Energy consumption of smart facade

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Abstract. Expanding awareness of multi-layer smart facades and their use and comparison with external thermal insulation composite system (ETICS). Numerical calculations being used to present energy use of given facade in comparison with ETICS on the same building with identical boundary conditions.

1 Introduction

Ventilated facades are nowadays already a well-known and commonly used way of realizing the building envelope. The construction of ventilated facades is suitable for their attractive appearance and a wide range of used cladding materials, durability, and many other advantageousness. Above all, they are used mainly for their advantages from the building physics point of view. For example, compared to the external thermal insulation composite system (ETICS), ventilated facades have a milder course in terms of the annual temperature balance inside the structure, and they drain moisture well from the perimeter shell. The course of heat flux is the subject of this article.

A key component of ventilated facades is the ventilated gap. This is the area between the external cladding, which is in direct contact with the exterior, and the perimeter wall, or its thermal insulation located on the outside of the perimeter structure. This ventilated gap allows air to move freely. Air is sucked into the structure at the bottom of the facade through an entrance opening usually equipped with a grid to prevent animal entry, is driven along the length of the facade behind the external cladding and is then released to the exterior through an outlet opening in the upper part of the facade. The air movement itself is ensured by a phenomenon called natural convection. In the vertical gap, warmer air rises upwards due to its lower bulk density – the so-called chimney effect. Air flows naturally in most ventilated facade systems. Forced ventilation is used in the system of double facades [1], which by their own design are more space-intensive and create larger air gaps.

The air is heated up the height of the facade in two ways – the first and most significant is the influence of solar radiation, which heats the outer cladding and then transfers the heat to the air in the ventilated gap. The second way with less influence is the heat loss of the building (from the perspective of the interior), where heat flows from a warmer to a cooler environment, in other words, from the interior to the ventilated gap. This particular phenomenon occurs at the moment when the air temperature in the gap is lower than the temperature on the interior side, mainly in the colder period of the calendar year. In this

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ingenious way, the heat load causing overheating of the building envelope is effectively removed, and consequently the requirements for possible cooling of the interior spaces in the summer season are reduced. In winter, a ventilated facade, very similar to ETICS, causes milder heat flows than a facade without any thermal insulation measures. Compared to ETICS, however, the ventilated facade may not be more effective in winter [2].

The concept of a smart facade developed at the Institute of Building Services, Faculty of Civil Engineering, Brno University of Technology, consists in the ability to regulate the air flow in the gap using a system of forced ventilation and closing flaps on the side of the inlet and outlet opening depending on the changing boundary conditions. Fans with adequate input power and performance located in a smart facade can ensure greater air flow to get rid of a greater heat load. Shut-off flaps ensure the movement or stopping of air flow to achieve the desired air temperature in the ventilated gap. They work in two modes: "open" and "closed". Multiple control steps in the terms of regulation for these flaps seem irrelevant at the moment due to the leaks in the outer casing - the lining through which air can freely escape from the ventilated gap. These leaks are some between 10% to 40% depending on the design of the cladding and the size of the gaps between the individual cassettes.

The FSVM software (acronym that stands for “Façade with Ventilated Gap” in Czech language), also created at our faculty, helps us calculate the heat flows through the ventilated facade and the temperatures in the specified facade. This software allows us to calculate the heat transfer coefficient of the perimeter wall construction with a ventilated facade based on the input parameters of the facade, taking into account the thermal bridges from the anchors supporting the external cladding. This calculation also appears in the freely available version of the program [3]. Other results are the parameters of the facade in hourly steps during the entire calendar year. The FSVM program calculates with corrected interior temperatures and takes into account the influence of climatic influences throughout the year, including the significant influence of solar declination after months and heat gains from solar radiation also throughout the whole year. A very valuable output is the simulated heat flows over the year by month steps. The heat flows are simulated for the specified ventilated facade, for the virtual relevant ETICS system (for comparison with the ventilated facade) and for the smart facade. The software is thus able to display the percentage reduction of heat flows by using a smart facade. The calculations of the FSVM software went through numerous checks and careful development within the project supported by TAČR (abbreviation for Technological Agency of the Czech Republic) FW03010062: Smart facade with optimized energy properties.

Our main goal in the smart facade research is to achieve a possible prediction of the structural physical behavior inside the facade based on measurable boundary conditions. Another goal is to be able to learn to respond to this behavior, to achieve optimal properties inside the perimeter wall structure with a ventilated facade, to achieve the smallest possible heat flows through the structure and thus ensure significant energy savings.

2 Methods

By measuring on real ventilated facades, we obtained valuable data regarding the temperatures on the inner and outer surface of the facade cladding, the temperatures inside the ventilated gap and the temperatures in the thermal insulation. In addition, by measuring the mentioned temperatures, we obtained relevant data related to the weather effects acting on the measured facade in real time.

The FSVM software is developed on the basis of data measured from a south-east oriented ventilated facade with orange and gray cladding material surface color on a building located in the Czech Republic in the regional city of Brno. Corrected calculations are used to approximate the calculation results of ventilated facades with other parameters. These corrections will be gradually refined with the gradual development of the software and the evaluation of data from other measurements already carried out on other facades.

Calculations in the software follow the procedures and relationships according to the standard [4], or when calculating the heat transfer coefficient with anchors according to the standard [5]. Our corrections were examined according to the already mentioned evaluation of data from the measured ventilated facade in Brno. The procedure for the appropriateness of using our corrected calculations is through the approximation of the own correction factors used in the normative calculations. After being used in the calculation, these must come close to the results of real measured data with the smallest possible error.

The input data for calculating the heat fluxes in the FSVM software are:

- structure composition and facade area,
- design temperatures of the interior and exterior in winter and summer and the amplitude of temperature fluctuations,
- geographic location and sun orientation of the facade,
- estimated dimensions of the facade,
- parameters of ventilation holes,
- wind map region, orthography, solar constant and atmospheric pollution,
- specific heat capacity and air density,
- position of flaps for the smart facade in individual months (closed by default in winter, open the rest of the year),
- thermal insulation properties of the external cladding.

A detailed breakdown of all input quantities can be seen in the freely available demo version of the software online [3]. The software is currently only available in the Czech language.

For further measurement and testing of the system of flaps and fans of the smart facade, a prototype of the facade located in the research center of the Technical University of Brno AdMaS (abbreviation for Advanced Materials, Structures and Technologies) was built and is being used. Research on this part is still in development.

3 Data

By measuring with the data logger AHLBORN ALMEMO 5690-2 and a series of temperature sensors at several control points on the facade and pyranometers, we obtained the values of temperatures, air flow speed, air humidity and the intensity of solar radiation acting on the measured facade. Subsequently, the research team took over the data from the measuring station after a certain time interval and transferred all the measured values to the MS Excel software, in which it was much easier to analyze the data.

The control points on the facade were set up to measure two series of temperatures in the lower part of the facade and two series of temperatures in the upper part of the facade, i.e., 4 control points. The height of the facade is 14 meters. There were 2 control points on the gray facade, one series of sensors in the lower part of the gray facade and one series of sensors in the upper part of the gray facade. In the winter, the measuring center was equipped with a heat-insulating cover against possible freezing.

We recorded all the data every 10 minutes 24 hours a day throughout the year and got a real insight into the physical phenomena present on the facade while processing and analyzing it.

4 Results

After processing the measured data, we were able to analyze and get an idea of the course of constructional-physical phenomena present on/in the ventilated facade. In the following graphs (Fig. 1., Fig. 2.) we can see the course of temperatures and the influence of solar radiation and outdoor temperature on air temperatures in the gap of the ventilated facade. The data always represent two successive reference days in one month of the given season. We distinguish two values of air temperatures in the gap for one moment in time, namely the temperature in the upper part of the facade (at a height of about 14 meters from the lower part) and the temperature in the lower part of the facade (height of the facade about 0.5 meters). The 14-meter-high ventilated facade itself was located at a height of 3 meters above the landscaped area around the building. In the graphs (Fig. 1, Fig. 2), these values are represented by a green curve for the upper part of the facade and a blue curve for the lower part of the facade.

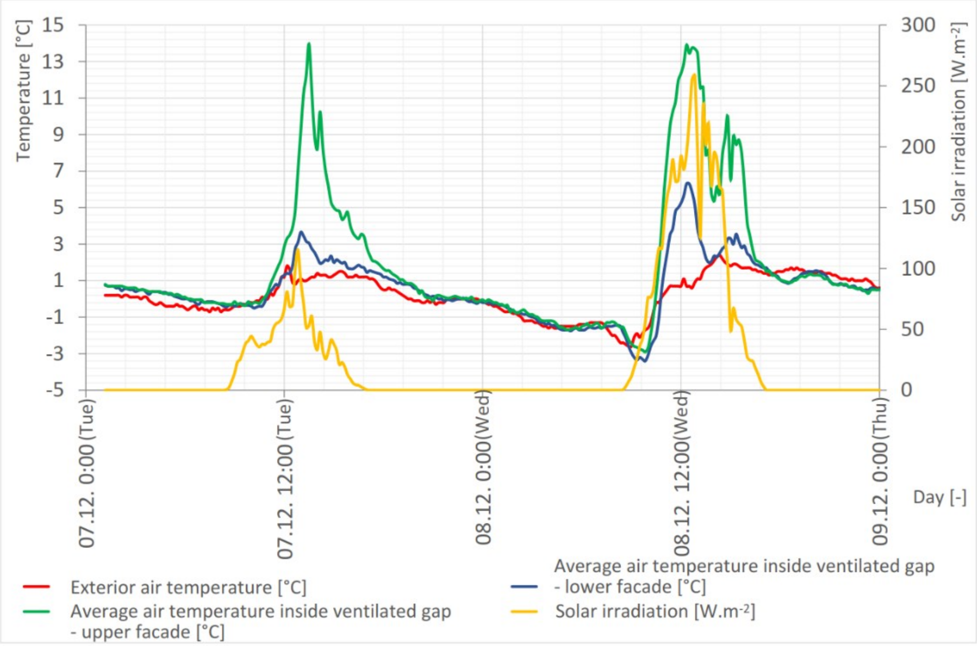

Fig. 1. The effect of outdoor temperature and solar irradiation on the temperature in the gap – winter, December 2021.

We can see that solar radiation causes a big spike on air temperature inside ventilated gap. The bigger intensity of solar radiation the bigger effect on both parts of façade – upper and lower. The upper part of façade gets heated more significantly because natural convection from lower part of façade brings the heated air upwards and the air is getting heated continuously more and more during its whole path of travel up to the point where the air exits façade. Meanwhile lower part of façade is supplied by exterior air that enters ventilated gap.

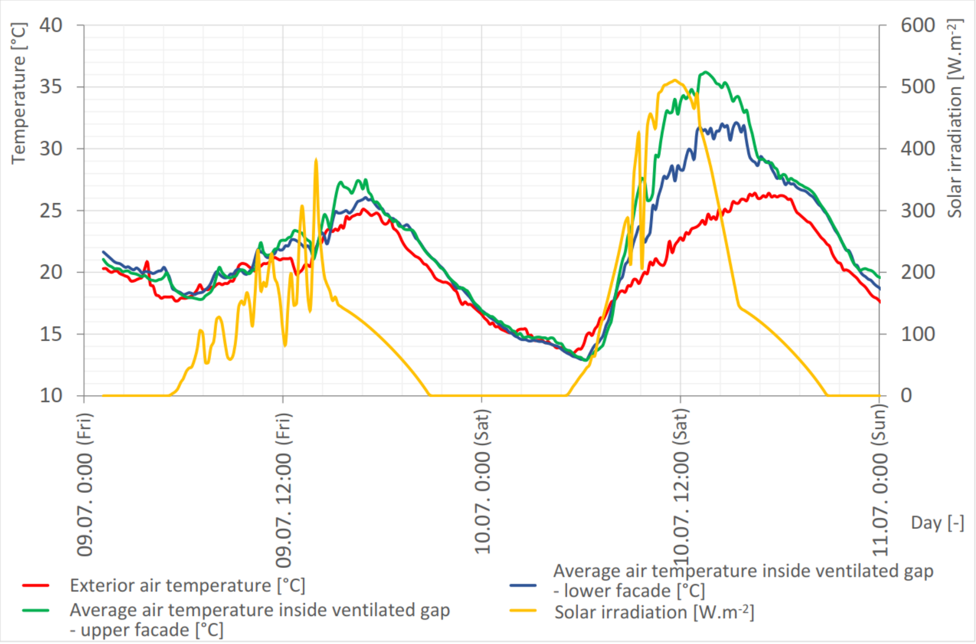

Fig. 2. The effect of outdoor temperature and solar irradiation on the temperature in the gap – summer, July 2021.

The graphs (Fig. 1., Fig. 2.) show how much influence solar radiation has on the temperature inside the ventilated gap. Both in winter and in summer part of the year. However, temperatures in graphs are real measured values. Rising temperature of air inside ventilated gap is not affected only by solar radiation but also from heat flow from interior. This phenomenon is not clearly visible in these graphs (Fig. 1, Fig. 2.) for comparison. Adding more information would make these graphs (Fig. 1., Fig. 2.) unclear. More information about more weather effects or more information about heat flow from interior to ventilated gap that affects air temperature inside gap is described in a thesis [2].

As part of determining the correction factors, it was necessary to approximate the values of the absorption coefficient of the cladding material ε [-] and the heat transfer coefficient α [W.m^{-2}.K^{-1}] to calculate the surface temperature of the cladding t_p [°C] according to the equation (1):

$$t_p = t_e + \frac{I * \varepsilon}{\alpha} \tag{1}$$

where:
t_p – surface temperature of the cladding [°C]
t_e – outdoor air temperature [°C]
I – intensity of solar radiation [W.m^{-2}]
ε – coefficient of light absorption of the cladding [-]
α – thermal transmittance coefficient [W.m^{-2}.K^{-1}]

We have approximated the values in such a way that the resulting temperature of the cladding surface is as close as possible to the external temperature of the cladding surface measured by us on the real facade. The result was one value of α and one value of ε for each month separately. The determined values of the coefficients in simplicity included the influence of the weather and climate conditions for the given month on the facade with the given parameters [2].

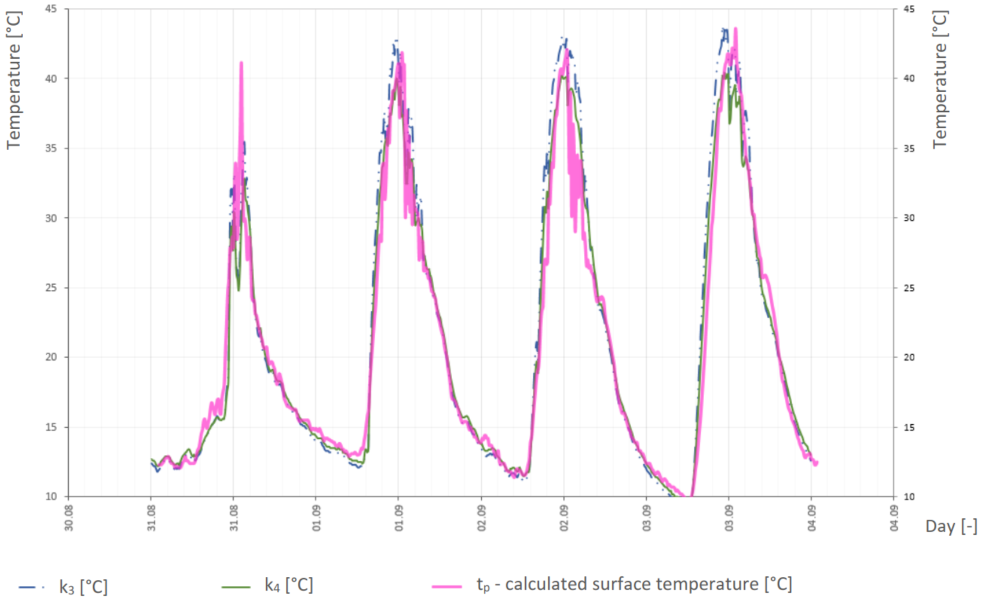

Fig. 3. Example of used calculations (1) with already approximated coefficients compared to measured temperatures on real facade. “k3“ stands for third control point located on upper left part of the facade and represents temperature of outer cladding surface. Analogically “k4“ stands for fourth control point located on the upper right part of the facade and represents temperature of outer cladding surface as well. 4 days of September 2021.

The approximate values of the coefficients α and ε are used for correction of calculations in the FSVM software. The following results will be presented as results directly from this program.

Table 1. Wall layers and their parameters.

Perimeter wall				
Construction No.	**No. of layer**	**material**	**d [m]**	**λ $[W.m^{-1}.K^{-1}]$**
S1	1	Thermal insulation	0,060	0,037
	2	Bearing wall structure	0,380	0,111
	3	Interior plaster	0,005	0,880

where:
d – layer thickness [m]
λ – coefficient of thermal conductivity of the material of the layer $[W.m^{-1}.K^{-1}]$

Table 2. FSVM input parameters [3].

Parameter	**Value**
Wall surface	100 m^2
Wall openings	20 m^2
Cladding type	Medium heavy (up to 40 $kg.m^{-2}$)
Bearing material	Steel
Pad thickness	10 mm
Winter exterior air temperature	-12 °C
Winter interior air temperature (t_{iz})	20 °C
Facade location latitude (lat)	50 °

Table 2. FSVM input parameters [3]. (Continues from previous page)

Parameter	**Value**
Facade location longitude (long)	16 °
Facade location altitude (H)	300 m AMSL
Facade angle with a horizontal plane (α)	90 °
Facade azimuth (γ)	120 °
Mean calculated facade width (š)	1 m
Facade height (h)	15 m
Facade height above ground (h_0)	1 m
Mean calculated facade height (h_x)	7,5 m (temperatures in the centre of facade)
Bottom inlet coefficient	0,4
Upper outlet coefficient	0,6
Ventilated gap depth (d_m)	0,12 m
Narrowing of the intake vent (Z)	80 %
Narrowing of the exhaust vent (Z_0)	70 %
Czech wind map area (O)	2
Orthography (o)	City
Solar constant (I)	1370 $W.m^{-2}$
Atmospheric pollution (z)	4 (throughout year)
Temperature fluctuations amplitude (A_m)	7 K
Summer interior air temperature (t_{il})	25 °C
Air density (ρ_w)	1,2 $kg.m^{-3}$
Specific heat capacity of air (c_w)	1010 $J.kg^{-1}.K^{-1}$
Closing flap settings	Oct-Mar closed, Apr-Sep opened
Cladding thickness (d_p)	0,08 m
Thermal conductivity of cladding (λ_p)	0,115 $W.m^{-1}.K^{-1}$
Relative solar absorptivity (ε_p)	0,7
Default convection heat transfer coefficient of outer cladding surface (α_e)	20 $W.m^{-2}.K^{-1}$
Air permeability of the cladding (n_p)	20 %

Possible graphic and numerical outputs from the FSVM software as of 17.3.2023:

- diffuse solar radiation,
- direct solar radiation falling on the facade,
- total solar radiation falling on the facade,
- equivalent solar temperature on the azimuth-oriented facade,
- outdoor temperature according to the season,
- corrected interior temperature according to the season,
- the temperature of the outer surface of the facade cladding,
- heat gain from total solar radiation on the facade,
- air temperature in the ventilated gap for the facade height h,
- air temperature in the ventilated gap for the selected height on the facade h_x,
- heat flux from the building into the air gap with opened shot-off flaps,
- heat flux from the building to the air gap with smart ventilation control,
- heat flux from the building to the exterior without a ventilated gap (virtual ETICS).

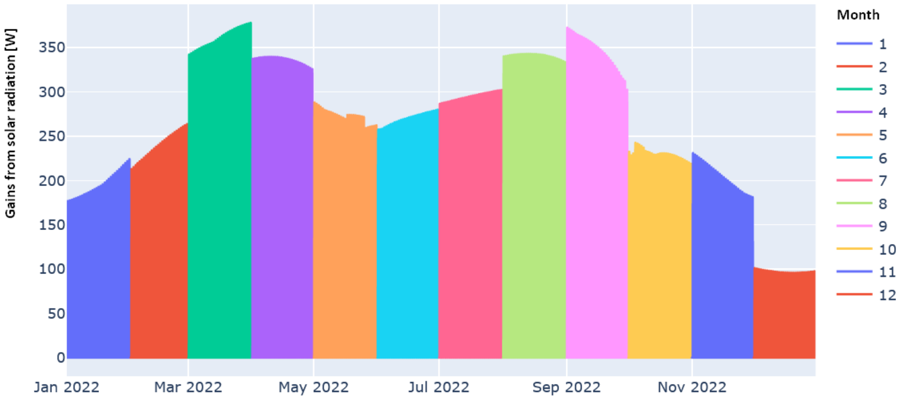

Fig. 4. Example of chart of simulated values of facade gains from solar radiations throughout the year – software FSVM.

Sudden and visible differences between months are an example of differences between correction coefficients for solar gains. Corrections differ by month, and they represent (among other weather conditions) simulation of how sun rays act on our specified surface – on 90° wall in our case. At our specified geographical location sun rays hit our surface at the most efficient angle in March and September. Thus, the solar irradiation heats the surface of cladding in an efficient way, and this produces significant solar gains which heats up air in the ventilated gap.

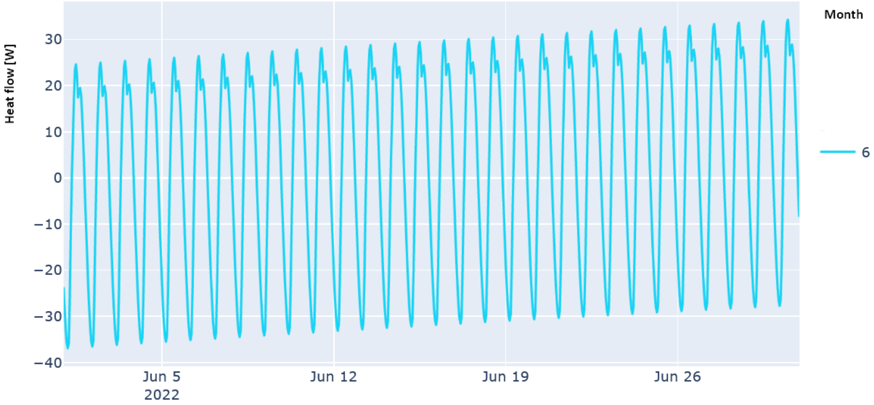

Fig. 5. Example of chart of simulated heat flow from interior to ventilated gap – closer look at month of June reveals that the detail of continuous graph is indeed represented by hourly simulated values. Increase in heat flow during month seems constant. This is caused by simplified calculations in our simulations which tells us with an approximation that the month's weather and building usage is considered in a simpler correction. More complex settings during specific months can be set in an upgraded version of software.
– software FSVM.

The table of heat flows passing from the interior to the exterior or to the ventilated gap (Table 3.) will give us a more detailed view of the simulated heat gains and losses during the year on the specified facade. The units used here are facade heat flows in kW recalculated for a period of one month. Therefore, the unit kWh/month, or *x* kWh per 720 h, where "*x*" value represents the output value from the software, is given here. The percentage reduction of heat flows through a smart facade expresses a relative saving of energy, or a change in the character of their action from negative values (heat losses) to positive values (heat gains) when using the flap system of a smart facade instead of a standard ventilated facade with natural and unrestricted air movement.

Table 3. Simulated total heat flow values for considered type of facade.

	ETICS [kWh/month]	Ventilated facade [kWh/month]	Smart facade [kWh/month]	Percentual reduction of heat flow with smart facade
1	-41,75	-57,09	-48,82	14,48%
2	-24,41	-36,88	-29,53	19,91%
3	-9,79	-21,85	2,62	111,99%
4	-1,66	-12,55	-12,55	0,00%
5	4,02	-7,28	-7,28	0,00%
6	8,19	1,51	1,51	0,00%
7	13,30	6,80	6,80	0,00%
8	17,35	11,66	11,66	0,00%
9	11,95	6,68	6,68	0,00%
10	-3,27	-10,59	3,33	131,44%
11	-17,04	-26,06	-16,51	36,63%
12	-37,00	-48,83	-44,76	8,33%

Simulated temperatures from the FSVM software in the following graphs (Fig. 6., Fig. 7.) point to the fact that the use of a ventilated facade is more effective in the summer months (Fig. 7.) and contact insulation, on the other hand, shows better efficiency in the winter months (Fig. 6.). According to the data from the graph (Fig. 6.), it can even be said that by using a smart facade, at noon on the simulated day of January 15, we even achieve a small thermal gain from the facade for a relatively short moment in time. In the summer months, the computer simulation did not consider the closing of the flaps and thus the effect of the smart facade on the change in heat flows is identical to the classic ventilated facade.

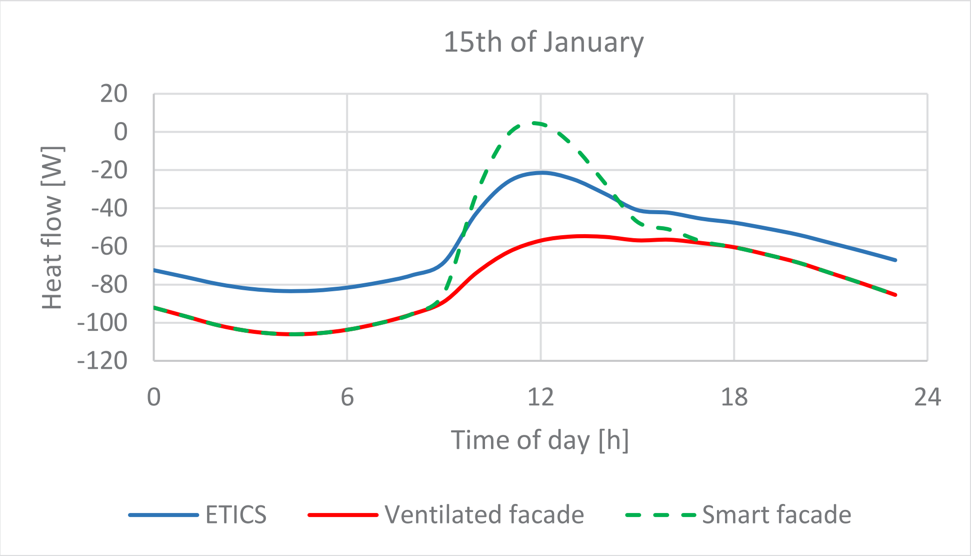

Fig. 6. Simulation of heat flow through a different type of facades throughout reference winter day on 15th of January.

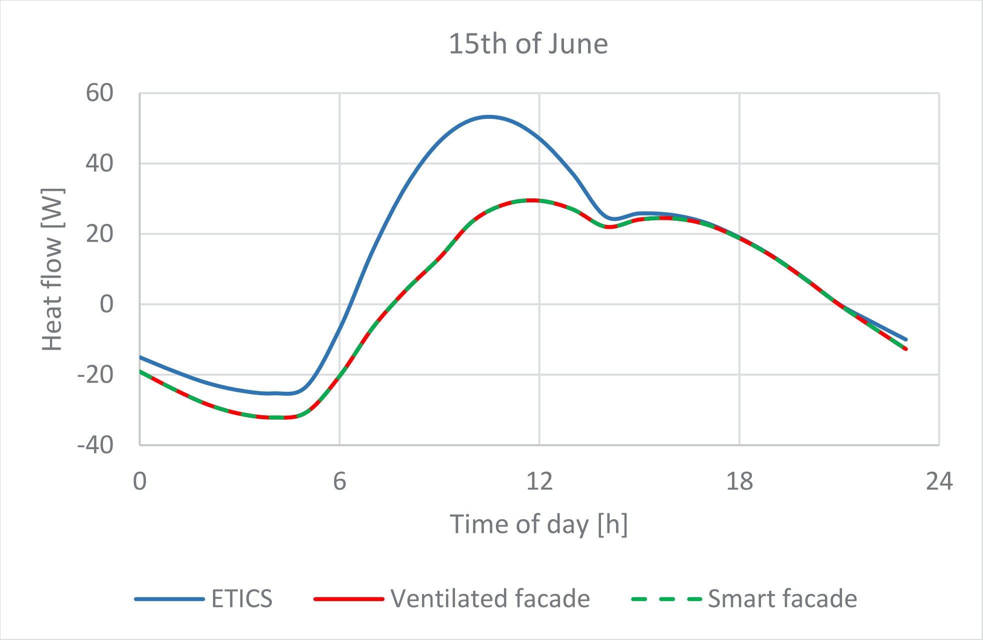

Fig. 7. Simulation of heat flow through a different type of facades throughout reference summer day on 15th of June.

5 Discussion

The FSVM program has proven to be an effective computational tool. It was created on the basis of our research, which deals with the solution of basic questions connected with the development of a smart facade. The results of the simulations correspond to a large extent to the actual condition that we measured and examined on the facade described in chapter 2 of this publication. However, the program is still being developed in terms of universality and accuracy, so that its calculations can be applied to as many types of classic ventilated facades with different parameters as possible. The outputs from the software are very rich and can serve as a cornerstone in the design and implementation of a possible future smart facade.

The most significant variable factors that will influence the thermal technical parameters of the facade will be the outside air temperature and the intensity of solar radiation. Our goal in research and development (besides improving the FSVM software) will further be the ability to respond to these variable influences acting on the facade in real time and to control the airflow in ways other than closing and opening the shutters at the air inlet and outlet of the air gap. The motive for the development of a smart facade is certainly energy saving, which should ideally be equal to zero consumption. With our abilities, we would like to at least come close to this ideal.

According to the professional publication [6], experts have been working on numerical calculations in the field of ventilated facades for over 40 years. Along with the expansion of the scope and possibilities of computing technologies, a lot of approaches arose, to which the authors of this publication devoted their attention and experimentally verified various methods, possibly their advantages, disadvantages, and their limitations [6].

Smart facade research also includes the investigation of modules with fans for air flow control, the influence of modules with a so-called "green facade" and the effect of plants on the properties of a ventilated facade or modules with air flow regulation together with photovoltaic cells.

6 Summary

Based on our results, it can be said that we can already partially predict the structural physical behavior on the surface and inside the ventilated facade according to variable boundary conditions. This result is a key step for further possible development and research of the smart facade system, from which we promise a significant contribution in the field of construction in terms of energy saving and construction sustainability.

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