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ORIGINAL ARTICLE

Ecological analysis of natural ventilated facade system and its performance in Tehran's climate

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Façade as the most outer part of building has very important role in building's energy exchange and its thermal comfort. Using of ventilated facade have been increased due to its positive points, including aesthetics, energy saving and sustainable approach so it is important to study its compatible in different climate conditions. In the present study to evaluate the effectiveness of this technology in Iran's climate compared to conventional systems as well as the effect of other factors in improving its performance, five models of a building with different situations have been modeled in Design Builder software and samples were examined in terms of the amount of energy needed to achieve comfort conditions. The result was that buildings with ventilation facades use 40% less energy than the building with conventional facade system. Its effectiveness in improving the cooling performance is better than its performance in the heat and its performance in the southern facade and areas that are exposed to direct sunlight looks much better. Factors such as the effect of height and number of floors also have an impact on system performance.
Key words: natural ventilated façade; facade systems; open-joint ventilated facades; energy consuming

Efforts to reduce energy consumption (Mahdavinejad, 2016) have led human beings to seek suitable alternative among renewable energies (Mahdavinejad et al., 2012) with more research and investigation (Mahdavinejad, 2016). The recent interest in energy efficiency (Mahdavinejad et al., 2012) and sustainability (Mohtashami et al., 2016) has led to the implementation of design strategies (Amini et al., 2014) in buildings that aim to achieve optimal utilization of daylight with minimum energy consumption for lighting, cooling, and heating (Mahdavinejad et al., 2013). The term "open-joint ventilated facades" refers to a building system in which coating material (metallic, ceramic, stone or composite) is hanged by means of a metallic-frame structure (Mahdavinejad et al., 2011) to the exterior face of the wall, creating an air cavity between wall and slabs.(Mahdavinejad and Javanroodi 2014). The open-joint ventilated facade (OJVF) is usually classified among the "light weight" or "Advanced Integrated Facades". They are replacing the conventional facade in many new buildings and particularly in the refurbishment of old ones. There are some reasons why these advanced facades have become so popular among architects, but perhaps the main one is because they can adopt nearly any color and shape.

Additionally to the aesthetic reasons, the set-up of the exterior coating is very easy and fast, making them a very competitive system, especially in building restoration. With respect to their performance, the manufacturers argue that there are two main advantages. First, the ventilation reduces the problems posed by moisture, and secondly, under the effect of the solar radiation, the energy performance of these facade systems (mainly the OJVF) improves in relation to conventional facades. The open-joint ventilated facade has been pointed as a building system that can help to reach the objectives of the energy efficiency standards, especially in countries where the peak in power demand occurs during the summer period (Sanjuan et al., 2011).

Facade installation systems classification

Ventilated facades are classified according to several criteria, like the type of ventilation, the partitioning of the cavity or the ventilation modes (Loncour et al., 2004). The most widely studied and implemented type of double skin facade is the glazed double skin façade. This type of facade has become very popular due to its aesthetically pleasing exterior (Kim et al., 2009). However, the use of double glazed facades increases the risk of overheating in the hot season (Gratia, 2007).

Moreover, glazed double skin facades are generally more expensive and the maintenance costs are high. To avoid the disadvantages of using a transparent façade in hot climates, an alternative solution could be using opaque ventilated façades (OVF). In an opaque ventilated façade the two layers are opaque and solar radiation is absorbed in the external layer, reducing

the overheating risk. Additionally, an opaque ventilated façade can be made up of conventional materials, thus leading to a smaller cost (López et al., 2012).
The most common materials are glasses (translucent), ceramic or metallic (opaque) or PV modules. According to the external board, facades are divided into three groups: sealed cavity facade, where the air cavity and the outside air are not connected; closed joints with open grills (at the top and bottom), in this case the air cavity is in contact with the outside air and an air flow exists through the cavity; the last type is the open joints and open grills, which represents the most common construction (Francés et al., 2013). According to Marinosci et al. the second model is simpler than the last one and their results can be used to describe both situations (Marinosci et al., 2011). In recent years, a variety of views have been studied. In a study titled “Empirical validation and modelling of a naturally ventilated rainscreen facade building " rain screen have been examined (Marinosci et al., 2011). In a study, titled “ the fluid mechanics of the natural ventilation of a narrow-cavity double-skin facade “, a multi-storey facade of this type was evaluated using a scale model (Mingotti et al., 2011). In researches “Thermal modelling of a building with an integrated ventilated PV facade” and “Thermo fluid-dynamic analysis of ventilated facades” three type of these facades that were combanition between photovoltaic panels and open-joint facades have been examined thermal (Mei et al., 2003; Patania et al., 2010).

Installing system’s definition

A conventional facade is usually composed of an exterior coating (brick veneer, stone or tiles fixed over a half brick wall, etc.), a closed air cavity about 5–10 cm, an insulation layer fixed over perforated brick or concrete blocks, and an interior finish (gypsum layer). The exterior coating is frontally anchored to the floor slab in such a way that, theoretically at least, the thermal bridge is broken. The air chamber height is thus about the floor height. The closed air cavity is sometimes omitted or filled with insulation. In these cases, the thermal behavior of the facade can be easily determined with a combined conduction coefficient (Sanjuan et al., 2011). Different type of traditional common façade installation system can be considered in three modes (Figs 1-3).

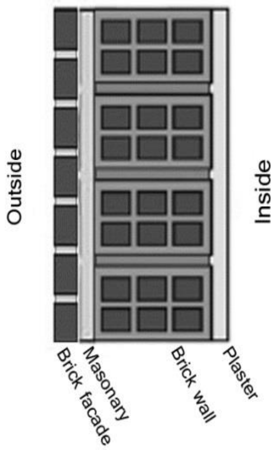


Figure 1. Conventional façade installation without thermal insulation

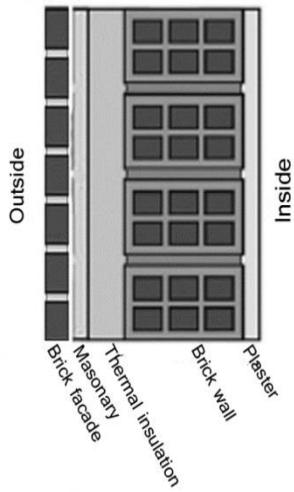


Figure 2. Conventional façade installation with

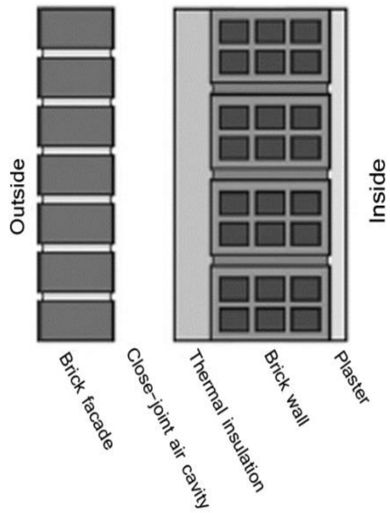


Figure 3. Natural ventilated facade

In light weight facades, the exterior “light” coating material (metallic, ceramic, stone or composite) is “hanged” over the interior wall (insulation, perforated brick, finish; basically, the same as before) by means of a metallic-frame structure or metallic bindings, leaving an air gap between them of similar dimensions to the one in the conventional facade. The air chamber height can be the whole building height, although it is usually broken by windows and other building elements, and sometimes even by the metallic-frame structure. In fact, in some advanced facades, the ventilation is quite restricted (Sanjan et al., 2011).
The main difference between the OJVF and other advanced facades is that, as a rule, the ventilated air chamber is only open to the exterior at the top and at the bottom while, in the OJVF, the exterior coating is placed in an arrangement of tiles or slabs and a series of thin gap (joints) are shaped from slab to slab, enabling the exterior air to enter and leave the cavity all along the wall (Sanjan et al., 2011).
Ventilated facades can be classified into two types according to their air-conditioning system (Fig. 4).

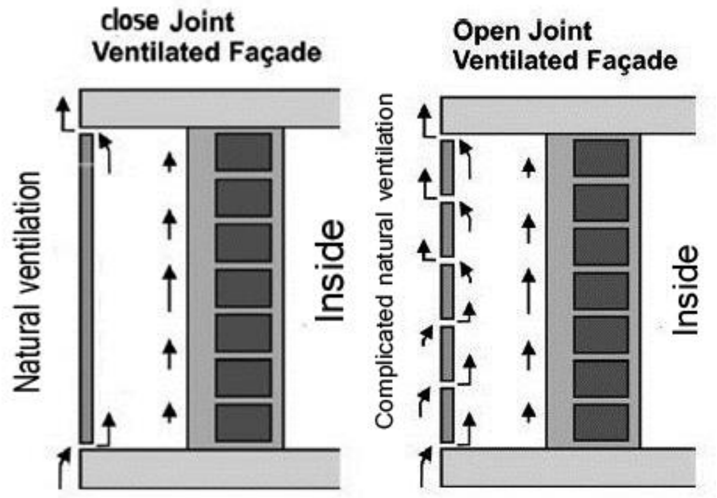


Figure 4. Open-joint and close-joint ventilated facade

For example details are described in Figs 5-6 are close joint one because the attachment of the panels to the frame is in a way that does not allow air to pass into the chamber behind.in this study close joint ventilated façade is considered in modeling of cases.

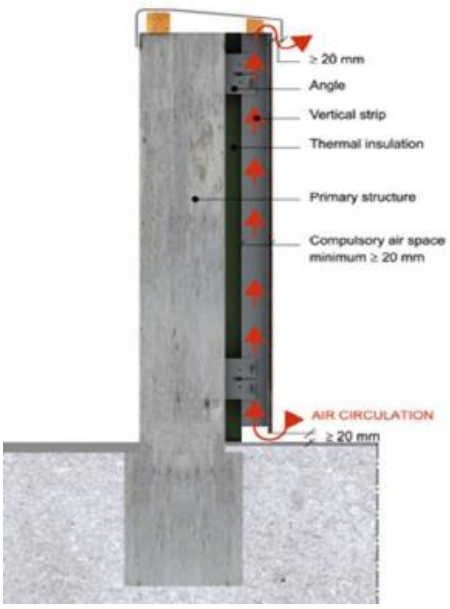


Figure 5. Close joint ventilated facade

Figure 6. Close joint ventilated facade

Study thermal behavior of systems

The ventilated facade geometry and the variables of interest are shown in Fig. 8. An open cavity is formed between the interior construction (typically including some thermal insulation) and the exterior skin, which could be made of different materials like ceramic, stone or metal. This finite channel of height L and spacing b is formed by two isothermal surfaces at temperatures Th (hot) and Tc (cold), while the ambient outdoor temperature is To. (Suarez et al., 2011)

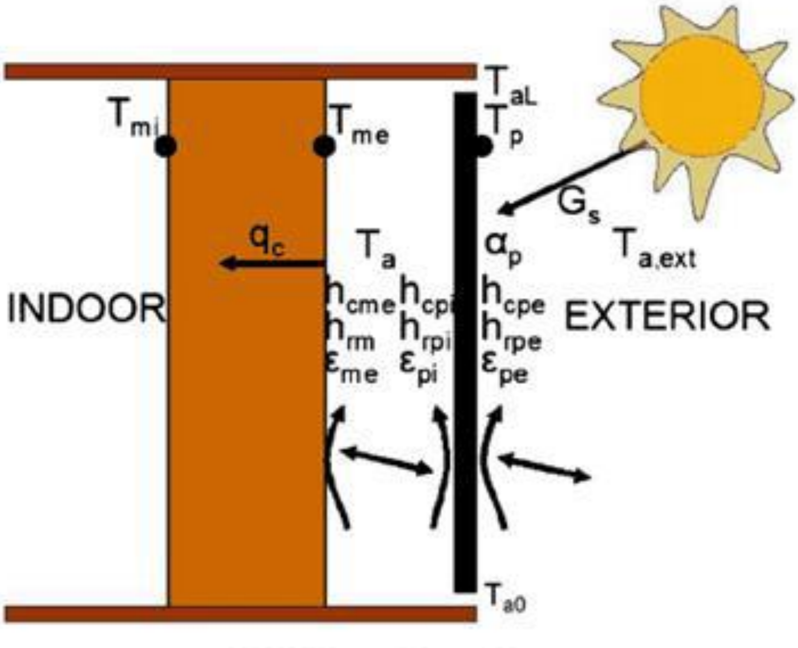


Figure 7. Thermal behavior comparison of conventional and ventilated facade

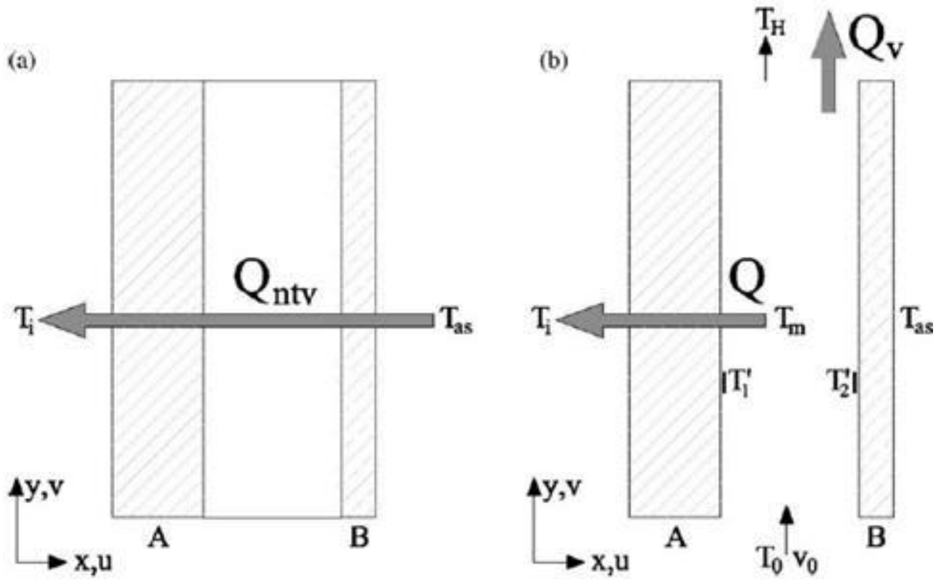


Figure 8. Heat exchange balance

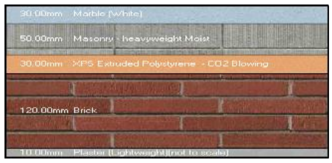
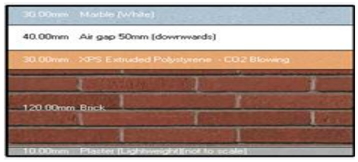
The buoyancy induced flow in the channel is supposed to be unidirectional so To ≤ Tc ≤ Th When Th and Tc are equal, the channel is symmetrically heated and otherwise the channel is asymmetrically heated. Due to heat transfer between air and the surfaces of the channel, a buoyant flow is induced in the channel.

Due to boundary conditions at the walls, the heat flux at the hot wall is always from the wall to the air but at the cold wall, the heat can either be transferred from air to the cold wall or to the cold wall to air, depending on the local temperature difference. The improved thermal performance of the OJVF under radiation conditions relies on buoyancy: The slabs of the exterior coating are heated up and produce an ascending mass flow of air (by natural convection) that enters and leaves the cavity through the joints. This flow removes part of the heat loads, reducing the heat transfer to the indoor environment. This phenomenon takes also place if the openings are only at the bottom and top of the facade, but the efficiency is not as high due to the reduced flow and the higher temperatures attained at the upper section of the air gap. In the conventional sealed cavity facade, the heating of the exterior layer produces a convective loop, with the flow raising along the hot wall and sinking along the cold wall. This effect is counterproductive, adding convection to the conduction and radiation heat transfer to the building interior (Sanjan et al., 2011).

Simulated models

In this study five modes of a building with 8*8 plan has been modeled. Features and physical specifications of layers are shown in table 1. All models are analyzed in Tehran weather condition. Details of simulated models are as following.
Model No.1 is a one floor building with 8*8 plans with conventional installation system without thermal insulation
Model No.2 is a one floor building with 8*8 plans with conventional installation system with thermal insulation
Model No.3 is a one floor building with 8*8 plans with natural ventilated façade.
Model No.4 is a two floor building with 8*8 plans with natural ventilated façade.
Model No.5 is a one floor building with 8*8 plans with natural ventilated façade that façade height is higher than roof level.

Table 1. Five modes of a building with 8*8 plan with features and physical specifications of layers.

Model number	Layer (from outer to inner)	thickness	heat conductivity (W/m K)	Density (kg/m3)	Specific heat capacity (J/kg K)	detail
Model no.1	Marble	3 Cm	2.770	2600	802	
	Masonary	5 Cm	0.810	1650	840	
	Brick wall	12 Cm	0.720	1920	840	
	Plaster	1 Cm	0.160	600	1000	
Model no.2	Marble	3 Cm	2.770	2600	802	
	Masonary	5 Cm	0.810	1650	840	
	Thermal insulation	3 Cm	0.034	35	1400	
	Brick wall	12 Cm	0.720	1920	840	
	Plaster	1 Cm	0.160	600	1000	
Model no.3	Marble	3 Cm	2.770	2600	802	
	Air gasp	4 Cm	0	0	0	
	Thermal insulation	3 Cm	0.034	35	1400	
	Brick wall	12 Cm	0.720	1920	840	
	Plaster	1 Cm	0.160	600	1000	
Model no.4	Marble	3 Cm	2.770	2600	802	
	Air gasp	4 Cm	0	0	0	
	Thermal insulation	3 Cm	0.034	35	1400	
	Brick wall	12 Cm	0.720	1920	840	
	Plaster	1 Cm	0.160	600	1000	
Model no.5	Marble	3 Cm	2.770	2600	802	
	Air gasp	4 Cm	0	0	0	
	Thermal insulation	3 Cm	0.034	35	1400	
	Brick wall	12 Cm	0.720	1920	840	
	Plaster	1 Cm	0.160	600	1000	

Features and thickness of models are based on a sample introduced in research titled "Experimental assessment and modeling of the performance of an open joint ventilated façade during actual operating conditions in Mediterranean climate" (Giancola et al., 2012).
The air mass flowing into the duct can be considered as an independent variable in cases of forced ventilation, whilst in the case of natural ventilation it is determined by the heat flux, the duct geometry, the fluid dynamic heat losses and the external atmospheric conditions. The air mass flow rate is influenced by external wind conditions too. To simplify the structure of governing equations the external effect of wind on the system are not considered in this study (Patanja et al., 2010).

Outputs

Variables to evaluate the efficacy and comparison of samples used in the model are as follows:
First one is indicator of heating and cooling load of building inorther to reach temperature of 22 ° C for heating and 24 ° C for cooling the interior per KWH.
Other one is Zone heating which by defiition of design builder software is energy supplied by local room heaters and reheat coils to maintain room internal heating temperature setpoint temperature when using Compact HVAC data. Last one is Zone cooling which by defiition of design builder software is the amount of energy a cooling device consumes to bring room's temoerature to the temperature that is set.
Here we presented Zone cooling for samples No.1 and 3 at 1 p.m. in summer (Fig. 9).

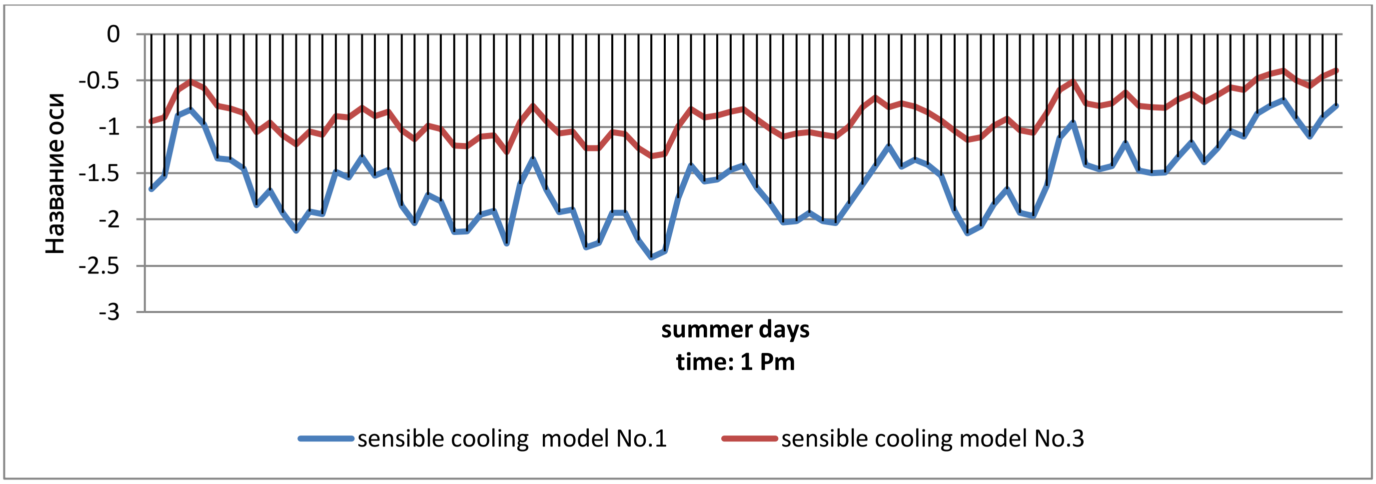


Figure 9. Zone cooling for samples No.1 and 3 at 11 p.m. in summer.

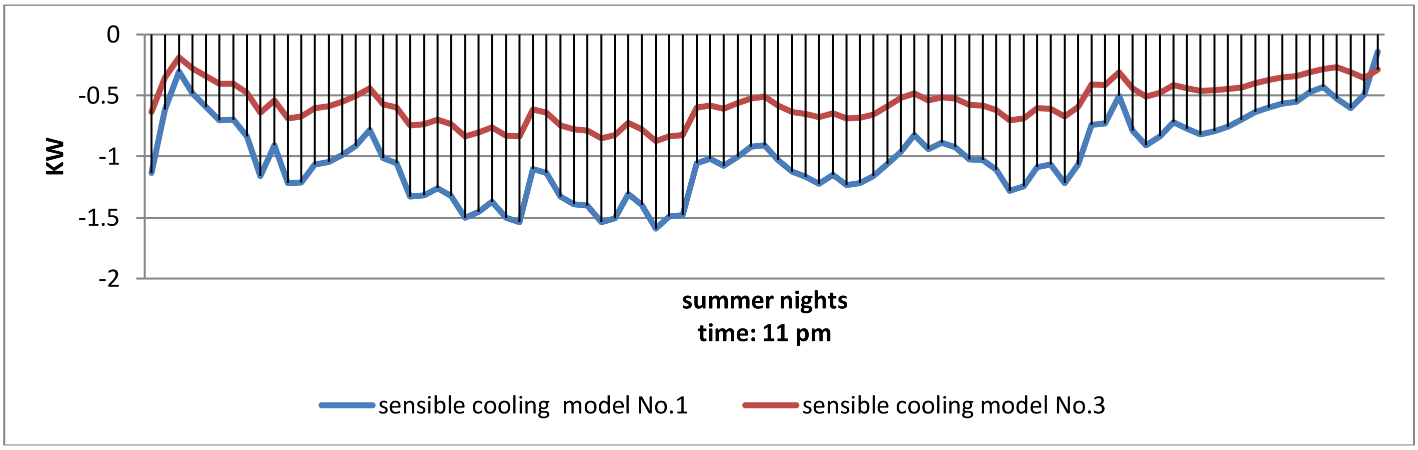


Figure 10. Zone cooling for samples No.1 and 3 at 11 p.m. in summer

In order to chart.1 and chart.2 it can be discovered that using ventilated façade instead of conventional system in Iran requires fifty percent less energy for cooling. Variation range of cooling load in model No.3 is more less and proper than model No.1 (Figs. 9-10). The performance of natural ventilation façade in peak hot condition is better than moderate conditions.
We presented Zone heating for samples No.1 and 3 at 1 p.m. in winter and Chart.4 describes Zone heating for samples No.1 and 3 at 11 p.m. in winter (Fig. 10). It can be discovered that using ventilated façade instead of conventional system in Iran requires fifty percent less energy for heating. Variation range of heating load in model No.3 is more less and proper than model No.1 (Figs 10-11).
The performance of natural ventilation façade in peak cold condition is better than moderate conditions.

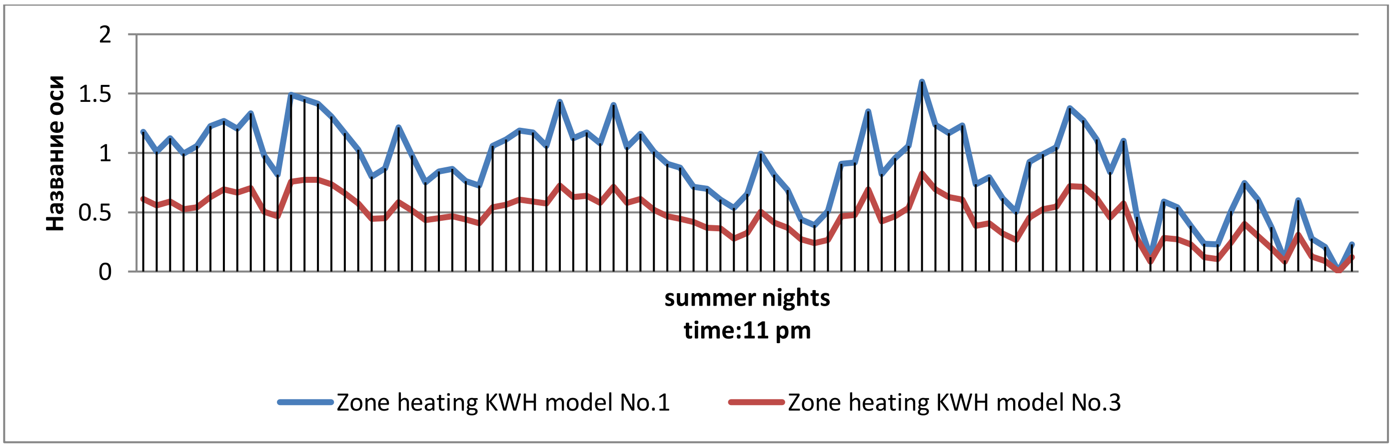


Figure 11. Zone heating for samples No.1 and 3 at 1 p.m. in winter

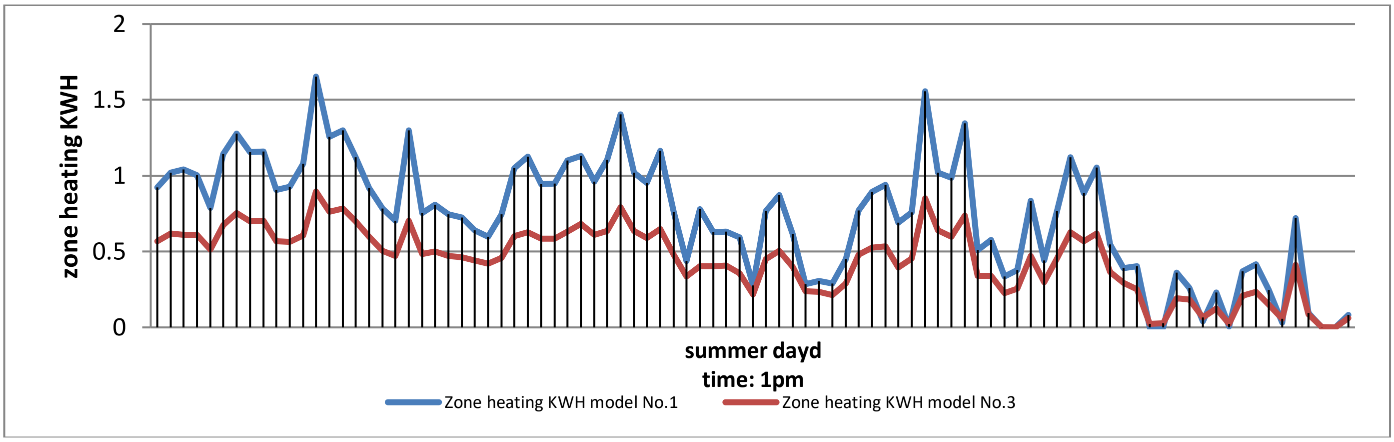


Figure 12. Zone heating for samples No.1 and 3 at 11 p.m. in winter

We also presented zone cooling for models No.1 and No.3 for 24 hours in 21 of July (Fig. 13) and zone heating for models No.1 and No.3 for 24 hours in 21 of January (Fig. 14). These charts corroborate the previous results and represent ventilated façade's positive effect in 24 hour in a day.

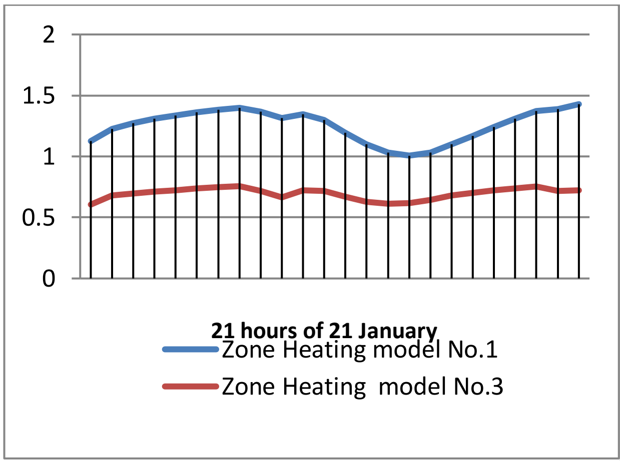


Figure 13. Zone cooling for models No.1 and No.3 for 24 hours in 21 of July.

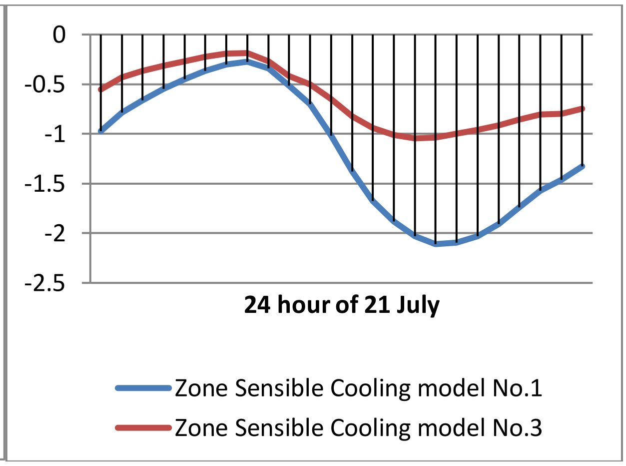
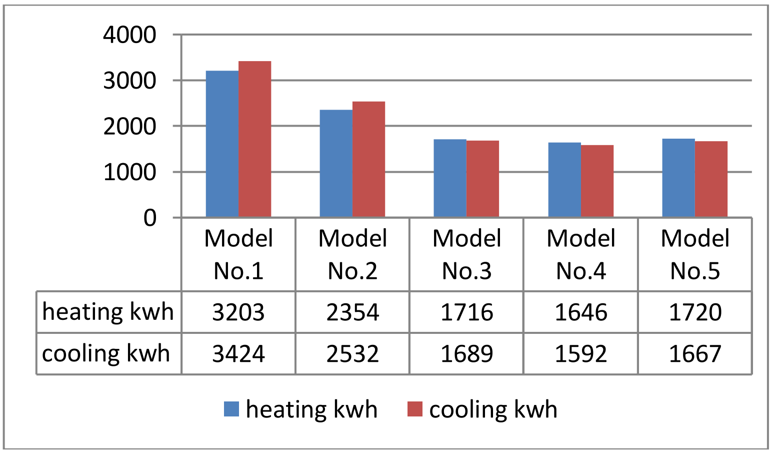


Figure 14. Zone heating for models No.1 and No.3 for 24 hours in 21 of January

Comparison of heating and cooling energy consumption between simulated models presented below (Figure 15). We suggested that using ventilated façade instead of conventional system in Iran requires fifty percent less energy for heating.
Energy consumption index in the two-floor building with ventilated façade is 3% less than one floor building.



	Model No.1	Model No.2	Model No.3	Model No.4	Model No.5
heating kwh	3203	2354	1716	1646	1720
cooling kwh	3424	2532	1689	1592	1667

Figure 15. Comparison of heating and cooling energy consumption between simulated models

Conclusion

It is possible to assert that the ventilated facades, during summer period, achieve high energy saving rates, typically above 40%, compared to the same facade unventilated. These energy performances are less advantageous for low values of solar radiation (i.e. facades exposed to the north)

The author believes that performance of these facades become more efficient when outer layer have greater specific heat capacity, higher density and less heat transfer.

According to the output value of software can be stated that natural ventilated façade compared to conventional one without thermal insulation use 43% less energy in heating and 48% less energy in cooling. Using ventilated façade in two floor building save 45% energy in heating and 51% in cooling. Energy consumption index in the two-floor building with ventilated façade is 3% less than one floor building with ventilated façade that it can resulted from increasing absorbed radiation energy.

In terms of model No.5 cooling condition partly gets better but the heating condition gets unfavorable.

In general, according to the outputs ventilated façade in the southern façade' efficiency is much higher than the northern façade and in climates that have a direct radiation are much better because of funneled phenomenon acts. As well as its performance in night and day and in different seasons is desirable.

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