internal part of the vertical partition. These elevations are called ventilated facades.

Ventilated facades allow the formation of external cladding from different materials, structures, textures or colours. Looking from the outside, they consist of an outer layer (called external cladding) fixed with substructures and connectors to the supporting wall. There is an air cavity between the external cladding and the insulation. The width of the air cavity in ventilated facades is usually in the range from 20 to 50 mm [8, 18]; some sources also provide higher values: from 40 to 100 mm [14]. In most cases, the width of the air cavity is determined by the manufacturer of the whole system using the method of external cladding assembly and the type of substructure. However, for technological reasons, two types of ventilated facades are distinguished: open-joint ventilated facade and closed-joint ventilated facade (opaque ventilated facade). Examples of such facades are shown in Figure 3 [14].

Despite many advantages, ventilated facades are a little known set of construction products. Particularly little is known and researched in terms of their thermodynamics. The authors of this article have made an attempt to bring this issue closer based on the office buildings and multi-family residential buildings with higher utility requirements. Users of such buildings have high requirements concerning thermal comfort of use, amongst others, constant temperature distribution in the room (no heating and cooling of the rooms at the windows and the external wall), possibly small draughts, constant temperature in the winter and summer period.

2 Literature Review

[11] There are studies on ventilated facades, but most of them refer to the so-called double skin facade, that is, facades with glass partitions, used in the vast majority of high-rise buildings for service or office purposes. Of course, some of the issues identified there can be adopted to typical ventilated facades, including the danger of fire development, air flow in the air cavity. However, as far as the energy benefits of the conductivity of materials and wall construction are concerned, the parameters are different and, in the opinion of the authors, these types of facades should not be compared in this way. Ventilated facades in their traditional version, that is, with closed joint and open joint, mostly concern low and medium-high buildings intended mainly for residential purposes and in the minority for services and hotels. There are also a small number of scientific studies on ventilated

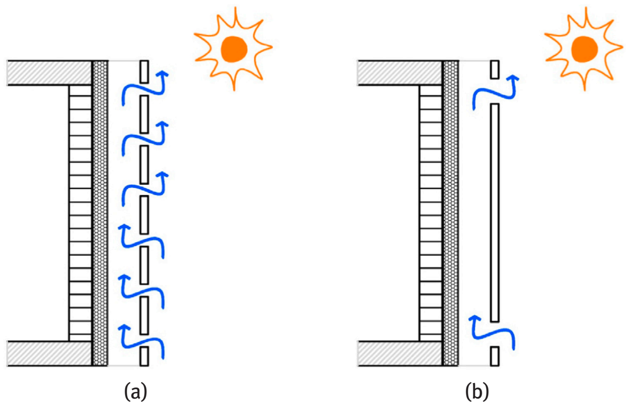

Figure 3: Types of ventilated facades: (a) open joint and (b) closed joint [14].

facades (closed joint and open joint), referring to the results for facades without an air cavity, that is, external thermal insulation composite systems (ETICS). Scientific studies by Griffith [12], Naboni [17], and González et al. present the methods of analysis of ventilated facades with the explanation of all their elements. In addition, Naboni [17] presented a description of thermodynamic dependence in the numerical model of ventilated facades. On the basis of experimental research, validation with the numerical number was carried out and the results obtained were compared with the results of the standard facade (facade without air cavity). Numerical simulations performed by Naboni [17] were conducted for Italy. The energy savings for the summer season in the case of the southern wall were in the range of 7–8.1% (energy savings for air conditioning). There is also a minimum saving in the range of 1.1–2.6% in winter (energy savings for heating). The article by Mahdavinejad and Mohammadi [16] presents a numerical study comparing the ETICS facade with a ventilated facade for a building located in Tehran. The energy savings in summer and winter were recorded at 27% and 33%, respectively. In turn, Sanjuan et al. [18] analysed the thermodynamic issues of the ventilated facade, referring them to the three-layer wall with air cavity. The results presented by Sanjuan et al. [18] show very positive functioning of the ventilated facade in relation to the three-layer wall with air cavity, without the possibility of replacing this air. The savings in the summer period with high insolation are about 26%; in the case of the northern side in the winter period with night-time effects, heat losses are more than 50%. The model showed the daily influence of the outside temperature on the outside wall during the summer and winter for the Madrid area in Spain. In the article [18], the authors made a verification of the thermal impact by performing experimental studies of closed-joint ventilated facades with different variants of external cladding. Suárez and others [20] presented the results of numerical simulations for the region of Spain, where the ventilated facade was compared with the standard one. On an annual basis, ventilated facades recorded energy savings on cooling – 9% in summer and more energy on heating in winter, 4%.

Ventilated facades are a good solution for warmer regions of the world, because of the limitation of the convention between the exterior cladding and the insulation. In winter, the efficiency of such facades decreases significantly, but as some scientific studies indicate, they can still yield minimal benefits compared to standard ETICS facades. Efficiency in winter is lower because they have a lower thermal conductivity value and have a limited solar gain effect through convection (no direct contact between the insulation and the cladding).

Owing to the lack of such studies for the Central European region, the authors performed numerical simulations for the summer period. In addition, the authors decided to compare ventilated facades, closed joint and open joint, in terms of thermodynamics in the summer period, examining whether the impact of the technology affects the energy efficiency of facades. The comparison also includes standard ETICS facades (without air cavity).

3 Creating A Numerical Model And Making Assumptions For The Simulation

Numerical analysis was performed using computational fluid dynamic (CFD) software: Ansys Fluent module based on Navier-Stokes equations. The reason for choosing such software is confirmed by articles [4, 5, 7, 10], which present similar issues solved with this software. In addition, the article by Cirillo et al. [7] presents the results obtained for the validation of the numerical model also performed using this software. The results obtained confirmed the significant compliance with the experimental study. K-ε (RNG), discussed by Launder and Spalding [15], has been adopted as the numerical flow model. In turn, Chen [3] demonstrated that the accuracy of the flow model adopted in this way is good and is applicable for this type of tasks. The radiation model based on Chui and Raithby [6] was adopted as discrete ordinates (DO), which was presented as fast and accurate.

3.1 Technological and material assumptions of the numerical model

In order to compare the energy efficiency of the facade, three numerical models have been created, reflecting the following types of facades: standard facade (without air cavity), closed-joint ventilated facade and open-joint ventilated facade. All models were made of the same materials. It was assumed that the supporting wall was made of 240-mm-thick silicate blocks, the thermal insulation was made of 150-mm-thick polyurethane, and the external cladding was made of fibre cement boards in the so-called dark colour and 20 mm thick. For the best possible representation of the global effect of the influence of the external temperature on the internal temperature, a model corresponding to the wall height of 4000 mm was adopted. The thermal characteristics of all materials are shown in Table 1.

The first model was adopted as a standard type facade, where fibre cement boards are placed directly on the insulation and the bodies are in contact (marked in the work as A), as shown schematically in Figure 4. The next two models were adopted as ventilated facades in two variants, namely:

– closed-joint ventilated facade/opaque ventilated facade (marked in the work as B),
– open-joint ventilated facade, marked as C.

Models of ventilated facades (B and C) have a 50-mm-wide air cavity between the insulation and the external cladding of the fibre cement boards. In the case of a model with close joint (model B), air enters the air cavity through two slots: at the bottom and top of the external cladding, each 30 mm wide. In the case of the model with open joint, the air can enter not only through the previously mentioned slots but also through the 20-mm-wide additional slots, reflecting the assembly of the fibre cement boards. All the adopted diagrams are shown in Figure 4. A full-wall fragment of the facade was analysed without taking into account the influence of window openings and thermal bridges. The analysed fragment of the facade was located directly above the ground level, allowing air to drain only upwards.

3.2 Climate assumptions of the numerical model

External and internal temperature parameters were adopted based on the standard in force in Europe: standard EN 1991-1-5 [8]. The most unfavourable calculation situation related to the influence of temperature and

Table 1: Thermodynamic parameters of materials.

Materials	Density (kg/m^3)	Specific Heat (J/[kg·K])	Thermal Conductivity (W/[m·K])
Silicate blocks	1900	880	0.800
Polyurethane – insulation	30	133	0.0207
Fibre cement boards	1800	920	0.400

insolation during the summer period was assumed. The facade is located in Poland (Wroclaw), and it is situated on the southern side because of the biggest insolation. The standard does not take into account the impact of height above ground level; an element directly above ground level is adopted. It is assumed that the facade will be made in the so-called dark colours because of the highest absorption of sunlight. The parameters related to such assumptions are given as follows:

– indoor temperature is 293.15 K (20°C),
– outdoor temperature is 311.15 K (38°C),
– temperature inside is 293.15 K (20°C),
– additional temperature difference due to 42 K (42°C) of sunshine
– total temperature acting on the facade at the peak 311.15 K (38°C) + 42 K (42°C) = 353.15 K (80°C).

3.3 Numerical model

Numerical simulations were performed in two-dimensional (2D) manner in Ansys Fluent, the Ansys Workbench module. The size of the model was 2390 mm wide and 4000 mm high in order to reproduce global airflow and heat transfer conditions. In the central plan of the model, the wall is modelled so that there is air space on the right and left sides. The details of the assumed parameters of the model are presented in Figure 5. According to the authors, such a model makes it possible to reproduce global conditions of air flow (outside) and heat transfer. The inflow of air with a preset velocity parameter of 2.5 m/s and a temperature of 311.15 K (38°C) simulate wind. In addition, an appropriate temperature of 353.15 K (80°C) on the external edge of the fibre cement board simulates insolation. The initial air velocity allows the warm air to be evacuated from the air cavity. It is assumed that the conditions inside the building are constant and the air inside has an initial temperature of 293.15 K (20°C) and is not replaced or cooled. For the creation of the finite element grid, triangular 3 node elements were used; the

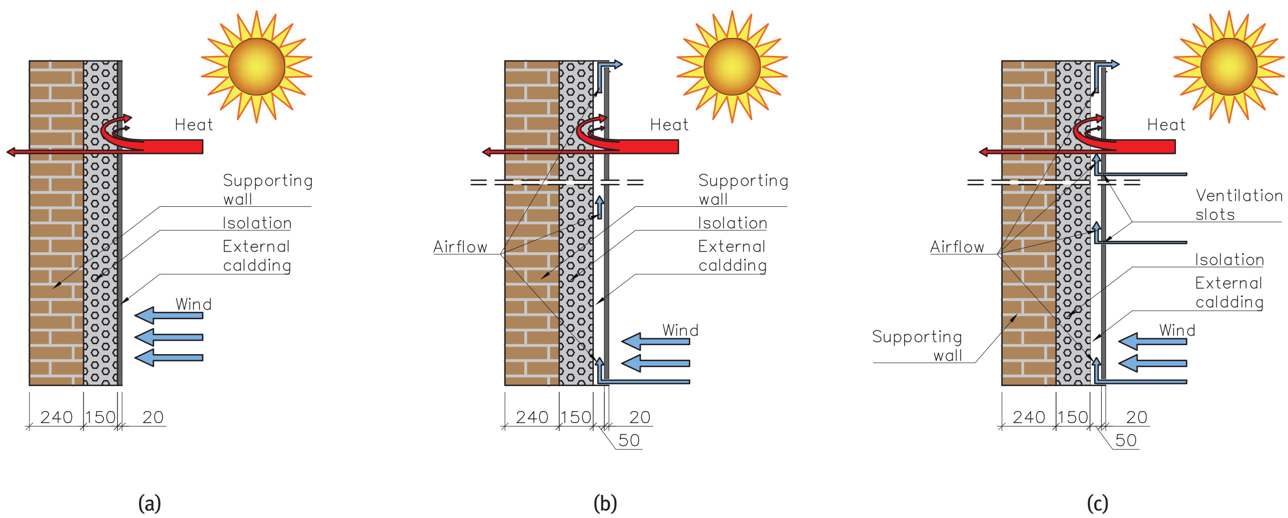

Figure 4: Facade diagrams for numerical simulations: (a) standard facade, (b) closed-joint ventilated facade and (c) open-joint ventilated facade.

dimensions of individual finite elements were selected depending on the location with a size ranging from 1 to 50 mm – details are shown in Figure 5. The diagrams for a standard facade and an open-joint ventilated facade were adopted analogously to the presented diagram of a closed-joint ventilated facade in Figure 5. The situation adopted for the purpose of the analysis is the most unfavourable form of high temperature and insolation impact; if other temperature conditions are applied, the results may have a different course. It should also be noted that the temperature distribution is influenced by the parameters of the ventilated facade.

4 Numerical Simulation Results

The results of the numerical simulation are presented in the form of a distribution of temperature maps, shown in Figure 6 (the colour scale for all temperature maps is the same). The temperature maps of all facades show isolines in different colours, showing temperatures in solids and gases. The external edge of the external cladding for all facades A, B and C has a similar temperature, mainly due to thermal radiation. As can be seen in Figure 6, the use of ventilated facade technology significantly reduces the temperature on the inside (cooler colour shade on temperature maps). This is caused by the limitation of heat transport in the way of direct contact of solids and is related to their conductivity. The heat from the outside, in the case of a ventilated facade, is transmitted mainly by radiation. In an open-joint ventilated facade, aberrations are noticeable in the places of additional ventilation slots, allowing air to enter the air cavity. The models deliberately do not take into account the energy consumption by the inner edge of the wall, cooling it down by the colder air inside the room.

The results shown in Figure 6 are then presented in order to compare the values obtained more accurately. It should be explained that the temperature was controlled at the following points: inside the room, 6 measurement points; inside the edge of the supporting wall; edge of the supporting wall, insulation; edge of insulation, external cladding in case of standard facade; external edge of insulation in case of facades B and C; air cavity in case of facades B and C; and external edge of external cladding. The height at which the temperature was controlled is 2000 mm from the floor, with a few exceptions for an open-joint ventilated facade. The aberrations caused by the air flow at the additional ventilation slots forced temperature controls for the external edge of the external cladding and the air cavity at 1505 mm. The measuring points are illustrated in Figure 7. Characteristic temperature values with percentage reference are presented in Table 2.

Chart 1 shows the results of temperature control at temperature measurement points for facades A, B and C. The line of the standard facade diagram differs significantly; the values are much larger. The graph lines for open-joint ventilated facade and closed-joint ventilated facade connections present similar values, except for the temperature inside the air cavity. The temperature in the air cavity between the insulation and the external cladding for open-joint ventilated facades is approximately 3 K (3°C) higher. This is likely to be due to the higher number of ventilation slots that supply and discharge air. Analysing the internal edge of the supporting wall, the temperature in a standard facade is about 3 K: 342.73 K (69.58°C), which

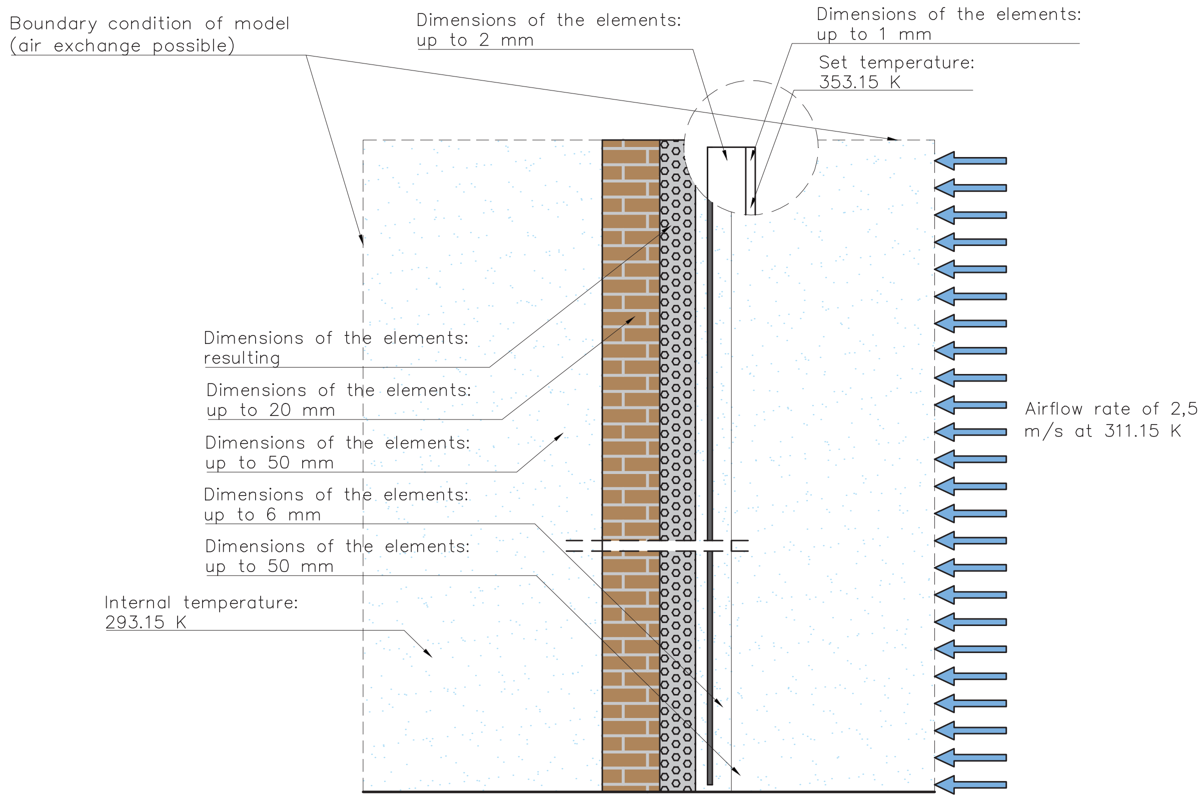

Figure 5: Numerical model of the closed-joint ventilated facade.

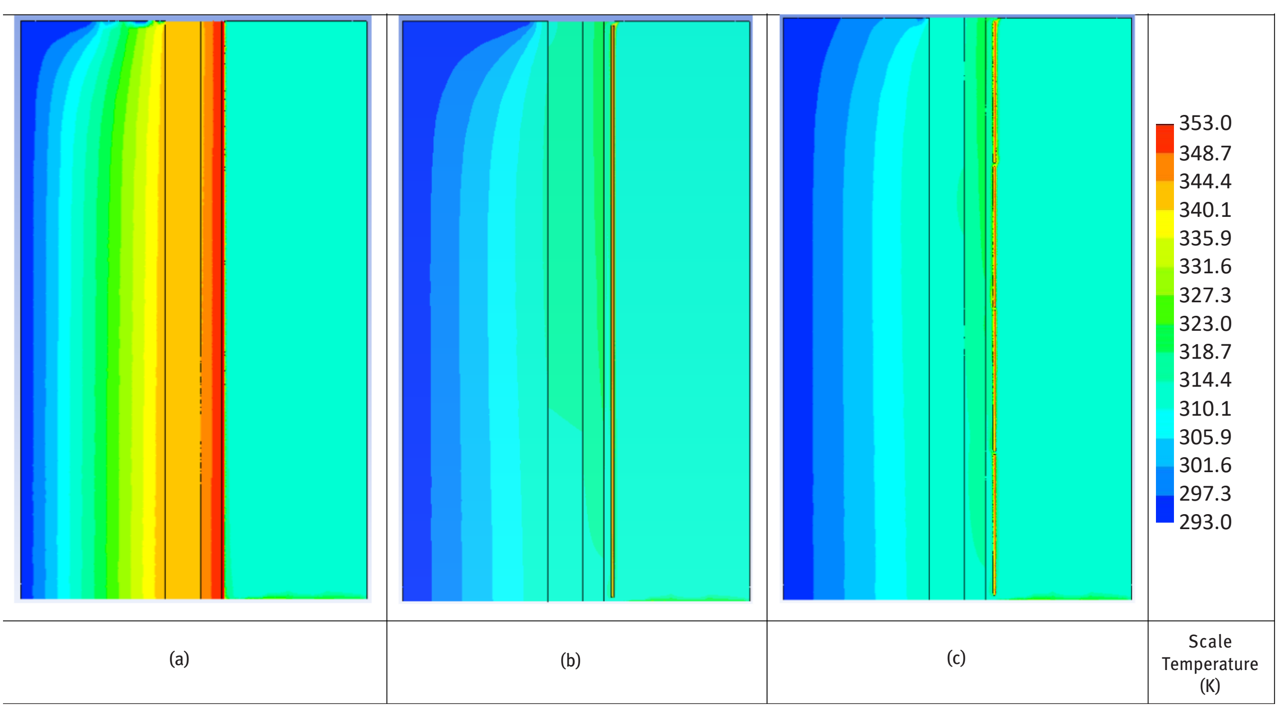

Figure 6: Temperature distribution maps of the facade obtained during numerical simulation: (a) standard facade, (b) closed-joint ventilated facade and (c) open-joint ventilated facade.

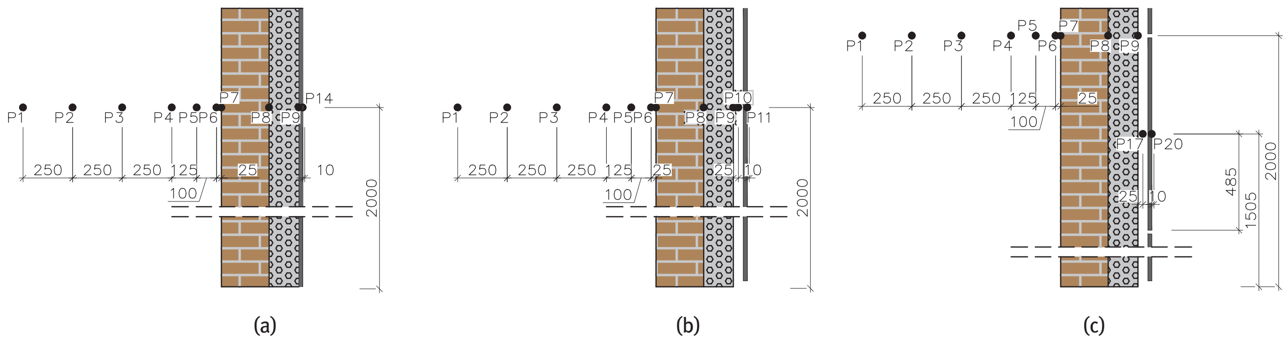

Figure 7: Location of temperature measurement points: (a) standard facade, (b) closed-joint ventilated facade and (c) open-joint ventilated facade.

Table 2: Characteristic values of temperature.

	P1		P3		P7		P10/P17		P11/P14/P20	
Localisation	**Starting point**		**40 cm from the wall**		**Internal edge of the**		**Air cavity**		**External edge of**	
Standard facade	293.15 K	100%	319.07 K	100%	342.73 K	100%	-	-	341.51 K	100%
	(20°C)		(45.92°C)		(69.58°C)				(68.36°C)	
Closed-joint	293.15 K	100%	303.96 K	95,3%	315.34 K	92.0%	313.81 K	99.3%	340.93 K	99.8%
ventilated facade	(20°C)		(30.81°C)		(42.19°C)		(40.66°C)		(67.78°C)	
Open-joint	293.15 K	100%	303.55 K	95,1%	313.91 K	91.6%	316.02 K	100%	338.59 K	99.1%
ventilated facade	(20°C)		(30.40°C)		(40.76°C)		(42.87°C)		(65.44°C)	

is 46.92 K (46,92°C) higher than the indoor temperature, where it is 293.15 K (20°C). In ventilated facades, this is 314.77 K (41.62°C) for the closed-joint ventilated facade and 313.91 K (40.76°C) for the open-joint ventilated facade. The temperature difference, indicating that ventilated facades are more favourable, is about 28 K (28°C), which is about 44% lower than that in the case of a standard facade. It can also be noted that despite the higher temperature in the air cavity, for an open-joint ventilated facade, the temperature on the internal edge of the supporting wall is lower, probably due to the better heat dissipation near the insulation.

5 Summary

Ventilated facades are very well suited to the increasing demands placed on buildings in terms of thermal comfort and their use. These facades can be used not only in regions of the world with high temperatures but also in regions with the so-called moderate climates. A solution should be sought to improve the efficiency of these facades during periods of reduced temperatures. Another unquestionable advantage of increasing the popularity of ventilated facades may be the reduction of their costs compared to standard facades (which are several times cheaper today). The research results also indicate trends in the use of these facades – they are much more popular in hot regions, especially in South Asia and the Middle East.

On the basis of numerical simulations presented in this article, it has been shown that the temperature at the internal edge of the supporting wall is about 28 K (28°C), lower, for ventilated facades, which is about 44% lower than that for a standard facade. The selection of the ventilated facade technology in close or open joints has minimal influence on thermal efficiency of the whole partition – the difference is less than 0.85 K (0.85°C). Numerical simulations are a very good and cheap alternative to experimental tests; they allow to direct the trends for the tested elements. The direction of successive numerical simulations of ventilated facades should, in the opinion of the authors, aim at testing the influence of air flow velocity on the air cavity and explaining the aberrations in the places of additional ventilation slots.

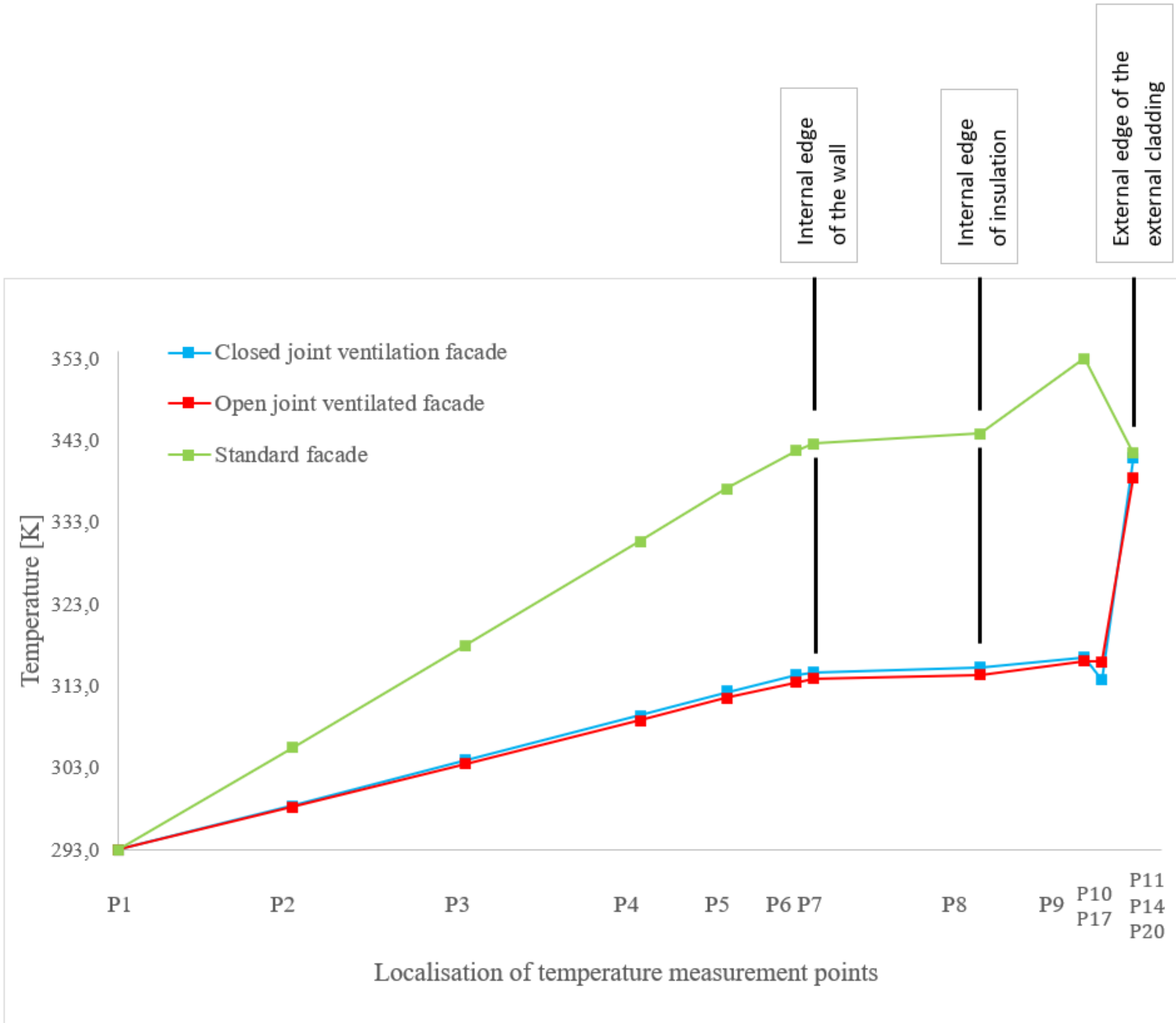

Chart 1: Temperature overview for the control points of the individual types of facade.

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