COMPARATIVE ANALYSIS OF NATURAL VENTILATION PERFORMANCE IN NON-UNIFROM DOUBLE SKIN FACADES IN TEMPERATE CLIMATES

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ABSTRACT

This study compares the performance of three different double skin facade configurations in prevailing summer conditions in a temperate climate. CFD simulation results compare cavity air velocity profiles and indoor temperatures to examine the potential for natural ventilation. Of particular interest, is the possibility of vitiated air flowing from one level to the other and increasing the contamination level on subsequent floors.

Results indicate that with almost similar air volumes inside the double skin cavity, the air velocities inside the cavity and into the rooms are unaffected by the changes in the outer skin configuration. Staggering the inlets and outlets of the internal skin leads to a negligible amount of return air entering into subsequent floors

INTRODUCTION

Traditional double skin facades are designed as two glazed facades separated by a uniform cross-section air gap. It is widely accepted that if properly designed it could have a beneficial impact on improving indoor thermal, visual and acoustic conditions in perimeter areas, while increasing the provision of natural ventilation and acceptable levels of internal surface temperatures.

Acting as a stand-alone solar chimney or coupled with mechanical systems for mixed mode ventilation of deep plan environments (Poirazis, 2006) or in extreme climates as hot arid climates; double skin facades can lead to a substantial reduction in cooling loads (Hamza, 2008). Studies have predicted that in moderate climates; cross natural ventilation can lead to indoor thermal comfort in summer conditions in multi storey office buildings (Gratia and De Herde, 2007).

Doubles skin facades are attractive as a possibility to provide natural ventilation by opening windows to the cavity. The opportunity to open windows for natural ventilation in office environments is linked with reduced sick building syndrome. Burge et al (1987) and Muhnic and Butala (2004) among many others studying the relationship between building sick syndrome (SBS) and natural ventilation found a significant link between lowering attributes of health problems in naturally ventilated buildings than in mechanically ventilated buildings.

Between 1990 and the beginning of the 21st century, double skin facades had uniform cross sectional air shafts that could be extended over a number of floors. Recently, there is an increasing interest in changing the configuration of the uniform double skin facades realized in different climatic regions as varied as the hot humid to the cold moderate climates. Instead of a uniform shaft configuration, the outer facade layer is starting to present itself as an architecturally engaging surface. Contemporary examples head towards changing the norm of a smooth glazed outer surface into a faceted layer that extends the function of the air shaft into a social place for gatherings such as the Health Department building in Bilbao, Spain by Coll-Barreau Arquitectos in 2008.

Varying the aesthetic expression of the facade and the depth between the double skin layers has uncertain effects on the air flow and thermal performance of the double skin facade (DSF) and hence its impact on the potential for natural ventilation through the rooms connected to the DSF.

Alloca et al (2003) found that wind and stack effect can reinforce each other at lower air speeds but as air speeds increase there is no consistent pattern and wind speeds over 4m/s can lead to flows which oppose the buoyancy-driven flow in the occupied spaces. Double skin facades provide a layer of low air speeds (maximum at 1m/s) as a cloak around internal spaces, which combined with stack effect can aid both internal air change rates and dissipation of internal heat gains, as well as into the cavity.

In its preliminary set of simulations, our research acknowledges that CFD simulation results have' justifiably' been treated with caution due to their simplifying assumptions and limitations in modelling buoyancy-driven flows. However, with vigilance to control' errors in inputs, CFD can be used as a comparative tool to test the impact of these changing configurations on air movement in cavities and their consequential effect on human comfort and carbon reduction strategies.

This paper departs from previous attempts in changing the design of the outer surface of a Double skin facade configuration to examine:

- The impact of changing the flow channel configuration on buoyancy and heat stratification in the double skin facade
- The effect of coupling the flow inside the cavity by a single sided ventilation scenario to internal occupied spaces, in order to evaluate air distribution and air change rates indoors
- Whether flow coupling of double skin cavity and indoor spaces will lead to vitiated air, leaving through room outlets, finding a flow path through room inlets and contaminating intake air on subsequent floor levels

MODEL GEOMETRY

CIBSE (2005) guidelines were used as a preliminary check that inlets were sized exceeding the minimum standard required for single sided ventilation. In this case; 1/12 of the floor area (CIBSE (2005) recommendation is 1/20 of the floor area and width of room ≤ 2 height of room) for single sided ventilation with double openings. The Window to wall ration of both inlet and outlet for each internal facade is 8% of the facade for each floor.

The room configuration is 6.25m by 8m and a height of 3.25m. Room inlet and outlet are 2m x 0.5m but are placed on opposite corners and juxtaposed on every floor level. Air movement is controlled by louvers to help direct the natural buoyancy caused by air decreasing in its density as it picks up internal gains. The lower internal pressure at the bottom opening drives inflow while the higher internal pressure at the upper opening drives outflow

Pressure tends to drop significantly with facade cavity height after the second floor Ding. et. al (2005). In this study the double skin facade extends over the first and second floors. The double skin inlet is 2 m above ground level and is assumed to have no obstructions or walkways to decrease the effective inlet opening area thereby minimizing thermal exchanges with the ground and providing better air quality intake. The flow domain in this case is the Double skin facade cavity, where temperatures at inlet are assumed equal to outdoor temperatures. The DSF outlet openings are 2m^2, which is 25% of the inlet area Mingotti et al (2011) research found that the inlet to the DSF needs to be larger than the cavity outlet under summer conditions to create an effective air flow in the cavity and reduce heat stratification

Alloca et al. (2003) found that in a room with single sided ventilation the interaction of flows between vertical spaces cannot be ignored as return air finds its way into air supply inlets on higher floors when inlet and outlets are above each other with a small vertical distance in between. Compared to a single window opening; a separate inlet on the lower level of the room and an outlet at the higher level in the

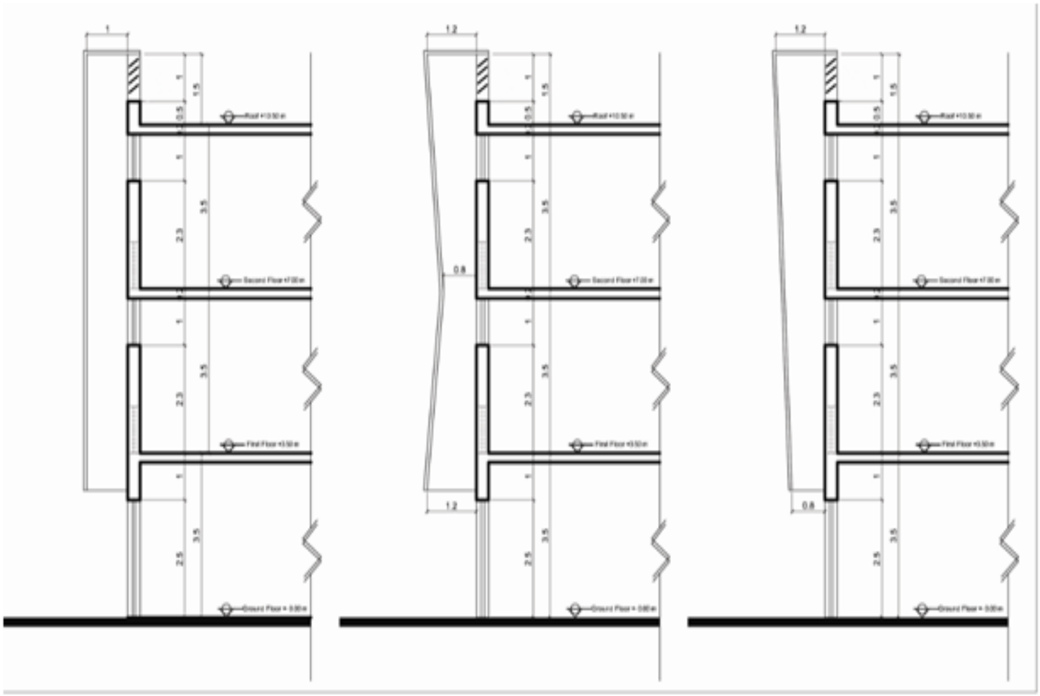

Figure 1 Straight, Necked and Raked double skin facade configurations

room increased the ventilation rates and is supported by the stack effect. Ostreale et al (2001 p.20) also recommend staggering inlets and outlets in double skin facades, based on simulations of the air flow studies for the 'City Gate' by Petzinka, Pink and partners . In this study, the internal ventilation inlets and outlets to rooms are staggered to opposite corners of the internal DSF. Staggering inlets and outlets aims at increasing the vertical distance to the maximum and avoid vitiated air entering through the upper floor inlets.

Ding et al (2005) studied varying the height of the solar chamber on top of the double skin facade and found that increasing its height has a beneficial effect on substituting for lost pressure in the cavity .when ventilating upper floors. They recommend that the cavity height is a minimum of 2 storeys high above the top floor. In this research, we substituted the parapet height on the roof level by the solar chamber, this means that is only 1m above the roof height and placed vertically above the double skin cavity which is seen as more practical in architectural and construction costing terms. Pasqauy (2004) suggest that when natural ventilation is used through double skin facades that is beneficial to use the thermal storage capacity of the structural slabs to aid in absorbing indoor heat gains, as well as restricting openings to the cavity instead of a fully glazed internal walls to prevent excessive overheating indoors. This was taken into consideration in the model construction and openings are tested to provide an acceptable ventilation rate indoors.

Sources of internal gain, human occupation, computers and lighting are modelled as hypothetical boxes 18 people modelled on each floor with a heat flux of 40 W/m^2 and a surface area of 1.82 m^2 or 9 people occupying about 4m^2/p and with internal loads from ICT and lighting.

The façade was modelled as south facing in a leeward direction. The time chosen was 15:00 on 20th June when the ambient temperature was approx 21C. At that time, the sun was at an azimuth angle of 230 deg, i.e.50 deg West of South, and an altitude of 54 deg. Thermal modelling using IESVE version 6 was used to implicitly model the impact of direct solar radiation on buoyancy in the DSF. Results were coupled to the CFD modelling using a CFX code

Three configurations were chosen; a raked, a necked (constricted flow) and a straight facade, as a possible architectural variation to the external surface while maintaining the air volume inside the cavity (Figure 1). Note that all CFD illustrations presented have omitted the ground floor to focus on the representation of air floor within the double skin.

The CFD used in this work is ANSYS CFX, version12 (2001), which is a widely validated code that has been successfully applied to buoyancy-driven natural ventilation in buildings (Ji et al (2006), Cook and Short (2005), and Hanby et al (2008). The CFX employs a coupled, fully implicit solver using a transient evolution of the flow from the initial conditions. The physical time-steps used in the transient evolution provide a mean of controlling the solution procedure. CFX uses a multi-element typr mesh comprising hexahedrals, tetrahedral, wedges and pyramids. The conservation equations are solved using Finite Volume method (Versteg and Malalasekera, 2007).

Performance Comparative Analysis Simulation results indicate that all three configurations have a similar heat stratification and buoyancy profile and that indoor temperatures distributions are very similar in the cavity and in the occupied spaces (Figure 2 and 4)

As expected; the air temperatures rise above ambient by 2-3 ^{0}C at room inlets through the double skin facade; this is consistent for all three-facade configurations (Figure 4). Room outlet temperatures

Table 1 Comparison between temperatures and ventilation at inlet and outlet levels

	Straight		**Necked**		**Raked**	
	Temp (°C)	**Ventilation (m^3/s)**	**Temp (°C)**	**Ventilation (m^3/s)**	**Temp (°C)**	**Ventilation (m^3/s)**
Façade Inlet	21.01	1.18	21.01	1.18	21.01	1.19
Façade Outlet 1	26.94	0.62	26.83	0.62	26.91	0.62
Façade Outlet 2	26.63	0.56	26.74	0.55	26.67	0.57
Room 1 inlet	23.77	0.50	23.79	0.50	23.62	0.50
Room 1 Outlet	26.51	0.50	26.50	0.50	26.57	0.50
Room 2 inlet	24.34	0.40	24.79	0.40	24.44	0.40
Room 2 Outlet	28.04	0.40	27.92	0.40	28.00	0.40
Room 1 plane(1m)	24.86	-	24.79	-	24.79	-
Room 2 plane(1m)	25.82	-	25.69	-	25.00	-

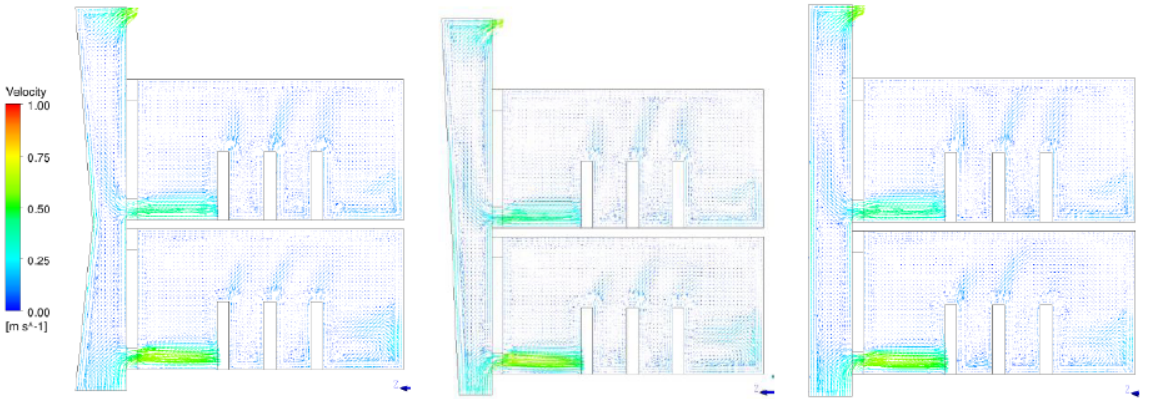

Figure 2 Vector analysis showing air velocity at inlet levels

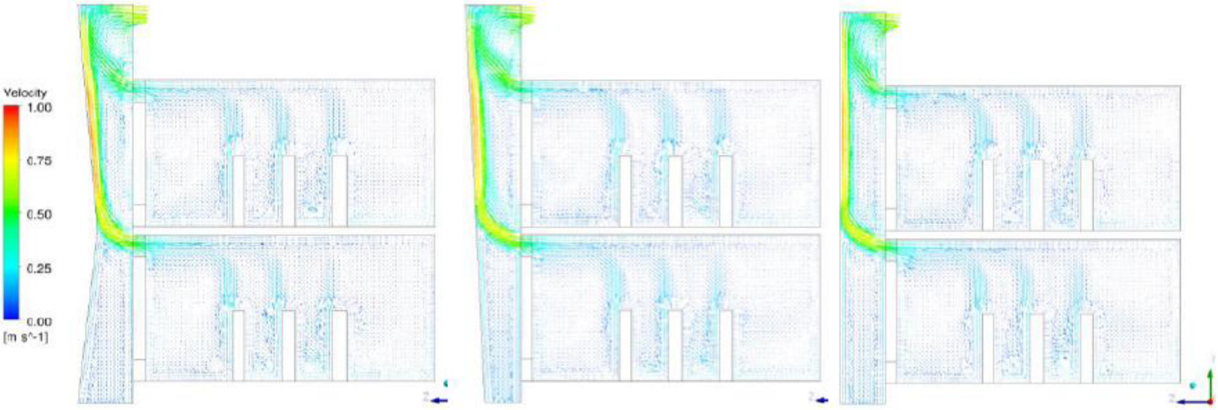

Figure 3 Vector analysis showing air velocities at outlet levels

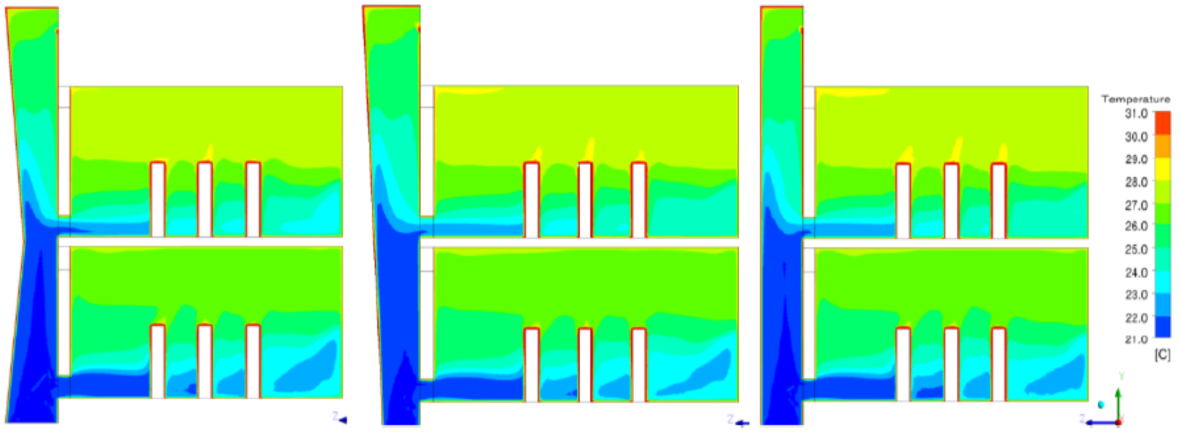

Figure 4 Temperature profiles inside cavity and room inlets

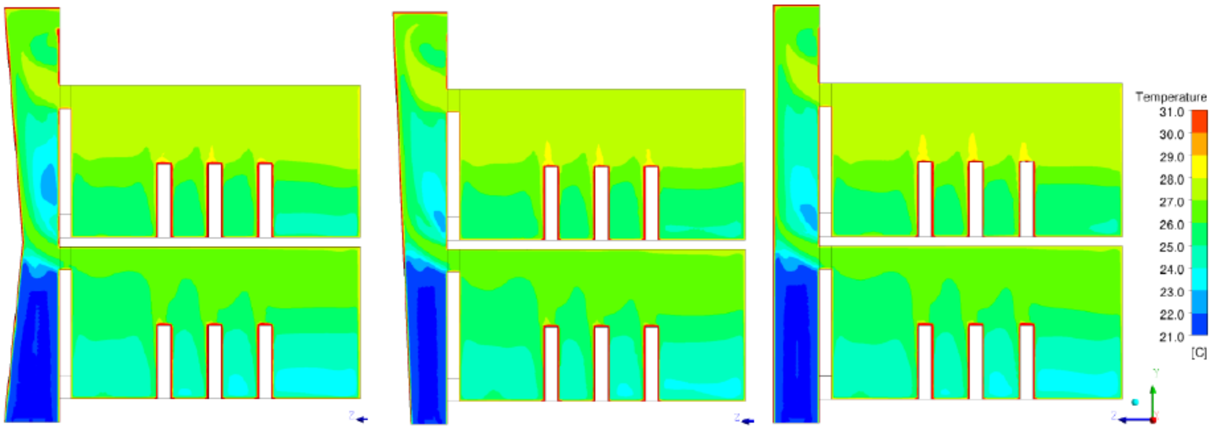

Figure 5 Temperature profile at outlet levels

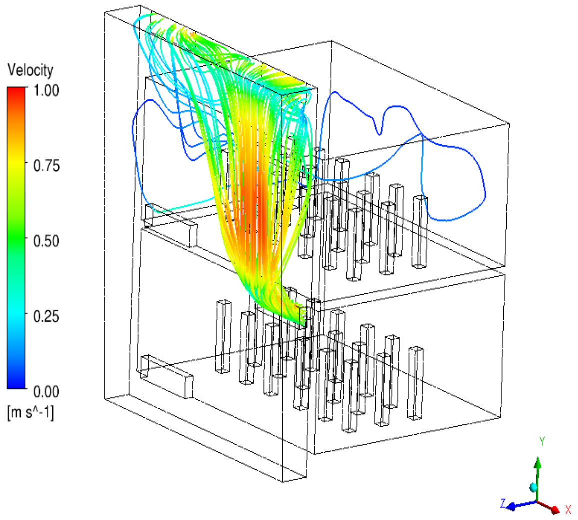

Figure 6 study of vitiated air movement and velocity in cavity

show that the stack effect is established by internal room air picking up internal heat gains. Table 1 shows that although there is a small difference in the DSF inlet areas due to the architectural configuration; there are negligible differences between room outlet temperatures and the volume flow rates in all three configurations tested (Table 1). This gives architects the freedom to change the external surface without incurring penalties in the predicted thermal and ventilation performance provided the cross section area of the facade does not fall below the sum of the areas of the outlets from each space.

CFD modelling indicates a jet-like emission of vitiated air at the outlets of the two rooms of increased air velocities between 0.5-0.75 m/s, this was used to determine if such increased velocities would push contaminated air into the air inlets on subsequent floor levels. Figure (3), shows that most of the air leaving the lower room (under these conditions) jets out into the cavity and, aided by buoyancy in the cavity, joins the air stream nearer to the exterior facade layer and flows up the façade and out at the top.

Only a small amount of return air is entrained in the flows within the façade and finds its way to the inlet of the upper room (Figure 6). The behaviour of the plume is related to the peak temperatures of the double skin facade domain lying on the inner surface of the outer skin. The outer surface temperatures exceeds ambient temperatures as solar radiation increases on the surface and can reach a difference of about 30C if the solar intensity increases to about 700W/m^2, the air velocities are at its highest adjacent to the warmest cavity surface and tend to decrease linearly in the cavity towards the inner glazed surfaces (Hamza and Underwood, 2005). The increased velocity occurs at the outer surface of the cavity as this is the warmest surface at 34 ^{0}C in the flow domain (compared to inner cavity surface temperatures of 31 ^{0}C). This leads to the vitiated air coming out of room outlets to join the air stream in the gap and disperses on the outer layer until it is exhausted from the upper double skin outlet. This behaviour is consistent in all three facade configurations figure (Figure 3,5)

To understand the impact of the double skin facade configuration on indoor environments a calculation of the internal fresh air supply rate was used to test whether openings were sufficient to provide natural ventilation through the configuration

HSE (2000); recommends that fresh air supply rate should range between 5 and 8 litres per second per occupant (8 L/s fresh air is equivalent to an elevation of 600 ppm of carbon dioxide (CO_2) which, when added to the normal outdoor CO_2 of 400 ppm, gives an internal CO_2 concentration of 1000 ppm; 5 L/s would be equivalent to 1350 ppm internally.) The higher ventilation rate of 8 L/s per person is recommended

However; the air supplied through the inlets is 28 L/s per person (11 ac/h) on the first floor and 22L/s per person (9 ac/h) on the second floor which is above the required supply rate recommended by HSE (2000). Higher rates of fresh air supply lead to better indoor air quality and dissipation of heat. The air change rates predicted are commensurate with those expected in well designed naturally ventilated buildings.

Thermal conditions indicate that the first floor has a lower temperature distribution and average temperatures than the second. This is expected due to the reduced buoyancy driving force on the upper floor. Mean air temperatures predicted at 1m level suggests that the mean air temperatures are above comfort levels and will necessitate some form of mechanical cooling (with an average of 25^{0}C at both levels for all facade configuration)

CONCLUSION

Interest in the potential of double skin facades as an architectural configuration while harnessing its benefit as a buffer for climatic and noise external conditions is manifesting itself in an increasing number of buildings. Simulation work is currently lagging behind in providing an understanding of how non-uniform cavities will have an impact on the volume flow rates inside the cavity, pressure drops and the possibilities of natural ventilation indoors in temperate climates.

This paper attempts to open this discussion and like many preliminary investigations; it raises more questions and warrants the need for further research to give architects and professionals engaged in using this facade technology some evidence that enables robust design decisions

The three configurations tested show a similar behaviour in the cavity and its influence on indoor thermal and air quality conditions that give architects more freedom to design engaging external surfaces.

Although air quality is predicted to be met by the current levels of window to wall ratio on the inner facade, the thermal predictions indicate the need to supply some form of mechanical cooling to lower the temperatures to comfort levels. Considering that the ambient temperature used was an average of 21^0C then this need will increase in peak summer conditions.

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