CLIMATIC BASED CONSIDERATION OF DOUBLE SKIN FAÇADE SYSTEM: NATURAL VENTILATION PERFORMANCE OF A CASE STUDY WITH DOUBLE SKIN FAÇADE IN MEDITERRANEAN CLIMATE

Azarbayjani, Mona

University of North Carolina at Charlotte, United States of America

ABSTRACT

There is an unexploited opportunity to employ either fully naturally ventilated, or partially, when mixed with mechanical ventilation in buildings in Mediterranean climate. The possibility of exploiting natural ventilation due to complexity of physical phenomena that is non-linearity, chaotic behaviour of air movement, demands a major tool "Computational Fluid Dynamics" (CFD)1 for design analyses. Fluent was used to study the airflow and temperature distribution in the occupied spaces evaluating different possibility of exploiting natural ventilation for different outside conditions. In this study two driving forces-wind and stack effect (buoyancy forces)- are investigated to study the possibility of providing comfort in the building. The results document the indoor climate, the boundary conditions for further planning and the possibilities for high-rise buildings with the new innovative enclosure. The primary goal of this research is to clarify the state-of-the-art performance of DSFs, so that designers can assess the value of these building concepts in meeting design goals for thermal comfort, ventilation, and sustainability. This investigation adopts an analytical approach using dynamic simulation software (Energy Plus/Designbuilder), to understand the performance of a double skin façade based on research rather than intuition

INTRODUCTION

The double-skin façade is an architectural phenomenon driven by the aesthetic desire for an all-glass façade and the practical desire to have natural ventilation for improved indoor air quality in buildings. Until recently the use of double-skin facades had become more popular in many high-rise buildings in Europe.

Design strategies need to consider the climatic conditions and local characteristics such as temperature, solar radiation, wind velocity and temperature in order to results in energy consumption reduction. The aim of this study is to reflect on strategies for double skin facades that are responsive to particular cold climate type. The potential of using a double façade of the building in climates other than Europe has not been fully studied though. A number of interesting investigations and findings are reported in the literature pertaining to passive ventilation in buildings with double-skin facades.

Even though most of the research has been done in temperate climate conditions, studies have revealed a close link between natural ventilation design and the DSF function. A number of studies, research and several simulation programs have been done on employing the natural ventilation in buildings and thermal performance of double skin facades. Most of them have been carried out for solar chimneys -one way to increment natural ventilation and to improve indoor air quality- and Trombe walls prior to double skin facades. Most of

[1] CFD codes numerically solve the differential equations, which govern fluid dynamics (Navier-Stokes equations). It is solving for three dimensional fluid flow problems by solving conservation of heat, mass, momentum and other transport equations using control volume technique.

them found out the natural ventilation is possible in summer even for multi-story buildings (Wong, 2006). The potential of using a double façade for natural ventilation of the building in climates other than Europe has not been fully studied though.

Even though most of the research has been done in temperate climate conditions, studies have revealed a close link between natural ventilation design and the DSF function. Grabe et al. (2002) developed a simulation algorithm to investigate the temperature behavior and flow characteristics of natural-convection DSFs through solar radiation. It was found that the air temperature increased near heat sources that are close to window panes and shading device. Gratia and Herde (2007a, 2007b, 2007c) attempted to look at natural ventilation strategies, greenhouse effects, and the optimum position of sun- shading devices for DSFs facing south in a northern hemisphere temperate climatic. They found that a sufficient day or night ventilation rate can be reached by a window opening, even if wind characteristics are unfavourable.

METHODOLOGY

Simulation was performed with climatic data of Oregon Weather data recorded by the World Meteorological Organization and includes 12 actual months. Natural ventilation is possible during the shoulder season in Oregon. For this study, the months of May, June, September, and October were chosen.

The final goal of the research is to look into the possibility of natural ventilation in this office building in a mediteranean climate(Oregon). In order to achieve that goal, three dimensional grid model of the office module of the building has been created in Gambit.

The building has been simulated with Energyplus/Designbuilder to draw the data for solar heat gain radiation and temperature of the surfaces. The next step, the boundary conditions has been calculated based on the wind velocity and the temperature data and it plugged into Fluent to study the airflow speed and calculate the thermal comfort.

The office modules equiped with the multi-story type DSF is constructed in 3 dimensional Gambit-Fluent with the geometrical dimensions of 27x7 m, with 3.5 m ceiling height. The external screen model has openings on panes with 6mm thick glass. In this configuration, the double-skin facade has a cavity of 0.9 m depth and 3 story height with two openings on the lower and high level of the cavity. This stack effect and the natural ventilation help to extract the heat from the offices and to improve the airflow rates required to reach thermal comfort level within the interior office space.

The first stage of the airflow modelling is to construct a simple model of the enclosure system the multi-story DSF in DesignBuilder/Energyplus. The numerical model is three-dimensional and the model is based on a control volume method. The geometric model of the entire building is constructed using a matrix of numbers to represent the points at which surfaces meet.

Based on the data from energy simulation for the specific data and time, the boundary conditions were solved, the grid size refined, and number of necessary iterations determined. The generated model solved for wind velocity along with buoyancy forces. In order to define the external boundary condition, the airflow needed to be solved for the external wind. For this study, only wind direction which is perpendicular to the DSF has been considered.

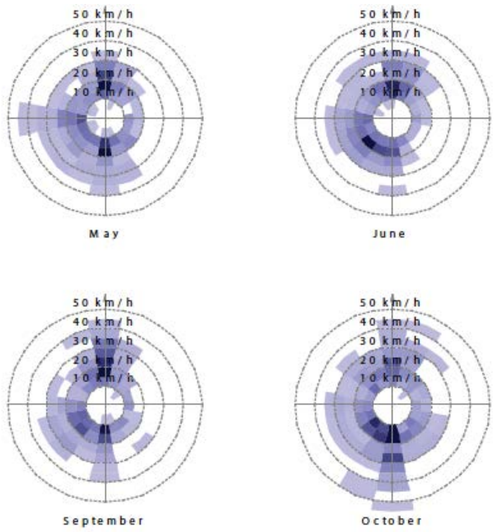

Figure 1.Selected Monthly wind wheels

The weather in Eugene, Oregon is very mild and temperate in comparison to many other cities and states. The diurnal swing in the winter months is very low at under 5 degrees Celsius, while in the summer months it can swing over 25 degrees Celsius in one day. This often can cause issues with the heating and cooling of the building, as it is hard to keep a stable internal temperature. One advantage to being in Eugene is that 7 months out of the year, the daily swing hits the personal comfort zone, allowing for minimal loads during those times. Also, due to an abnormal amount of overcast days, there are less than normal direct solar gains gained by the building (which is also offset by the double facade and window shading devices). The building has 3 floors, and the zones are divided by the use of each one. The cavity is treated as one single zone inside DesignBuilder, with openings in the floor and ceiling of the corresponding floors connecting them.

The effectiveness of ventilation driven by thermal buoyancy, or stack effect, is determined by the inlet air temperature, height between the inlet and outlet openings, size of these openings. Fig. 5 shows the section of office modules and the configuration of openings inlet and exhasut.

Figure 2. Building on the site

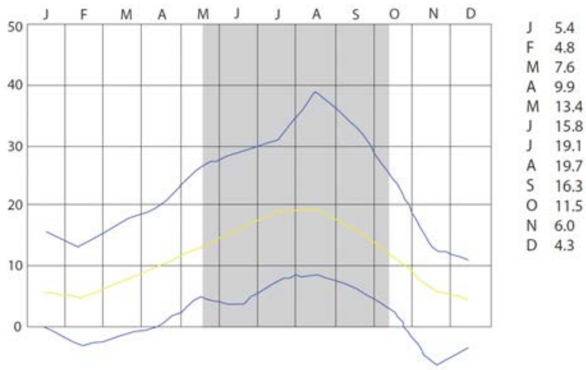

Figure 3. Average temperature in Farenheit

Figure 4. Double Skin Façade building

AIRFLOW MODEL DESCRIPTION

The first stage of the CFD modeling is to construct the module with the geometrical dimensions of 27x7 m, with 3.5 m ceiling height and 0.9 m cavity corridor in front of the offices in gambit. The single-skin external facade of the model has openings on panes with 6mm thick glass. The model is constructed in 3d in Gambit and the boundary conditions illustrated in Figure 5. To verify the comfort level and the temperature of the office, the Computation

Fluid Dynamic (CFD) software Fluent was implemented.

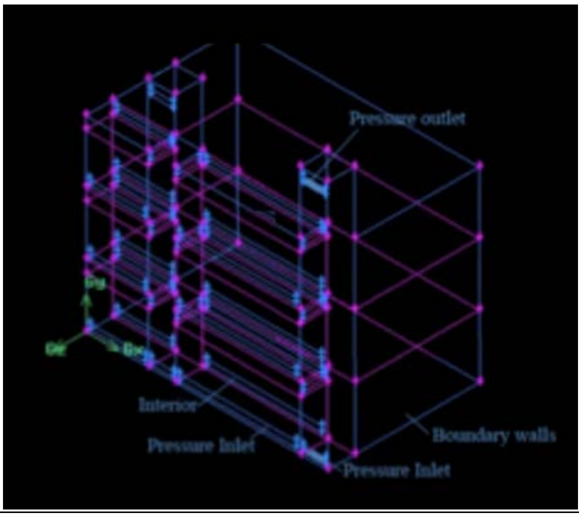

Figure 5 Boundary conditions of CFD model

The boundary conditions for all stages of the modeling are:
_ Simulations run for 2 periods of time morning (9 a.m.) and afternoon (3 p.m.)

Average hourly Dry bulb temperature C

Month/Time	May	June	Oct.
9:01-10:00	22	25	18
15:00-16:00	25	27	20

Average hourly Relative humidity%:

Month/Time	May	June	October
9:01-10:00	77	79	81
15:00-16:00	56	57	58

Daily average wind velocity m/s:

Month	May	June	October
Average m/s	4.5	5	5.6

_ Wind direction perpendicular to the wall system
_ DSF opening size for inner pane 0.3m
_ Cavity Depth 0.9 m.
_ DSF opening size for outlet 0.3m

Domain material	Air-outdoor temperature
Reference pressure	100,000 pa
Gravitational Acceleration	-9.81 in Y direction
Heat source external	11.43 W/m2
Heat source internal	7.93 W/m2
Velocity inlet	5 m/s
Buoyancy model	Boussinesq
Buoyancy reference Temp	Outdoor temperature

Table 1. Boundary conditions

MODEL DESCRIPTION

The John E. Jaqua Academic Center for Student Athletes is a new, 37,000 SF center for students athletes who attend the University of Oregon. It is placed on a site, which is located between the main hubs of the university and the city of Eugene. The site around the building was placed to create a more scenic surrounding for those inside the building. This includes winding paths, extensive landscaping work, and a pond, which surrounds the building constantly with flowing water.

The specifications of the project are:

A Unique High-Performance Facade:

• The double-skin facade (two surfaces of glass, creating an insulated airspace) is a multi-story (full height), full depth (0.9), thermal flue. The facade allows for complete transparency while ensuring protection from excessive heat gain, heat loss, and glare:

Energy Savings:

• The 0.9 m airspace can be open in summer to keep heat from entering the building and closed in the winter to create an insulating “thermal blanket;” (figure6)

Natural Light:

• The facade brings a significant amount of balanced natural light into the building, carefully controlled by fixed and movable sunshades.

Natural Ventilation:

• The double skin façade ventilates to the outside during the shoulder season.

Figure 6.View towards double skin façade on the first floor

Model parameters and inputs for DSF:

Please note the R-Value unit is h.ft..°F/Btu and the U-value unit is BTU/(h °F ft.)

Equipment Gain: 10 W/sqft

- Typical floor = 20 W/sqft
- Entrance = 10 W/sqft
- Procedure Rooms = 20 W/sqft

Linear Equipment Corridor = 30 W/sqft [zone 12, 19]

Office areas: 6 W/sqft

Lighting Energy: 0.050 W/sf/foot-candle

Display and Task Lighting: 2 W/sf

Widow area: 100% on the South facade, 30% over all

Glazing Type:

Exterior: Double Clear 3mm/6mm Air [U-Value: 0.568]

Interior: Double Clear 6mm/13mm Arg [U-Value: 0.449]

Construction Template: Medium Weight

External Walls: R-16

Roof: R-22

Ground Floor: R-16

Infiltration: 0.5 ac/h

HVAC Template:

VAV with fan-assisted terminal reheat, Ventilation: 6 ac/h

Heating CoP: 0.60

Cooling CoP: 1.30

Fuel: Electricity for Heating and Cooling

Wind pressures

The distribution of wind pressure around a building depends very closely upon the local variation in wind velocity which the building produces. In accordance with the elementary pressure-velocity relationship, the pressure distribution is represented by a dimensionless pressure coefficient C_p :

$P_w = C_p \frac{\rho U_r^2}{2}$ Where,

P_w= wind pressure, Pa

ρ = air density, kg/m^3

V_r = wind speed at specified height, m/s

This formula has been used to calculate the boundary condition for the inlet and outlet pressure in Fluent.

The geometry of the CFD model

The double skin facade configuration take the advantages of the strategies include ventilation driven by different combinations of wind and external stack. This configuration is multi-story type through the building's facade. The cooling stacks allow for further ventilation on hot, stagnant summer days so the building can always remain cool within reasonable comfort levels.

Figure 6 shows how air flows through the facade and provide ventilation. Air gap inlet draw in fresh air at a low level and direct the fresh air into the room. The air exhausted through the outlet at the high-level gap of inner pane. Multi-storey chimneys suck exhausted air via a bypass opening at the top of the inner level. The vertical height of the glass chimney creates stronger uplift forces due to increased stack effect.

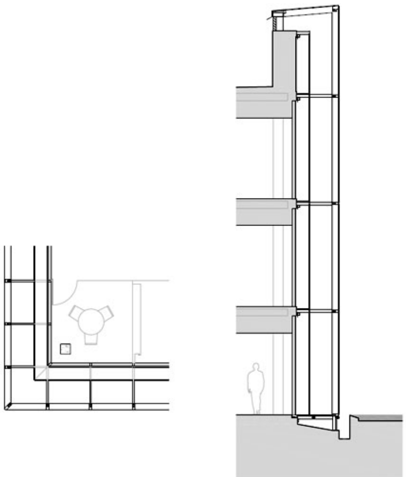

Figure 7. Plan and Vertical cross-section of the DSF

CFD

Ventilation rates are calculated by solving a network consisting of nodes connected by flow elements that correspond to openings between spaces and between spaces and the outside. Buoyancy driven flows predicted using space temperature calculated with 1000 iterations between airflow and thermal calculations.
The flow is produced by a combination of wind and stack effects.
Through analysis, it was discovered that thermal buoyancy in the cavity was great enough resulting in warmed return air extracted from the space from the top of the façade.

DISCUSSION

For the analysis of airflow and temperature in DSF and adjacent space, the multi-story DSF has been generated and airflow patterns and temperature profile within the DSF has been illustrated for specific times of the year. Based on those data, the level of thermal comfort within the space will be predicted. The CFD analysis for the summer afternoon suggests that the double façade is performing as expected. Cool air is entering the bottom of the façade cavity and warm air is exiting through the top.

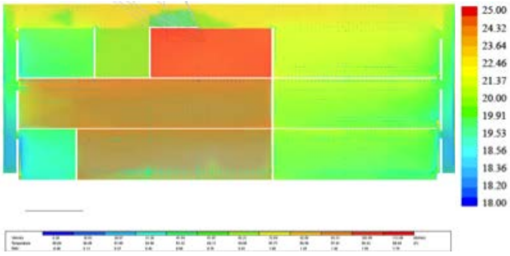

Figure 8. Temperature stratification from first to top floor

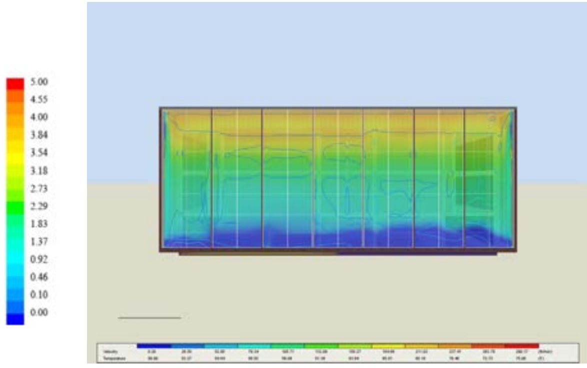

Figure 9. Velocity in Double Facade Cavity

It is a fact that the higher the exhaust opening is located from the inlet, the stronger stack effect within the air gap. This effect will then pull more air from office spaces to circulate throughout the building. The other factor that impacts on air velocity are inlet and outlet sizes. Due to the ventury effect, the smaller the size, the more the velocity. Figure 8 illustrates the room's temperature gradient, which is clearly lower than the outside temperature of 20 ˚C. There is some temperature variation as the cavity is ventilated. The room air temperature increases towards the top as shown in figure 8.

The stack air temperature increases towards the top of the chimney in a fairly linear progression, as shown qualitatively in Figure 8.

The top floor would be hottest and probably uncomfortable for occupants during the summer month. It is interesting to discover that the office's mid-portion for all the floors are having higher temperatures compare to the front part. This could be due to the airflow pattern shown in the Figure 10.

The air velocity through the cavity is due to buoyancy and wind forces, and it is quite high. Figure 9 shows the building's air velocity model. The velocity in this model ranges from 2 m/s inlet to 4 m/s outlet.

Table below shows the PMV ranges for naturally ventilated spaces with 80 percent acceptable limits indicated for the third floor in May. There are broader acceptable temperature ranges for naturally ventilated spaces. Air movements determine convective heat and mass exchange of the human body with the surrounding air. In this climate, high air velocities will increase the evaporation rate at the skin surface, which results in a cooling sensation. The recommended upper limit of indoor air movement is usually 0.8 m/s for human comfort; such air velocity permits the interior space to be 1-2 degrees higher than the human comfort temperature to maintain desirable a comfort level (Hien et al, 2005).

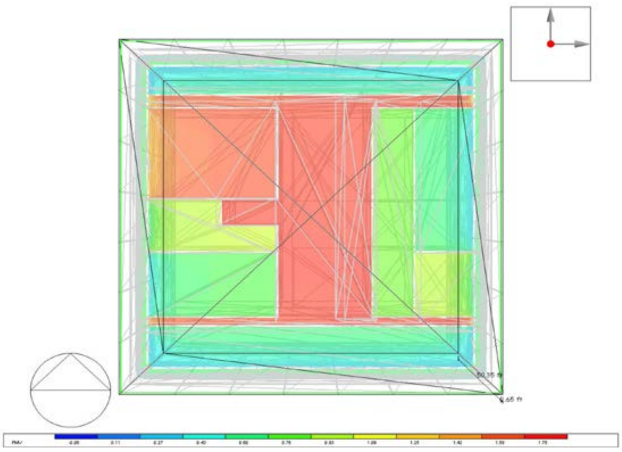

Figure 10.View towards double skin façade on the third floor

RESULTS

The results for multi story DSF with external wind velocity of 5 m/s and air humidity of 50% respectively are tabulated in Tables 2. Results as shown in Figure 11 indicated that the DSF air gap size of 0.3m gives the comfort result for the particular conditions in the building.

The lower floor of the office space would generate the lowest operative temperature due to the 'stack effect' provided by the DSF configuration. This has enhanced the natural ventilation strategy to provide better internal thermal comfort condition for the office spaces.

	Floor Level	Temp. C	Air Velocity	Radiant Temp	RH %	PMV	OT
May	1	20	0.58	22.93	40.7	0.18	20.2
	2	22.4	0.16	22.53	47.3	0.29	20.3
	3	24.8	0.11	33.64	45.6	0.37	20.5
June	1	23.7	0.50	27	51.1	0.5	20
	2	24	0.19	37.50	50.7	0.66	21.3
	3	24.6	0.15	27.19	56.6	0.76	21.1
Oct	1	22	0.57	23.3	36.4	-0.32	22
	2	22.3	0.20	23.4	42.4	0.11	22.8
	3	22.8	0.19	24.6	45.4	0.23	22.0

Table 2. PMV results

The DSF has produced an 82% Acceptability Limit for the 0.3 m opening for external temperature 23C, according to the Thermal Environment Conditions for Human Occupancy from ANSI/ASHRAE Standard 55-2004.

Figures 7 through 11 illustrated detailed indoor temperature, velocity magnitude, velocity vector and base on those PMV index was calculated. From the PMV index, it can be seen that indoor thermal comfort are non-uniform and the area with higher air velocity provides better indoor thermal comfort than the stagnant spaces.

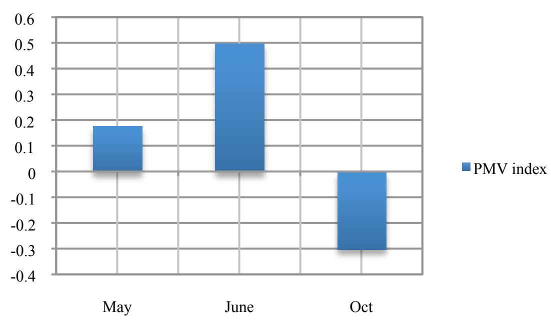

Figure 11 Thermal comfort evaluations

CONCLUSION

The CFD results appear to confirm the design's effectiveness. The airflow follows the top opening and exits through them, which suggests that the cool night air will effectively draw the heat out. This study has shown that the DSF has a possibility of providing acceptable internal thermal comfort through natural ventilation strategy.

Convective forces inside the cavity could be used to promote air extraction from the room, although it is needed to promote air movement within the room to release the excess heat.

From the climate analysis, it is inferred that building orientation has been decided considering the prevailing winds; which can make the natural ventilation possible in the summer and/or in shoulder seasons.

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