DEVELOPMENT AND CONSTRUCTION OF BIOCLIMATIC DOUBLE SKIN ACTIVE FACADE FOR HOT AND HUMID CLIMATE OF UAE

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ABSTRACT

Transparency in architecture is desirable for many reasons. In order to build transparent buildings with high levels of occupant comfort without compromising energy performance, façade technology and integration of facade and environmental systems become still more advanced. The present paper deals with the development and construction of mechanically ventilated double skin façade with HVAC integration for hot and humid climate like UAE. A case study is presented, illustrating potential benefits of careful application of the available technologies adopting an integrated approach from the early design phases. Moreover, the paper gives an introduction to test and demonstrate the performance of the facade and HVAC integration.

1.0 INTEGRATED DESIGN

Intelligent application of advanced facade technology in conjunction with innovative HVAC systems results in significant energy savings and – at the same time – improve indoor comfort (IEQ). It has been shown that, when designed carefully, innovative systems do not represent additional initial costs, running and maintenance costs are also lower and energy costs can be reduced by approximately 40% or higher in some cases compared with conventional systems. Successful application of these systems depends closely on the adoption of an integral design approach from the early stage, schematic phases of a given project. Too often the facade design is developed when fundamental decisions, for instance pertaining to the layout of the ventilation system, have already been taken. At this point it can be too late to benefit fully from application of advanced façade solutions. If facade and HVAC system are engineered as two parts of the same solution, not only will the performance most likely be superior – both initial and running costs may moreover be reduced significantly.

To this end, there is a need for a change of approach bringing together facade and M&E engineers during the early design phases. Moreover – and this is a problem we experience frequently these days – there is a pronounced need for a common language in order to characterize and communicate the performance of innovative systems such as the mechanically ventilated facades. For instance, parameters such as U-value and g-value (Solar Heat Gain Factor) are not readily applicable when the facade interacts with the ventilation system, and traditional ways of designing HVAC systems may not be adequate when assessing possible application of innovative solutions.

Alternative to Conventional Commercial Environments: The new integrated façade system controls the indoor thermal comfort of the building by integrating a double skin façade with individually controlled radiant floor cooling, active chilled beam ceiling system, daylight tracking venetian blinds, LED (light emitting diodes) lighting and Building Management system.

1.01 Modeling And Simulation Of Double Skin Active Facade

The modeling and simulation of the Double Skin Façade Cavity is a complicated task, since different elements interact with each other influencing the function of the cavity. Efforts to model the cavity are focused mostly on:

- Air flow simulations
- Calculation of the temperature at different heights (Thermal Performance)
- Daylight simulation
- Shading analysis
- Sun path diagram
- Local climate data
- Shape and construction of inlet and outlet air vents
- Shading analysis, sun path diagram etc.

2.0 CASE STUDY: REEM EMIRATES ALUMINUM OFFICE BUILDING, ABU DHABI, UAE.

2.01 Double Skin Active Facade In Conjunction With Building Mechanical Ventilation System

The following case study has been selected to illustrate the potential benefits of careful combination of advanced facade and HVAC technology. This particular case study describes the 'happy marriage' between a mechanically ventilated

Figure 1. South Façade Office Building

double skin active facade and ventilation system of the building. This type of facade posed an ideal compromise offering a smooth, glazed external surface and, at the same time, providing the necessary solar protection. Mechanical ventilation was required in order to extract the solar heat from the facade cavity.

2.02 <u>Investment & Payback period</u>

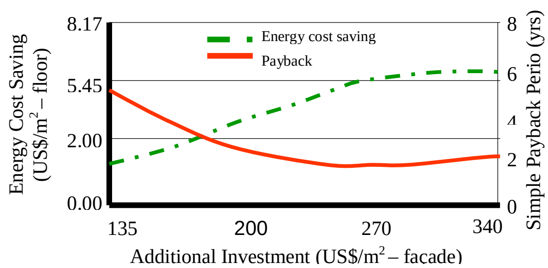


Figure 2. Energy Savings & Payback Period for a Double Skin Active Facade

A comparative cost analysis of the alternative solutions was carried out. Both initial costs and expected running costs were compared. The conclusion of the study was that the solution with double skin/chilled beam resulted in better comfort and did not result in higher initial costs, compared with a solution based on conventional facade and fan-coil units. The building has been in use for four years, and the expected advantages have all been confirmed.

3.0 TECHNICAL DESCRIPTION OF MECHANICALLY VENTILATED DOUBLE SKIN ACTIVE FAÇADE

Integrated components of Double Skin Façade

- Double Skin Façade
- Day Light Tracking Blinds
- Radiant Floor Cooling System
- Active Chilled Beams
- HVAC Interface (Inlet Air Vent & Extract duct)
- LED Lighting
- Building Management System

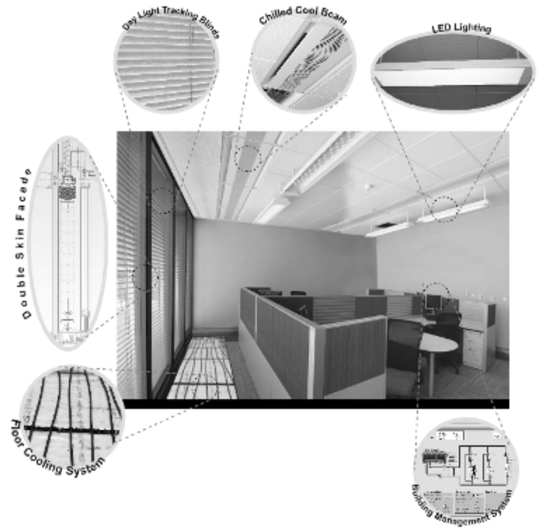


Figure 3. Mockup Test Room - Inside View

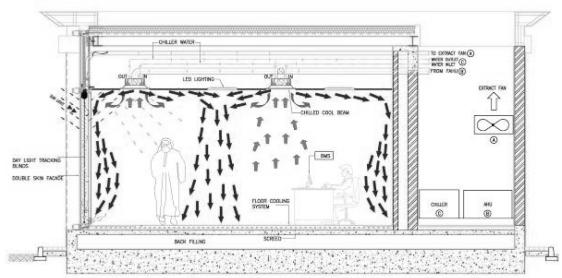


Figure 4. Mockup Test Room - Section View

3.01 <u>Double Skin Active Façade</u>

An active façade consists of two glass units separated by an air cavity between which there is an adjustable shading device. Also within this air plenum is a continuous air curtain with its inlet at the base and outlet at the head of the glazing frame. The definition of a DSF is creating an enclosure element that is intelligently connected to a mechanical exhaust and integrating an additional light of glass inside to create a cavity where air

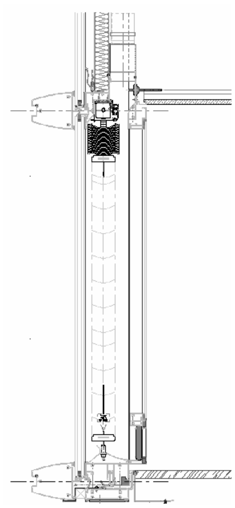
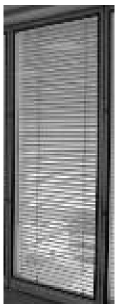


Figure 5. Double Skin Active Façade Section

can be drawn into the cavity from the room and exhausted at the top. The moving air passing through an integrated solar control blind, removes the heat caused by sun blocking.

Intelligent mechanical ventilation system is adopted, in which the air flows at the rate of 35 - 45 m3/h enters at the bottom of the façade from inside room, travels along the cavity of the façade and exhausts out through a chimney shaped outlet.

3.02 Day Light Tracking Blinds



Day Light tracking intermediate blind (80mm wide ½ perforated) is positioned inside the cavity, whose function is to reflect and absorb the high frequency/short wave radiation. The reflected portion of solar energy is reflected back through the glass whilst that which is absorbed is converted into sensible low frequency/long wave radiation.

Figure 6. Intermediate Blinds inside the Cavity

In this form the heat is extracted via the continuous air flow between the inner and outer glass units. By placing the blind between the two glass units, the short comings of the both external and internal shading is over come. The slat's guidance function of the blinds positioned in the cavity of the active façade gives the possibility of changing the slat angle according to the intensity of light inside the building. The high luminance of the blinds reflects the sun light back into the room's ceiling. This makes it possible to keep the direct sun out and to use the diffuse light inside the room.

3.03 HVAC Interface

Figure 7. Chimney shaped Outlet Profile at Top

Intelligent mechanical ventilation system is adopted, in which the air flow enters at the bottom of the façade from inside room, travels along the cavity of the façade and exhausts out through a chimney shaped outlet, which is connected to the main extract ducting system of the building. The integrated approach of façade with the floor cooling system and the chilled beam further enhances the thermal performance of the inner glass surface of the double skin façade.

3.04 Floor Cooling System

Floor cooling system supports the transfer of heat through radiation. Floor cooling system cools the floor surface in a room directly. Cold water with an variable supply temperature of 15 – 17 ˚C and ΔT = 4 ˚C is continuously pumped through a closed circuit pipe networks in the floor that in summer time would be changed and controlled via BMS.

Figure 8. Radiant Floor Cooling Pipes Layout

This results in optimal thermal layering and therefore high level of comfort. The pipes, which contain cold water, are directly involved in the heat absorption process of the floor and also accumulate in the slab and construction of the building with huge cooling capacity. The constant close-circuit operation of the floor cooling system with high chilled water temperature of 16 ˚C guarantees a significant reduction in energy consumption.

3.05 Active Chilled Beam

Active chilled beam is used for cooling and ventilation in spaces where good indoor climate and individual space control are appreciated. An Active Chilled Beam is an air-water system that uses the energy conveyed by two fluid streams to achieve the required cooling in a space.

The air supplied by the central air handler to the active chilled beams is called primary air. The primary air is supplied to the active chilled beams at a constant volume and at a relatively, low static pressure. Within the Active Chilled Beam terminal unit the primary air is discharged into a mixing chamber through a series of nozzles. A zone of relative low pressure is created within the mixing chamber, thereby inducing room air through the secondary water coil into a mixing chamber. The induced room air is called secondary air.

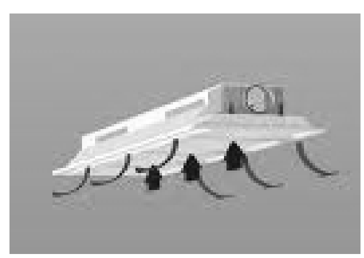


Figure 9. Active Chilled Beam

In the cooling mode the primary air is cool and dry, satisfying a portion of the room's sensible load and its entire latent load. The secondary water coil within the active chilled beam terminal unit is supplied with chilled water to offset the remaining internal sensible load of the room. The chilled water temperature is always provided above the room design dew point temperature to preclude sweating/condensation on the water coil.

3.06 LED (Light Emitting Diode) Lighting

The building is illuminated using extremely energy efficient LED's which last 5 times as long as fluorescents and 50 times longer than typical incandescent. So energy is saved in maintenance and replacement costs. Heat build-up of LED's are comparatively very low or nil, which contributes to less cooling load requirements in the building.

Figure 10. LED Lighting

3.07 Building Management System

The entire integrated components of the active façade is connected to a building management system in order to automate and take control of different operations in the most efficient way possible, apart from maintaining a comfortable working environment. A standalone computer system is designed that can calculate the pre-set requirements of the building and control the connected system to meet those needs. Its inputs, such as temperature, air flow, occupancy sensors and outputs, such as on/off signals are connected to the various systems such as HVAC, ventilation, intermediate blinds inside the façade, floor cooling, chilled ceiling, LED lighting in the building.

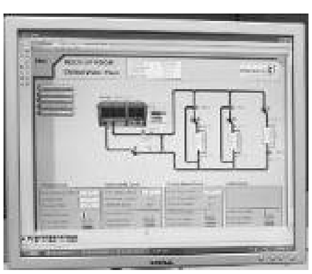


Figure 11. Building Management System

4.0 MOCKUP ROOM TESTING & MEASUREMENT

The main purpose of the test procedure for the mock-up office is to determine if a comfort situation can be created by using an integrated solution of mechanically ventilated double skin façade in combination with floor cooling system and chilled cool beam. For this purpose (operative) room temperatures, humidity and air velocity need to be monitored. The second purpose of the test procedure is to measure more information of the climate façade by monitoring the temperatures of the construction during the test operation.

4.01 Spot Measurements for Temperatures - Inside Façade

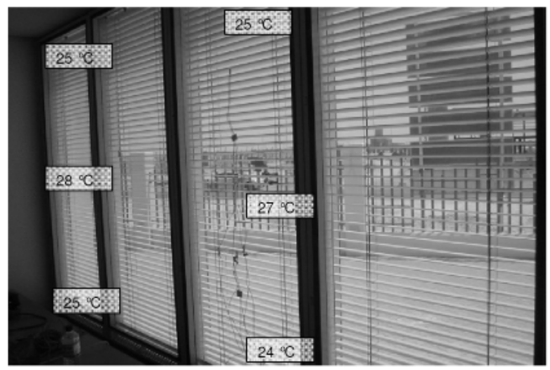


Figure 12. Surface temperature spot measurement at the façade at 2 pm

Figure 13. Surface temperature spot measurement at the ceiling at 2 pm

4.02 Spot measurements for temperatures on the outside façade

The observed outside surface temperatures are much higher than the outside temperature during that time. The results of the surface measurements show that the temperatures at the bottom of the façade are higher than the temperatures at the top. Obliviously the influence of reflected radiation is much higher than the influence of the transmission from the inside.

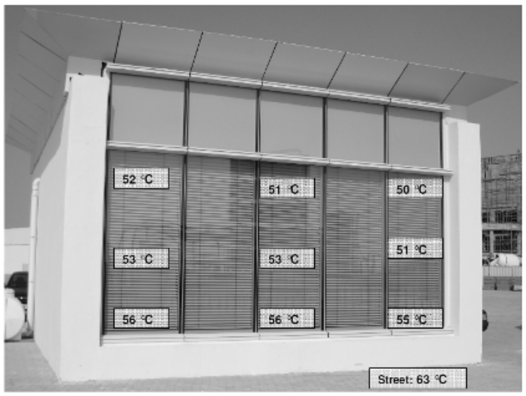


Figure 14. Surface temperature spot measurement at the outer facade at 2 pm

4.03 **Spot measurements for temperatures on the floor & walls**

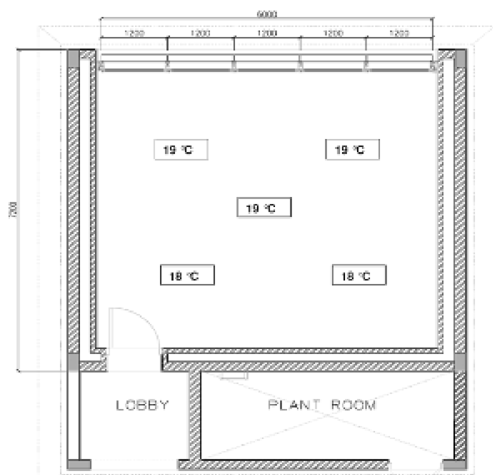


Figure 15. Surface temperature spot measurement at the floor at 2 pm

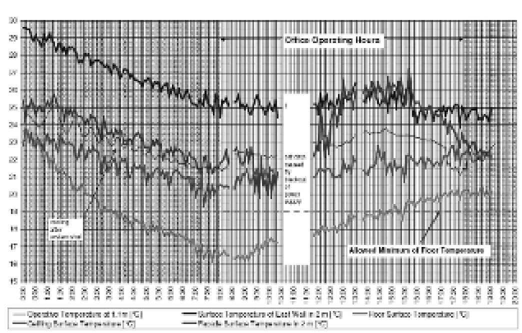


Figure 16. Surface temperatures in the mock-up office

4.04 **Luminance measurements on the floor & walls**

time	Roof [lux]	1.5 m from facade [lux]	3.0 m from facade [lux]	4.5 m from facade [lux]
9:00	73300	1174	940	645
13:20		2415	2000	1400
18:00	94700	1347	1002	420

Table 1. Luminance spot measurement - table height

time	Roof [lux]	0.75 m from facade [lux]	2.0 m from facade [lux]	4.0 m from facade [lux]
9:00	73300	2022	1335	770
13:20		3950	3250	1800
18:00	94700	484	363	257

Table 2. Luminance spot measurement - Walls

time	Roof [lux]	0.75 m from facade [lux]	2.0 m from facade [lux]	4.0 m from facade [lux]
9:00	73300	2420	1235	922
13:20		4200	2740	1700
18:00	94700	642	390	223

Table 3. Luminance spot measurement - Ceiling

4.05 **Temperature distribution of façade cavity**

The maximum temperature at the outlet (top) on the 6th September 2007 at 3:00 pm is 34.5 °C. The room temperature during that time is 23 °C, because of radiant floor cooling.

The supply air volume measurements performed on the chilled beams based on measured pressure differences have evidenced a total supply air volume of 88 l/sec using 10 active chilled beams, each chilled beam with 8.8 l/sec primary fresh air and pressure drop of 100 pa with supply temperature of 17 °C. Orientating measurements at the air supply within the façade have evidenced an air volume at every façade element between 45 m^3/h and 50 m^3/h indicating a total exhaust air volume between 225 m^3/h and 250 m^3/h. Assuming an air volume which was sucked though one façade element of 48 m^3/h and a temperature difference between inlet and outlet of 11.5 °C a resulting energy balance of about 180 W can be calculated. The resulting specific energy input into the façade is then calculated to be 50 W/m^2 which is about 8 % of the total radiation on the façade.

In the following picture the surface temperatures are shown which could be used for validation of further simulation calculation which would allow determining the exact specifications of the double façade.

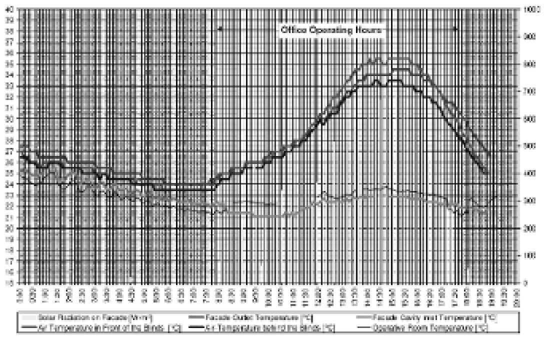


Figure 17. Air-temperatures within the façade cavity

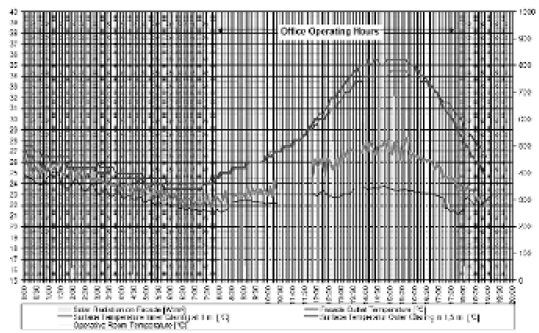


Figure 18. Surface-temperatures within the façade cavity

4.06 Summary of Testing & Measurement

The mockup room with a fully integrated double skin active façade, which has a supply fresh air via chilled beams and exhaust air via top plenum of each unitized panel, in combination with intermediate sun blinds, radiant floor cooling and LED lighting, was examined. The aim of the measurements was to determine the performance of the integrated system especially under the aspect of comfort. Therefore the air temperature, surface temperature and operative temperature at several locations as well as the humidity, illumination and some other parameters were monitored over a period of three days (from 4th September until 6th September).

The measurements have shown that the fully integrated intelligent double skin active façade system is able to fulfill the highest comfort criteria referring to a “category A” building defined in the ISO 7730 and also the criteria described in the actual ASHRAE 55-2004 Standard.

5.0 DATA SHEET OF MOCK-UP TEST ROOM

Active Façade composition :

Glass type from outside	: 6mm C366, 16mm air spacer 6 mm clear
Cavity	: 200mm
Single glazing inside	: 6 mm clear
U-value total	: 0.87 W/m^2 K
Visible light transmittance	: 56%
Visible light reflection OUT	: 14%
Visible light reflection IN	: 17%
Solar Energy transmittance	: 21%
Shading Coefficient	: 0.29
SHGF	: 0.15
Air flow	: 12 dm^3/s per unitized panel

Ambient testing condition:

Testing Date	: Sep. 4th – 7th (4 days,24 hours)
Temperature (Max.)	: 47 °C
Relative Humidity(min.)	: 34%
Temperature (Min)	: 34°C
Relative Humidity(max.)	: 61%
Solar radiation(max.)	: 720 W/m^2

Indoor Environment quality (IEQ):

Air Temperature	: 20 ±2 °C
Operating Temperature	: 22,5±1°C
Floor Surface Temperature	: 18±2 °C
Ceiling surface temperature	: 22±1.5 °C
East wall surface temperature	: 25±1°C
Air velocity, horizontally	: 0.13±0.3 m/s
Air velocity, vertically	: 0.14±0.3 m/s
Glazing surface Temp.(inside space)	: 23 °C
Glazing surface Temp.(outside)	: 56 °C
Façade cavity Temp.	: 41 °C
Relative humidity	: 55%
Luminance on desk level	: 2415 Lux. at 1.5 m from façade at 13.20 hrs.
Luminance on single slat of blind	: 9501 cd at 13:45 hrs.

HVAC condition:

Temperature Fresh Air supply	: 17 °C(1.5°C> dew point)
Temp. CHW supply Cool beams	: 15 °C (1.5°C>dew point)
ΔT. CHW cool beams	: 2 °K
Floor surface Temp.	: 18 °C (1.5°C>dew point)
Air flow Max. in Cavity per module	: 11.75 l/s(25 CFM) ASHRAE 62-2007

Lighting:

LED lighting	: Each 600x600 LED panel with 42 watt consumption

6.0 ENERGY COMPARISON STUDY

(for façade construction only without considering the effect of chilled beams and radiant floor cooling)

ACTIVE WALL

Average Solar Energy - 720 W / m^2

Mock-up Room Area (6m * 6m) - 36 m^2

Solar Transmission Factor - 0.15
(for the Active Façade of 6mm C366 + 16mm Air spacer + 6mm clear + 200 mm Cavity + 6mm clear tempered) with design air flow in the space 2.0 dm^3/sm^2 at 21°C

Solar Heat Gain – 0.15 * 720 – 108 W / m^2

Glass Area - 6 * 2.8 – 16.8 m^2

Heat Gain - 108 * 16.8 - 1814 W

Energy Production due to Active Wall – (1814 / 36) - 51 W / m^2

Inside energy due to people - 12 W / m^2

Inside energy due to equipment / PC - 15 W / m^2

Inside energy due to LED lights - 5 W / m^2

Total Heat Gain - 83 W / m^2

Refrigeration requirement – 42 m^2 / Ton

PASSIVE WALL

Average Solar Energy - 720 W / m^2

Mock-up Room Area (6m * 6m) - 36 m^2

Solar Transmission Factor - 0.40
(for Façade of 6mm + 16mm Air spacer + 6mm clear)

Solar Heat Gain – 0.40 * 720 – 288 W / m^2

Glass Area - 6 * 2.8 – 16.8 m^2

Heat Gain - 288 * 16.8 - 4838 W

Energy Production due to Passive Wall – (4838 / 36) - 135 W / m^2

Inside energy due to people - 12 W / m^2

Inside energy due to equipment / PC - 15 W / m^2

Inside energy due to lights - 15 W / m^2

Total Heat Gain - 177 W / m^2

Refrigeration requirement – 20 m^2 / Ton

7.0 AIR TEMPERATURE & AIR VELOCITY SIMULATION OF MOCKUP ROOM

7.01 Input

1.) Results from other simulations like, climate façade (CFD) and the office (TRNSYS), are used as input for this model. Also refer to the Data Sheet of mockup room for other input data.
2.) The internal heat load used for both CFD and TRNSYS simulation is 60 W/m^2 floor surface.
3.) The inlet temperature of the façade cavity is assumed as 21 °C.
4.) Abu Dhabi climate data is used for all simulations.

7.02 Output

The air temperature and air velocity are being simulated. The results are presented in figures. 19 to 22.

The air in the office is warmed up by people and computers as can be seen in figure 19. Air comes from underneath the desk where it is warmed up by computers and will be warmed up further by the people in the office. The mean air temperature between the desks in the middle of the room is approximately 23 °C.

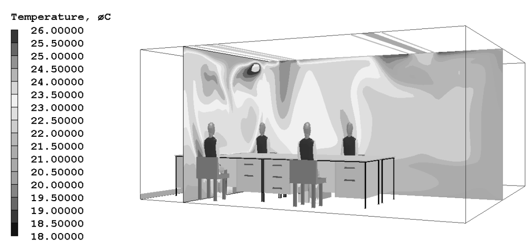


Figure 19. Air temperature in the office

The part of the ceiling close to the façade also warms up the air which can be seen in figure 20. The air coming from the first row of cool beams warms up very quickly. The air from the second row of cool beams units stays cool longer (blue area close to the ceiling).

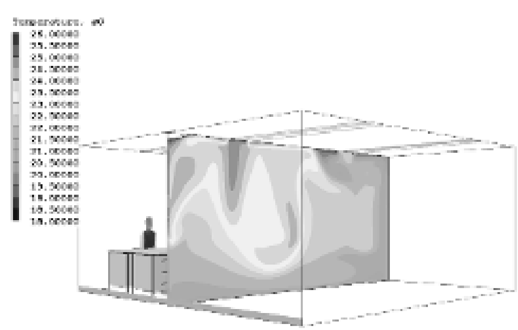


Figure 20. Air temperature in the office

The cold air from the second row of cool beam (right side of figure 21) mixes with the warmer air and flows down into the office. This air mixes close to the floor with the cold air that comes down along the right wall and flows along the floor to the glass façade (left side of figure 21)

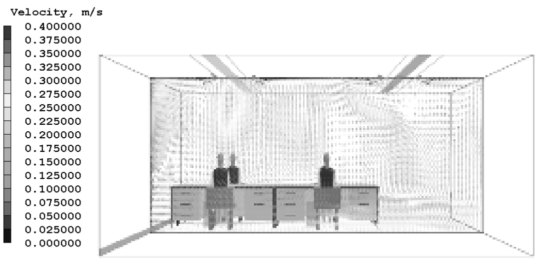


Figure 21. Air velocity in the office

This air can have a speed between 0.25 m/s and 0.4 m/s as can be seen in figure 21 and 22.

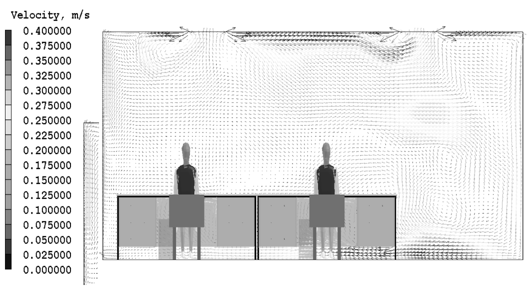


Figure 22. Air velocity in the office

7.03 <u>Result of CFD Simulation</u>

The overall climate in the office is good. The mean air temperature in the comfort zone of the office is approximately 22 °C – 23 °C. Close to the glass façade the operative temperature will be higher, because of the temperature of the façade surface. The mean air speed in the comfort zone of the office is approximately 0.2 m/s which is good.

8.0 DAY LIGHT TRACKING BLINDS – LUMINANCE & GLARE

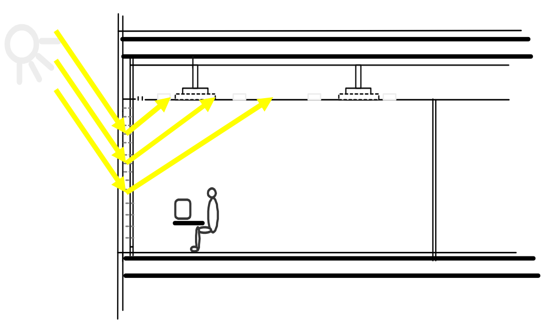


Figure 23. Day Light Blinds Luminance in the office

In the office space, there is a light sensor which gives command to the control unit of blinds to adjust the required luminance at desk level. It can be seen that, the angle of blinds about 45° - 35° from the horizontal will not cause any glare in the occupancy height of the façade.

9.0 TRNSYS SIMULATION OF DOUBLE SKIN ACTIVE FAÇADE

TRNSYS-calculations of the double skin active façade are performed in order to be able to evaluate the effect of the following measures:

- the air flow of 35 m^3/h per 1.20 m façade
- the g-value of the glass = 0.87 * 0.29 (= shading coefficient) = 0.25 (theoretically)
- the orientation of the climate façade is south, surface glass 11.2 m^2
- 60% of the solar radiation is reflected to the ceiling, 20% to the walls and 20% to the floor

The result of the TRNSYS-simulations is that the average maximum surface temperature of the glass at the office-side can become max. 33°C at an indoor temperature of 24°C. At the top of the facade the temperature of the glass will become 42°C and at the floor the temperature will be 24°C. The solar energy for a south facing facade in Abu Dhabi is 850 W/m^2 in winter and about 450 W/m^2 in summer. But the measured solar energy was 720 W/m^2.

	Blinds closed winter	Blinds closed summer	Blinds open winter	Blinds open summer
Solar energy W/m^2 (glass surface)	850	450	850	450
Outdoor temp	20°C	45°C	20°C	45°C
External Heat load to office W/m^2 (glass surface)	88	80	220	130
Heat load of inside office W/m^2 (floor surface)	40	36	100	59
Effective g-value	0.10	0.18	0.26	0.29

Table 4. Overview of temperatures, energy transport, external heat load and g-values (south façade)

9.01 Result of TRNSYS Simulation

With open blinds (angle with horizontal less than 45°) and average calculated cooling load of 85 W/m^2, in combination with chilled beams and radiant floor cooling it is possible to keep thermal comfort within the design temperature ranges.

- The maximum operative temperature can become ca. 24^{o}C.
- The maximum air temperature will remain ca. 23^{o}C.

10.0 CFD SIMULATION OF DOUBLE SKIN ACTIVE FACADE

In this section we describe how the façade works, and what can be done to improve on this. To evaluate the performance of the façade, CFD-calculations were made. The performance is evaluated using two indicators. The first one is the surface temperature of the glass that faces the room. This temperature influences the comfort in the room directly. The second indicator is the maximum temperature in the façade itself. If the temperature becomes too high, this might affect the construction elements.

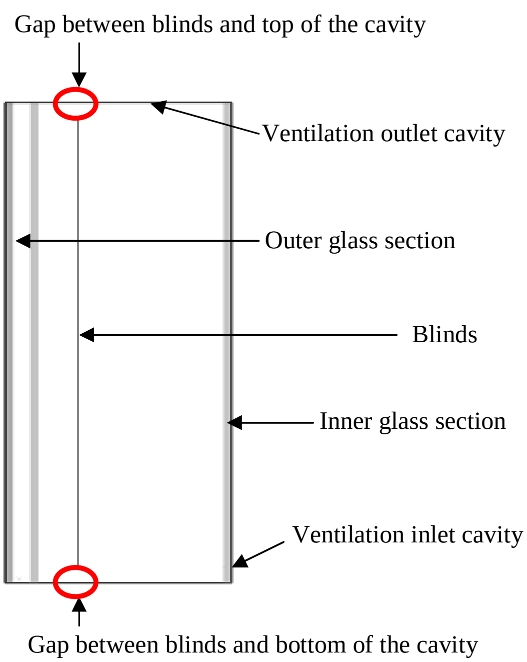


Figure 24. Cross Section of the Façade

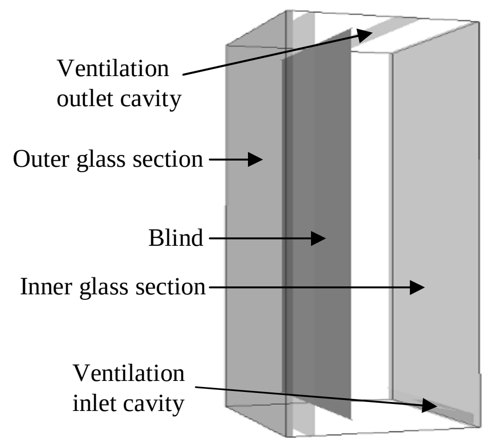


Figure 25. 3D View of the Façade

10.1 Input

The boundary conditions that are used in the simulation include:

- Outdoor temperature of 48°C
- Outdoor heat transfer coefficient of 25 W/m^{2}K
- Indoor temperature of 22°C
- Indoor heat transfer coefficient of 8 W/m^{2}K
- Gap ventilation supply temperature of 22°C
  Outermost pane of glass
  - 23% solar energy transmission
  - 36% solar energy reflection
  - 41% solar energy absorption
- Solar radiation on the façade of 850 W/m^2 (by testing it was not higher than 720 W/m^2)
- Gap between the top blind and the top of the cavity, and between the lowest blind and the bottom of the cavity

10.2 Output

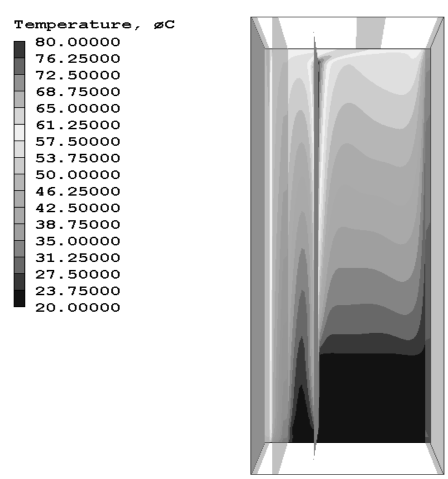


Figure 26. Cross Section of the Façade, Air Temperature in the Cavity

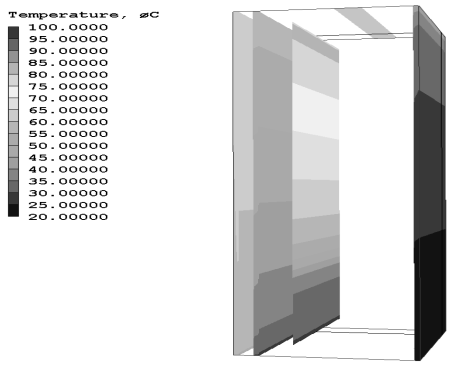


Figure 27. 3D View of the Façade, Surface Temperatures of the Glass and Blinds

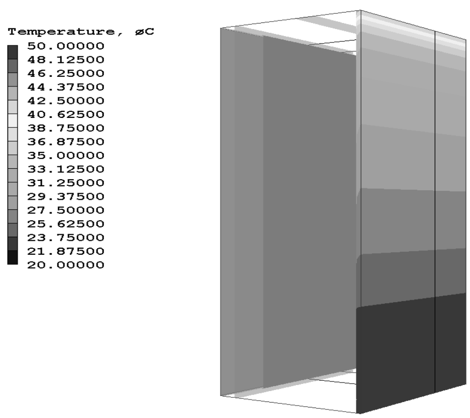


Figure 28. 3D View of the Façade, Surface Temperatures of the Inner Glass Pane

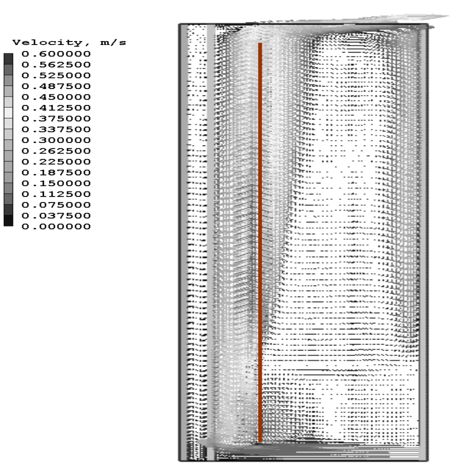


Figure 29. Cross Section of the Façade, Air Velocity in the Cavity

11.0 THERMAL PERFORMANCE OF DOUBLE SKIN FACADE SECTION (AS PER ISO 15099)

11.1 Heat Transfer Model of Double Skin Active Façade

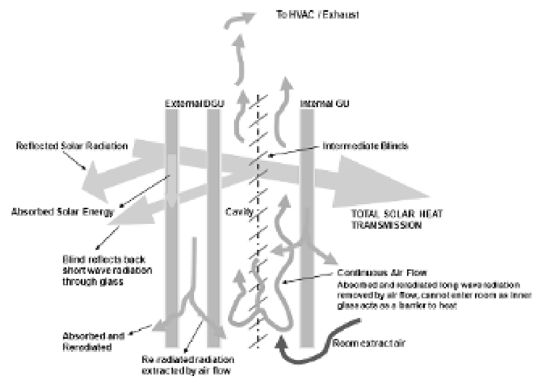


Figure 30. Heat Transfer Model of DSAF

Middle cavity area composition

6mm glass pane :	E366-6.CIG with low-e coating on face #2
16mm air gap:	100% air
6mm glass pane:	CLR-6.CIG
External cavity:	30mm air cavity
Blind:	E 80L – 80mm half perforated blind
Internal cavity:	100mm air cavity
6mm glass pane:	CLR-6.CIG

11.2 Environment condition (Outdoor)

Solar Radiation:	780 W/m^2
Outdoor ambient temperature:	46°C
Convection coeff. outdoor:	20.0 $W/m^2 K$

11.3 Environment condition (Indoor)

Air flow rate:	35 m^3 / hr.m
Indoor ambient temperature:	22°C
Convection coeff. indoor:	8.0 $W/m^2 K$

11.4 Intermediate Blind Geometry

Blind Type:	80mm half perforated RAL 9010
Slate Angle (α):	45°
Slate width (w):	80 mm
Slate thickness (d):	0.5 mm
Crown height (c):	10 mm
Pitch (p):	46 mm

11.5 <u>Double Skin Facade System</u>

Height :	2.8 m
Width:	1.2 m
Area Frame:	0.614 m2
Transparent Area:	2.746 m2
Perimeter length:	7.36 m

11.6 <u>Weighted U-value of Double Skin Facade Frame (Summer)</u>

Mullion frame (U_{mf}):	1.932 W/m^2-K
Sill frame (U_{sf}):	4.262 W/m^2-K
Head frame (U_{hf}):	3.440 W/m^2-K
Mullion frame length (L_{mf}):	2.8 m
Sill frame length (L_{sf}):	1.2 m
Head frame length (L_{hf}):	1.2 m
Weighted U value (U_w):	2.508 W/m^2-K

11.7 <u>Double Skin Facade Transparent System</u>

U_{trans} Value:	0.42 W/m^2-K
g_{trans} Value:	0.10
Solar direct Transmission:	0.03
Light Transmission:	0.12

11.8 <u>Description of the simulation outputs</u>

a.) Primary outputs:

U Value:	0.91 W/m^2-K
g Value:	0.08
Solar direct Transmission:	0.03
Light Transmission:	0.10

b.) Temperatures at the centre of each of the layers:

Temperature of the outer surface of outer glass (T_1):	57.1°C
Average temperature of outer glass1 (T_{glass1}):	57.9°C
Temperature of the layer between the outer and the intermediate glass (T_{gap1}):	51.0°C
Average temperature of intermediate glass2 (T_{glass2}):	44.0°C
Temperature of the layer between the intermediate glass and blinds (T_{gap2}):	31.8°C
Temp of the layer between the intermediate glass and blinds at exit (T_{gap2-e}):	37.5°C
Average temperature of the blind (T_{blind}):	38.3°C
Temperature of the layer between the inner glass and blinds (T_{gap3}):	27.9°C
Temp of the layer between the inner glass and blinds at exit (T_{gap3-e}):	31.1°C
Average temperature of inner glass3 (T_{glass3}):	27.1°C
Temperature of the inner surface of inner glass (T_2):	26.9°C

c.) Calculation of Air Flow Rate required to remove heat inside the Active Façade Cavity :

Average Solar Energy:	780 W / m^2
Solar Energy Transmittance of DSAF (6+16+6+210+6):	8%
So, transmitted energy inside the cavity (0.08 * 780)	63 W / m^2
Façade area projected to solar transmission(1.2m*2.8m)	3.36m^2(per module)
So, total heat to be removed per module (H) (63 * 3.36)	212Watts 12.06 Btu / min

The ventilation airflow rate required to remove a specific amount of heat can be calculated using the following equation: (ASHRAE , 1989)

$Q = H / c_p p\ (t_o - t_i)$
$Q = 38\ m^3$ / hr per module
$Q = 32\ m^3$ / hr / m (Design Air flow in the cavity)

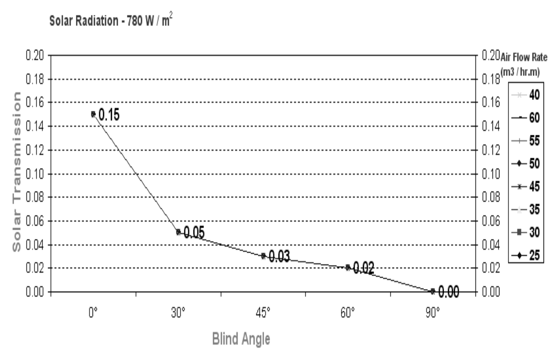


Figure 31. Solar Transmission of Double Skin Façade

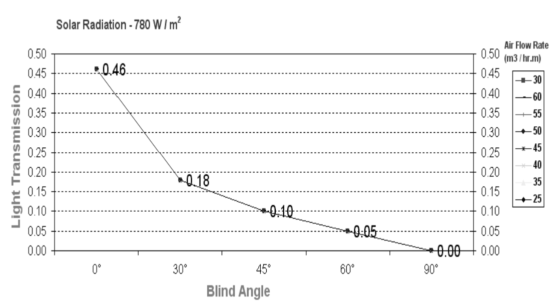


Figure 32. Light Transmission of Double Skin Façade

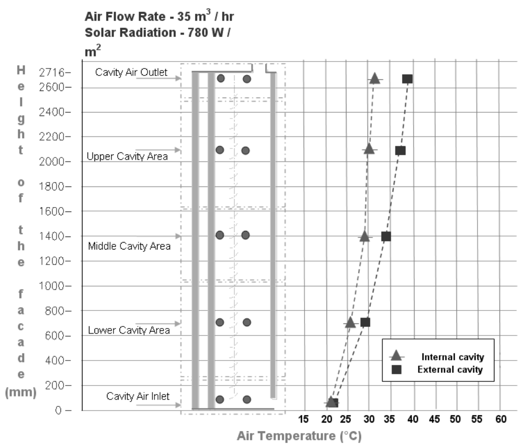


Figure 33. Vertical Temperature Profile of the Air Cavity

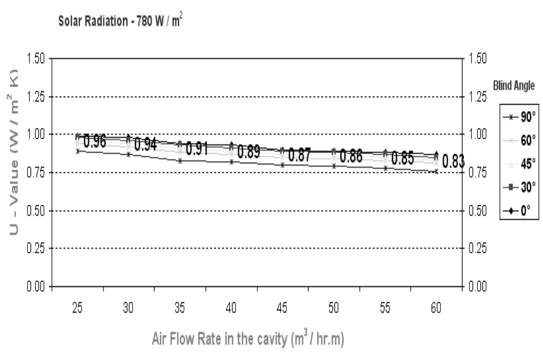


Figure 34. U-value of Double Skin Façade

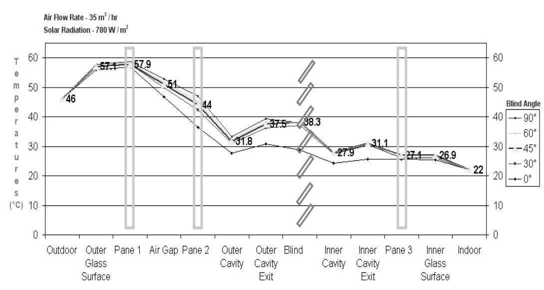


Figure 35. Horizontal Temperature in the Middle of Double Skin Façade

12.0 CONCLUSION

The above work shows the advantages of a double-skin active façade construction in terms of reducing the cooling load. Coupling a double-skin façade to a mechanical system represents challenges as shown in this paper. These are due to the temperature and airflow distribution in the façade construction. This paper has shown that to predict the performance of this type of system constitutes a modeling and simulation exercise that should be based on a thorough methodology and good working practice. When modeling these types of systems, it is typically necessary to take into account a large part of the building with dynamic interactions between several zones and ambient conditions. A strong thermodynamic coupling exists between the air flow through the mechanically ventilated double-skin façade and the air temperature difference between the cavity of the double-skin façade and outside. This interaction can only be predicted by sophisticated and state-of-the-art building energy modeling and simulation techniques as was done in the current study.

The most important parameters in designing the double skin façade are dimensions of the cavity, its height and width. Dimensions have the greatest influence on the heat and flow performance in the double skin façade. It is really important to understand the performance of the Double Skin Façade by studying the physics inside the cavity. The geometry of the façade influences the air flow and thus the temperatures at different heights of the cavity. Different panes and shading devices result in different physical properties. The interior and exterior openings can influence the type of flow and the air temperatures of the cavity. All together these parameters determine the use of the Double Skin Active Façade and the HVAC strategy that has to be followed in order to succeed in improving the indoor environment and reducing the energy use.

13.0 REFERENCES & ACKNOWLEDGMENTS

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ISO 15099 - Thermal performance of windows, doors and shading devices -- Detailed calculations.