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Energy efficient facades for Hot and Dry climate in India.

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***Abstract*— The Building industry is one of the largest energy consuming sectors and has encouraged as a major factor impacting natural environment. Generation of energy primarily depends on conventional sources, which is the basic cause of environmental pollution. To improve environmental performance of building it is essential to involve all parameters which control its energy efficiency. Present paper identifies Double skin façade as a viable and healthier solution for Hot and Dry climate in India.**

I. INTRODUCTION

There is an increasing demand for higher quality office buildings in India. Occupants and developers of the office building ask for a healthy and stimulating working environment. They also demand the buildings that create less environmental damage. The need for energy conservation and sustainable design in buildings is the main reason for this study. The commercial sector posted the highest economic growth rate and accounts for larger share of energy consumption in India. Double skin façades are getting ever-greater importance in building practice in modern building practice in the developed countries of the world. Providing comfortable environment to the building occupant is a major challenge for building designer in Hot and Dry regions. The objective of this study is to review the existing literature in the field of Double Skin Façade for office buildings and the impact of its usage on the thermal comfort of the occupant in Indian context. Better Thermal Comfort in the building can contribute greatly in increasing the work-efficiency of the occupants in office building.

As per the Ashare Standard, [1] Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment. The environment conditions required for comfort are not the same for everyone. There are six primary factors that must be addressed when defining the conditions of thermal comfort.

1. Metabolic rate.
2. Clothing Insulation.
3. Air temperature.
4. Radiant Temperature.
5. Air speed.
6. Humidity.

All six of these factors may vary with time. Ashare Standard only addresses the thermal comfort in a steady state. As a result people entering a space that meets this standard may not immediately find the conditions comfortable if they have experienced different environmental conditions just prior to entering the space. The effect of prior exposure or activity may affect comfort perceptions for approximately one hour. Hansa.R. [2] have studied the relationship between thermal comfort and user satisfaction and have emphasized that special care should be taken for the user satisfaction in Hot and Dry climate.

Saberi.O et al[3] have observed that the people now spent more time in the building or urban spaces. He believes that the indoor environment should be designed and controlled so that occupants' comfort and health are assured. He has studied various models for comfort conditions as given below:-

1. Fanger Thermal Equation.
2. Adaptive Model.
3. Design strategy model.
    - Building bioclimatic charts.
    - Oglay bioclimatic chart.
    - Givoni bioclimatic chart.

The design and construction of the buildings being built today, depends on various factors – aesthetical appearance, available land, thermal comfort, etc. In the urban area we could find most of the newly constructed buildings as highly glazed. The energy efficiency and thermal performance of highly glazed building are often questioned. The main reasons of using highly glazed façade as summarized by Poirazis.H.[4] are:-

- Growing tendency on the part of architects to use large portions of glass that lead to higher transparency.
- Users (who do not take into account the risk of visual and thermal discomfort that occur due to construction type) often also like the idea of increased glazing area, relating to better view and more pleasant indoor environment.
- Companies who want to create a distinctive image of themselves (e.g. transparency and openness) often like the idea of being located in glazed office building.

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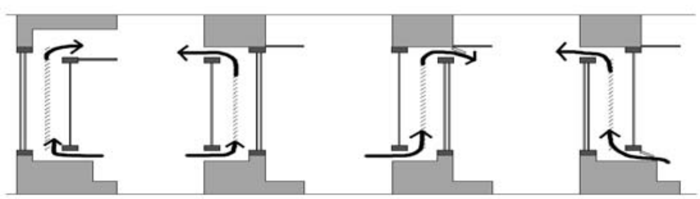
The increased glazing area may reduce the electrical internal lighting load of the building but may considerable increase the solar heat gain in hot and dry climates. This is one of the major drawbacks in using single skin glazed facade. The above stated problem can be considerably controlled by the introduction of double skin façade.

II. IMPORTANT ASPECTS OF DOUBLE SKIN FACADE

A. Airflow in the cavity

The air flow in the double skin cavity is one of the most important aspect of the system, as the heat transferred through the façade shall determine the energy consumption of the building.

The walls can be thought of as ventilated facades .There is three breathing that are identified: outside ventilated, inside ventilated and hybrid ventilated. Outside ventilated walls bring outside air into the interleaf cavity and vent back to the outside. Inside ventilated facades bring air from occupied space through the cavity and exhaust it to the plant. Hybrid systems bring air from either the interior or the exterior and vent it to the opposite side [5]



A. B. C. D.

Figure 1: Air Flow Pathways A. interior vented, B. exterior vented, C. hybrid supply air and D. hybrid exhaust air.

In order to provide fresh air before and during working hours, different types of double skin facades-ventilation can be applied in different climates, orientations, locations and building types to minimize the energy consumption and improve the comfort conditions of the occupants.

The air behavior in the ventilated façade is different than the conventional facades. As can be observed in figure 2, the rises along the whole cavity height gaining heat by convection from the tiles as well as from the interior wall. In the tile area the exterior airs enters through the bottom joints and keeps rising as it heats up. When reaches a sufficient temperature (higher than the environment temperature) the begins to exist cavity-through the top joints-, extracting thermal energy from the cavity. The air close to the brick wall rises by chimney's effect absorbing heat from such wall. The air average temperature in the cavity is between the exterior air temperature and the temperature of the solid surfaces (tiles and brick wall) on both sides of the chamber. In this façade, the cavity air-temperature is lower than the temperature reached in a conventional façade with a sealed air chamber. The thermal energy extracted by ventilation depends on the mass flow rate of air that circulates inside the cavity. This flow, been driven by natural convection, is a function of the temperature field, The effectiveness of the ventilated façade relays on the amount of the amount of energy absorbed by the air as it rises in the cavity. The extracted energy does not enter the building and therefore the cooling thermal load is reduced. In the areas of high solar irradiation the described mechanism can be quite intense, although the angle between the sun position and the façade (time of day, season, latitude) is also a major factor [6].

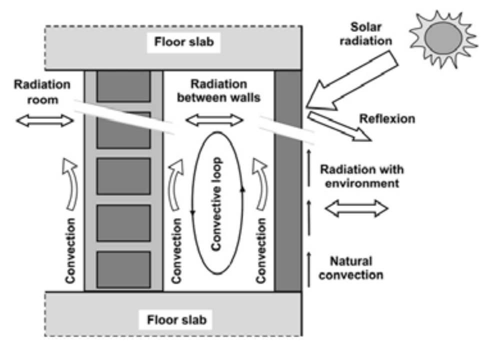


Figure. 2 Heat transfer processes in a conventional sealed cavity façade.

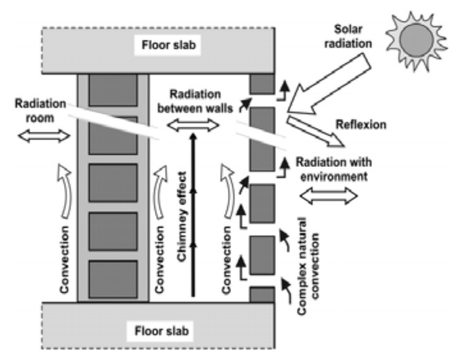


Fig. 3. Heat transfer processes in an OJVF.

The air velocity and the type of flow inside the cavity depend on:

- The depth of the cavity(both for mechanical and natural ventilation)
- The type of interior openings (both for mechanical and natural ventilation)
- The type of exterior openings (for natural ventilation.)

B. Depth of cavity

The range of cavity depths varies significantly. In existing buildings, the range tends to be between 200mm and 1400mm as measured face to face between the inner and outer skins. In the new buildings there are three predominant styles:

- The compact style is usually about 200mm to 500mm, the later allowing enough space to allow for maintenance occupation of the cavity primarily to accommodate cleaning of the surface within the cavity.
- The wide style is typically about 1m wide, this allows for the space to be used as a fire egress corridor. There are also architectural and daylight implications.
- The third style is the expanded style that includes atrium spaces and buildings with in buildings.[4]

C. Horizontal extent of cavity

This refers to the length along the façade. Cavities may be divided in relation to interior partitions. This extends the sound barrier of the partition to the outside face of the facade. But this is not always the case. Where the interior façade has windows within opaque walls, the exterior skin may mirror that form , creating a "a box window". In other cases, particularly in renovations where a second skin is applied over an existing building, the inside may be a window, but the exterior skin may be continuous glass. The cavity may be continuous as well. A deep façade with such an uninterrupted cavity a 'corridor façade' is created .When the corridor is intended to be used as a walk way, the floor/ceiling may either a grate ,open to air movement, closed, but the horizontal length of cavity must be uninterrupted.[4]

D. Vertical extent of cavity

The vertical extent of cavity refers to the distance between air supply to the cavity, and ultimate exhaust to then cavity, without intermediate interference such as floor plane. There may be operable windows or other vents along the height of the cavity. There are multi story facades that as referred as 'atria' if they are relatively wide or 'flues' if they are narrower , Among single story double façade there is an array of styles .If the cavity extends for the full height of the story ,it may be called as double skin façade. If it is only partial height with spandrel panels or other windows between, then it may be called as double skin window. Practitioners that design and built inside-ventilated facades tend to call them' airflow facades or airflow windows .Still, they are double skin assemblies with air moving between the skins.[4]

E. Ventilation inside building through Double Skin Facade

The ventilation system of a building is one of the important factors for creating comfortable indoor climate. In a double skin there is potential to utilize the cavity of the system to ventilate the building. In early days of developing the double skin façade the natural ventilated cavity was most often preferred system. The function of the natural ventilated double skin based on the same principle as for the conventional buildings. The only difference is that windows are opened into a controlled climate. Naturally ventilated system use the cavity control, the air-flow with stack affects and pressure from the wind effects. The mechanical system can function in several different ways .Two systems are mostly used in this situation: airflow window and supply window .In principles the system mechanically supplies the building with air from double skin cavity.[7].Xu.X et.al[8] have numerically solved the heat transfer in double skin façade with CFD and compared it with experimental data.

F. Solar shading devices

Solar shading devices are placed between the inner and the outer skins. Typically this is an adjustable, horizontal blind that may be rotated or raised and lowered. Once the radiation passes into the building, it is absorbed by the building fabric and re-radiated

as short wave, infrared energy that does not pass back through the glass. Instead it serves to heat the air. The role of the solar shading device is to absorb (or reflect) solar radiation, particularly during the cooling season, that would otherwise enter the occupied space. The heat absorbed by the sun shading devices can then be removed, primarily through convection, if air flow is moved along the surface of the blinds and removed from the cavity. The effectiveness of this heat removal is evidenced by a reduced shading factor (SF).If in addition, the air passes through a cavity is cooler than the outside air, and then the difference in the temperature across the inner glazing will be reduced. This lower heat flow (by conduction and convection) across the inner pane as evidenced by a reduced u-value.[4].It is recommended to place the sun shading system inside the double skin cavity so as to protect them from rain, wind etc. The position of the shading within this space therefore plays a major role in distribution of the heat gains in the intermediate spaces. As Oesterle et.al. describes, 'the smaller space will heat up to a greater extent than larger. If the sun shading is situated just in front of the inner façade and if the inner space between the two is not optimally ventilated, the air in the front of the window can heat up considerably – an un satisfactory phenomenon, regardless whether the windows are opened or closed .When they are closed, a secondary heat emission occurs; when they are open, the situation is even worse, since there will be direct inflow of the heated air. Thus, the authors agree that the sun shading should be positioned in the outer half of the intermediate space. The ideal position is roughly a third of the façade cavity, with good ventilation to the outer space above and below the sun shading. It should not be too close to the outer pane of glass, either, so as to avoid excessive heating up and thermal loading of this layer. For the mentioned reason and for proper ventilation purpose it is recommended a minimum distance of 15cm between the sun shading and the external skin of the façade. The absorbance of the shading device should not exceed 40%, and the proper shading device suggested is the venetian blind Gratia .E.[9]have studied the most efficient position of shading devices in double-skin façade and have concluded that the cooling consumption decreases until 23.2%can be reached by paying attention to the location of the blinds, the blind color and the opening of the double skin. The study emphasizes that the judicious choice of the location and the size of the blinds makes it possible to save upto14.10%of the cooling consumption of all the buildings during sunny summer day.The study also highlights the importance of opening of double skin façade.

IV. CONTRIBUTION OF THE DOUBLE SKIN FAÇADES TO THE HVAC STRATEGY

As Stec et al., (2003) describe, an HVAC system can be used in the three following ways in a Double Skin Façade office building:

- Full HVAC system (the Double Façade is not a part of the HVAC) which can result in high energy use. On the other hand, the user can select whenever he prefers a controlled mechanically conditions inside or natural ventilation with the use of the Double Skin Façade).
- Limited HVAC system (the Double Façade contributes partly to the HVAC system or is playing the major role in creating the right indoor climate). In this way the Double Façade can play the role of
  - ¤ the pre-heater for the ventilation air
  - ¤ ventilation duct
  - ¤ pre-cooler (mostly for night cooling)
- No HVAC. The Double Facade fulfills all the requirements of an HVAC system. This is the ideal case that can lead to low energy use.

During the heating periods the outdoor air can be inserted from the lower part of the façade and be preheated in the cavity The exterior openings control the air flow and thus the temperatures. Then, through the central ventilation system the
air can enter the building at a proper temperature. During the summer, the air can be extracted through the openings from the upper part of the façade. This strategy is applied usually to multi storey high Double Skin Facades. This type provides better air temperatures during the winter but during the summer the possibility of overheating is increased.

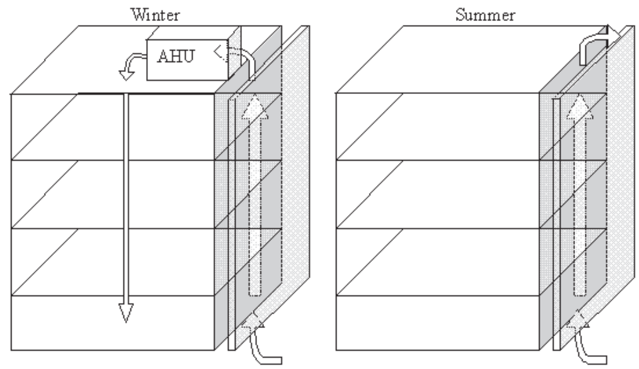


Figure 4 Double Skin Façade as a central direct pre-heater of the supply air.

During the whole year, the double skin façade cavity can be used only as an exhaust duct without possibility of heat recovery for the HVAC system . It can be applied both during winter and summer to the same extent. The main aim of this configuration is to improve the insulation properties in the winter and to reduce the solar radiation heat gains during the summer. There are no limitations in individual control of the windows' openings.

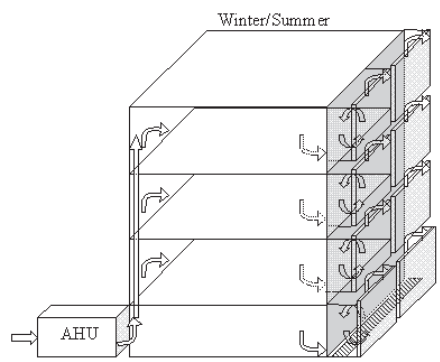


Figure 5 -Double Skin Façade as an exhaust duct.

The possibility to use the Double Skin Façade as an individual supply of the preheated air also exists (figure 5). This strategy can be applied both in multi-storey and box window type. An exhaust ventilation system improves the flow from the cavity to the room and to exhaust duct. Extra conditioning of air is needed in every room by means of VRV system or radiators. This solution is not applicable for the summer conditions since the air temperature inside the cavity is higher than the thermal comfort levels. Also in this case there are no limitations in individual control of the windows' openings.

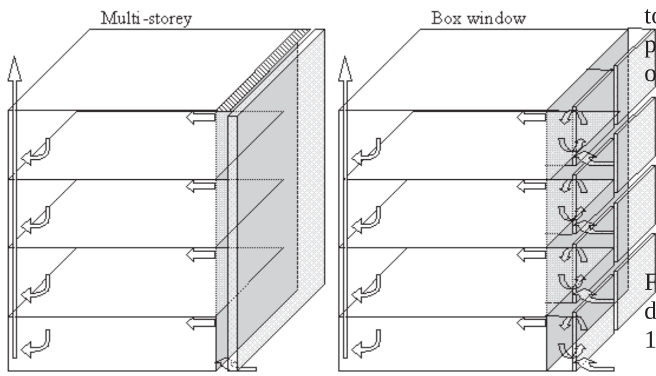


Figure 6- Double Skin Façade as an individual supply of the preheated air.

Finally, the Double Skin Façade cavity can be used as a central exhaust duct for the ventilation system (figure 7). The air enters through the lower part of the cavity and from each floor. Supply ventilation system stimulates the flow through the room to the cavity. The recovery of air is possible by means of heat pump or heat regenerator on the top of the cavity. The windows cannot be operable due to the not fresh air in the cavity.

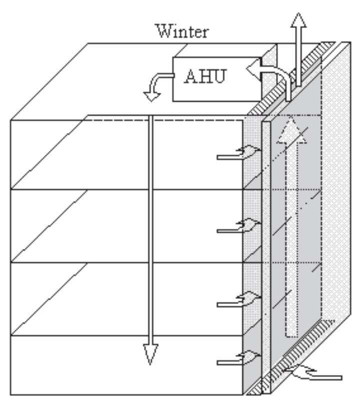


Figure 7- Double Skin Façade as a central exhaust duct for the ventilation system.

As Stec et al., (2003) describe, "Generally supply facades couple better with the winter systems in which their preheating properties can be used. The exhaust façade is more efficient to cool the cavity in the summer. Problem arise one façade need to couple both of the periods what cause that the construction need to be adjusted for summer and winter conditions".

V. COUPLING DOUBLE SKIN FACADES AND HVAC-EXAMPLES

Stec and van Paassen in "Controlled Double Facades and HVAC" in 2000 wrote a paper that deals with the preheating aspects of Double Skin Facades. The authors claim that for the winter period the most significant parameter should be the heat recovery efficiency. The main aim of the paper was to show the usability of the cavity air for ventilation purposes. According to the authors, "With the simulation one can define how the heat recovery efficiency depends on:

- Outside conditions
- Dimension of the cavity, (width of the cavity is taken into account)
- Area of inlets and outlet of outside air
- Height of the building (number of floors)"

For the simulations, the authors chose the following four different Double Skin Façade types.

1. Double Skin Façade with controlled airflow through the cavities The façade is a multi-storey with no opening junctions that allow the air to be extracted out. There is only one inlet for the ventilation airflow at the bottom of the façade. It is controlled by an air damper such that the air supply to the cavity is just enough for ventilating all the rooms above. The controlled trickle ventilator delivers the desired airflow to each room (80 m^3/h) 2
2. There are no open junctions on each floor, no controlled airflow in the cavity and no dampers at all in this system .Additionally, the upper part of the façade is open allowing the air to be extracted.

3. There are open junctions between the outside and the cavity on each floor, which cause heat exchange between air inside the cavity and outside air. The main airflow is the same as in the second system . The authors claim that "This should be the best system for summer time when cooling is required, but due to the open junctions preheating of the cavity air will be much lower than in the other systems with closed junctions".
4. There are open junctions on each level, but each storey is separated from each other . Consequently each storey creates its own system. The authors claim that "In practice this will be the most convenient system because the same module can be used on each storey. Also the problems due to large temperature gradients in different height of the cavity can be avoided (on each storey there is more or less the same temperature in the cavity)".

VI. CONTROL STRATEGY

A crucial point when integrating Double Skin Façade systems in buildings is to define a control strategy that allows the use of solar gains during the heating period and provides acceptable thermal comfort conditions during the whole year. The risk of overheating the offices during the summer months is high when the design of the Double Skin Façade is not coupled properly with the strategy of the HVAC system. According to Stec et al., (2003) this system allows the outside conditions influence the indoor climate. As the authors describe, "Efficient control system needs to be applied to manage rapidly changing outside conditions. A successful application can only be achieved when the contributions of all the devices can be synchronized by an integral control system".

According to the authors, "The control system of the "Passive climate system" of the building should be done according to the following principles:

- The occupants must be able to influence everything, even if their intervention spoils energy. (A.H.C. van Paassen, 1995).
- In order to save energy, the control system must take the maximum advantage from the outside conditions before switches over to the air conditioning system. . All the control system must be focused on the realization of the comfort with the lowest energy consumption.
- During the unoccupied period the control system is focused only on the energy saving, while during the occupied period must be focused on the comfort as well.

The control system has three tasks to fulfill with the use of the passive and active components. These tasks are following:

- keep the right level of the temperature inside the building
- supply sufficient amount of the ventilation air to the building
- ensure the right amount of light inside the building".

VII. ENERGY PERFORMANCE OF DOUBLE SKIN FAÇADES

A complete study of energy performance was presented by Saelens, Carmeliet and Hens in "Energy performance Assessment of Multiple Skin Facades" in 2003. The authors claim that only few combinations of Multi Storey Façade - modelling and building energy simulation are available.
According to the authors, "most of these papers are restricted to only one MSF-typology. Müller and Balowski [1983] analyse airflow windows, Oesterle et al [2001] give a comprehensive survey of double skin facades and Haddad and Elmahdy [1998] discuss the behaviour of supply air windows". In the above mentioned paper the authors focus on the energy saving objectives of three Multi Storey Façade typologies used in a single office.
The MSF-model is coupled with TRNSYS. As they describe, "to simulate the energy demand of the office, a cell centred control volume model, describing the MSF, is coupled to a dynamic energy simulation program. The results of the energy simulations are compared and confronted with the objectives found in literature". The authors focus on one storey high solutions:

- a conventional facade with an insulated glazing unit (IGU)
- a naturally ventilated double skin facade (DSF)
- a mechanically ventilated airflow window (AFW)
- a mechanically ventilated supply air window (SUP)

The reduction of the transmission losses, the possibility of recovering the transmission losses by the airflow, the position of the shading device sheltered from climatic conditions and the ability to remove the absorbed solar heat are the most commonly mentioned energy advantages.
The authors conclude that: "It is shown that it is possible to improve the building's energy efficiency in some way by using multiple skin facades. Unfortunately, most typologies are incapable of lowering both the annual heating and cooling demand. Only by combining typologies or changing the system settings according to the particular situation, a substantial overall improvement over the traditional insulated glazing unit with exterior shading is possible. This implies that sophisticated control mechanisms are inevitable to make multiple skin facades work efficiently throughout the year. In order to correctly evaluate the energy efficiency an annual energy simulation focusing on both heating and cooling load is necessary.
Furthermore, the analysis shows that the energy performance strongly depends on the way the cavity air is used. In order to correctly evaluate the energy efficiency of multiple skin facades, it is imperative not only to study the transmission gains and losses but also to take into account the enthalpy change of the cavity air and to perform a whole building energy analysis".

VIII. CONCLUSIONS

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.

- A high-rise building with a very thin cavity may not ensure the airflow in the cavity needed for ventilation purposes.
- In general double facades with airtight junctions and properly airflow control in the cavity is an interesting pre-heater for ventilation air. In a four storeys building and a cavity width of 0.2 m an overall heat recovery efficiency of 40% can be obtained. This efficiency can be increased to 72% if the ventilation flow inside the cavity is properly controlled. In that case the second skin can compete with a mechanical ventilation system with heat recovery. A disadvantage is the vertical temperature gradient inside the double façade. It gives less comfort or higher cooling capacities at higher floors.
- From the previous conclusion and simulation results it can be concluded to split cavities of high rise buildings in separated parts by combining for example four storeys with their own inlets and outlets. If this is done for each floor the efficiency will drop to 35%.
- In order to use the double façade as well as for night cooling, as for heat recovery controlled dampers in

the open junctions are necessary. In summer they should be fully open.

- The asymmetric behavior of the double façade gives less comfort or higher cooling capacities at higher floors".

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