

Thermal Performance of Air Flow Windows via CFD Simulation

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ABSTRACT: The purpose of this paper is to investigate the thermal performance of such air flow windows in which air flow windows integrate windows and ventilation system by drawing the fresh air through the cavity between the panes before it enters the room. By the extensive CFD modeling it is shown that the method prescribed by the existing ISO standard is inadequate in predicting the convective heat fluxes in the ventilated cavity. The transient method is implemented in a program called Win Vent, developed in connection with this project. There is a large potential for lowering heating demands in buildings with exhaust ventilation by using air flow windows. The multi-node resistance model that is the ISO method is used for calculating the thermal performance for normal windows and air flow windows vision area. The parameter (geometry, boundary conditions, and mesh generation, near wall treatment, turbulence model and radiation model) study is done by using the CFD model.

KEYWORDS: Thermal, heat fluxes, Air Flow Windows, ventilated cavity, CFD model.

I. INTRODUCTION

Being an important factor of human comfort balanced ventilation with heat recovery is not the only solution to lower ventilation heat loss. Another proposed solution to lower heating demands in exhaust ventilated buildings is the air flow window. The concept is also known as supply air window and ventilation window.[1] We focus here primarily on the heat loss characteristics of improved window systems and components, including both commercially available products which are not widely utilized as well as more speculative buildings often have high ventilation rates and therefore heat recovery has a much greater impact. Approaches which are under development or perhaps deserve additional development, testing, and appraisal. In the Dan-ish building regulation code [2] the minimum ventilation rate for the average apartment is highest. Balanced ventilation systems with heat recovery can significantly reduce the ventilation loss Commercial.

II. MATERIALS AND METHODS

The fundamental motive behind this project is to evaluate the thermal performance of air flow windows and the potential energy savings. The main aim of this project is to find out the satisfying method for calculating the characteristics of air flow windows. The main issue is the convective heat fluxes in the ventilated cavity. Convective heat fluxes depend on temperature differences and flow pattern of the fluid. The short time frame and the need to analyze many different configurations make CFD modeling the tool of choice for this part of the project. [3]

An approach to improve the calculation method for the ventilated cavity is analyzed:

- The multi-node resistance models that ISO standard method is based on.
- Transient heat flux and temperature development with the time dependency linked to the height of the cavity.

Description and Validation of CFD Models

Geometry and Boundary Conditions: It is a geometrical symmetry plane. If the flow is almost symmetrical it is possible to cut the computational domain in half by implementing a symmetry boundary condition. This would greatly decrease the computational time. To make sure the flow is symmetrical the velocities normal to the symmetry plane is investigated. (Fig.1)

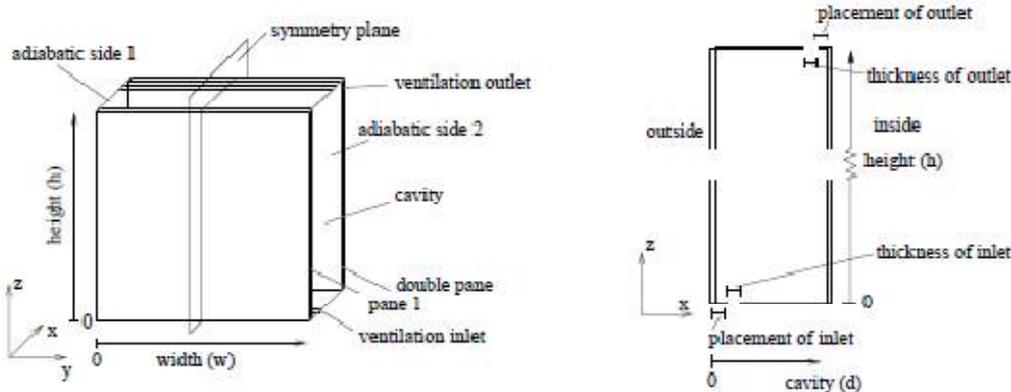


Figure 1: Dimension of air flow window cavity

Inlet and Outlet: A fixed flow rate is wanted for the CFD simulations. The boundary condition of the ventilation inlet is therefore a fixed velocity. It is assumed that there is a uniform distribution of inlet air in the width of the window. The outlet is assumed to have no effect on the cavity and is therefore simulated as a simple outflow boundary.

Table 1: Boundary conditions

	Type	Setting	Emissivity
Adiabatic walls	heat flux	0 W/m^2	0
Outside pane	convection	18 W/m^2K	0.9
Inside pane	convection	1.72 W/m^2K	0.9
Inlet	velocity inlet	0.6 m/s-0 °C	0
Outlet	outflow	[-]	0
Symmetry	symmetry	[-]	[-]

Symmetry: The computational domain is cut in half by imposing a symmetry boundary on the geometrical plane of symmetry. A symmetry boundary simply imposes that no flux can exist through the boundary.

Radiation: The influences of the adiabatic boundaries on the radiation are excluded by setting the emissivity factor of these surfaces to zero. The emissivities of the panes are set to 0.9, which is roughly equal to an uncoated pane. [4]

Grid Dependency Analysis

The grid dependency is investigated by conducting simulations for the reference case with an increasing number of cells. The grid adaption function in FLUENT cannot be used together with the DTRM radiation model. This grid factor is varied between 0.7 and 2.0 producing between 56000 and 15000 cells, see table 2.

Table 2: Parameter variation for grid dependency analysis

Grid factor		0.7	1.0	1.5	2.0
Size function	initial size [mm]	0.35	0.50	0.75	1.0
	Growth factor [-]	1.1	1.1	1.1	1.1
	Size limit [mm]	1.75	2.5	3.75	5
Boundary layer	first layer [mm]	0.35	0.50	0.75	1.0
	Growth factor [-]	1.115	1.115	1.115	1.115
Cooper method	distance [mm]	7	10	1.5	20
Number of cells		1490929	306225	193809	56150

It can therefore be concluded that the results are grid independent for the reference case mesh, with a grid factor of 1.0 ≈ 300000 cells.

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Radiation Model

Radiative heat fluxes play an important role in normal windows. It is very crucial to include the radiative heat fluxes in the CFD simulations. The best radiation model for enclosed spaces and where the fluid doesn't partake in the radiation, like our ventilated cavity, is properly the Surface to Surface model. The Surface to Surface model is a view factor model and calculates the view factor between all surfaces in the domain. The participation of the air is omitted by setting the absorption coefficient to zero.[5]

III. RESULTS

The purpose of the CFD simulations is to analyze the relationship between the specific geometry, conditions and the convective heat fluxes in the cavity.

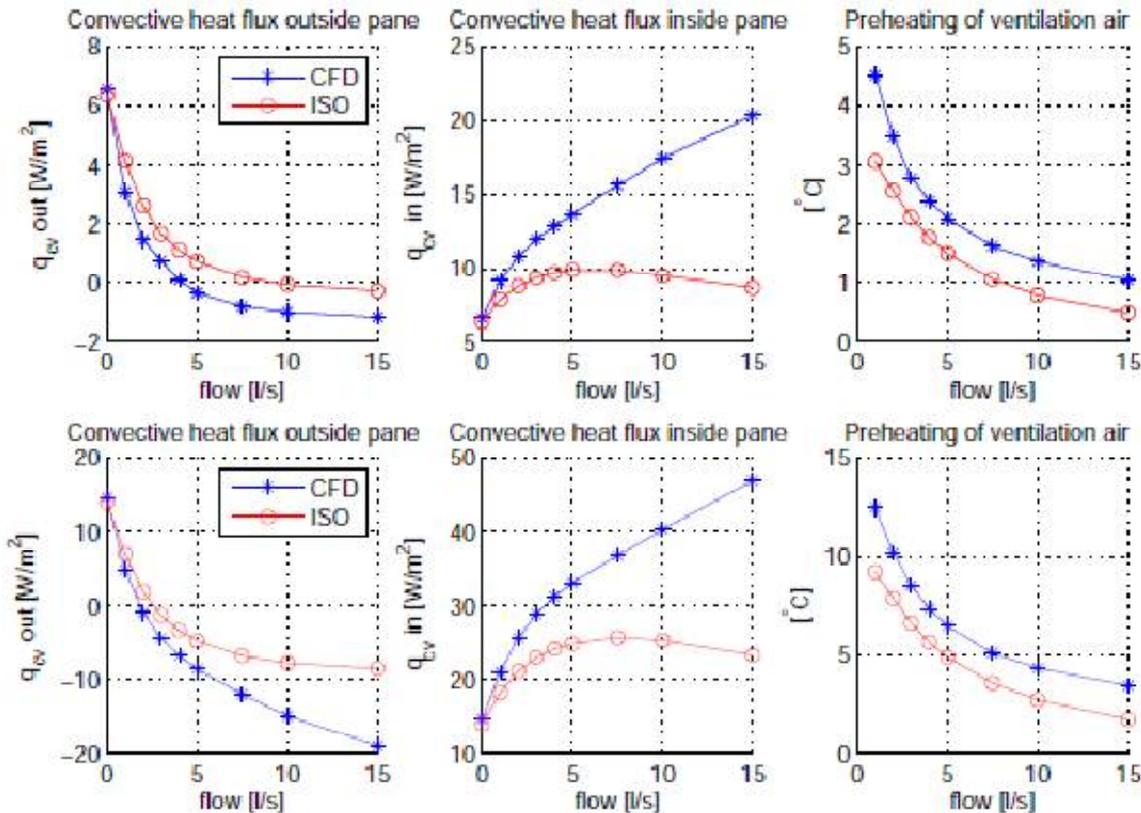


Figure 2: Dependency on ventilation flow rate. Comparison of main results from CFD simulations without solar irradiation, top, and with 500 W/m² solar irradiation bottom and corresponding ISO standard calculations.

The ventilation flow depends on the pressure difference across the window. But the cause of the pressure difference is of no particular interest for the air flow pattern. It is the aim of this project to present a method for calculating the thermal performance for specific conditions.

Ventilation rate: The ventilation volume flow is varied between 1 and 15 l/s per meter width of the window. Corresponding to an average velocity in the cavity between 0.02 and 0.3 m/s.

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Solar irradiation: The surface temperatures of the cavity are increased by applying internal heat generation to the pane boundaries. The internal heat generation corresponding to an absorption of 12% in the outside pane and 10% in the inside pane of the total solar irradiation.[6]

Cavity depth: The depth of the cavity affects both the average velocity of forced air flow and thermal resistance of the cavity. The cavity depth is varied between 50 and 150mm.

Window height: The height of the window determines how long it takes for the air to flow through the cavity. The higher the cavity the higher the potential preheating of the air. The height is varied between 0.75 and 1.5m.[7]

Analysis of CFD Simulation Results

The convective heat flux q_{cv} is calculated from the convective heat transfer coefficient, h_{cv} and the temperature difference between the surface and the air.

$$q_{cv} = h_{cv}(T_{surface} - T_{air})$$

Modification of the ISO Standard Method

$$T_{gap} = T_{av,surfaces} - \frac{\rho \cdot C_p \cdot d}{H(h_{cv,in} + h_{cv,out})}$$

By increasing $(h_{cv,in} + h_{cv,out})$ the average air temperature, T_{gap} becomes closer to the average surface temperature, $T_{av,surface}$. It follows that a higher T_{gap} makes it even more impossible to capture the large negative heat flux observed in the CFD simulations.[8]

$$V(T_{cav,out} - T_{cav,in})$$

For $\frac{Gr}{Re^2} \ll 1$ the natural convection can be assumed negligible and for $\frac{Gr}{Re^2} \gg 1$ the forced flow can be assumed negligible.

Grashof $G_r = \frac{g\beta(T_s - T_\infty)L^3}{\nu^2}$ Ratio of buoyancy to viscous forces

Reynolds $Re = \frac{VL}{\nu}$ Ratio of inertia to viscous forces

and $\frac{Gr}{Re^2} = \frac{g\beta(T_s - T_\infty)L^2}{\nu^2}$

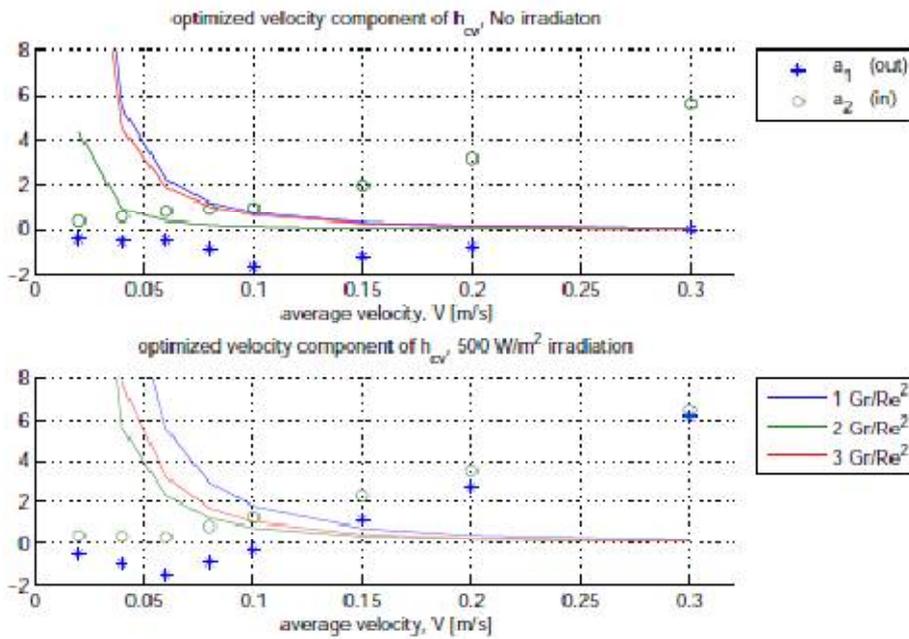


Figure 3: Results of the optimization of the velocity component for the heat transfer coefficients plotted together with possible calculations of $\frac{Gr}{Re^2}$.

Boundary Conditions for Transient Calculations

The surface temperature of the outer surface is rather stable according to the temperature profiles. It does not undergo any change very much over the height of the window.[9]

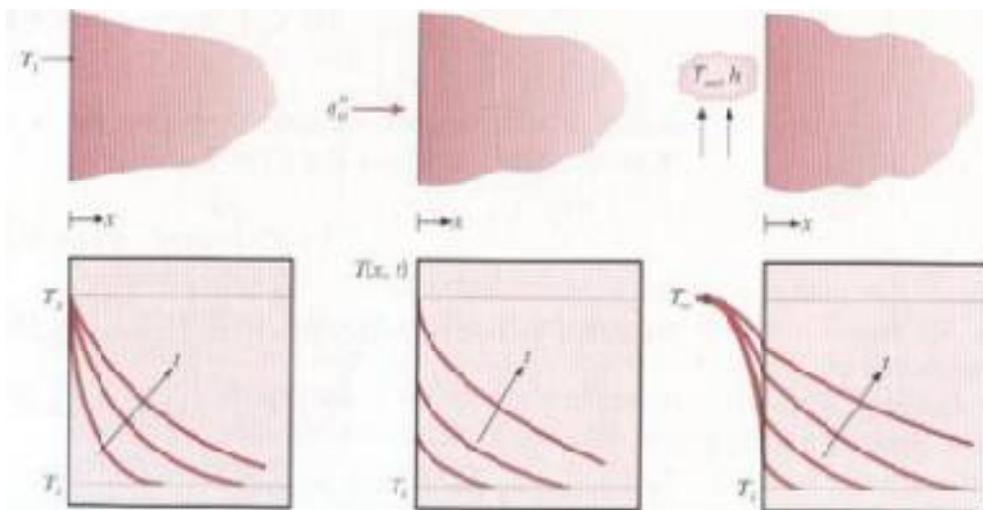


Figure 4: Transient temperature development for three surface conditions: constant surface temperature, constant heat flux and surface convection.

Radiations between the two panes are included in the CFD simulations, it is also necessary to take this radiative heat flux into account as well as any solar irradiation.[10]

The radiative heat flux is calculated as:

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$$q_{\text{rad}} = \sigma_s \sum (T_{\text{out}}^4 - T_{\text{in}}^4)$$

Impact of Transient Method vs. ISO Standard Method

Table 3: Comparison of windows thermal performance for transient or ISO standard method for ventilated cavity

Method	parameter	case 1	case 2	case 3
Transient	$U_{\text{eff}} \left[\frac{W}{m^2K} \right]$	0.69	0.55	0.41
	Preheating [°C]	10.2	8.4	5.6
	g-value [-]	0.62	0.63	0.65
ISO standard	$U_{\text{eff}} \left[\frac{W}{m^2K} \right]$	0.76	0.69	0.61
	Preheating [°C]	8.5	6.5	4.0
	g-value [-]	0.61	0.62	0.63
Improvement	$U_{\text{eff}} \left[\frac{W}{m^2K} \right]$	9%	25%	33%
	Preheating [°C]	20%	29%	40%
	g-value [-]	2%	2%	3%

A significant improvement of the ISO standard method, in terms of prediction of the convective heat flows in ventilated cavity. But they are only a small part of the total heat fluxes in the window and it is important to know whether the method for the ventilated cavity has any impact on the total performance of the window. [11]

Table 4: Main thermal characteristics of different panes including coating (Values are calculated with WIS)

Name	IR emissivity		solar transmittance [-]
	Inside [-]	outside [-]	
iplus SE	0.037	0.837	0.466
$W_{\text{in}}D_{\text{at}} \text{ law}E_{\text{soft}}$	0.092	0.837	0.666
$W_{\text{in}}D_{\text{at}} \text{ hard}$	0.160	0.890	0.699
$W_{\text{in}}D_{\text{at}} \text{ clear}$	0.837	0.837	0.847

Thermal performance characteristics of normal windows are shown in table 5 in which there are presented both a standard and an optimized 'super' version of double and triple glazed windows.

Table 5: Thermal performance characteristics of normal windows

Type Quality		double glazed		triple glazed	
		standard	super	standard	super
U-value	$\left[\frac{W}{m^2K} \right]$	1.28	1.12	0.82	0.72
g-value	[-]	0.65	0.55	0.56	0.45

Stable g-value

The g-values dependency is on solar irradiation for three different flow rates are shown in figure 5. The g-values are not completely stable, but they change so little that they can be assumed stable.

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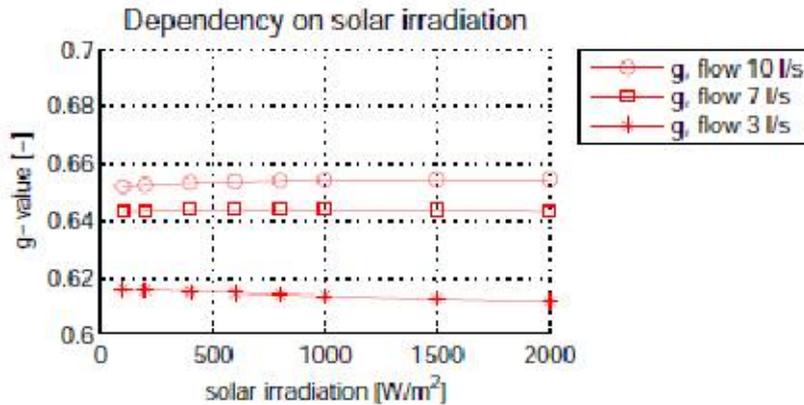


Figure 5: G-values dependency on amount of solar irradiation.

Thermal Performance with Solar Irradiation

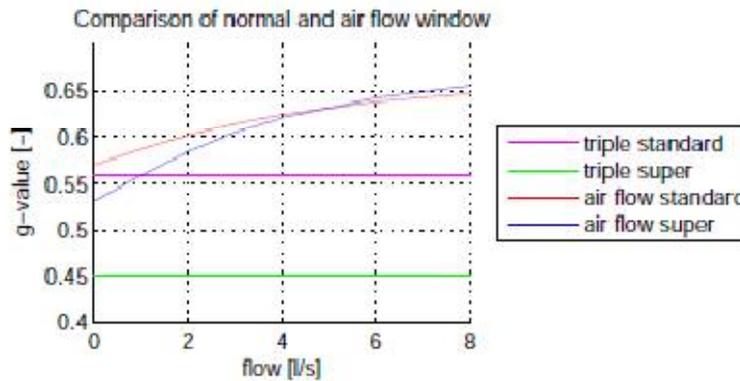


Figure 6: Comparison of g-value for different ventilation window

The effect of solar irradiation is evaluated at reference winter conditions including solar irradiation of respectively 100, 300 and 500 [W/m²]. The ventilation rate does not affect the g-value of normal windows. The normal 'super' window has the lowest g-value.

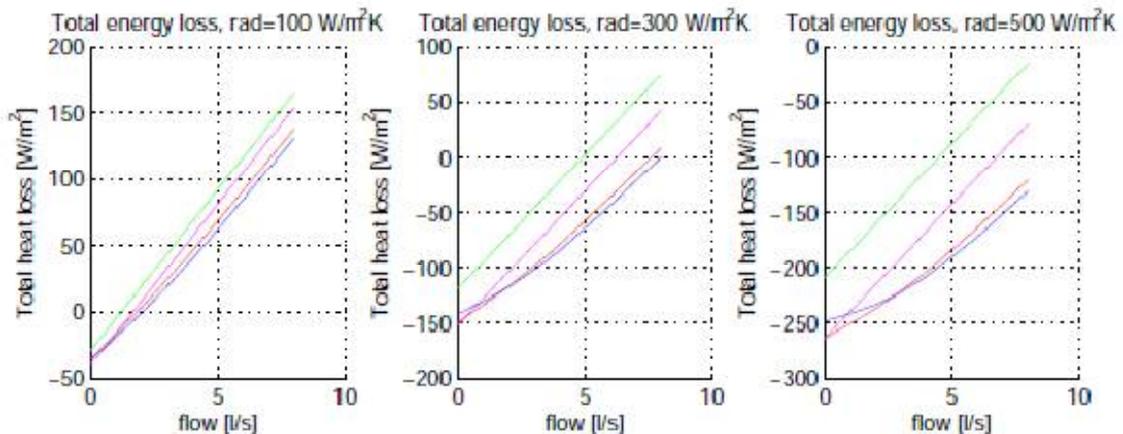


Figure 7: Comparison of total heat loss with solar irradiation

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IV. CONCLUSION

The CFD model is therefore validated against a well known and extensively researched case: natural convection in a closed vertical cavity. Comparison with the ISO standard method for closed cavities has shown that the Renormalization Group (RNG) turbulence model has the overall best results. But for low surface temperature differences, where the flow is expected to be laminar and without multi cellular flows, the laminar or the RNG-model with Viscosity Differential Model (VDM) enabled, produces the best results. The grid dependency analysis has shown that refinement of the grid will only cause minor changes to the results. It is therefore reasonable to assume grid independency of the simulations.

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