Taking Cues from the Dubai Expo 2020 for sustainable ventilation and thermal comfort - An Analysis of the Singapore Pavilion

~ Group 1

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Abstract:

The motive of the Dubai expo is for each country to showcase their culture and tradition which has led to 192 countries coming forward and setting up pavilions all around the expo to innovatively project their unique traits and features which identifies them as a nation. The expo has been divided into three large thematic districts. Each one dedicated to one of the sub – themes of Expo 2020 – ***Opportunity, Mobility and Sustainability****. The Singapore Pavilion is situated in the Sustainability district of the expo. The Singapore pavilion upholds its reputation as a* ***biophilic structure*** *as it is covered with* ***green plantation*** *on all sides. It is a completely* ***open pavilio****n allowing the whole pavilion to be a part of nature while showcasing to us that comfort and solace can be maintained through integrating* ***modern scientific methods*** *along with* ***natural means****. The introduction of* ***dry mist fans*** *combined with the* ***natural ventilation*** *techniques allows the pavilion to maintain a continuous air flow inside it. Due to* ***shading****, the* ***evapo-transpiration cooling*** *of the surrounding* ***vegetation*** *cools the temperature and helps in providing thermal comfort Implementing such innovative means to apply ventilation and maintain thermal comfort in the pavilion gives us an overview of why sustainability is very much essential for us to implement in order to pave a path towards a* ***pollution free and technologically developed future.*** *Such natural methodologies can in turn*

help many nations where there is an energy or economic crisis and also help people there live a comfortable life with low maintenance methods

Introduction:

This world is a spectacle that unleashes in front of us as we all play our roles in it. Many forget that the course of history is defined by our own actions in day to day life. A world expo does just the work in reminding us that our world is vibrant but also at the same time reminds us of the problems and gives the possible solutions to the issues. The Dubai expo is such a world expo.

A World Expo is an exhibition which is held in different places all around the world. The World Expo is a recurring, six-months long event that happens every five years. It's a large exhibition showcasing inventions, ideas and creations from all over the globe and invites every nation on earth to participate and showcase their innovations. The first Expo was the **1851 Great Exhibition** held in **London;** it was named as "Industry of all Nations". In **1853, the second World Expo** was held in **New York, U.S.A**., during which the young United States of America exhibited its achievements to the world for the first time. The **1855 Paris World Expo**, concrete, aluminium, and rubber products were exhibited for the first time. At the **1862 London World Expo**, new industrial products, including textile machines, printing presses, and trains, were showcased. And during the **1862 Vienna World Expo**, the new power unit—the electric motor—was presented to the world for the first time. The **World Expos held during the 19th century** were manifestations of an extraordinary **"age of invention,"** extensively presenting the latest achievements of industrial civilization during that period. The World Expo, born from a technical world, attempted to look further into the **vast horizon** ahead, look beyond technology and begin to pay more attention to human and cultural conditions.

"Nature, Nurture, Future". There is no better line than the theme of the Singapore pavilion to start with. In this world, with the advancement of technology and development in the field of science somewhere we forgot about the harm we are causing to our dear mother nature which is not a good sign as if we forget the very origin, we came from it will lead to catastrophe.

“Sustainability” is a term that was coined for the sole purpose to help us save this planet. In the past many attempts have been made like the **“Green Movement”** and many more. But later people have come to realise that in order for us to **“move forward”** we need to find the perfect balance between nature and science and implement a perfect correlation between them. Singapore has been the pioneer in implementing such a correlation for years now as it is also known as the **“Garden City”.** It is also a perfect example of a biophilic city as the development of green areas and green buildings are being shown as regenerating the natural systems in the city and creating an urban ecosystem similar to the original structure, but with better biodiversity outcomes.

Singapore pavilion embodies the ideals of the Singapore city and tries to showcase its culture and tradition in it. The pavilion shows us that all the necessities required to create a **sustainable and technological advanced future** can be implemented with scientific as well as natural methods at the same time, it is a mostly open pavilion which provides us the best shot at analysing the best possible ventilation in the dubai expo region that could be attained sustainably.

<u>Climatic analysis of Dubai:</u>

- September's climate is similar to the summer months although the temperatures are a few degrees less. Humidity is often higher than in the summer - again, worst times are late afternoon/early evening but often all day. **Mornings up until 10:00 or 11:00 can be pleasant outdoors, same for evenings after about 18:00 if there's less humidity**. Morning fog occasionally appears but usually burns off quite quickly once the sun rises.
- Water temperature in the ocean starts to become more tolerable, although still over 30 degrees celsius until November.
- Extremely rare to have any rain.
- October and November is when weather becomes much more comfortable for outdoor activities with lots of sunshine and pleasant mornings and evenings.
- Strong winds (**Shamals**) sometimes come through in November - strong enough to take down trees and signs, and make sea conditions dangerous.

- Sunrise from **5:30 to 6:30** and sunset from **18:00-19:00.**
- **The latitude of Dubai Exhibition Centre, UAE is 24.959969, and the longitude is 55.147400**

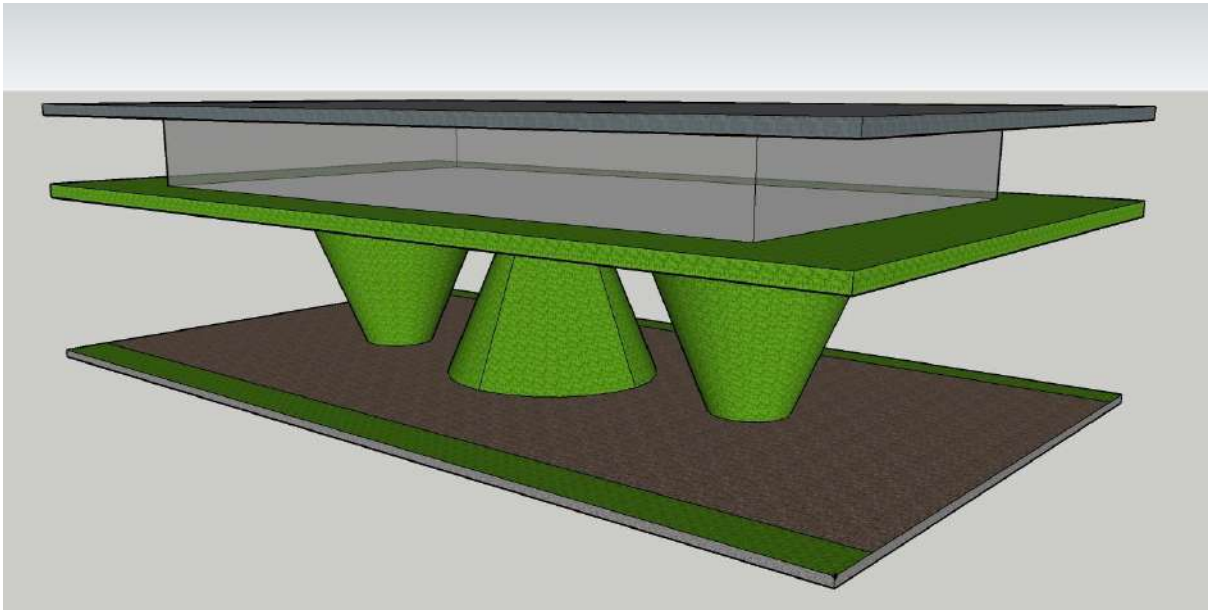
<u>The Dubai Expo:</u>

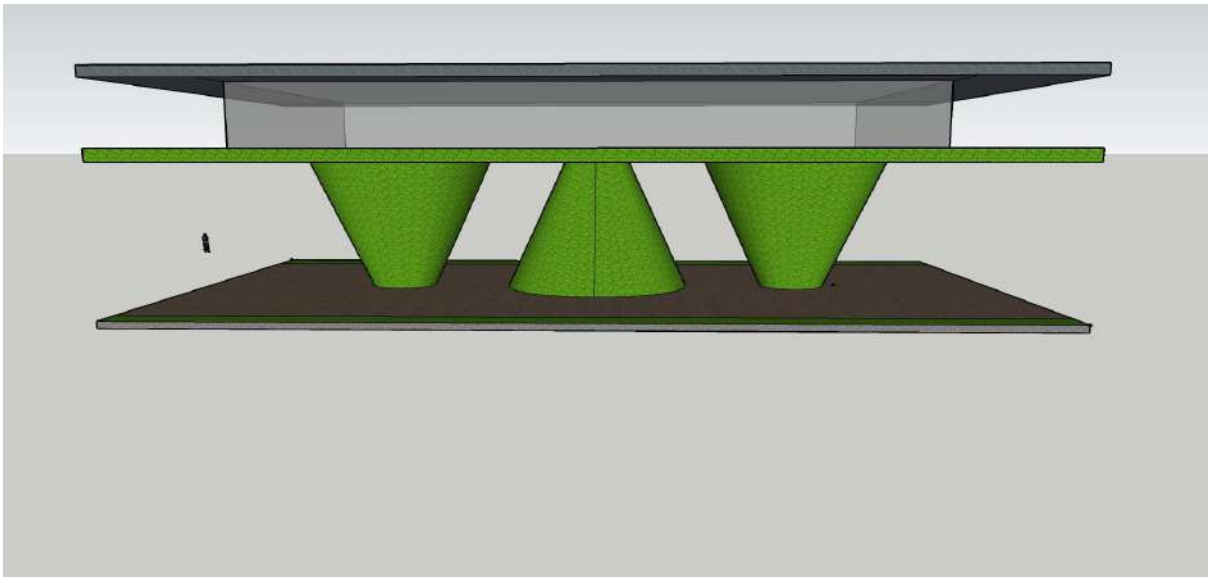
Figure 1: An aerial view of the Dubai expo

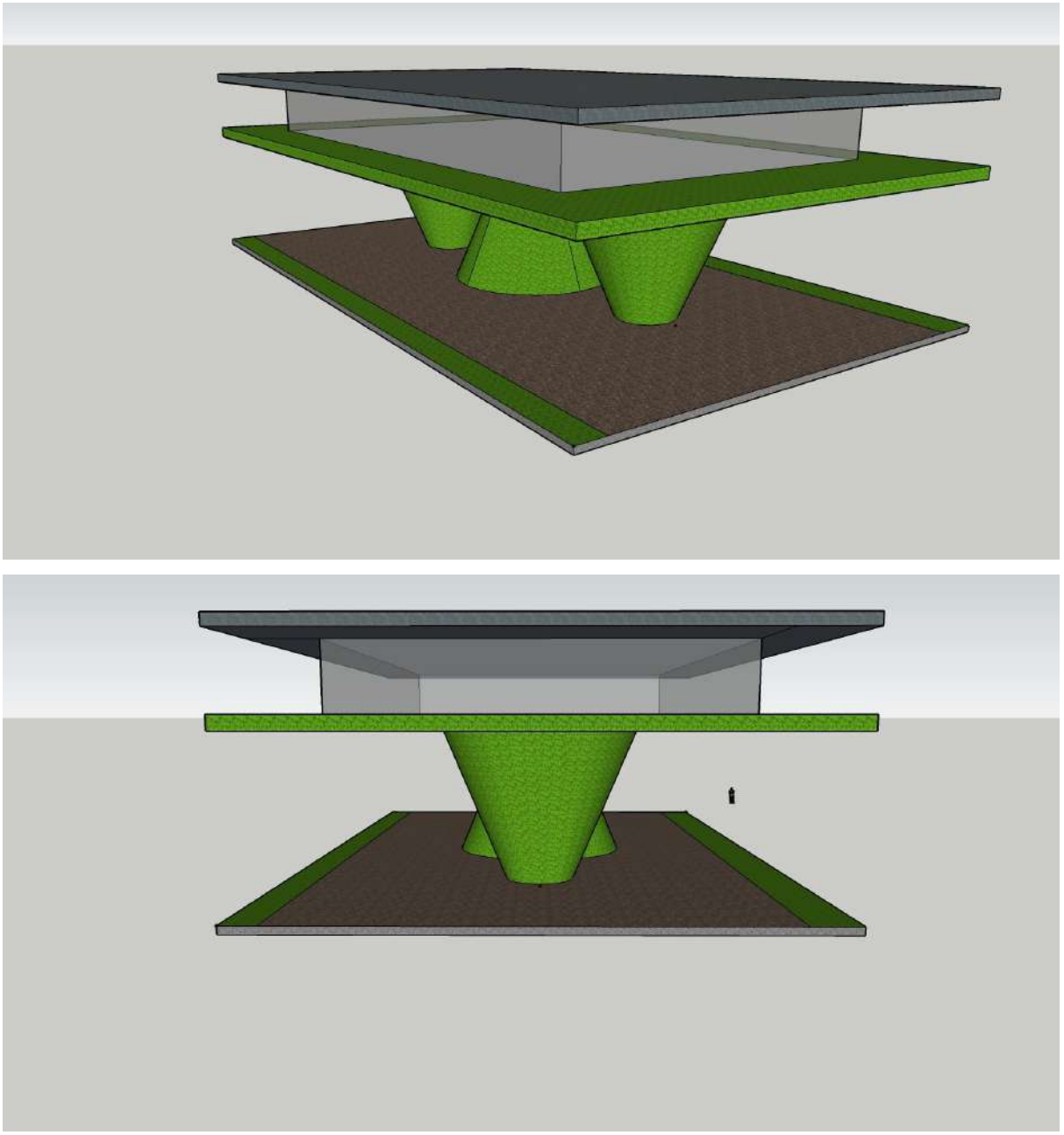
Figure 2: Internal view of the expo

The Dubai expo is situated in the Arabian desert, in the outskirts of the city approximately 13-20 Km from the sea. No high rise buildings (skyscrapers) near the expo exits except the Dubai expo residential complexes. Hence, there is no significant obstruction for natural air flows.Due to the presence of sea and hot weather conditions, the air flow is observed to be strong. To keep with it, the construction of the expo has been made with smooth boundary edges. The shape is contoured. If the edges wouldn't have been contoured then the sharp edges would have created turbulence and hampered the construction of the expo.

The Singapore pavilion:







Figures 3-6 : The google sketchup replica of the singapore pavilion made by us.(The green roof should be a bit lesser than the actual roof in the real structure)

The pavilion is made of three cones of height 9m. The path in the pavilion has a very slight slope and thus gives the visitor a better experience in the pavilion. The ponds and trees in the different elements used help in creating a singaporean microclimate and make it look like a natural heaven in the technical expo. It's a net-zero pavilion and the mist from the mist fans is used to cool the

top layer. The flower cone is especially enchanting, with an array of colours that greet every visitor that visits the pavilion.

Different types of ventilation: General Discussion:

•Mixed ventilation: When there is only one way for the air to move out i.e. there is no specific gradation/ layering of air in the room. Even if there is a second opening, it's generally near the other opening.

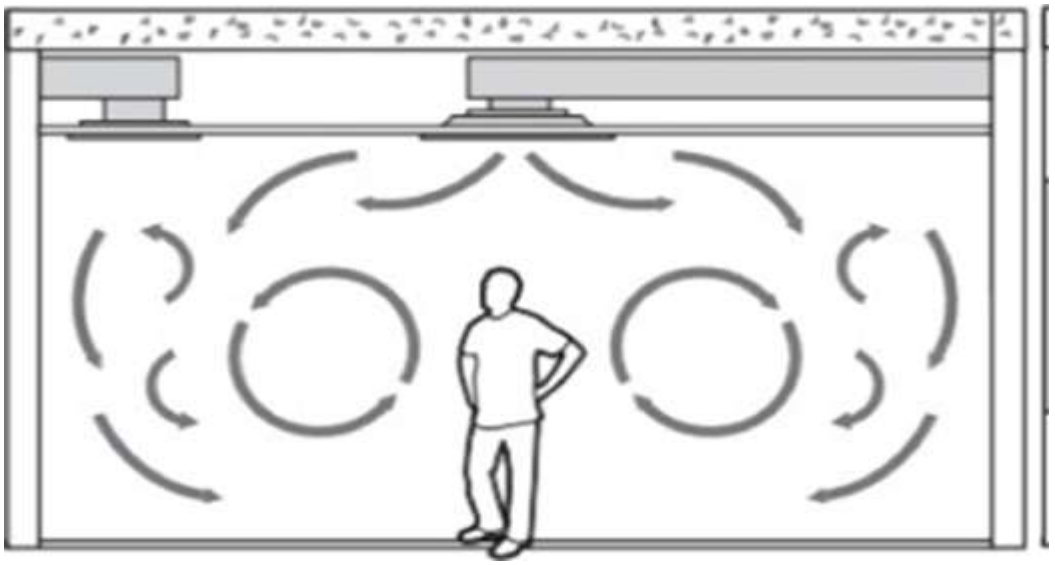


Figure 7: Mixed ventilation depiction

•Displacement ventilation: The cold air from outside enters via a vent (usually the lower one) and the warmer air moves out from another vent (generally the higher one). In this type, clear stratification of air due to buoyancy exists.

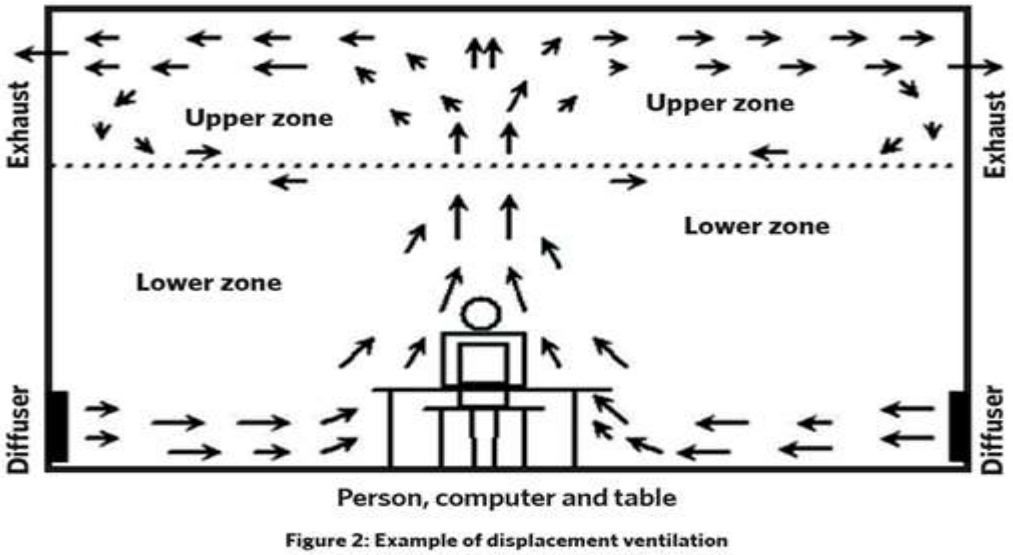


Figure 2: Example of displacement ventilation

Figure 8: Displacement ventilation depiction

Ventilation in Singapore Pavilion:

Singapore pavilion is designed in such a way that there are no classically structured walls that can act as boundary to the pavilion's main building, instead it has a variety of plants, ponds and walkways that act as boundaries to the pavilion, which yet again adds to the pavilion's motto and makes the space around humidified due to a lot of plantations. Also, the **ventilators in Singapore pavilion are long and big to provide the optimal ventilation for the pavilion**, but at the same time they have been designed and added to the structure in a manner that they seamlessly fit in with the interior rather than simply being large vents. *A clear layer of stratification is visible in the building design as well, where it is easy to observe that the lower regions have cooler air and the upper regions are exposed to higher solar radiation, which results in a comparatively hotter surrounding air.* The pavilion is facilitated with **fans for ventilation** assistance, that not only helps in circulating air but also adds mist which helps in reducing the temperature of the surroundings. We can better observe the above, through the figure given below.

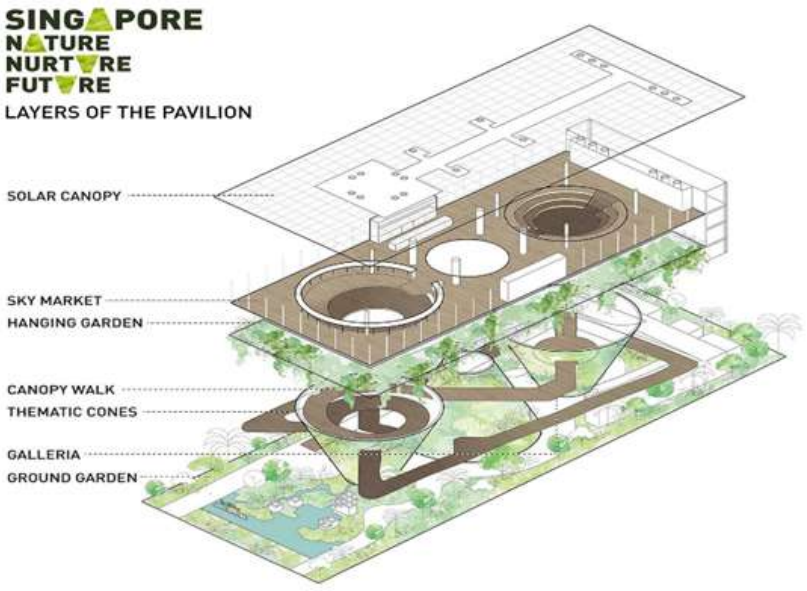


Figure 9: The cross-section view of the singapore pavilion

It is also observed that the plants on one side of the pavilion are taller, when compared to the other side, as shown in the figure below. When

looking at a design perspective we can infer that this is intentional and an ingenious architectural aspect of the pavilion. This is because, as *on one side of the pavilion the plants are tall, they will obstruct the wind and decrease its speed while on the other side, where there are shorter plants, there is no such obstruction and the wind can flow normally, this leads to an increase in the velocity gradient i.e, the difference in velocity between adjacent layers of the fluid, thus increasing the air flow resulting in strong wind currents flowing outside. These strong wind currents provide a means of natural ventilation, which reduces the energy consumption of the ventilation system of the pavilion, and as such decrease the total energy requirements of the pavilion as a whole as well.*

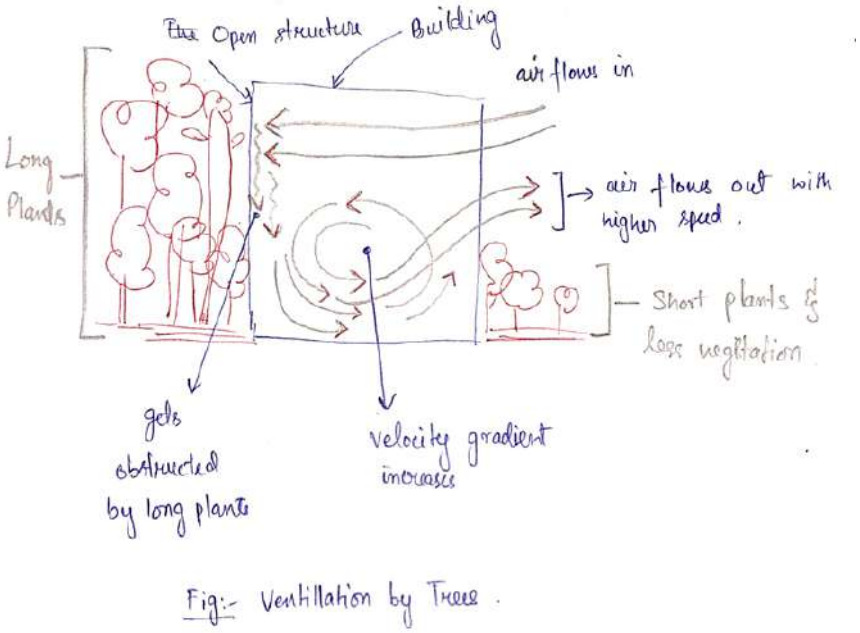


Figure 10 : Ventilation effect produced by trees

It was also observed that Singapore pavilion has a **high roof pitch** which helps in proper ventilation by providing a path for **cross ventilation**. In addition to that, the **opening present in the cones** inside the building, also play a role in the air flow in the pavilion by allowing both **displacement and mixed ventilation** to take place, as the opening allows for an unobstructed path for the wind to freely flow around. All this leads to the pavilion using all the three above-mentioned types of ventilations at the same time, which complement each other resulting in a far more efficient ventilation as a whole.

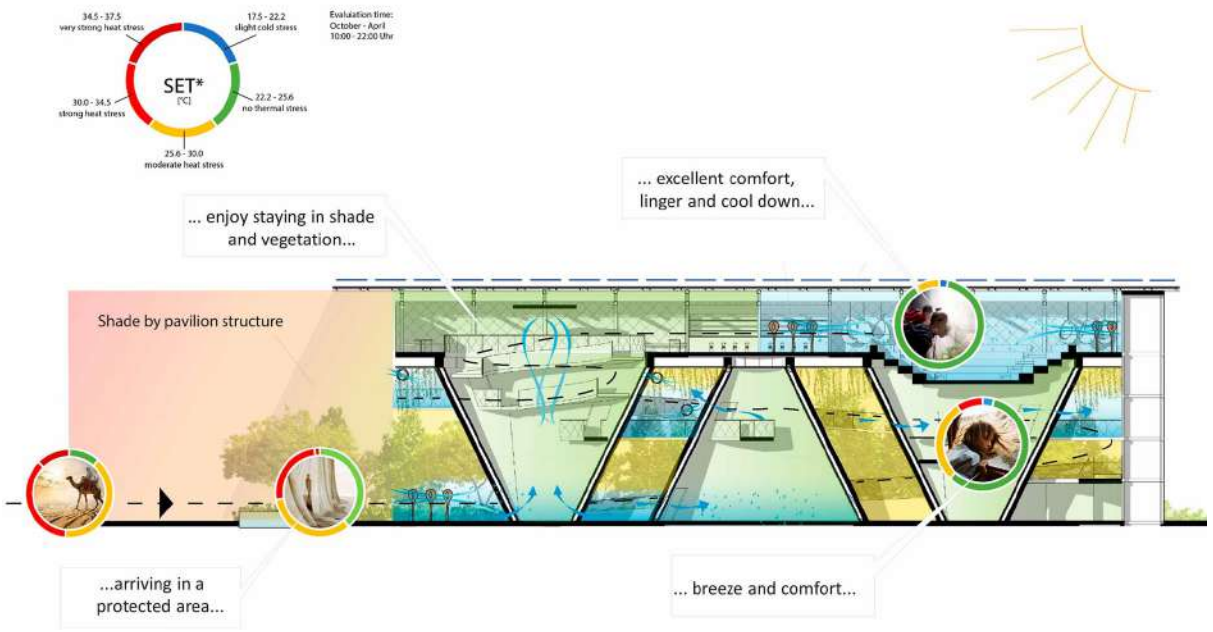


Figure 11 : Ventilations in the Singapore Pavilion

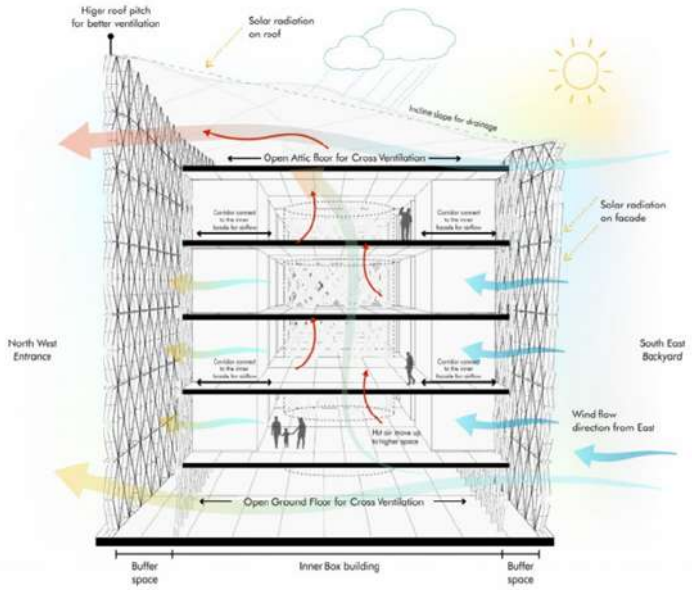


Figure 12: Depiction of cross-ventilation

Moreover, the height of plants on either side of the pavilion is also another commonality. The height of the plants on the side of the **Czech Republic pavilion** is much **higher** than that of the Netherlands pavilion as can be seen from the google map images. *The narrow tunnel like pathway for natural air entry at either side of the pavilion creates the winds from the desert and the sea to be tunnelled and passed with increased speed and the speed is controlled to the requirement by the variation in plantation density on the either sides which creates the velocity gradient and causes wind flow from one side to the other.*

Figure 13 : Showing the alignment of the Singapore pavilion.

WindSpeed Analysis of the Singapore Pavilion:

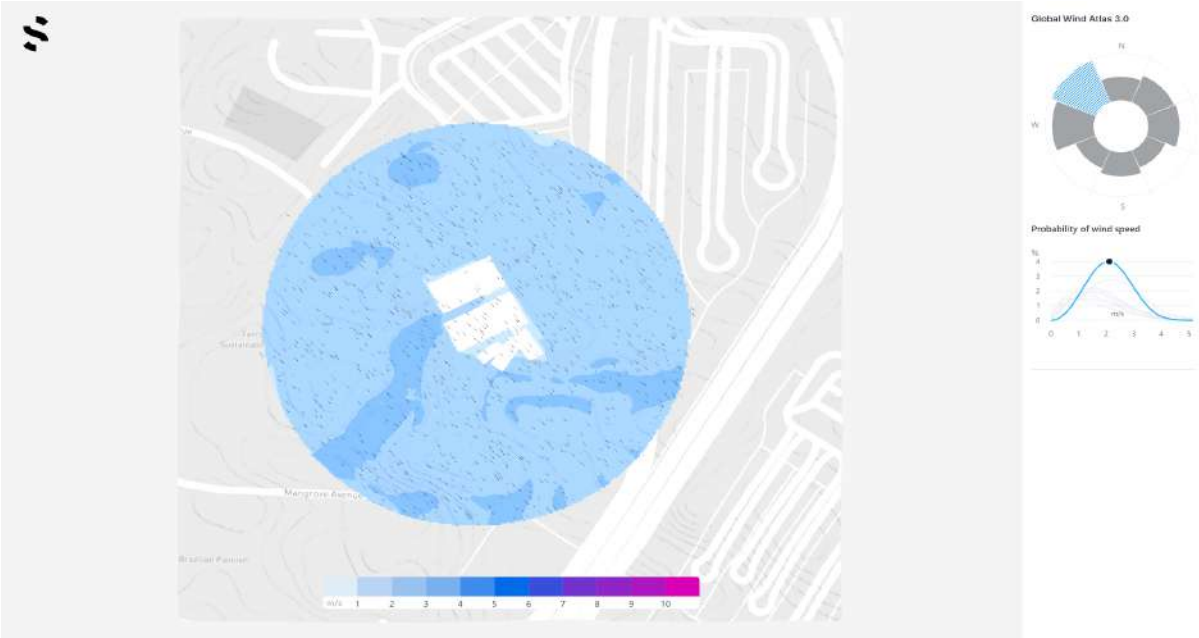


Figure 14(a): This analysis shows the variations in wind speeds in a 150m radius around the singapore pavilion when the wind is moving in North-West direction.

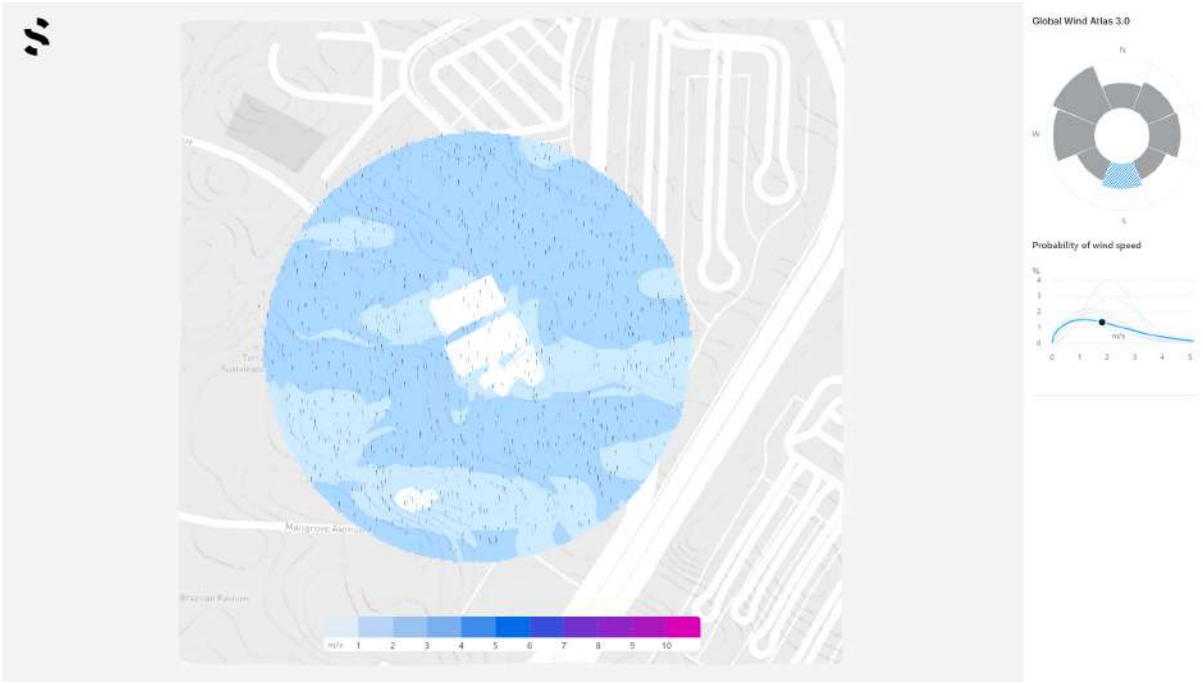
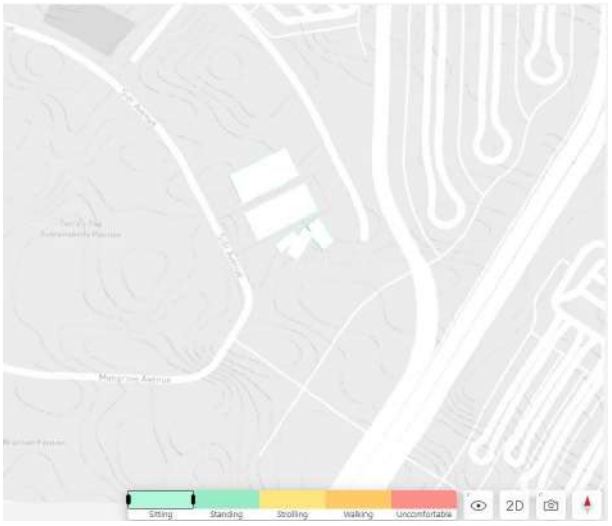


Figure 14(b): This analysis shows the variations in wind speeds in a 150m radius around the singapore pavilion when the wind is moving towards South

This wind speed analysis supports our theory of the tunnelling effect caused by the two adjacent pavilions and the trees, modulating the speeds for the most

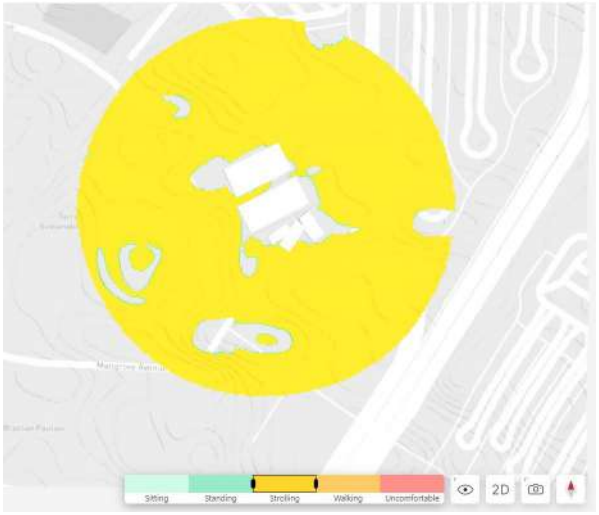
prevalent winds in the Dubai region (the north-westerly and the southerly winds)

Wind comfort Analysis in the singapore pavilion:



15(a)

15(b)



15(c)

15(d)

Figure 15: The above are Autocad Spacemaker simulation of ventilation comfort analysis around a 150m radius of the Singapore pavilion and the walkways in the Dubai Expo 2020. **Figure a) shows the area where comfort for sitting is there. Figure b) shows all the areas where standing is comfortable. Figure c) shows the areas where strolling is comfortable and Figure d) shows all the areas where walking is comfortable**

The above picture shows that the pedestrian zones around the pavilion are very much apt for strolling and standing but are difficult for walking.

Thermal comfort and Microclimate Analysis:

Despite the heat of the desert, the visitors' journey through the Singapore pavilion is comfortable and enjoyable due to shading the evapo-transpiration cooling of the surrounding vegetation and the strategic placement of fine mist fans that cool the air by about 5-10 degree Celsius. It is fully ventilated. They are using trees and dry mist to lower the temperature internally by 6 to 10 degrees. When you come in, you will feel the difference.

Figure 16: The mist fans inside the pavilion

Glazing Ratio :

The proportion of glazing to opaque surface in a wall. Also called window-to-wall ratio, it is a key variable in facade design affecting energy performance in buildings.

As for the Singapore pavilion, it doesn't have a dedicated wall, but the plants and trees around it act as a green wall, thereby causing both ventilation and also giving shade and efficient use of energy. This shade functions as a glazing ratio.

For the purpose of calculating the glazing ratio,
We are dividing the complete build structure of the pavilion into **3 zones** on the basis of floors –

1. The Top floor (Red Zone)
2. The Middle floor or the second floor (Orange Zone)
3. The Ground floor (Green Zone)

Figure 17: Defining the layering in the pavilion

•The Red Zone consists of the **top floor** of the pavilion. It is named so as the *intensity of the sunlight is highest* on this floor. The **open nature** of the top floor structure of the pavilion supports the fact.

•The Orange Zone consists of the **middle floor** majorly populated with the **corridors** which can be considered as the passive zones for calculating the glazing ratio. The corridors are mostly open and vulnerable to sunlight.

•The **Ground floor** of the pavilion is considered to be the Green Zone.
•The zone is named green because of the large amount of green plants that surround the area around the floor.
•In this floor most of the sunlight energy is blocked by the plants.

<u>Fiji simulations to calculate respective glazing ratios(Gr):</u>

Since, we didn't have access to the glazing ratio data of the pavilion and nor we had been there, using the photos taken during the virtual tour, we planned on executing the finding of the glazing ratio.

There were two major hurdle's.

1. Presence of another building and its reflection also contribute to the wavelength factor and,.
2. The slow gradual increase in elevation of the path.

So, to overcome the second hurdle, we divided the pavilion into three zones. For the first problem, we devised a procedure that is generally followed in bio-sciences.

Procedure:

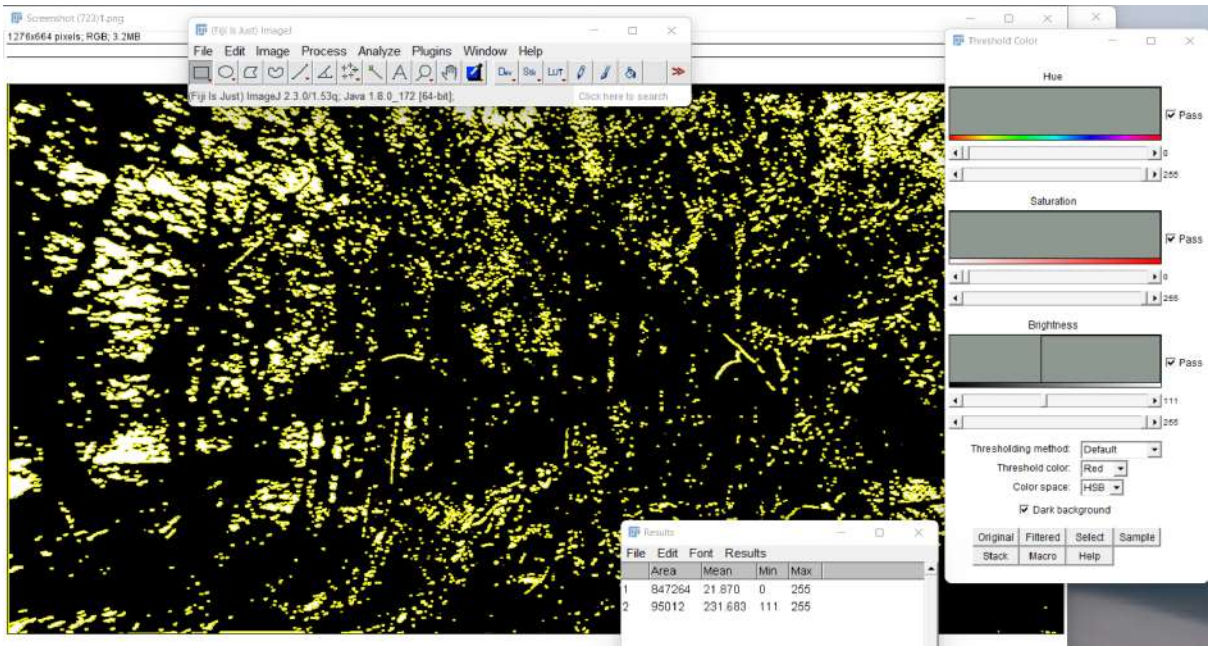
1. Select the image you have.
2. Then convert it into b&w and using the Auto threshold, find the most accurate translation of the open and closed areas.
3. Use that translation, and in the colour threshold select the open areas and then, find the area in pixels of the white portion and the total portion in pixels.
4. The glazing ratio can be obtained using the (area of white portion/area of total portion).

In this procedure, all the values used have been gathered using a scaling image of the Pavilion using Fiji (imagej) and from different articles that have been available for the Singapore pavilion.

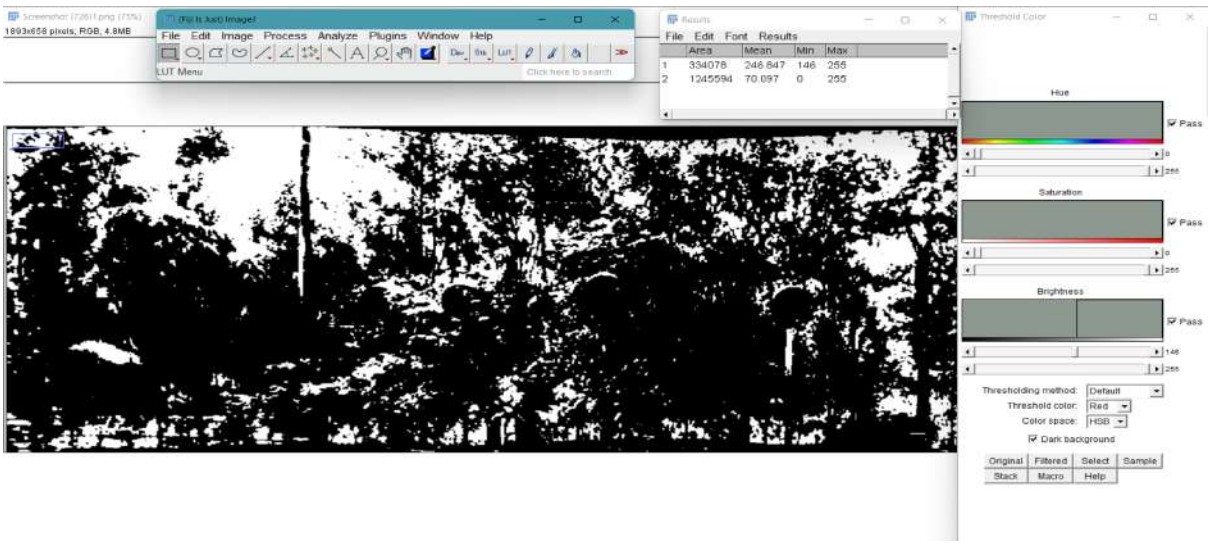
The calculations are done on calculator and at every stage manual checking has been done if the selections and the variations have been aptly done or not.

Outputs:

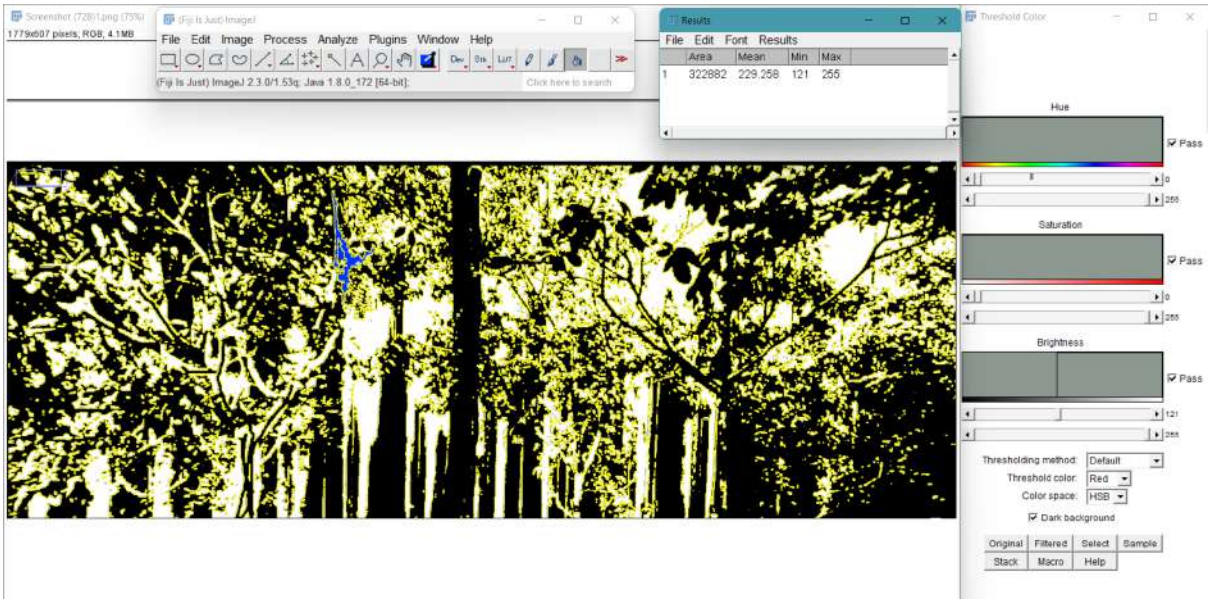
Ground floor(green layer):



Gr1=(95012/847264)=0.112139.



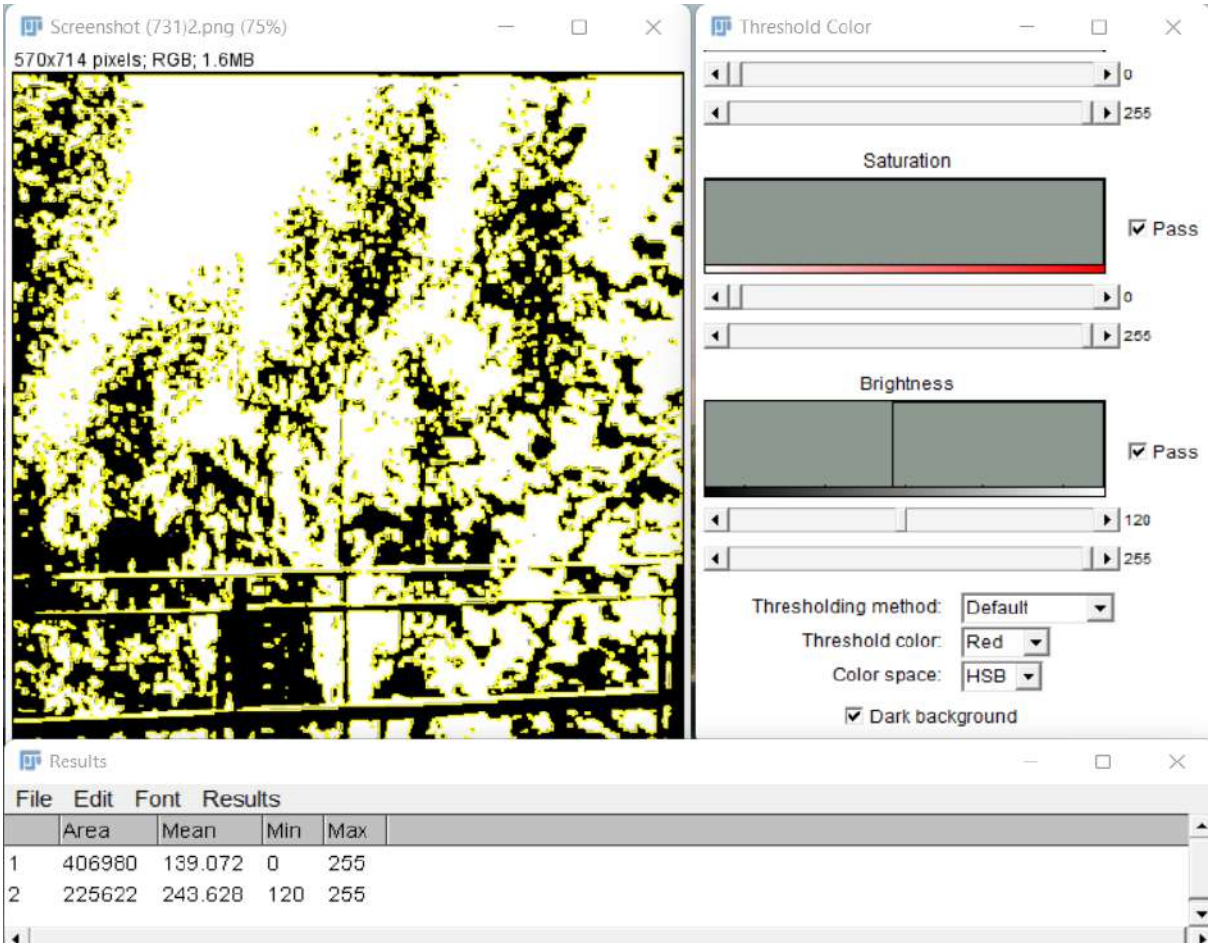
Gr2= (334078/1245594)=0.26820



Gr3 = (322882/1079853)= 0.299005

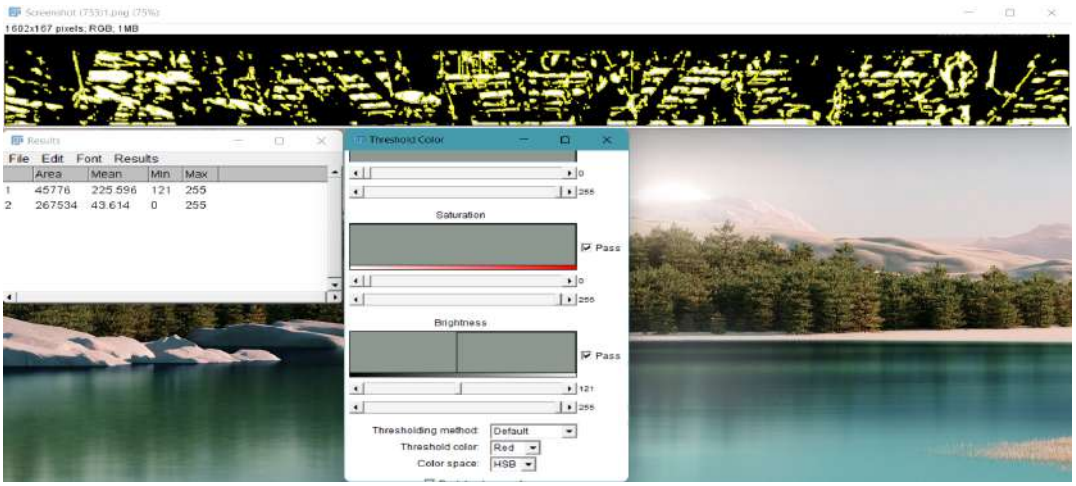
For, comfort of calculation, we divide the orange layer into upper orange and lower orange.

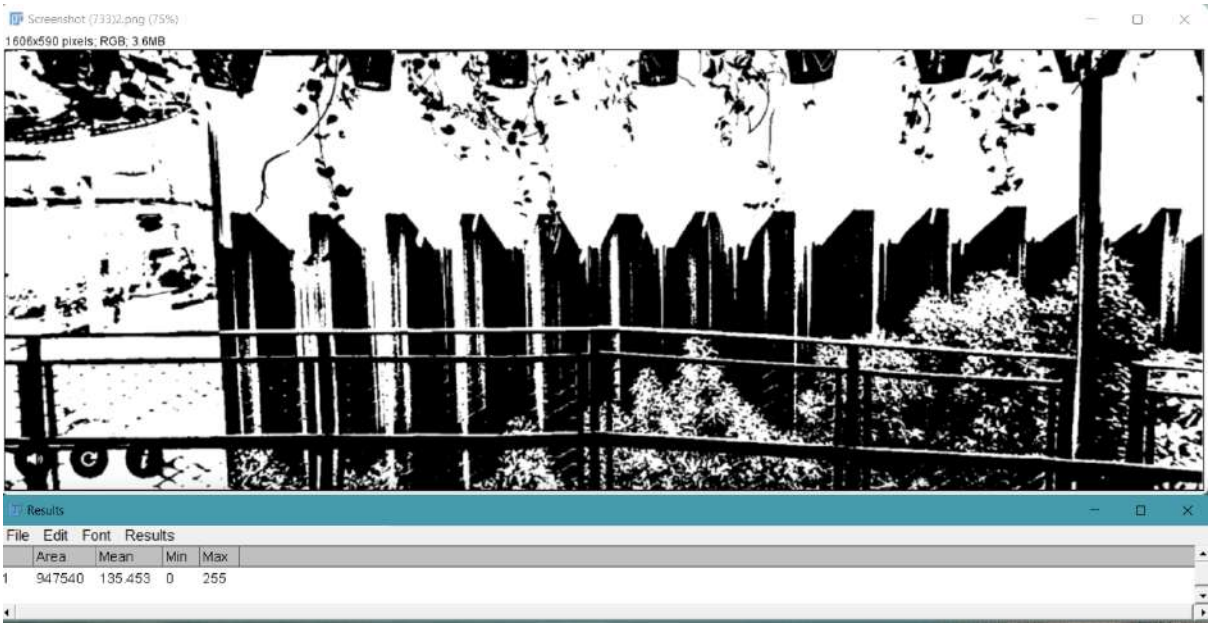
Lower Orange Layer:



Gr4=(225622/406980)=0.554381

Upper Orange Layer:





Here, the picture taken for the upper layer is a bit angular and not completely straight, hence, the whole space in the second image is open and only the part in the first image covers and has an effect on the final glazing ratio in the

Gr5=(45776+947540/267534+947540)=0.817494

Now, the glazing ratio obtained at different layers will be extrapolated to the whole layer.

1. **Grg(Glazing ratio for the green layer) = (0.112139+0.26820+0.299005)/3 = 0.226448.**
2. **Grlo(Glazing ratio for the lower orange layer) = 0.554381**
3. **Gruo(Glazing ratio for the upper orange layer) = 0.817494**

These ratios obtained will be extrapolated for that zone of the pavilion. Thus, the final glazing ratio for red and orange ratio(Grro) combined is:

$$Grro = ((hg*Grg)+(hlo*Grlo)+(huo*Gruo))/(hg+hlo+huo)$$

Where, hg= Height of the green layer = 4.5m
hlo=Height of the lower orange layer = 1.295m
huo=Height of the upper orange layer= 3.205m

So, final Grro = 0.4467762

In dubai, most buildings have a glass of glazing ratio of 0.6. Assuming, the glass of the red zone of height 2.727m has the same glazing ratio, then

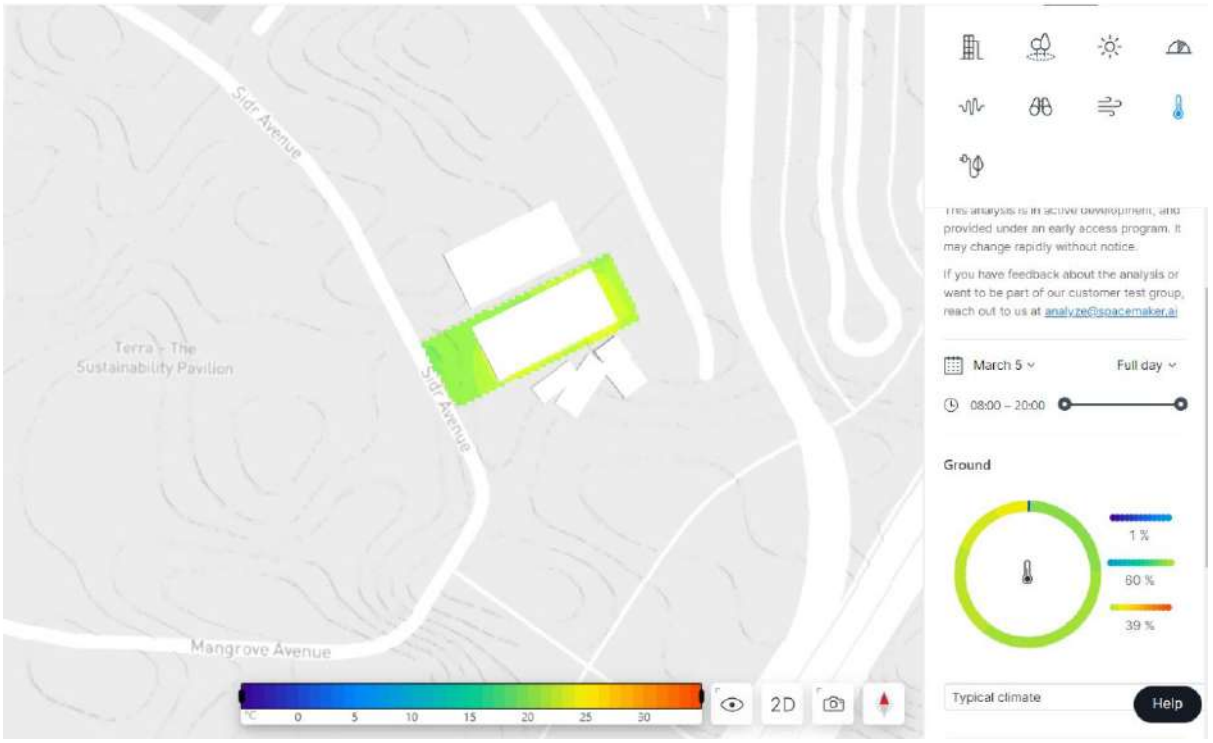
The glazing ratio of the total building = ((9*0.4467762)+(2.727*0.6))/(2.727+9)
= 0.482407

Thus, the total glazing ratio of the pavilion is around 48.24%.

A glazing ratio of 48.24% indicates that almost half of the area of the room will allow natural lighting which can increase the passive zones of the building. Hence, lessening energy consumption of the building.

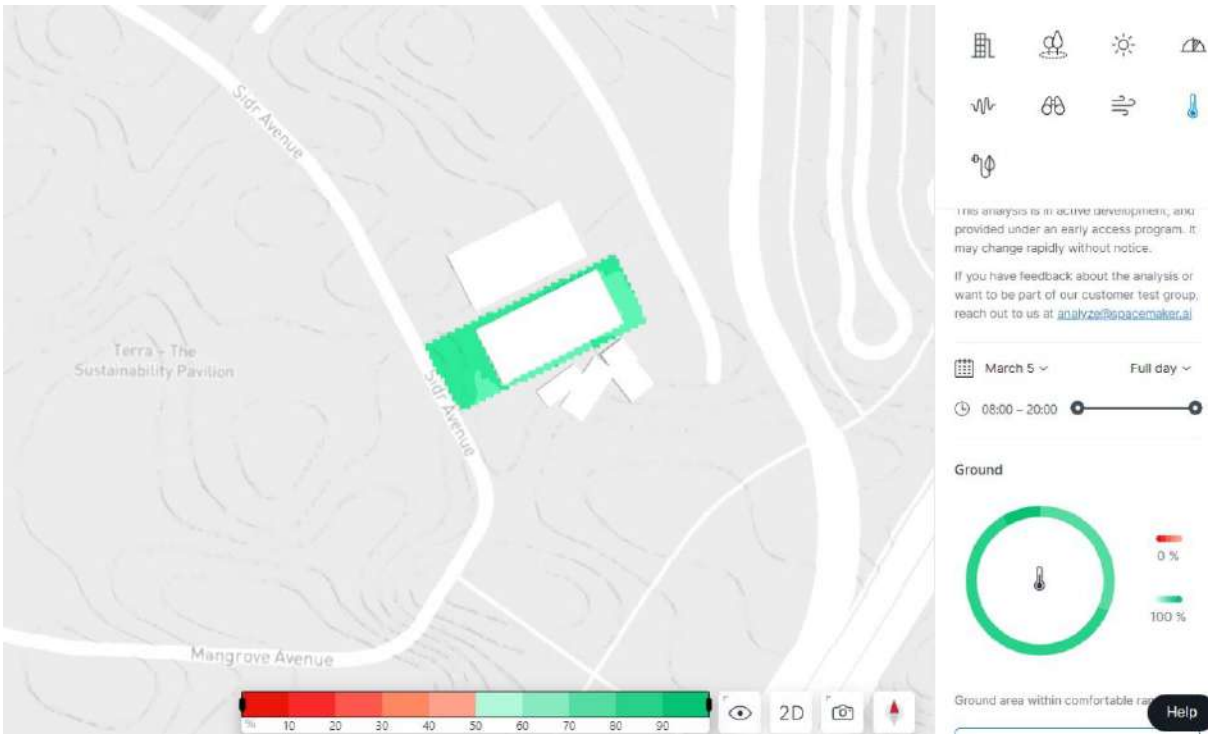
This weird but awesome combination of efficient ventilation and availability of high passive zones, creates the best atmosphere for an efficient ecosystem, a better microclimate around the building making it very pleasant and also regulating the temperature.

Temperature analysis around singapore pavilion:



The above analysis shows that during the time of expo, the construction and the structures around the pavilion were in a comfortable temperature range

Microclimate Analysis around the singapore pavilion:



The microclimate ensures a higher probability of comfort around the pavilion.

Real Life Applications of the thermal comfort and ventilation techniques used :

1. The usage of trees for ventilation and thermal comfort will not only help us attain a sustainable living but also help in the survival of many tree species and help in the revival of many medicinal plants in houses which previously would have been left to grow in the wild or just in plantations.
2. The techniques of using solar panels will also help in accelerating the renewable energy market thereby accelerating our goals for making ourselves sustainable for the planet.
3. The pavilion proves that usage of native methods for thermal comfort and ventilation can be revived aptly into the modern setting.
4. Many developing and undeveloped nations could use the principles involved in constructing such as usage of the tree heights in achieving ventilation, tunnelling effects for sucking in wind in a very crowded locality etc., for reducing the energy load on both the planet and the country's government.
5. In healthcare settings, natural settings help in the rejuvenation of health and happiness of a person.
6. The increased use of water bodies for thermal comfort in a living setting can also help in creating sources where the rainwater collected can be saved in the ground, thereby improving the water table and also, increasing the availability of usable waters.
7. Will also be encouraged in studies where local sustainable methods can be applied into a modern setting.

Conclusion:

In this paper, we have tried to do an in depth analysis of the Singapore pavilion and tried to give a basic idea on the climatic condition of Dubai city. In the analysis we have tried to deduce various indegenous and modern methods administered in the pavilion to attain various aspects of human comfort in a building like ventilation, thermal comfort, optimum temperature difference etc to attain a net zero building. We have used google sketch-up to show a 3D model of the Singapore pavilion, used imagej software to calculate the glazing ratio of the pavilion and thereby know its energy limitations in each stages, and used spacemaker software to do microclimate, temperature and wind analysis of

the pavilion to analyse if our theories and conclusions were true or not. Thereby, even confirming our hypothesis digitally. We have found that various ventilation techniques like the usage of vents for cross, mixed and displacement ventilations have been found and also, the efficient usage of plantations, water bodies the heights of various levels, and the energy and heat presence at different levels for optimum human thermal comfort and ventilation have been obseved. There has also been an observed significant improvement in the microclimate due to such methods where the nature has been integrated into the structural domain and the least use of energy but yet able to bear many visitors has been obseved. We have also tried to give possible real life applications for our project and the methods administered in the pavilion on a large scale and its possible positive impacts on a greater scale too.