AIVC 12176

HEAT TRANSFER THROUGH FASADE ELEMENT COMPOSED BY DOUBLE PANE WINDOW AND VENTILATED INSULATION SCREEN

Sašo Medved

University of Ljubljana, Faculty of Mechanical Engineering, 1000 Ljubljana, Slovenia, saso.medved@fs.uni-lj.si

ABSTRACT

Low energy buildings should satisfied two main tasks: to assure a low energy use and provide an excellent residence comfort. The building envelopment elements, especially the transparent one, have major influence on both tasks. The paper presents research results of heat transfer and fluid flows through double pane window with tight, opaque insulation screen. The insulation screen was installed in such a way, that a semi open air gap was formed. An air gap is connected with the building interior through an opening on the bottom and with exterior through siphon at the top. This "S" shape air gap enables the reduction of the heat loses in the winter time by heat recovery through ventilating air and it reduces the heat loads during the summer as shading and solar chimney element.

KEYWORDS

Energy conservation, buildings envelope, windows, insulating screen, ventilated insulation screen

HEAT TRANSFER THROUGH WINDOW AND VENTILATED INSULATION SCREEN

The flow of an infinitesimally small volume of a fluid is described with differential equations for mass, motive force and energy conservation and the constitutive law of Fourier law of heat conduction, Newton law of cooling and Stefan-Boltzmann law of heat transfer by radiation. The finite-volume method and the PHOENICS computer code were used for numerical evaluation of heat transfer in observed system. Both the finite-volume method and the code are described in detail in [1,2,3,4,5]. The code was supplemented with an external module for the calculation of Gebhart radiation coefficients. The following main assumptions are considered: heat transfer is quasi steady-state and two-dimensional, the fluid is incompressible, Newtonian and ideal gas , the flow is laminar, the Boussinesq's buoyancy approximation is used. Geometrical model of window with ventilated screen is shown on Fig.1, while simplification of geometrical model and boundary conditions of numerical model are shown on Fig. 2.

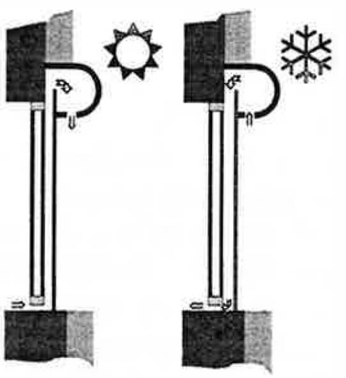

Fig. 1: Geometrical model of the window with ventilated screen

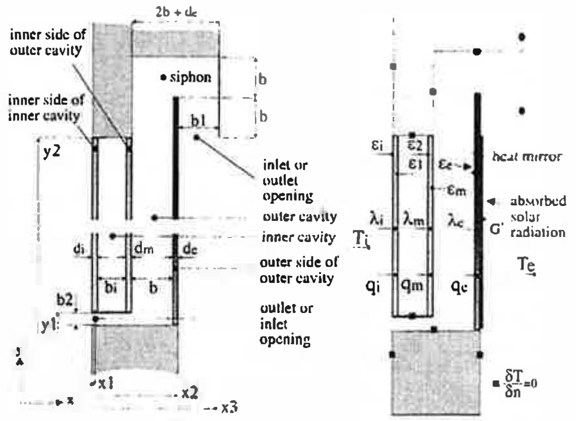

Fig.2: Numerical model and boundary conditions

The numerical model was verified by measuring temperatures, heat fluxes and velocities and the visualization of fluid flow on a experimental component. For the fluid flow observation cool tracing smoke was used together with a digital video imaging system. As velocities were very low ($v_{max} < 0.3$ m/s) the digital video imaging system was also used for the velocity measurements. The results are stated in [1]. After a successful verification various parametric numerical studies were performed.

Window with ventilated insulation screen as an element of dynamic thermal insulation

A newly designed facade element with a ventilated insulation screen enables natural ventilation by simultaneous heat recuperation. The element acts as dynamic thermal insulation. Ventilation remains based on buoyancy. The height of the opening on the lower part of the outer cavity was selected such that ($b_2 = b/4 = b_1/4$), which provides sufficient ventilation of the imaginary space behind the component and ensures the required residential comfort.

The following numbers were introduced to assess the efficiency of ventilation and heat recuperation:

- degree of ventilation γ which is the ratio between the actual intensity of ventilation **n** and the reference value $\mathbf{n_{ref}}$; the reference value corresponds to the ratio of he size of analyzed building envelope component and the ground plan of the room and typical floor height in residential buildings; in our case the n_{ref} was 16.8 m^3/h;
- effective heat transfer coefficient of a double-cavity component:

$$U_{ef} = \frac{q_i . L.s - Q_{rec,prim} - Q_{rec,sec}}{L.s.(T_i - T_e)} \tag{1}$$

where **s** is component's length and $Q_{rec,\ prim}$ is the share of heat transferred through the inner cavity towards the outside, which is taken up by air entering the cavity through a siphon and exiting into the room through an opening with height b_2. It is determined using the following expression:

$$Q_{rec,prim} = \rho.\overline{v_{out}}.c_p.b_2.s.(T_{out} - T_{in}) ; \quad T_{out} = \frac{1}{b_2}\int_{yl-b2}^{yl} T|_{x1}\,dy \quad \text{and} \quad T_{in} = \frac{1}{b_1}\int_{x2}^{x3=x2+bl} T|_{y2}\,dx \tag{2}$$

$Q_{rec,\ sec}$ is the share of heat transferred through the outer wall of the outer, which is taken up by cold ambient air to the entry to the siphon's cavity. This is determined using the following expression:

$$Q_{rec,sec} = \rho.\overline{v_{out}}.c_p.b_2.s.(T_{in} - T_e) \tag{3}$$

On Fig. 3 effective heat transfer coefficients in two-parametric form ($\gamma = n/n_{ref}$, $T_i - T_e$) for two selected emissivities ε_e. of inner screen surface are shown. As can be seen, effective heat transfer coefficients at both observed emissivities are almost independent of the temperature difference, but strongly dependent on the degree of ventilation. They fall steeply up to a degree of ventilation of $\gamma \leq 0.4$, but their values are almost constant in the range $0.8 \leq \gamma \leq 1.2$, in which the minimum is found as well. Since these degrees of ventilation are optimum from the viewpoint of residential comfort, optimum functioning of the double-cavity and siphon component is also ensured. A large influence of the heat mirror is proven. Effective heat transfer coefficient is reduced at $\varepsilon_e = 0.9$ to 0.48 W/m^2K and to 0.145 W/m^2K when heat mirror is used (both cases for

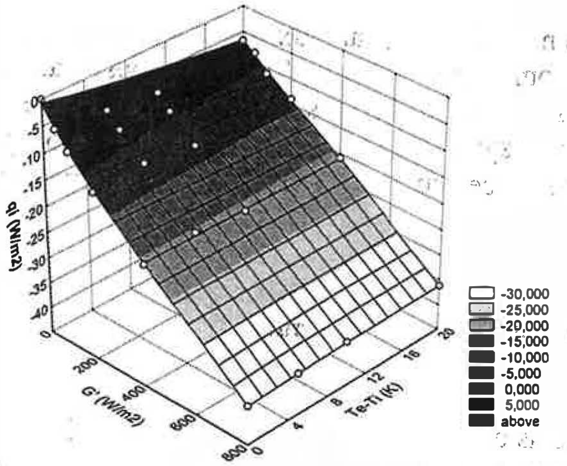

Figure 4: Heat fluxes though of double pane window with ventilated insulation screen

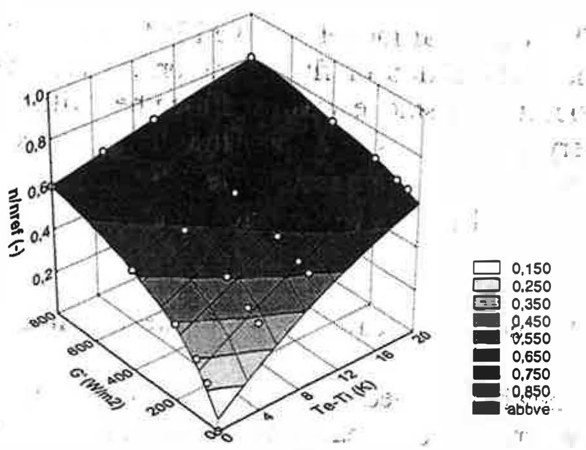

Figure 5: Degree of ventilation through opened screen cavity

WINDOW WITH INSULATION SCREEN AS PART OF THE ENVELOPE

Despite of all good characteristics of window with ventilated insulation screen the real value can be seen when this element is observed as envelope element of the building in non steady state all year conditions. The TRNSYS code was used to analyze the thermal response of the typical residential office with such envelope element dur ng the winter and summer per od. One or several TYPEs 9, 14, 16, 19, 25 and 33 were used inside TRNSYS code. The code was verified by measurements of indoor temperatures and meteorological datas in Cell A shown on Fig. 6. The results are presented on Fig 7. According to the good agreement between measured and simulated values, the TRNSYS code has been used for further simulations. Cell with $4m^2$ window and $20m^2$ floor area was chosen for observations (Cell B on Fig. 6). The winter and summer periods were analyzed separately using 6 month periods from Test Reference Year for Ljubljana (central Europe climate, DD 2985).

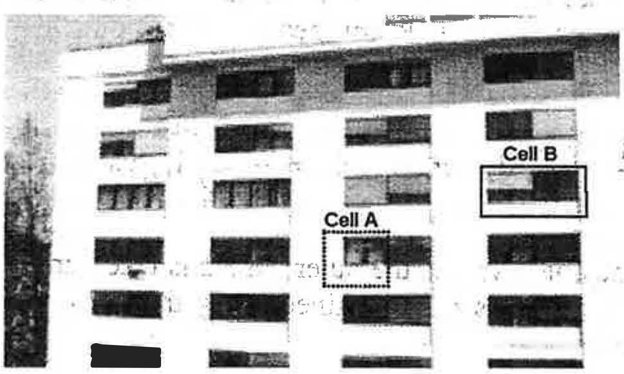

Fig. 6.: Multi story building with Cell A and B

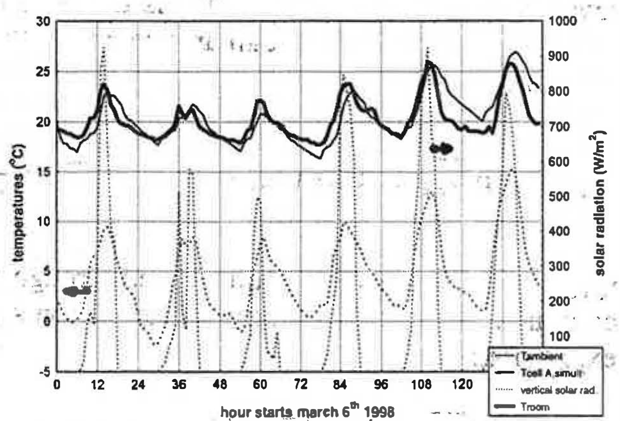

Fig. 7: Comparison between measured temperature (T_{room}) and simulated one ($T_{CellA,simul}$) for Cell A from Fig.6

Winter operation mode

For winter period analyzes the data from TRY between the 1st of October and the 30th of April were used. TYPE 14 in TRNSYS code was used to "close" insulation screen between 6 pm and 6 am next morning for every day. In this time U_{ef} (eq. 1) has been used instead of regular U value of the window. Two parametric polynom (from Fig. 3) has been used for U_{ef}

$\gamma = 1$). The latter value therefore represents only 1/16 of the value of heat transfer coefficient of a standard window with double glazing. The risk of the condensation of moisture on the inner glass surface was examened too. It was found out that it is possible to ventilate screen without radiation shield with a degree of $\gamma \leq 0.4$ without surface condensation, and up to a degree of $\gamma \leq 1.0$ with installed radiation insulation on inner screen surface. Such ventilation fulfills the criteria for sufficient ventilation of residential premises.

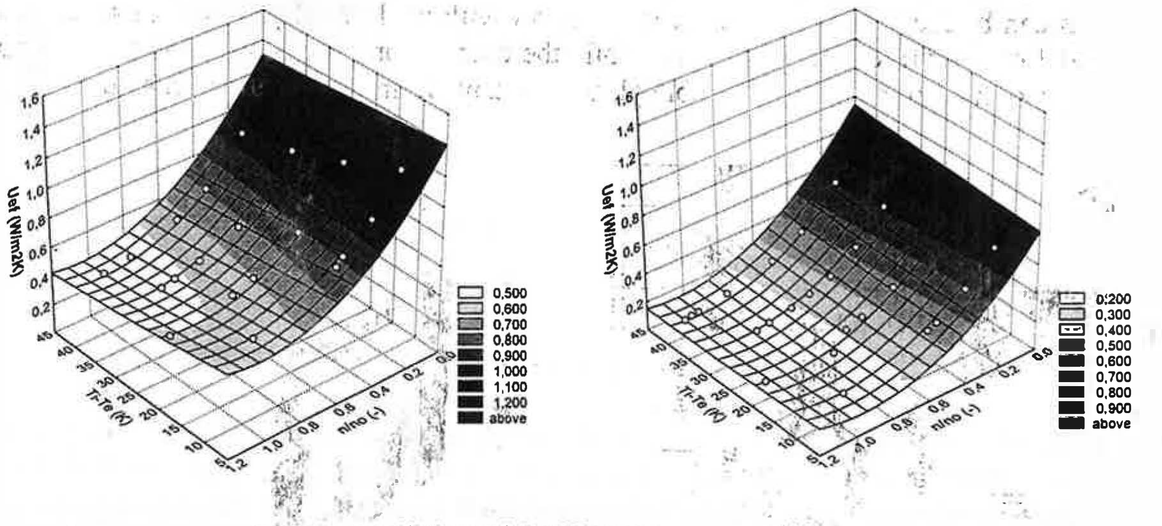

Fig. 3: Effective heat transfer coefficient of double pane window with ventilated screen by heat recovery; left for $\varepsilon_c = 0.9$, right in case of $\varepsilon_c = 0.04$

Window with ventilated insulation screen as an element of shading and ventilation

During the summer, residential comfort is often reduced due to overheating of premises. This section therefore emphasizes that transparent components of building envelope are the main source of heat gains and a possible cause of overheating of rooms in spite of the use of of standard outside shading. From the results of numerical observations, Fig. 4 states the values of heat fluxes q_i through a closed window with ventilated screen vs. intensity of absorbed solar radiation on the outer surface of the screen ($0 \leq G' \leq 800$ W/m^2) and the differences between ambient and room temperatures ($0 \leq T_e - T_i \leq 20$ K). It can be seen that heat flux never exceeds the value of $q_i = 35$ W/m^2, not even under most favorable circumstances. In extreme meteorological conditions ($G' > 400$ W/m^2) heat flux into the component is even inversely proportional to the temperature difference, which is a consequence of a more effective functioning of the "solar chimney", which also affects the temperature of the inner component's surface. This never exceeds 5 K, so that they it is never higher than the value people are able to sense as radiation nonuniformity.

Cross ventilation and cooling of buildings are two of the basic principles of passive solar architecture. Our research focused on the interaction between heat transfer and volumetric flow of ventilated air which enters the outer cavity at the bottom, travels upwards due to buoyancy and exits the outer cavity through a siphon at the top. From results of the simulation the degree of ventilation γ through open screen cavity are presented in Fig. 5. The degrees of ventilation increase with an increase in both parameters and reach the highes t value of $\gamma = 0.8$. This is the lower limit of prescribed ventilation of premises, but it was determined for ratio of heights of outlet and inlet openings $b_2/b_1 = 0.25$ and it can reach value of $\gamma = 1.3$-1.4 by extreme meteorological parameters and ration $b_2/b_1 \approx 1$. This the degree of ventilation entirely fulfills the ventilation criteria from the viewpoint of air quality.

determination. Four different orientations and four different cases were studded: **case A** - window with insulation screen and well ventilated interior ($n=1.2\ h^{-1}$), **case B** - window with insulation screen with poor ventilated interior ($n=0.2\ h^{-1}$), **case C** - double glazed window ($U_w=3\ W/m^2K$) without screen and **case D** - double glazed low-e Ar filled window. As an example the hourly average values of the heating power during the winter period for two cases are presented on Fig. 8. On Fig. 9 heat loads for heating Cell B for all observed cases are shown. As can be seen characteristics of the window with well ventilated insulation screen are as good as low-e Ar filled windows, meanwhile the energy consumption can be reduced up to 20 - 23% according to the ordinary double glazed window during the heating season.

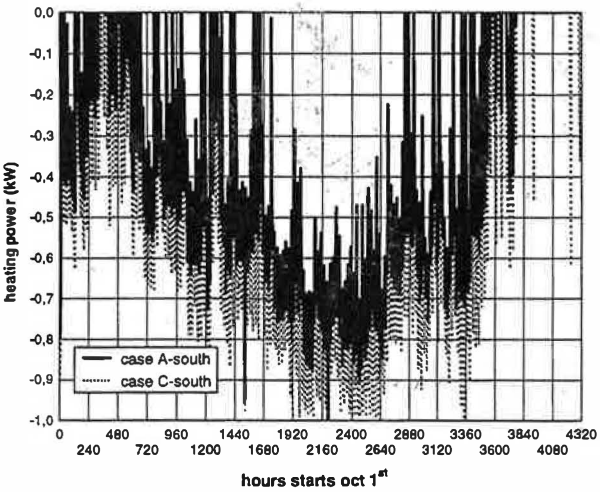

Fig. 8: Average heating power for case A and D and south orientated Cell B

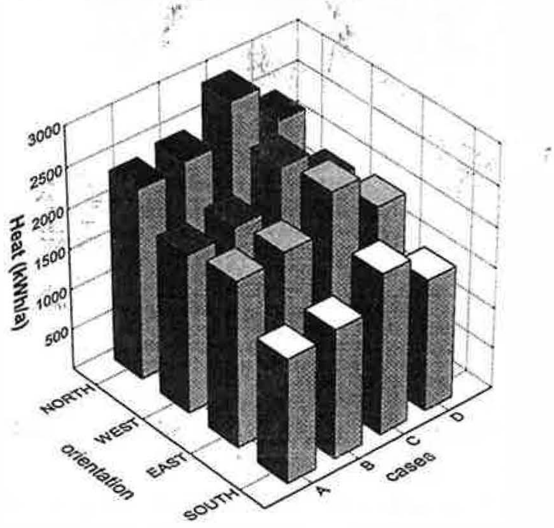

Fig. 9: Energy consumption in Cell B for all observed cases

Summer operation mode

In summer time ventilated insulation screen operates as shading and ventilated device. Two the most critical orientations of Cell B in this period have been observed - south and west. TYPE 14 (timer) has been used inside TRNSYS code to close insulation screen during different day hours. When insulation screen is down (closed) the incoming heat flux through window and ventilation rate are approximated by different two parametric polynoms (from Fig. 4 and Fig. 5). Several different cases were analyzed: **case a** - ordinary double glazed window ($U_w=3W/m^2K$), **case b** - window with ventilated screen lowered between 11am and 3pm each day during the summer period, **case c** - same as case b but screen lowered between noon and 2pm, **case d** - same as case b but screen lowered between 1pm and 5pm, **case e** - same as case b but window with ordinary nonventilated screen without heat mirror with screen lowered between 11am and 3pm, **case f** - same as case e but for west orientation and when screen in lowered between 1pm and 5pm hour.

As an example the hourly average values of the cooling power during the summer period for two selected cases are presented on Fig. 10. Summer cooling loads for all observed cases are presented on Fig. 11. As it can be seen ventilated screen reduces cooling loads for 5 times in the most efficient case. Also the strategy of screen closing should be selected very carefully. As an important fact we would like to emphasize that ventilated screen with heat mirror helps to reduce cooling load up to 100% comparing to the ordinary dark painted nonventilated screen which is commonly used now.

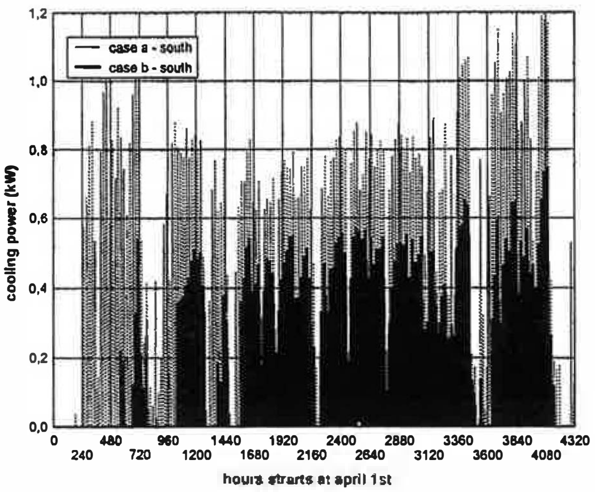

Fig. 10: Average cooling power for case a and b for south orientated Cell B

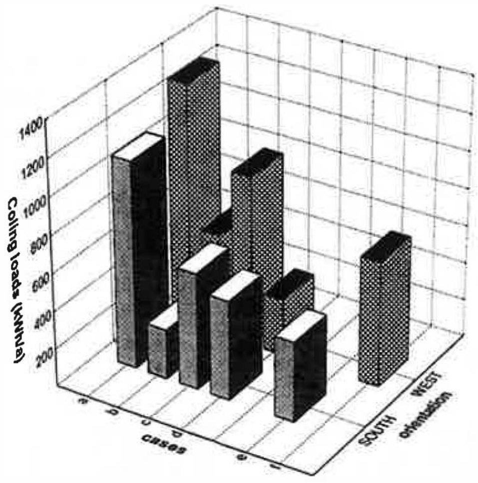

Fig. 11: Cooling loads in Cell B for all observed cases

CONCLUSIONS

On the basis of the presented results it can be concluded that:

- the predominating radiation heat transfer in "S" shape air gap formed by insulation screen was detected
- effective heat transfer coefficient can be reduced down to the 0.145 W/m^2K
- a maximal heat recovery ventilation degrees were identificated in such a way that the condensation of vapor from interior air on inner surface of window is prevented
- from total energy consumption for heating windows with ventilated screen can be compared with low-e and Ar filled windows; this is important for economical decisions by renovation of older buildings
- 400% reduction of heat loads can be achieved during extreme summer meteorological conditions according to the classical shading devices of the same construction
- solar chimney effect caused a natural ventilation so that recommended indoor ventilation level can be achieved
- cooling load using ventilated screen with heat mirror can be reduced to one half according to ordinary nonventilating outer screen
- approximately 1/10 of the screen should be transparent to provide daylighting even when the screen is closed.

REFERENCES

[1] S. Medved; *Prenos toplote in snovi v poševni planparalelni regi s sifonom*, Dissertation, Univerza v Ljubljani, 1997

[2] National patent no.: 9700150 on 6.6.1997 - Ureditev toplotne zaščite pri oknih, izumitelj S. Medved

[3] PHOENICS 2.2. (Parabolic, Hyperbolic, Elliptic Numerical Integration Code System), CHAM, Wimbledon, England, 1996

[4] S.V. Patankar; *Numerical Heat Transfer and Fluid Flow*, Hemisphere Publ.Co., New York, 1980

[5] R. Siegel, J.R. Howell; Thermal Radiation Heat Transfer; McGraw-Hill Book Co. 1972

[5] S. Medved, P. Novak; Heat Transfer Through a Double Cavity with Siphon, Journal of Mechanical Engineering,Vol 44, No 3-4, pp 71-83, STJVAX

[7] B. Todorović: Actual Cooling Load from Solar Radiation through Windows ... edition "Refrigeration Science and Technology, International Institute of Refrigeration, pp 205-215, Paris 1969

[8] I. Viličić, B. Franković: Influence of the Architectural Factors on Energy Conservation and Passive Solar Heating of Building, Proceedinds 7th International Conference VHC/84 on Ventilation, Heating and Air Conditioning, Piestany, 2 (1984) 98-114