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Comparison of Intelligent Façade's Energy Efficiency in Hot and Humid Climate against Passive Cooling Systems

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Abstract: **Energy conservation and sustainable designs are very hot topics in the world today. Currently architects and building designers greatly influence the level of energy conservation in the world, since buildings are the highest energy consumers. Generally the use of passive heating and cooling systems has had a huge impact in energy conservation, especially in the warm and humid climate. This research will therefore focus on comparing intelligent skins (case in point: double skin façade), which are adaptive and/or responsive to the surrounding environment and how efficient they can be in their energy conservation on the principles of passive designs for warm and humid climate such as natural ventilation and free air movement, providing ample shading systems, glare control and so on.**

Keywords: **Double skin façade, Energy Efficiency, Intelligent skins, Passive Cooling Systems Warm and humid.**

1. INTRODUCTION

For a long time the world had viewed the buildings facades as just static and unchangeable. But with the growing sustainability and energy conservation concerns, architects and designers alike have been forced to look at building facades as dynamic, responsive and adaptive.

Recently, building skins have been designed to mimic and reflect nature and the skins of living beings. Therefore, in the case of intelligent facades, if they are properly designed, they breathe, change form, and adapt to variations in climate. They play an important role in energy efficiency measures, and they are the main factor in the amount of energy required for heating, cooling and lighting in a building therefore are the forerunners in how energy efficient a building can be.

2. WARM AND HUMID CLIMATE

This climate is also referred to as humid subtropical climate. It is mainly experienced generally around the equator belt extending to about and 15° north and south. The climate is characterized mainly by high rainfall and high humidity. The temperature range is relatively high ranging to about 35°C and is fairly even during the day and throughout the year. Due to minimal temperature differences, winds are light or even non-existent for longer periods. However, heavy precipitation and storms occur frequently. Some examples of the countries experiencing this type of climate are Singapore, Malaysia, Jakarta and Hawaii, US [4]

3. PASSIVE COOLING SYSTEMS

In this climate most of the issues buildings face is high humidity, high solar radiation, high rainfall and storms with fairly even temperatures throughout the day and year. Therefore it is important for the façade to embrace some of the design principles that are currently being used in the passive systems to create energy efficient buildings. These are the two main principles this paper will focus on.

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- **Natural Ventilation:**

Natural ventilation is the most important passive cooling technique. In general, the ventilation of indoor environments is also necessary to maintain the required levels of oxygen and air quality in a space. Outdoor breezes create air movement inside the building by the effect of positive air pressure on the windward side and negative pressure (suction) on the leeward side. The building should have maximum ventilation and free air movement which can be achieved by placing openings at opposite pressure zones [4]

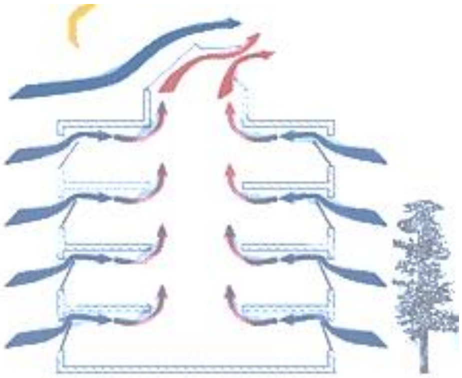

Fig. 1 Diagram showing openings on opposite pressure zones in stacking effect. [18]

- **Shading:**

Solar control is a critical necessity for the cooling-load dominated and passively solar-heated buildings. Shading provides part or absolute obstruction of the sunrays toward a building surface by an intervening object or surface. The shadow differs depending on the relationship between the sun and the surface [24]. In the warm and humid climate, designers must be careful to provide maximum shading on windows, roofs and walls to reduce direct and diffuse solar radiation from the building interior. Designing overhangs, louvres and awnings on the façade window is one of the main ways to achieve this. Each project has to be evaluated and calculated independently to ensure the correct placement of the overhangs according to the sun orientation. For example, simple fixed overhangs are very effective at shading south-facing windows in the summer when sun angles are high. [4]

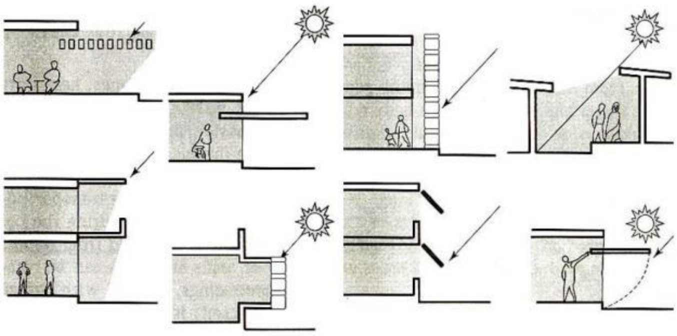

Fig 2. Different types of shading devices [20]

4. ENERGY CONSERVATION

The energy conservation concern emerged after the price the world was paying for neglect of environmental forces was too high. In light of that, sustainable design and buildings therefore became a high priority in the market. They largely depend on renewable energy and resources in designing ventilation, cooling and lighting aspects of the building. Passive cooling systems have been rendered to be the most dependable and efficient way in energy conservation that targets mainly to use readily available materials and technologies to naturally cool buildings through the processes of radiation, evaporation, ventilation, shading and insulation [3]

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This paper will mainly analyse the intelligent facades' ability to achieve some of these passive cooling systems mentioned above; focusing mainly on ventilation and shading; and see how they achieve some of the design guidelines for the warm and humid climate while at the same time creating a low energy profile.

5. INTELLIGENT FACADES

The concept of 'intelligent building' emerged recently in the last couple of decades. The term intelligent building has been in play since the late 20th century and several definitions for the term have surfaced since then.

There are around thirty four definitions of intelligent buildings and about thirteen definitions of intelligent skin/ facades by Wigginton and Harris (2002) [2] which according to them can be summarized to a simplified definition. Intelligent façade therefore is "A facade incorporating variable technology, which would amend itself to provide comfort conditions inside the building whatever the external environmental conditions, might be, in any particular building location" [2]

There are several existing and conceptual ideas of intelligent façade systems since it's still a growing concept. Quite a large number are already in the market and are highly functional and have been well received by architects, clients and users alike, while some conceptual ones also look promising. This research, however, will mainly zero in and compare the double skin façade system to existing passive cooling system principles mentioned above.

5.1 Double Skin Façade (D.S.F):

Double skin façade is an integrated building system that aims to achieve a number of properties to improve a building's performance. The system is comprised of

Outer glazed façade; normally used to provide weather protection and sound insulation**,**

Interior façade, an insulating double glazing unit with clear, low E coating or solar control glazing, can be used, but this façade is not glazed in most cases.

A cavity which is an intermediate space used to protect thermal impacts on the interior façade which can be totally natural, fan supported or mechanically ventilated. The facade can also be integrated with a shading system to fully optimize the system function and control the solar radiation. [6]

In summer, especially in the hot climates, when there is high solar radiation, the double skin façade provides excellent solar control protecting the air inside the cavity from external conditions using blinds within the cavity. This in turn causes the inside the cavity to cool several degrees lower than the actual temperature on the outside. [5]

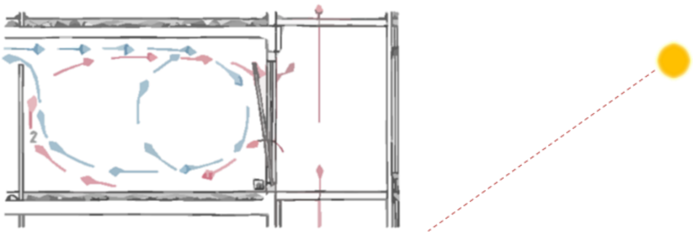

Fig 3. Ventilation in summer through the façade cavity Modified from [19]

In winter, the façade now reverses its functionality to heat the interior space and retain the heat inside the building. This means it will now allow solar radiation into the building, the air located in the cavity between the exterior and interior walls (glass skins) is heated up and in turn warms the interior space. [5]

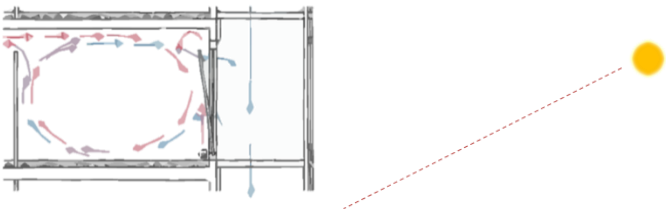

Fig 4. Winter performance of double skin façade Modified from [19]

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5.2 Classification of Double Skin Systems:

There are several ways to classify different types of a double skin facade. The most common way of categorizing different types of the system was made by Oesterle Etal [8]. His definition is the most used by researchers to classify the system.

Box window type: This type of has horizontal and vertical partitioning dividing the façade in smaller and independent boxes.

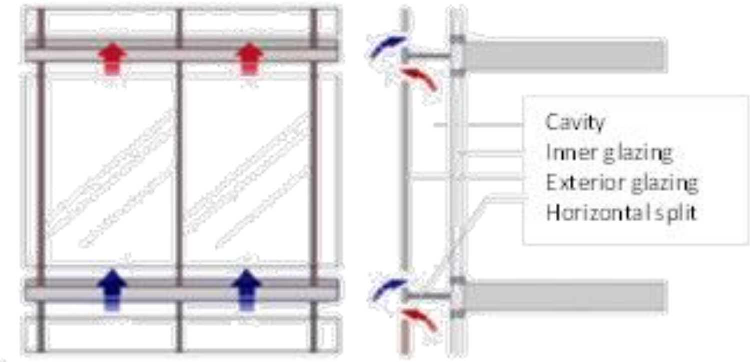

Fig 5(a). Double skin façade Box window type Modified from [22]

Shaft box type: This type has set of box window elements placed in the façade. These elements are connected via vertical shafts situated in the façade. These shafts ensure an increased stack effect.

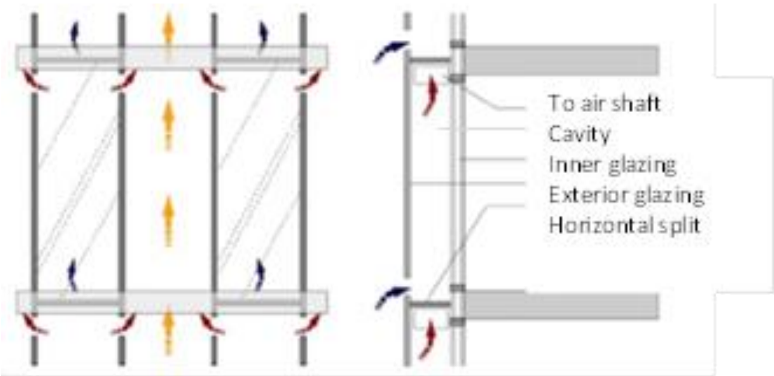

Fig 5(b). Double skin façade Shaft Box window type Modified from [22]

• ***Corridor façade***: In this type, horizontal partitioning is realized for acoustical, fire security or ventilation reasons.

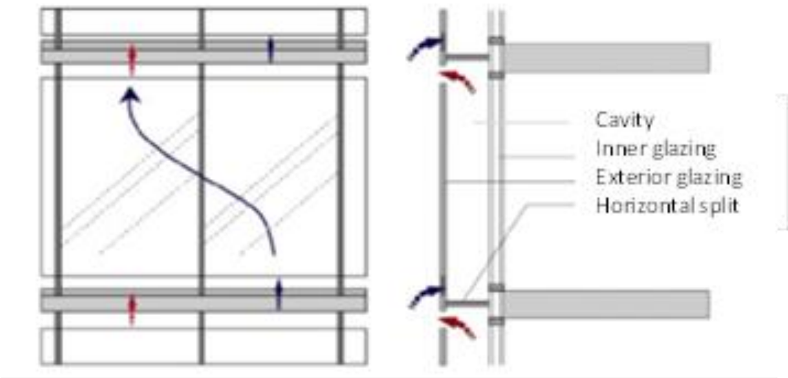

Fig 5(c). Corridor Double skin façade Modified from [22]

• *Multi-storey Double Skin Façade*: In this type no horizontal or vertical partitioning exists between the two skins. The air cavity ventilation is realized via large openings near the floor and the roof of the building. [6]

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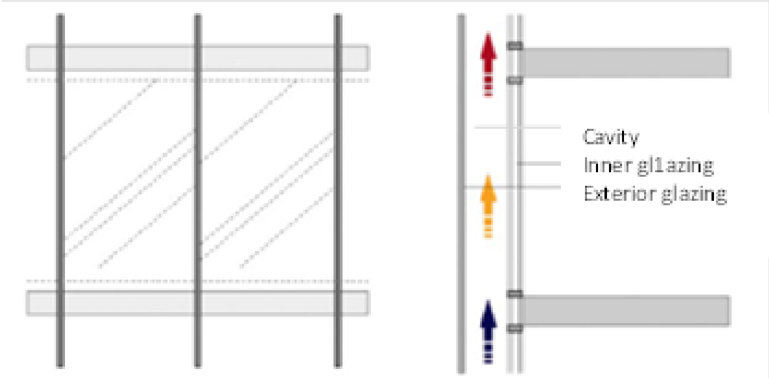

Fig 5(d). Multi-storey Double skin façade type Modified from [22]

5.3 Improving Performance of the Double Skin Façade:

To improve the façade system performance after reviewing the functions of the façade it is clear that it is important to:

- Select the correct type of glass for both facades
- Balance the percentage of transparent and opaque surfaces
- Use sun shading devices (Louvers, awnings, etc.)
- Designing the depth of cavity appropriately
- Checking the type and location of inlets and outlet of air
- Use air intake systems (Mechanical ventilation)
- Use appropriate systems for air exchange with the room. [6]

5.4 Advantages and Disadvantages Of Double Skin Façade:

Advantages

- Better acoustic insulation and improve Noise protection.
- Reduce the cooling and heating loads.
- Provide thermal insulation.
- Provide transparency.
- Low U-Value (thermal transmission) and g-value (Solar heat gain coefficient).
- Low Construction costs. Reduction of the Wind pressure

Disadvantages

- Need higher construction costs compared to conventional facades.
- Decrease fire protection.
- Reduction of building useful spaces.
- Need additional maintenance and operational costs.
- Overheating problems if not properly designed.
- Increasing air flow velocity.
- Increasing construction weight.[12]

6. CASE STUDY

To further analyse the intelligent façade's energy efficiency in warm and humid climate, this section will study a building in a warm and humid climate with a double skin façade, against the passive cooling systems of ventilation and shading to see how the intelligent facades are using the principles of passive cooling to adapt and respond to the environmental and climatic requirements.

Pearl River Tower, Guangzhou, China

Location: Guangzhou, China

Design Completion: 2010

Site Area: 10,635 m^2

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Project Area: 214,100 m^2

Number of Stories: 71

Building Height: 309.60 m

Market: Commercial + Office

The building was constructed under the supervision of CNTC Guangzhou Tobacco Company, it was designed and constructed by Skidmore, Owings & Merrill with partner Adrian Smith and Gordon Gill during the period of 2006-2010 and it has been awarded in 2008 for Green, Carbon- Lowering& Environmental Category: Gold Award.[5]

Climatic Conditions of the Site:

The building is located in Guangzhou in Southeastern China. The Climate is hot and humid with heavy rain and predictable prevailing North, South and southwest winds. There is mild and dry winters generally without snow with average mean temperatures and long summers which are wet, hot and humid. [10]

Strategies:

The design of the office Building incorporates different sustainability strategies by employing a combination of passive cooling and ventilation strategies in the building. Using Glass double skin façade and energy efficient building form the building is able to block direct solar radiation from entering the space. [10] Some of the sustainable strategies used are **Ventilation** using high performance energy efficient façade, articulate **shading techniques** and **energy conservation** by making use of natural lighting and energy generation

a. Ventilation:

The tower incorporates and integrates different technologies on the envelope. It uses a double glazed wall system in the North and south façade, the curtain wall offers insulation that reduces heat gain and leads to less demand on the HVAC system which consists of double glazed insulated unit with integral spandrel as shown in the figure below(Fig 6)

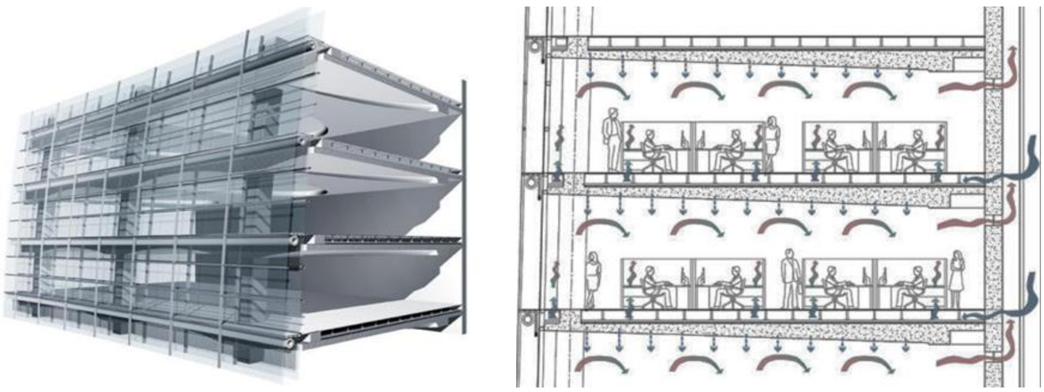


Fig 6. Air supply and exhaustion system [17]

Exterior glazing material is insulated, tempered glass with a low-E coating; the inner layer is an operable clear glass panel on the building south face [10] where low-emittance glass is coated with a microscopically thin, virtually invisible, metal layer that reduces thermal conductivity.

Triple-glazed facades can be found on the East and west facades are associated with external shades and automated blinds within the façade's cavity. A photovoltaic system is integrated into the building's external shading system and glass outer skin. [5]

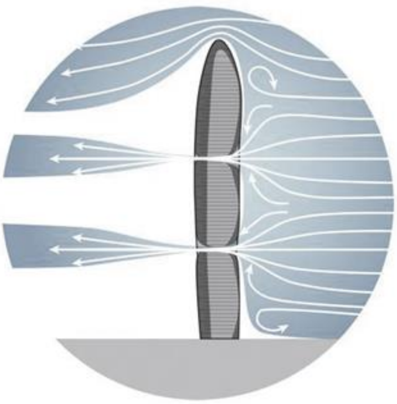
b. Shading Technique:

Since all the facades of Pearl River tower are double glazed facades, shading blinds are placed within their cavities where a motorized Venetian blind is in the east and west double façade. The blind position is determined by a photocell that tracks the sun position and is connected to the building management system which activates the blind position to ensure occupancy comfort from both solar gains and glare. [10]

c. Energy Conservation:

Pearl River tower is targeting to combine different energy conservation strategies that could reduce the building's energy use by nearly 65% over a baseline of Chinese building codes [16]. To achieve the goal of a net zero energy, the building design incorporated three power-generating technologies integrated within building facades**: wind turbines, integrated photovoltaic and hydrogen fuel cells**

- ***Wind turbine*****:** The most innovative aspect of the façade are the vertical axes integrated wind turbines that are used for catching prevailing winds from the south and the north with minimum loss where building's east and west facades are flat while the south façade is the façade facing the south wind[5]



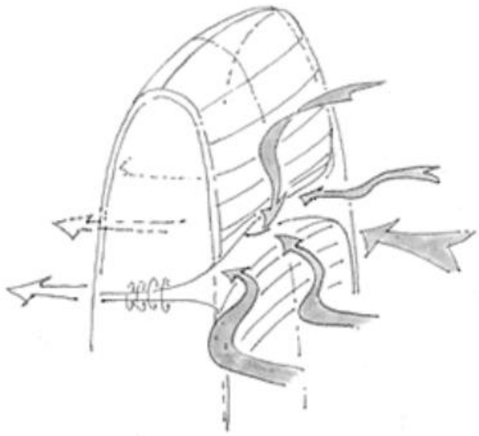


Fig. 7(a) South façade is curved to catch all Prevailing winds to the mechanical floor [16]

Fig. 7(b) Diagram showing wind movement through the building [17]

Photovoltaic panels**:** They have been integrated into the façade to transform the sun energy to usable AC current where it was determined that the use of PV cells could be productive if used on certain portions of the building envelope as shown in the figure below (Fig 8)[15]

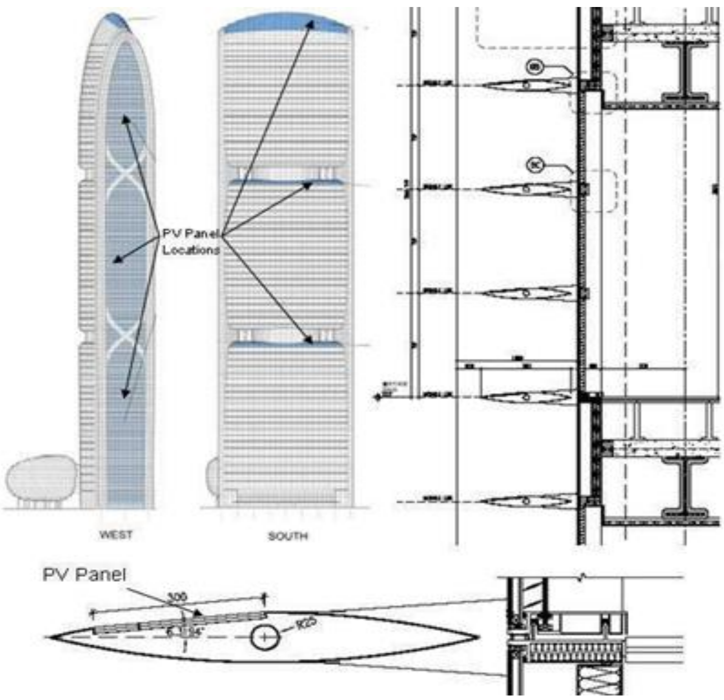


Fig. 8 Perforated Silver Ventilation blinds is in the east and west double façade PV panels mounted to the exterior sunshades on the western façade [15]

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- ***Hydrogen Fuel Cells*:** Pearl River Tower is planned to utilize Hydrogen fuel cells into building façade to store excess generated energy and convert gas to electricity with more than 50 percent energy efficiency which is also could be used as power energy for cooling and ventilation. [15]

Pearl River tower is presenting a number of highly innovative technologies Wind turbines, ventilated facades and integrated photovoltaic. These technologies work together to significantly achieve net zero energy and ensure highest level of human comfort and indoor air quality and reduce energy. The expected performance is 58% reduction of energy consumption according to a hypothetical comparison to a building of the same geometry. [5]

The integration of the double skin façade and passive cooling system makes this an appropriate case study to show the interaction between the two systems. The double skin is of course one of so many different intelligent facades but this case study just helps to shed light on the adaptability and the responsive nature of the intelligent facades.

7. COMPARATIVE DISCUSSION

Buildings' energy consumptions differ from one building to the next, normally influenced by factors like building function, building components, system controls and settings. Which means the energy efficiency of a facade is affected by all these factors therefore the energy efficiency of a building is equally subjective.

The intelligent facades are adaptive and responsive to their environment as are the passive cooling systems widely used in different climate types. They may vary in their strategies but they are designed to respond to the conditions of their surroundings. That is why it is a challenge to compare different intelligent facades against each other and against passive cooling systems because they all vary in their method of response according to the criteria of a specified building and surrounding. The intelligent facades have however come in to fill the niche of sustainable designs in high-rise buildings, since the passive strategies are working well for the general building types mainly of substantial height and size.

There are multiple ways to apply different strategies of the passive cooling systems, for example using vegetation for shading or using louvres and awnings. Therefore the passive cooling systems design strategies that were mentioned earlier in the paper like natural ventilation can be well incorporated into a double skin façade, where the exterior glazing creates a layer of air next to the outside wall of the building which is typically not affected by high speed winds. The cavity in between the glazing and wall, which is also the buffer zone and the use of operable windows in the exterior glazing makes for good access of natural ventilation.

In the case of shading in the double skin façade the shading systems can be designed and incorporated within the cavity. The shadings can be automatic and kinetic responding efficiently to the sunray exposure, or user controlled shading systems like in the case of venetian blinds. All in all, the double skin façade integrates so many other passive design strategies for warm and humid climate like daylighting, solar heat gain and insulation.

The main difference between the double skin façade and the passive cooling systems is that in most cases the occupants or users of a building with double skin façade and /or any other intelligent façade system in most cases can control most of the functions in the facade to accommodate their preferences and thermal comfort.

However, in comparison, the double skin façade like the other intelligent facades have higher liabilities and disadvantages compared to passive cooling systems, sighting high construction costs unlike the passive cooling systems that are affordable and easily manageable with minimal effort and use of available local materials. Reduction of building useful space which is a high price given that these systems are used in high-rise buildings normally on very expensive sites where every square meter space matters. They also need proper design skills for efficient performance, unlike the passive cooling systems design strategies that are more natural and demand less costs and expertise and manpower compared to intelligent facades. They can be applied even by the simplest users of an area on the simplest buildings and structures whereas the intelligent systems create a challenge in design and construction.

8. CONCLUSION

When comparing the two systems, they tend to be more similar than opposites which was the expectation going in, since the intelligent façade systems naturally have to adapt and respond appropriately to the surrounding. But since there are many different types of intelligent facades, it is therefore difficult to comprehend the level of differences in each and every one of them against the passive cooling strategies and design for any given climate.

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However in the case of the double skin façade, it seems to be well responsive to the climatic issues but will only be efficient for warm and humid climate if:

• The building design orientation and room placement are appropriately placed for optimal response to sun and wind.
• The building form will provide protection from solar radiation where required.

• The system will provide as many shading systems as required.

• The system will provide proper ventilation and exclude climatically adverse side-effects.

The intelligent facades can be a major step in the right direction for energy conservation and efficiency in warm and humid climates, but even though they are "intelligent" their design and customization for a climate and building usage has to be adequately designed.

Architects and designers need to embrace the intelligent facades that are still growing by the day. Find ways to make them more socially, economically and environmentally sustainable. They can be modified to a given location, surrounding, user profile and building function making them a suitable choice for energy efficiency IF properly designed.

The passive cooling systems for warm and humid climate are still a great way to go since they are the most efficient, sustainable and economical ways yet. If they can be integrated into high-rise buildings to minimize construction, operation and maintenance costs that the intelligent buildings are still struggling with, then energy efficiency and conservation will get much easier all around the world.

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