An innovative curtain wall system

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SUMMARY

Buildings are responsible for significant amount of energy consumption and $C0_2$ emission. Obviously, façades are the most important building element considering energy consumption, environmental effects and user's comfort. Therefore, different design strategies are being developed according to different climatic zones for sustainable, energy-efficient, high performance buildings.

Today, different systems such as double-wall façades, ventilated windows, solar and green walls are already being used in building envelopes. The first priority of these systems is decreasing energy consumption by utilization of natural ventilation and solar energy. Such systems operate independent from the central HVAC systems; hence, do not reduce the installation cost of mechanical works. Moreover, their investment, operating, maintenance and cleaning costs are very high compared to conventional facade systems. Therefore, innovative and low cost façade systems, which are responsible for less energy consumption, continue to be the subject of research. In this study, a newly developed façade system is discussed.

INTRODUCTION

In this paper, an innovative curtain wall system which is fully integrated with HVAC system is discussed. This **patented** façade system has been developed for heating/cooling and ventilation functions of buildings and which, in addition to such functions thereof, can also perform the function of coating external façades.

Aims followed in development of this external façade cladding system are to:
• use the external façade cladding system as a ventilation system, heat recovery system and heating/cooling equipment as well,
• make this façade system fully integrated with HVAC system and,
• facilitate the use of renewable energy resources.

METHODS

The design approach of the research is summarized below:

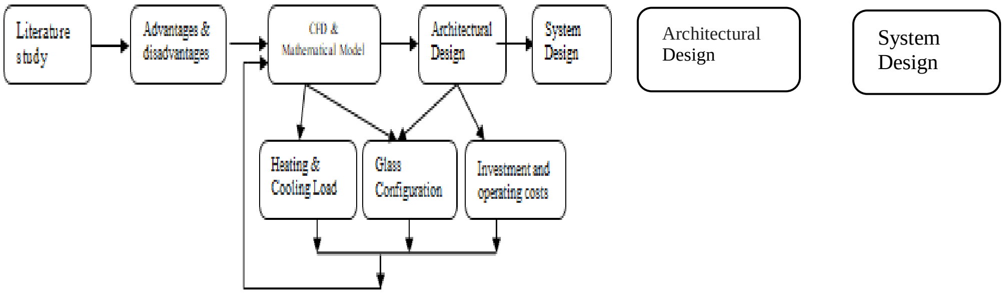

Figure 1 Design workflow

LITERATURE RESEARCH

Similar applications in literature have been investigated. Mechanically ventilated double-skin façades and supply windows (SUP) are the most similar types.

Saelens, (2002) [1] defines the multiple – skin façade as "an envelope construction, which consists of two transparent surfaces separated by a cavity, which is used as an air channel. This definition includes three main elements: (1) the envelope construction, (2) the transparency of the bounding surfaces and (3) the cavity airflow." Therefore, in this research the optimum configuration of cavity, construction and glazing types are studied.

As indicated in Figure 2, there are five types of ventilation modes:

1. Outdoor air curtain, also called double-skin façade (DSF)
2. Indoor air curtain, also called airflow window (AFW)
3. Air supply, also called supply window (SUP)
4. Air exhaust, also called exhaust window (EXH)
5. Open and close buffer zone, can be used for various purposes depending on climate, orientation, construction type, and the HVAC system[2] (Loncour 2004, 6-14). Buffer zone is also named channel or air gap and this gap varies from a few centimeters to one meter or over.

Extensive literature on DSF-typologies can be found in Poirazis (2004) [3]. Saelens (2005) also investigated energy performance of AFW, DSF and SUP regarding the conventional façades. [4]

Type 5, (buffer zone) has high thermal performance in winter. Type 3 and Type 4 are good applications for natural ventilation. Finally, type 1 and 2 are effective ways to prevent overheating between glass panels and reduce energy demand in summer conditions. Also the combination of a SUP-window in winter and a DSF with sufficient cavity ventilation in summer, could both lower the heating and cooling load.

According to Regazzoli [5], a Multi-Storey Double Skin Façade with 1000 mm cavity depth configuration provides increased annual percentage efficiency in terms of energy consumption of 31%.

PROBLEM

Before the thermal and structural analysis, it is helpful to investigate the existing façade systems' advantages and disadvantages. As a summary, the most important advantages of DSFs are natural ventilation, low U-value (especially in winter) and acoustic performance. Besides, the most important disadvantages are high investment cost, fire safety restrictions and reduction of utilizable area. It is clear that to take advantages of all operation modes of multi skins façade, a very complex façade design, motorized dampers and automation system are needed. These, of course, are crucial factors that increase both initial investment and operational costs.

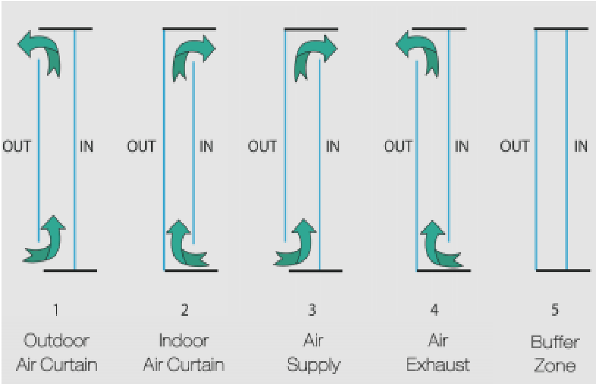

Figure 2 Ventilation modes

STRATEGY

To overcome these difficulties, a different design strategy is developed. First, to achieve a relatively inexpensive design, the smallest possible cavity between the glasses is searched. Secondly, in order to have a better control on operation modes, the system is linked to the HVAC plant. And finally, the system is designed to cover heating, cooling and ventilation functions. Thus, an ideal design with all the advantages of AFW, SUP, EXH and DSF systems has been tried to be created. In accordance with these approaches, many different models are developed and finally the three models seen in Figure 3 are decided.

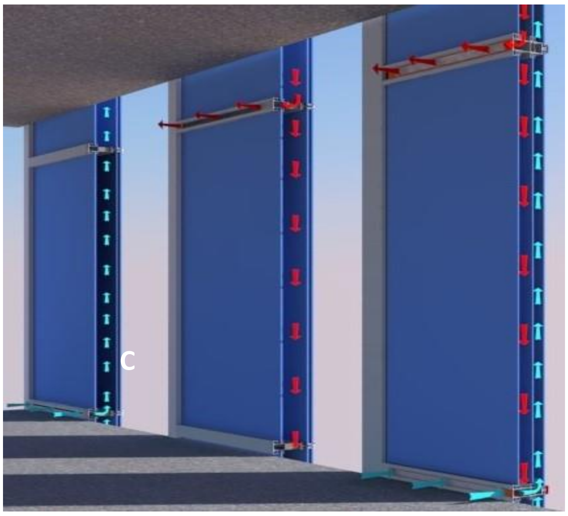

Figure 3 Design models

Model A: double glazed + single glass, exhaust air
Model B: double glazed + single glass, supply air

Model C: three single glass, supply + exhaust air (Model c has an alternative configuration with double glaze at the outdoor side but it is too expensive to construct.)

For different glass configurations mathematical model and CFD analysis are conducted.

3D analyses are performed in the FlowVision CFD software, which uses the finite volume method, by means of the necessary numerical methods and a convergent approach. In the analysis, the outer façade of a five-story building is modeled, having main air inlet/outlet and entrances/exits to/from the rooms at each floor (Fig.4). Glass and aluminum materials are also assigned to corresponding solid regions allowing heat conduction in solids and conjugate heat transfer with fluid zones. One window width, as displayed in Figure 3, is accepted to represent the whole system where full 3D, half-symmetric 3D and 2D models are generated and compared. Resultantly, 2D model, generating insignificant discrepancies in results, is preferred for the sake of optimizing computational power requirement.

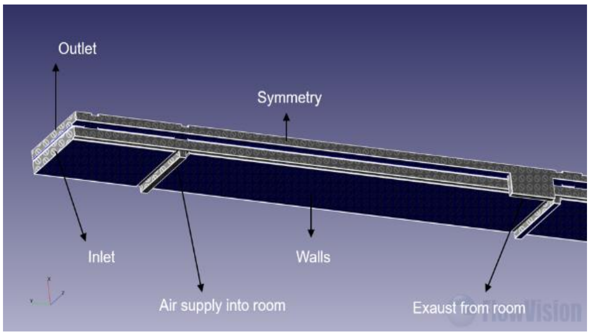

Figure 4 Boundary conditions

The geometrical model used for the CFD simulations, including the U shaped air region and thin solid sections, results in high aspect ratios which brings difficulty in generating the computational grid and ensuring the computational efficiency. The grid generation method utilized in FlowVision starts with formation of an initial Cartesian grid sized differently with respect to locations and followed by grid adaptations in the regions where higher flow gradients are expected. At the same, the software automatically detects the air, glass and aluminum sections and divide the grid cells with respect to those, resulting in appropriate final computational grid having separate cells in different regions while at the same time providing connection for conjugate heat transfer calculations.

Computational Cartesian grid, having total of 2.5M, 670k and 170k cells for respectively full 3D, half-symmetric 3D and 2D models, is composed of rectangular cells having sizes of 0.3 mm in the direction perpendicular to flow and sizes between 2 and 7 cm in the direction aligned with flow (Fig.5). Wall functions are utilized in near-wall turbulence modelling where average y+ values around 40 confirm suitability of this approach.

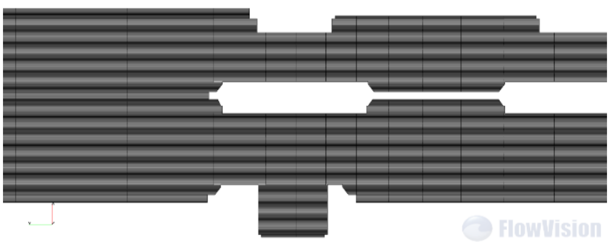

Figure 5 Computational grid

Mathematical model is also applied by using same initial and boundary conditions. Some assumptions are made in terms of the simplicity of the model. As in Fig .6 unlike 3D CFD analysis, 1D model was studied in MS Excel program. The cross-section of the model is assumed to be uniform, and the velocity of the air passing through the cavity is constant. For 3 glasses, 6 nodes and for air cavities, 2 nodes are described. Finally for each node, a simple steady-state heat balance is written.

T_{inlet} and T_{out} are temperatures entering and leaving the façade. After heat equilibrium equations are solved for 8 nodes by Excel matrix method for 8 unknown temperatures (T1 to T6 for glass surface; T7 and T8 for mean temperatures of cavities).

And while T_{inlet} is kept constant at 30 °C, T_{out} is calculated using both mathematical model and CFD according to changing outdoor weather conditions.

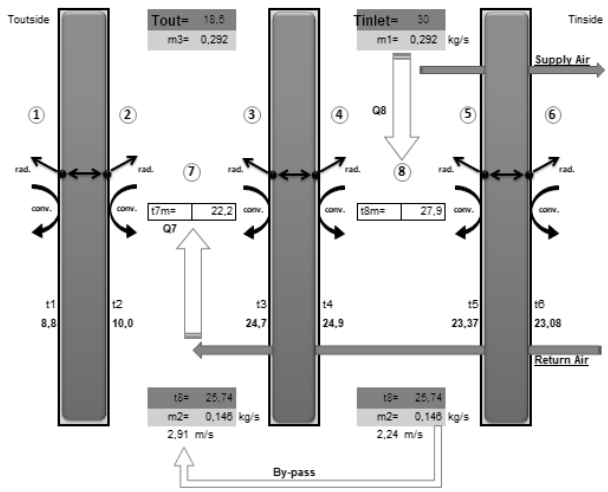

Figure 6 Mathematical model

The heat transfer equations for node 1 are shown below:

$Qsolar1=0$ eq.01

$Q\ rad1 = F.\sigma.\varepsilon.((t1+273)^4-(t_{outside}+273)^4)$ eq.02

$Qconv1= F.h_{out}.(t1- t_{outside})$ eq.03 $Qcond1= F.(\lambda_1/l_{glass}).(t1-t2)$ eq.04

Heat balance equation for node 1:

$Q\ solar1-Qcond1-Qconv1-Qrad1= 0$ eq.05

SOLUTIONS

Mathematical model and CFD analysis are compared and the model is verified with acceptable error rate. In Table 1, comparison between results of CFD and mathematical solutions is shown.

T inside:	22 °C		
V in:	1000	m3/h	
Vsupply-exhaust:	500	m3/h	
Toutside	T inlet	Toutlet (CFD)	Toutlet (Mathematical)
-10	30 °C	**18,9**	**18,6**
-5	30 °C	**20,1**	**19,8**
0	30 °C	**20,9**	**21,0**
5	30 °C	**21,9**	**22,2**
8	30 °C	**22,7**	**23,0**

Table 1 CFD vs. mathematical model

RESULTS

As a result of the analysis made for different glass configurations, the combination of Model A + Model B is chosen as the most efficient solution both in terms of energy performance and investment cost.

This configuration is formed by adding a single layer of glass to the classical double-glazed cladding façade.

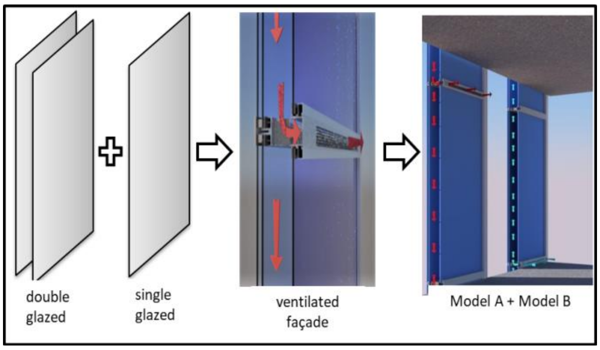

Figure 7 Model B

Unlike conventional triple glazed façade, the gap between the double glazing and the single glass is designed to allow air circulation. This gap continues all along the façade. At Model B, while the air is circulating along the façade, a certain amount of it is supplied to room and at the end, remaining air (by-pass air) is transferred to Model A. At this part, air moves up along the façade by exhausting the room air and is connected with the HVAC plant, so that the circulation can be completed (Figure 7).

For this combination, U-value calculation is performed to make energy efficiency analysis. Because of the circulating air in the cavities, it is difficult to calculate U-value accurately. Therefore, the coil load method is chosen. By keeping inside temperature (T_{in}) at 22°C and outside temperature ($T_{outside}$) at -10°C and setting supply air (V_{in}), ventilation air ($V_{ex\text{-}sup}$) and by-pass air at certain amount; it is easy to calculate coil load of air handling unit, shown in Fig.7.

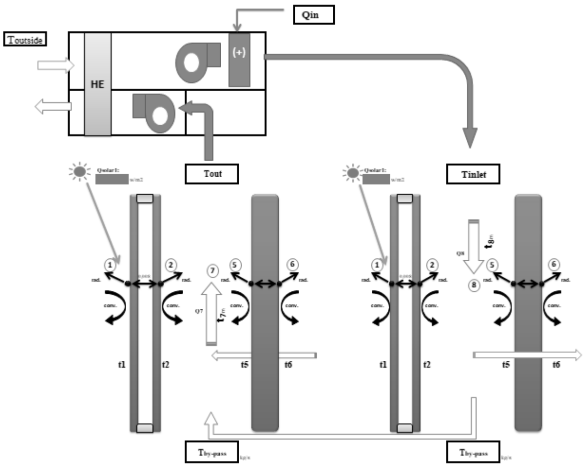

Figure 7 Model A + Model B

While calculating the U-value, T_{inlet} is kept constant at 30 °C and heat exchanger efficiency at %75. For a comparison, a standard façade with overall U-value is 2 W/m2.K, is selected and compared with calculated U-values of Model A + Model B.

The results are represented in Table 2. As it can be seen from comparison, U-value efficiency increases while the by-pass air rate decreases.

U value	Ueff.*	Tinlet	Tout	Vin	Vex-sup	% effiiency
W/m2.K	W/m2.K	°C	°C	m3/h	m3/h	%
2	2,28	30	23,2	1000	500	-0,14
2	1,40	30	22,2	1000	800	0,30
2	1,25	30	22,0	1000	850	0,38
2	1,11	30	21,8	1000	900	0,45

*Tinside: 22°C, Toutside=-10 °C
U value comparison at constant Tinlet

U value	Ueff.*	Tinlet	Tout	Vin	Vex-sup	% effiiency
W/m2.K	W/m2.K	°C	°C	m3/h	m3/h	%
2	1,25	30	22,0	1000	850	0,38
2	1,22	29,5	21,9	1000	850	0,39
2	1,19	29	21,8	1000	850	0,41
2	1,13	28	21,6	1000	850	0,44

*Tinside: 22°C, Toutside=-10 °C
U value comparison at constant by-pass air (%15)

Table 2 U value comparisons

It is also clear that at a constant amount of by-pass air, as the T_{inlet} temperature decreases, the efficiency increases. Of course, some factors must be taken into account to reduce the amount of by-pass air or decrease the T_{inlet} temperature. First, supply air temperature should be at least 3-4 °C above the room temperature; second, the temperature difference between the floors should not exceed 1-2 °C degrees in terms of comfort level.

ARCHITECTURAL SOLUTION

The following considerations are taken into account during the design phase of aluminum profiles and related details.

1. The distance between two panes of glass has to provide sufficient depth as air ventilation chamber.
2. Aluminum load bearing profiles should not generate obstacles to the air flow

3. Total system has to provide all necessary technical details such as fire smoke and noise barriers, anchorages, seismic and thermal dilatations.
4. Details in the chamber shouldn't create any weakness in static properties of the profiles.
5. All aluminum profile sections have to be combined with the HVAC system elements properly.
6. The total system shouldn't create any obstacles for maintenance.
7. Finally, the total cost of the system shouldn't be as high as available double façade systems.

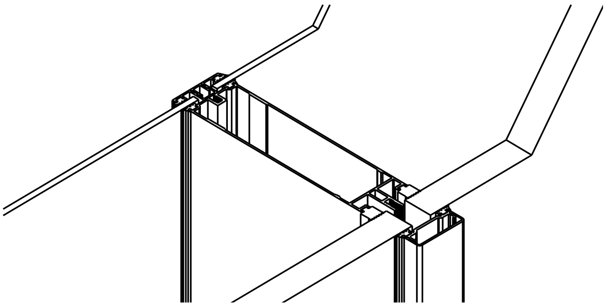

Figure 8

In order to obtain proper air ventilation, a double sided asymmetrical aluminum mullion is designed to provide proper glass holding detail for outer insulated glass and tempered single glass pane.

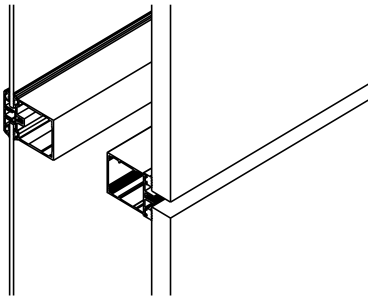

Figure 9

The horizontal connections of the glass panes are made up of two separate aluminum profiles. First one is standard aluminum transom which holds outer insulated glass pane and the second holds tempered single glass pane inside. By separation of both transoms, it is prevented to make holes in single transom profile. So the air flow inside the chamber does not face any obstacles and statically weakness problem in the transom profiles can be solved. In case of necessity, interior glass pane can be easily removed for cleaning and maintaining procedures.

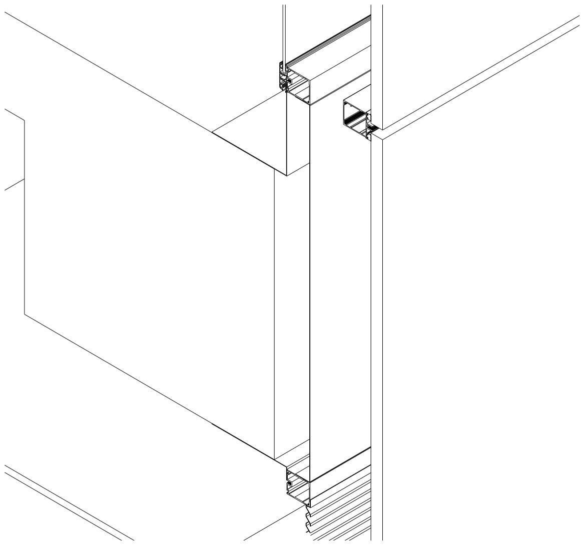

Figure 10

As it can be seen in the detail, the inner transom is used above the slab connection to connect galvanized plates of smoke fire and noise barriers. Also painted steel plate is used to provide shading box and hold mineral wool insulation.

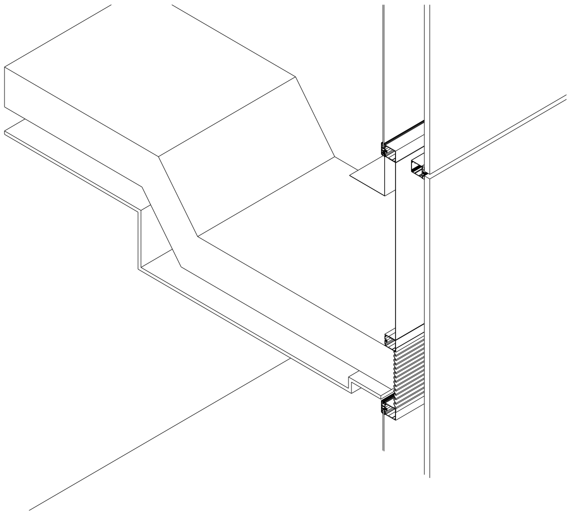

Figure 11

The space, between the transom profiles underneath the spandrel panel unit, is used as connection spot between HVAC system and air flow chamber. Aluminum profiles, both transoms and the mullions are providing a very good surface to install HVAC channels and ventilation grills.

COST ESTIMATION

The cost of the standard curtain wall assembly is determined by 4 equal inputs.

1. Aluminum profiles and accessories :

Compared to the ordinary glazed curtain walls main difference of the system is consumption of aluminum as the aluminum mullion is increased in size. And additional interior transoms and capping profiles adds 25 percent total cost to the construction. As our system does not require spandrel unit connection to the outer transoms, it allows us not to use double transoms over the slab connection.

2. Glazing:
Interior tempered glass pane is also adding 30 percent increase to the cost of the glass. Similar to the first clause, our system does not require enameled spandrel glass panes.

3. Insulation materials
Insulation and connection anchorages are the same as ordinary glass curtain wall assemblies.

4. Workmanship:
Workmanship cost calculation is the trickiest part of the curtain wall job. It is mostly based on the consumption of aluminum profile. As the aluminum consumption is increasing 25 percent this percentage can be used also as the production cost.

Installation workmanship cost calculation is based on surface area of the curtain wall assembly. Glass surface area is increasing 75% however interior glass, aluminum profile and capping profile installation will not increase as much as the glass surface area.

To sum up cost estimation, our new type of curtain wall will not increase the cost more than 40 percent compared to the conventional curtain wall assembly.

DISCUSSION

In this work, an innovative, energy efficient, facade work was carried out. Economic glass and profile configurations have been investigated and optimum models have been determined in terms of both energy efficiency and architectural feasibility.

As it can be seen from data, the façade has thermally high U values compared with the double glazed classical curtain walls. It is around 40 % more expensive than double glazed system but as a whole, the increase in the cost of the facade is generally not more than the increase in the mechanical installation cost.

If it is compared to three glazing systems, there is no significant cost difference. It is also clear that to construct façades like DSF, SUP, AFW there must be another «skin» apart from building «skin» but in our case, there is only one «skin» like curtain wall. Therefore, there is no loss in terms of utilizable area.

In this paper only results concerning the heating system were shown, as summer conditions analysis still continues. For complete analysis cooling system results should also be evaluated.

It is also seen that renewable energy sources can be used for the Model A, in which exhaust air is introduced. Since this section is under negative pressure and there is no hygienic contact with the building, heated or cooled air from another source can be used to save energy in this part. Preliminary studies have been carried out for this purpose; as an example, it is estimated that a considerable amount of energy saving can be established by ground source heat exchangers or solar energy. Of course, more research needs to be done to confirm these predictions.

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