A Process to Assist Architects Utilize Wind Information for Passive Cooling

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ABSTRACT: To practically design climate responsive buildings, architects need to know what cooling strategy is more suitable for the region they are designing for, to what extent these strategies are applicable, and how to apply them. Natural ventilation could arguably be the most important element of passive cooling, other passive cooling techniques (e.g. high mass and evaporative cooling) are more effective when coupled with wind, and therefore, understanding how to design with wind relies on analyzing climatic information in a useful manner, especially before starting the design process. This paper introduces a process that highlights each strategy's applicability by month. The process starts with a basic monthly categorization of the climate based on temperature, categories are then refined in a more detailed manner using a time table plot, guided by psychrometric and average diurnal temperature charts, information is extracted in conjunction with the wind wheel that graphically plots speed, direction, and frequency. Extracted information is represented quantitatively in a table that lists the appropriate hours suitable for natural ventilation. The process empowers architects with wind data to be considered in their climate responsive designs.
Keywords: passive cooling; climate responsive; climate analysis; natural ventilation

INTRODUCTION

Good climate responsive design relies on architects understanding of climate data and how to use analyzed data towards generating climate responsive concepts that develop during the design process. This process should be comprehended before the start of the design process and during the conceptualization of the project. The pre-design phase climate analysis should highlight the most effective passive cooling strategy that architects can depend on to create an energy efficient building, then decisions must be carried to the concept phase to be applied creatively in design. This paper is an attempt to provide architects with a process that would draw general guidelines for passive cooling that can be implemented with ease to the concept design phase. [1]

UNDERSTANDING CLIMATIC CHARTS

Passive cooling strategies understanding and applicability are dependent on bioclimatic charts generated by weather analysis software like Climate Consultant and Ecotect Weather Tool. Charts used in this paper are generated using Climate Consultant, different software can be used to generate similar charts to apply the process.

Five main bioclimatic charts are needed and will be used to graphically identify each strategy's possible application for a specific climatic region, these charts are Temperature Range, Timetable Plot, Dry Bulb X Dew Point, Psychrometric Chart, Wind Rose/Wheel.

Architects should start categorizing months based on temperate range bars in relation to the comfort zone into three sections (Figure 1)

Cold: most of the bar is under the comfort zone
Moderate: the bar is around the comfort zone
Hot: most of the bar is above the comfort zone

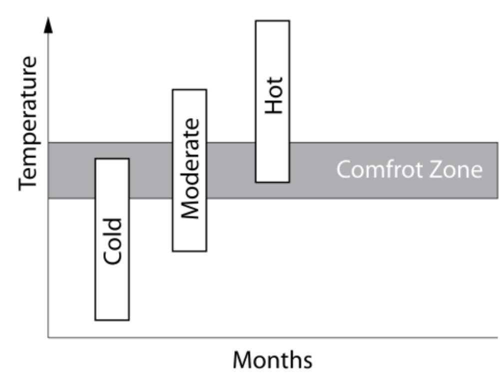

Figure 1: Categorization Months based on the Comfort Zone

The above would give an overall perception of the weather and might be modified in the next step, where the same categories are applied to the timetable plot chart that includes one more detail, which is day and night temperature also in relation to the comfort zone. The remaining charts are used according to the strategy considered and will be called for when needed.

NATURAL VENTILATION

Natural ventilation for comfort can be divided thermally into two zones based on the psychrometric-bioclimatic chart developed by Milne and Givoni [2]

- Comfort Zone (NV Zone 1)
- Natural ventilation Zone (NV Zone 2)

The purpose of these two categories is for the designer to differentiate between air speed requirements for each zone. NV Zone 1 requires little air movement (less than 0.25 m/s) [3] to keep people thermally comfortable, while the NV Zone 2 expects higher air speeds to sustain a thermally comfortable environment for people, where each 0.15 m/s increase in airspeed compensates for a 1°C increase in air temperature [4].

Comfort ventilation (NV Zone 1 and 2) is directed towards people, therefore, designers are expected to direct wind to seating areas by providing special purpose openings assisted by pressure zones around the building. In addition, only natural ventilation used for the NV Zone 1 can be used for night flushing and will be discussed later in this paper.

The comfort zone (shown in gray) in the monthly average Timetable Plot (Figure 2, light blue in Climate Consultant screen), the hours suitable for natural ventilation for this zone are extracted for each month and tabulated, then direction and average speed are acquired from the Wind Wheel for the listed hours.

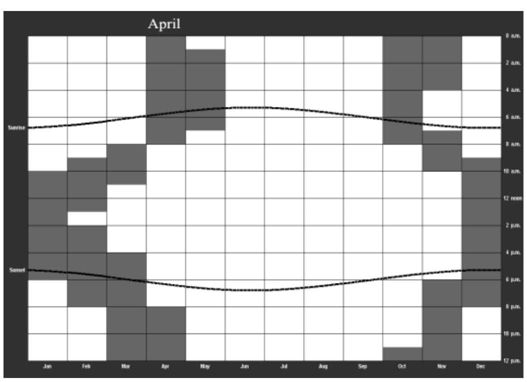

Figure 2: Abu Dhabi Comfort Zone shown in Gray

As an example, the month of April shows that the suitable hours for NV Zone 1from 8 p.m. to 8 a.m. of the next day, these hours are transferred to the Wind Wheel screen to show the prevailing wind for the selected hours and their average speed as shown in Figure 3, in the outermost ring, trapezoids shows the percentage of hours for prevailing wind, while the innermost circle shows the minimum, average, and maximum velocity for winds from each direction [5].

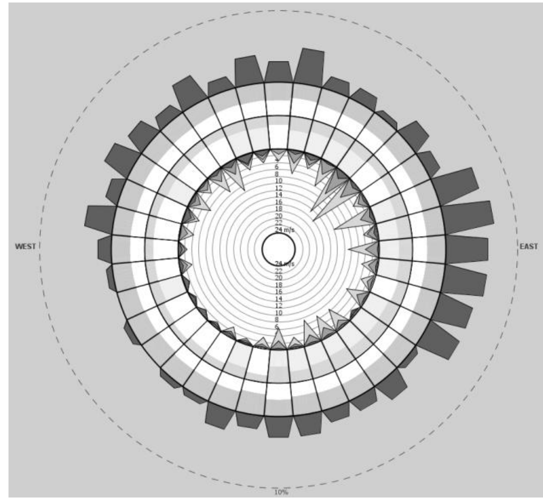

Figure 3: The Wind Wheel showing wind direction for selected hours

Table 1: Wind Data Extracted from Charts for the Comfort Zone

Month	Time	Hours	Direction	Avg. Speed m/s
April	8 pm to 8 am	12	East	4

A secondary prevailing wind can be noted if enough hours are blowing from an additional direction, for example, north and northwest in Figure 3.

The same process is repeated for NV Zone 2, however, a temperature upper limit should be set by based on the comfort model chosen. For example, if ASHRAE Handbook of Fundamentals 2005 comfort model is used, the upper temperature limit can be set to 30 °C based on the psychrometric chart which sets the maximum temperature for the NV Zone 2 (Figure 4).

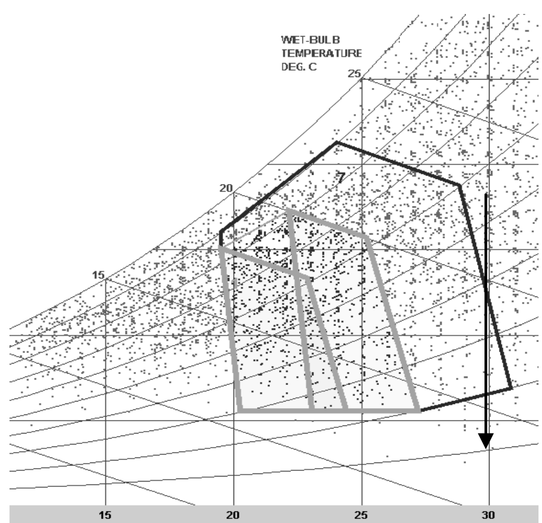

Figure 4: Using the Psychrometric chart to set the maximum temperature for the NV Zone 2

Based on the upper temperature limit, the Dry Bulb X Dew Point chart can help identify hours that are suitable for the NV Zone 2.

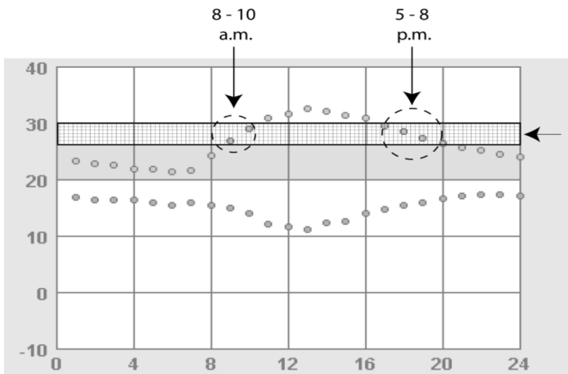

Figure 5: Extracting hours suitable for the NV Zone 2

The NV Zone 2 is highlighted above the comfort zone (Figure 5), hours that fall in the defined NV Zone 2 (27 - 30°C) are listed in Table 2, and then again, direction and average speed are acquired from the Wind Wheel and added to the table as shown below.

Table 2: Wind Data Extracted from Charts for NV Zone 2

Month	Time	Hours	Direction	Avg. Speed m/s
April 1/2	8 to 10 am	2	SW	2 m/s
April 2/2	5 to 8 pm	3	NE	3 m/s

HIGH MASS

High mass cooling strategy is used in regions when temperatures rise above the comfort zone at day time and drops below it at night, the extremes are tempered by the thermal mass of a building which is used as a sink to reject heat gained in daytime by cold nights. [6]

Using the Dry Bulb X Dew Point chart, months suitable for the high mass cooling strategy can be identified by analyzing the dry bulb mean temperature (Figure 6), the sinusoidal temperature curve should rise above the comfort zone range and drop below it. As a result, an internal temperature will be sustained in the comfort zone temperature range (Figure 7).

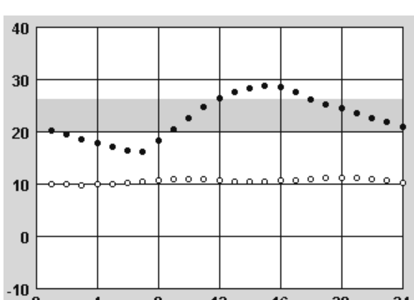

Figure 6: An Example of a Month Suitable for High Mass Cooling

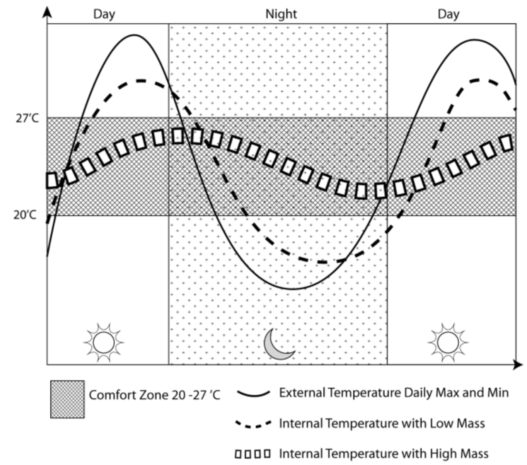

Figure 7: The Effect of High and Low Mass on Internal Temperature (based on [7])

Suitable months for this strategy can be investigated further using the psychrometric chart, Figure 7 shows the expected effect of high thermal mass on the internal temperature in relation to the external temperature swing, the graph also compares the high mass building to a low mass one. This can be translated into the psychrometric chart as shown in Figure 8, the line that represents the external diurnal temperature is shrunk by the thermal mass of the building to keep the indoor air temperature inside the comfort zone, bigger diurnal temperature swing requires higher thermal mass and vice versa.

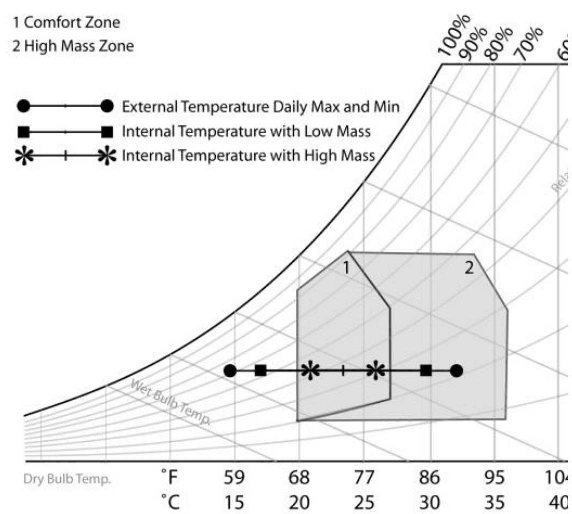

Figure 8: High and Low Mass Expected Effect on Indoor Temperature

The daily maximum and minimum temperatures can be plotted for each month using climate consultant. Months suitable for high mass cooling show lines stretching out of the comfort zone on both sides, the high day temperature extends to the right within the high mass zone (Figure 9).

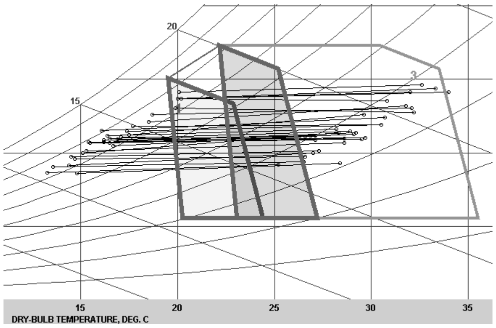

Figure 9: An Example of Suitable Month for High Mass Cooling Plotted by Climate Consultant

HIGH MASS WITH NIGHT FLUSHING

This strategy is used when day temperature rises way above the comfort zone, yet, night temperature does not drop low enough to compensate for heat gained during the day[8], this can be seen in the Dry Bulb X Dew Point chart. Appropriate months for this strategy can be recognized by examining the sinusoidal curve of the dry bulb mean temperature in relation to the comfort zone, the curve should be mostly above the comfort zone in daytime and drop in or below the comfort zone at night with enough hours to dissipate heat gained during the day (Figure 10).

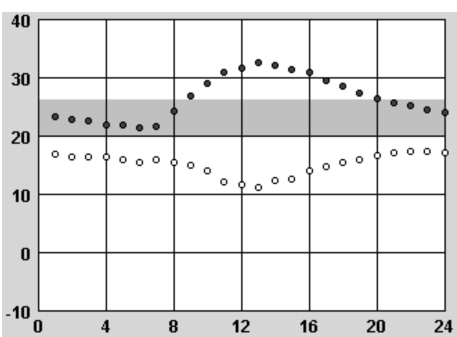

Figure 10: An Example of a Month Suitable for a High Mass with Night Flushing Cooling

High mass elements would damp the internal temperature closer to the average of the peaks, and since the average temperature is still above the comfort zone, night ventilation is used to lower indoor temperature to be inside the comfort zone (Figure 11).

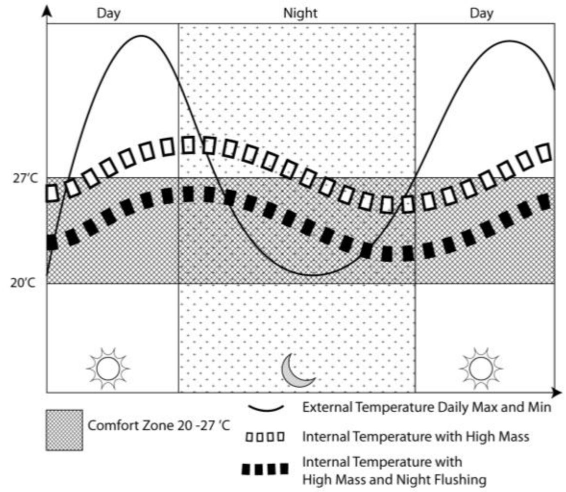

Figure 11: A Comparison between High Mass Cooling with and without Night Flushing

This can be translated to the comfort zone as seen in (Figure 12), where the indoor temperature would be damped towards the average of the external diurnal temperature, but would stay on the right of the comfort zone. Night flushing would shift the damped temperature to the left (inside the comfort zone).

High mass with night flushing can be applied successfully on months similar to the one plotted in Figure 13, which show lines representing high and low daily temperature extending from the comfort zone to the limits of the high mass with night flushing zone.

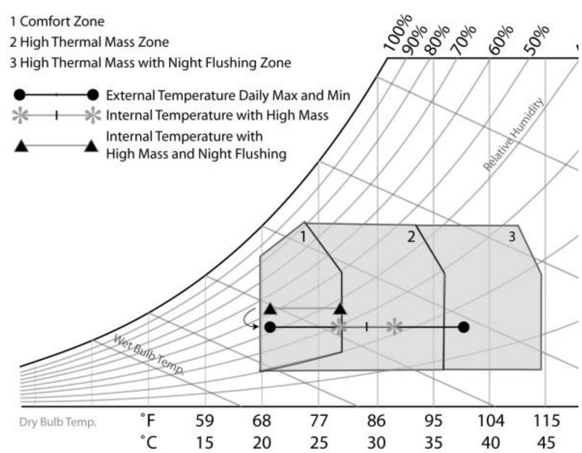

Figure 12: High Mass with Night Flushing Expected Effect on Indoor Temperature

The designer should direct airflow towards the high mass element using special purpose openings based on the hours, direction, and speed acquired earlier for the NV Zone 1 (Table 1).

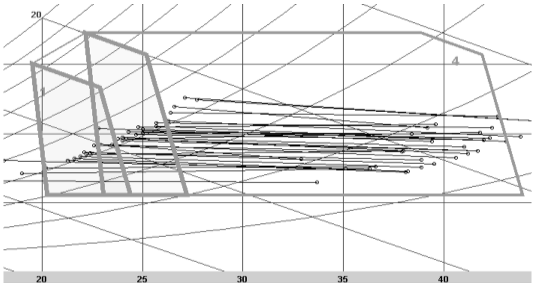

Figure 13: Suitable Month for Night Flushing

Application

The process is applied on the city of Abu Dhabi, United Arab Emirates. ASHRAE Handbook of Fundamental 2005 Comfort Model is selected, then the Temperature Range chart is plotted and months are categorized based on Figure 1, this would give architects an overall understanding of the climate.

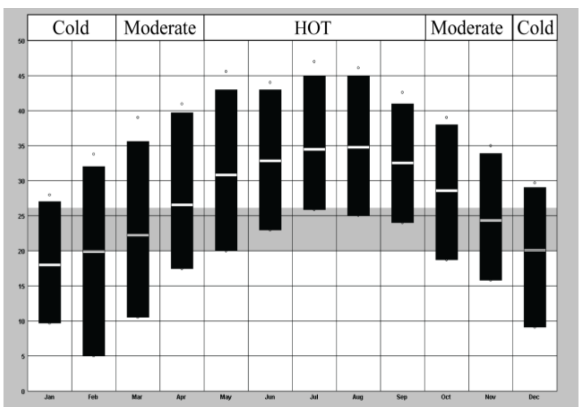

Figure 14: Temperature Range Categorized for Abu Dhabi

Hours for NV Zone 1 are extracted from Figure 15 and listed in the "Time and Hours" columns in Table 3, and then hours are plotted using the Wind Wheel chart to acquire wind information (i.e. Direction and Avg. Speed).

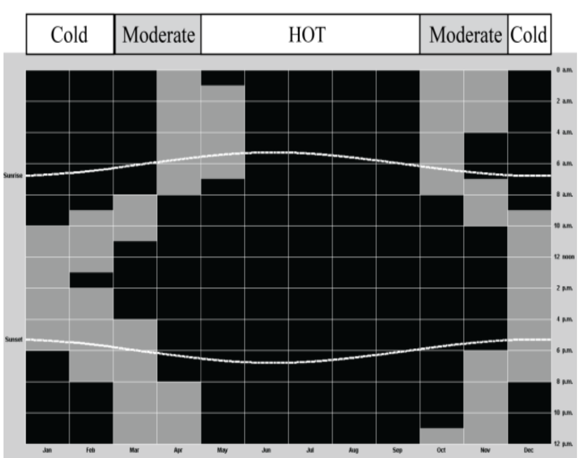

Figure 15: Timetable Plot fort Abu Dhabi

Table 3: NV Zone 1 Ventilation Information

Month	Time	Hours	Direction	AVG. Speed m/s
1	10 am - 6 pm	8	NW	4
2	9 am - 8 pm	11	NW & SE	4 & 5
3	8 - 11 am	3	E	2
	4 pm - 12 am	8	N	4
4	8 pm - 8 am	12	N	3
5	1 - 7 am	6	SW & E	2
10	11 pm - 8 am	7	W	3
11	7 - 10 am	3	S & SW	3 & 2
	6 pm - 4 am	10	NW & E	2
12	9 am - 8 pm	11	NW & S	5

June, July, August, and September are not suitable (too hot) for this kind of ventilation and were omitted from the table.

Hours for NV Zone 2 are extracted from the Dry Bulb X Dew Point chart following the procedure discussed earlier (Figure 5), information are listed in the "Time and Hours" columns in Table 4, wind direction and speed are acquired from Wind Wheel.

Table 4: NV Zone 2 Ventilation Information

Month	Time	Hours	Direction	Avg. Speed m/s
3	**12 - 4 pm**	**4**	**NW**	**6**
4	**8 - 10 am**	**2**	**SE & NW**	**2.5**
	5 - 8 pm	**3**	**N**	**5**
5	**7 - 8 am**	**1**	**SW**	**2**
	8 pm-1am	**5**	**E, N, NW, & SW**	**2**
6	**11 pm - 7 am**	**8**	**SW & E**	**2 & 3**
7	**3 - 7 am**	**4**	**S & SE**	**3**
8	**4 - 7 am**	**3**	**E & SE**	**2**
9	**12 - 8 am**	**8**	**E**	**2**
10	**8 - 9 am**	**1**	**SE**	**4**
	7 - 11 pm	**4**	**NE**	**4**
11	**10 am-6 pm**	**8**	**NW**	**5**

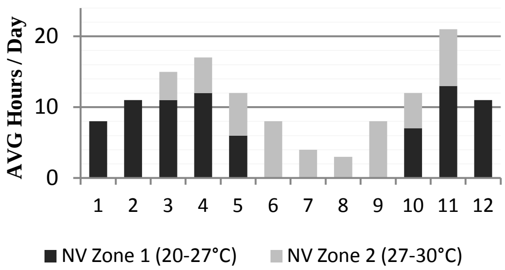

Figure 16:Natural Ventilation for NV Zone 1 and 2

Table 5 Strategies Suitable for Each Month

Months	NV Zone 1	NV Zone 2	High Mass	High Mass with Night Flushing
1	•			
2	•			
3	•	•	•	
4	•	•		•
5	•	•		•
6		•		
7		•		
8		•		
9		•		
10	•	•		•
11	•	•	•	
12	•			

The Dry Bulb X Dew Point chart shows that March and November are suitable for high mass cooling shown in Figure 6, both months are moderate months and adjacent to cold months, on the other hand, moderate months adjacent to the hot months are suitable for high mass with night flushing, April, May, and October temperature profile fits the profile shown in Figure 10 with 12, 6, and 7 hours access to night ventilation respectively. The information in Table 3 can be used for these months with specifically designed openings that direct wind towards the buildings high mass element.

Natural ventilation for comfort (NV Zone 1 and 2) can be used effectively for this climate, ventilation suitable daily hours averaged between 13 and 6. Wind speed ranged from 2 to 6 m/s. Prevailing wind from northwest dominated the cold months (January, February, and December), with some occurrence of south and southeast wind, however.

Northwest also was the main direction wind blew from for the moderate months, with prevailing wind from east and southeast for NV Zone 1 and 2, however, wind blowing from east, southeast, and southwest were more dominant for hot months.

Conclusion

Natural ventilation in cold months is only needed for health benefits (improving IAQ) or removing excess heat, it is more important for moderate months as they are used for comfort and structure ventilation. In addition, moderate months have overheating period and needs passive cooling more, which demand more attention when designing for natural ventilation in regards to orientation, building form, and openings. In moderate months, high mass with night flushing should be the first priority in regards to natural ventilation, since months suitable for high mass does not need natural ventilation to sustain comfortable conditions. Only comfort ventilation (NV Zone 2) can be used for hot months, evaporative cooling could be more appropriate for these months and needs to be investigated.

Furthermore, it is important to limit NV Zone 2 if high mass with night flushing strategy is used or designed with less interaction with the high mass elements of the building, NV Zone 2 is used solely for human comfort ventilation, and thus relay on the human body to aspirate and cool itself. NV Zone 2 temperature is higher than the comfort zone which would increase the temperature of the high mass elements and would become a liability.

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