

PASSIVE VENTILATION & CLIMATIC CONTROL IN HOT & HUMID REGIONS.

Goal 11- Sustainable Cities and Communities

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Abstract

All this started during a hot summer day in Chennai when I returned to college from the lunch break, heavily perspired and uncomfortable. I unintentionally stood by a small window in our classroom, but the gush of air from it completely evaporated all the sweat. I went on Quora to see what people from different walks of life had to say on combating heat with humidity and I was surprised to see how all of them said AC was the ultimate solution. “The Manual of Tropical Housing” which is the bible for climate-friendly building design, also suggests that ACs only combat humidity’s harsh effects. I wanted to work with wind, the only natural resource that seems shy of depletion, which led me to study wind, how it behaves under pressure, and what ancient building methods and current building methods do right/wrong in terms of using wind-based thermal comfort solutions, theoretically and practically. ACs and dehumidifiers can be used as active methods to provide thermal comfort, but AC emissions contribute to the urban heat island effect while dehumidifiers and eco-friendly ACs can be hard to afford for the monetarily underprivileged. So this dissertation concludes by developing a new conceptual building contraption via simulations that strives to provide thermal comfort in hot and humid regions solely using enhancing convective ventilation, which can be utilized by people from all walks of life. Wind can be the only efficient and cost-effective parameter as no one is charged money to reap the benefits of wind in its crude form.

Keywords: Wind; Shy of Depletion; AC; emissions; Building contraption; Convective Ventilation; Hot and Humid



1. Introduction & Study

1.1 The need for focusing more on passive ventilation for thermal comfort in hot and humid regions:

The Manual for Tropical Housing states that “the positive control of humidity is only possible with air conditioning, the use of such an installation is much more warranted here, than in any other climate. Air conditioning implies a sealed envelope, which in turn makes positive noise control feasible. Noise control requirements, especially in the case of highly noise-sensitive buildings, would assist or reinforce the case for the installation of air conditioning”). (*Manual of Tropical Housing*, 6.3.8). From this, we can infer that for air to create an atmosphere of thermal comfort inherently, it needs to be treated/dehumidified. Live observations were recorded in buildings situated in Chennai-OMR, which is taken as the area of study.

1.2 Main factors affecting thermal comfort in hot and humid areas:

Newton's law of cooling states that “A body's heat loss rate is proportional to the temperature difference between the body and its surroundings (to maintain thermal equilibrium) while under the effects of a breeze.” The body cools itself by perspiration, where all the excess heat in our body is sent out as sweat to transfer into the atmosphere, which is why people get dehydrated easily in hot and dry conditions. While in a humid setting, the sweat does not evaporate, due to high moisture content in the air, which makes people feel stuffy and uncomfortable. Another main factor is the heat that triggers this temperature transfer, which is why we feel rather comfortable when the climate is rainy and cold.

1.3 Using wind as a means to create passive thermal comfort:

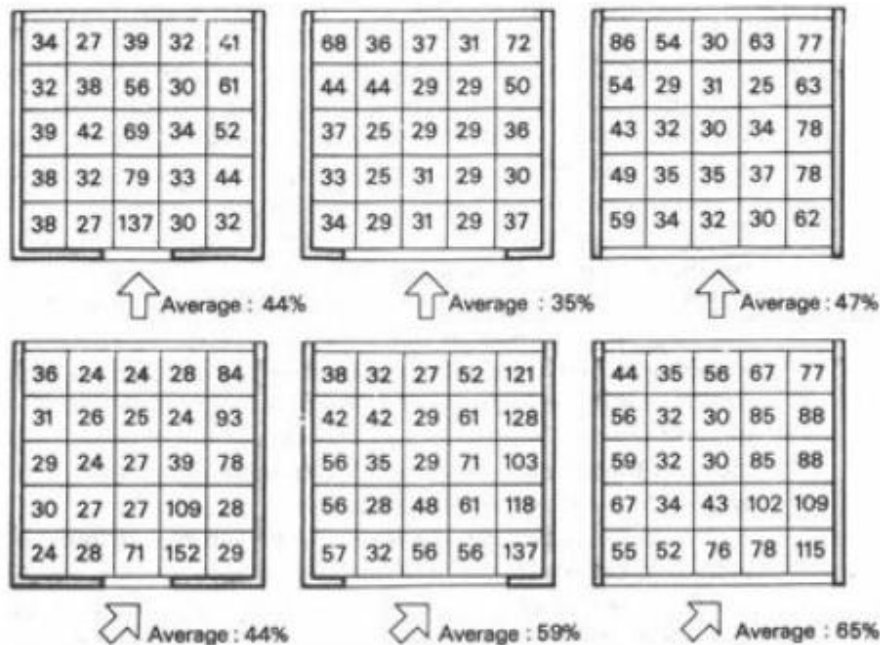
In hot and humid conditions, one can avert sweat stagnating by conditioning the air to suit thermal comfort levels, which is not sustainable and unavailable to people from all walks of life. Passive thermal comfort can be attained only using convective cooling, i.e. increasing the volume of air (which is of a high relative humidity). Increasing the means of ventilation is a universally known solution to battle hot and humid weather, “As a movement of air is the only available relief from climatic stress, therefore vital to indoor comfort, the building will have to be opened up to breezes and orientated to catch whatever air movement there is. Failure to do this would produce indoor conditions always warmer than a shaded external space which is open to air movement.” is an excerpt from the Manual Of Tropical Housing.

1.4 Manipulating wind speeds by understanding pressure

Pressure is inversely proportional to the fluid speed, as counterintuitive as it sounds, it can be proved by the law of conservation of mass.

Fig. 1: Bernoulli's theorem & law of conservation of mass





The diagram above are findings by Givoni in the Manual of Tropical Housing: the relative velocities (with the free air speed taken as 100%) measured at a height of 1.2 m above floor level.

From the diagram, we can infer that the average of wind speed retention is higher for a larger opening size. Givoni has also stated in his study that an incident angle of 45 degrees gives a more uniform breeze to the space.

The manual of tropical housing states this about the opening sizes “With a given elevational area – a given total wind force (pressure × area) – the largest air velocity will be obtained through a small inlet opening with a large outlet. This is partly due to the total force acting on a small area, forcing air through the opening at low pressure (Bernoulli’s theorem and law of conservation of mass), such an arrangement may be useful if the air stream is to be directed (as it was focused) at a given part of the room, which results in most of the room spaces being leeward due to the relatively low wind volume injected. When the inlet opening is large, the air velocity through it will not spike as seen in smaller openings, but the total rate of airflow (volume of air passing in unit time) will be higher. When the wind direction is not constant, or when airflow through the whole space is required, a large inlet opening will be preferable. The best arrangement is full wall openings on both sides, with adjustable sashes or closing devices that can assist in channeling the airflow in the required direction, following the change of wind.”

1.6 Effect of shading devices, buffers in heat dissipation, and do they give a need to induce thermal comfort passively?

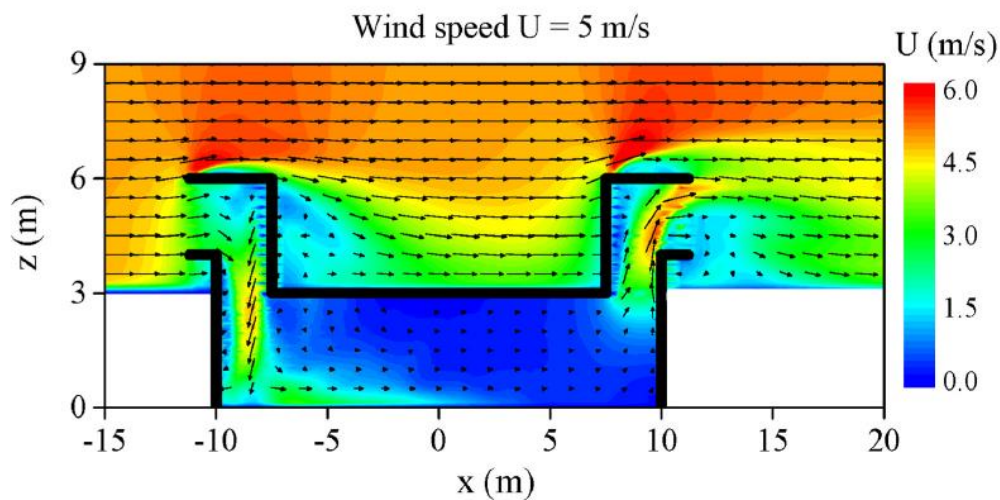
The Sun transfers heat to other media via radiation and the sun is the primary source of heat. In some instances when we feel a gush of wind that receives direct sunlight, we can see it carrying heat with it, so an effective way to negate heat would be to shield the wind from the heat source (I see wind as a vehicle medium, which can mirror the attributes of the conductor when moving. Give it heat it warms up, introduce it to water with a reactive surface area, it will cool down). In some instances, the buffers can be the sole climatic treatment required. A simple google search can lead us to this “Air is a bad conductor because, to conduct heat current molecules should absorb heat and transmit it to neighbor by vibrating. In the case of air molecules near the hot surface absorbs the heat and start vibrating, but the neighbor molecule is so far that this vibration should be very high and so the heat energy required is high for small conduction to start.”

1.7 Ancient and Modern passive cooling techniques in Hot and humid zones

Mud has been the staple to battling humidity, whose uses can be extensively seen in traditional Japanese housing. The walls were usually made of wood frameworks filled with mud, straw, and water. As for augmenting windspeeds, wind catchers were used in hot and dry climates to create the cooling effect produced by multiplied wind speeds. Windcatchers can provide a solid base for understanding pressure and fluid relation, from which we can arrive at what and what not to do.

1.7.1 Pressure Gradient and wind speed influenced by Windcatchers:

Fig. 3: Wind speed in a windcatcher system

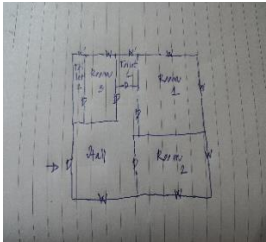


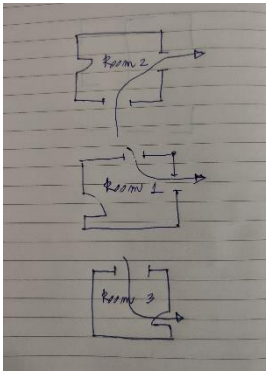
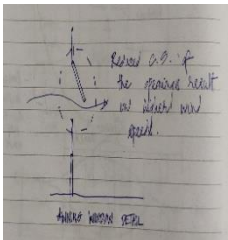
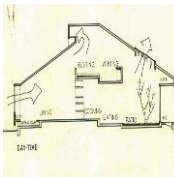
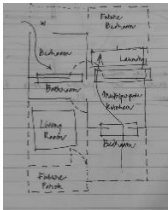
Velocity vectors on the central plane ($y = 0$) of prototype garage with two windcatchers (Case A) under wind speed $U = 5$ m/s.

This CFD simulation shows that there is a drastic drop in wind speed inside the built form. The mouth of the windcatchers offers a low cross-sectional area, which results in a spike in the fluid speed as seen in the shaft of the windcatcher. As the outlet opens to a larger volume, air expands interacting with the lamina, and drastically loses speed. From this, we can infer that pressure must be maintained to maintain the original wind speeds (as seen in the upper column of air in the diagram).

2. Comparative analysis of the case studies:

Table 1: Comparative study of the case studies

FACTORS OF INTEREST	RED BRICKS MEN'S PG, CHENNAI	MSAJAA, CHENNAI	TUBE HOUSE, GUJARAT	BPAH-COL, COLIMA, MEXICO	INFERENCE
Method of ventilation	Cross-ventilation Illustration 1: Red Bricks Plan 	Cross-ventilation (faulty) and stack effect Illustration 2: MSAJAA classroom 	Convection/ Stack effect	Convection/ Stack effect, thermal insulation & cross ventilation	Cross-ventilation and stack effect must go hand in hand to induce maximal thermal comfort in all temperatures

No. of openings per room	2 openings, 1 in 1 bedroom, (the ones with 2 windows are more comfortable, the 1 window room which is usually stuffy when a door is opened to promote cross-ventilation) <i>Illustration3: Individual Wind Flow of Red Bricks</i> 	2 normal windows and 4 awning windows. Convective cooling is pretty much non-existent as the span is too high. <i>Illustration4: Curtain wall section-MSAJAA</i> 	1 window in the front, 2 vents on the roof, and 1 toilet vent. <i>Illustration5: Tube House Sections</i> 	1 window for each room, and a partition wall with slits to bring wind from the front façade to the rear façade. <i>Illustration 6: Plan Analysis</i> 	The number does not matter until equilibrium is maintained in the volume of air flowing in and flowing out per second.
Performance during the humid season	Compared to the house's comfort in winter and spring, humidity takes a toll on thermal comfort in the 1 windowed room.	The botched cross-ventilation makes things much more uncomfortable.	Gujarat is dry. In case of a humid environment, this project would not be	One window in each room serves as an inlet, which means no individual cross-	If aesthetics matter, then dehumidifiers must be used in these conditions, but the

	(The effect is less in 2 windowed rooms)		convective cooling-friendly as there is just 1 air inlet for the 4 spaces. It shades man in an arid zone, yes but convective cooling is absent.	ventilation. This is why slits were introduced in the partition wall between the most occupied spaces to create a path for convective cooling.	usage of mud materials can offer versatile climatic control over humidity and heat.
Helpful observations	The ground floor feels much more comfortable than it is supposed to be (due to the no-slip forces), as there are no adjacent buildings (other man-made laminae). Wind speeds were preserved better on the terrace as there are no interfering lintels or roof planes that act as the no-slip force-inducing lamina.	The awnings present in the front façade of MSAJAA drastically reduce the even small cross-sectional area of the opening, which produces a dramatic gush of wind at times but wanes after 1.5 meters approx. The speed at which it comes nullifies the effect of humidity on perspiration.	An open plan can collectively isolate heat if the ceiling height is high. Rather than reducing the size of the inlet and increasing the size of the outlet, the inlet can be fairly bigger and the number of outlets can be doubled. This ensures speeding	Mud materials that come in thicker forms can offer thermal comfort due to their thermal mass. Even if there are means of cross ventilation, finding a way to squeeze it in can make the space better than it used to be.	

			and slowing of wind and can improve the rates of ventilation.		
Impact of material used to provide thermal comfort	Typical house construction methods are seen. Exposed bricks and the cross-ventilation share the job of providing thermal comfort.	The glass curtain wall in the southeast gives more heat gain to the classrooms.	The adjustable louvers used regulate the amount of heat and wind entering the building from the window.	The 0.15 m thick clay brick offers a time lag optimal for thermal comfort	
Demerits	The lack of cross-ventilation in one room makes that room more uncomfortable.	Use of non-sustainable materials and lack of design aiding cross-ventilation.	All convection and no good rate of airflow.	Even though cross ventilation is utilized, it cannot be deemed effective as 2 rooms cannot follow the same inlet and outlet path.	

2.1. Conclusions from the study:

- One must not use small windows to ensure convective cooling and the only options must be the medium-sized one and “wall window.”
- Not many houses can have the liberty of using the “wall window”, as many prefer a degree of privacy, so for the use of both medium and large-sized windows, the opening control must



be chosen wisely. Pivoted vertical louvers can be used to alter the angle of incidence, and they offer little to no resistance to the wind's speed as they are parallel to the line of action.

In places where pest control is required, the use of netlon is inevitable. The Manual of Tropical Housing offers a solution: "A cotton net can give a reduction of 70% in air velocity. A smooth nylon net is better, with only approximately a 35% reduction factor. The reduction is greater with higher wind velocities and is also increased with the angle of incidence, as shown by the findings of Koenigsberger."..As the angle of incidence affects the wind speed, pivoted louvers can be of great help to make sure that much speed is not lost.

3 . Formulation:

3.1 Using the Coanda effect to aid thermally forced ventilation:

The fluid following the shape of the solid is the Coanda effect. This can be observed in yet another CFD study involving windcatchers.

Fig.4, Plan of the CFD of two windcatchers employed to ventilate and underground parking lot



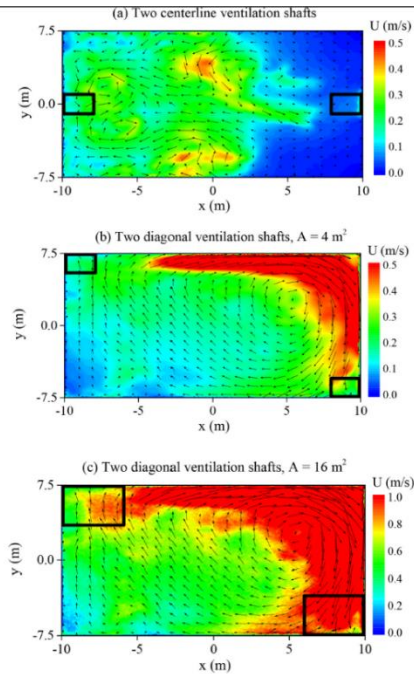


Fig. 11. Velocity vectors on the x-y plane at height $z = 1.5$ m with two ventilation shafts under $U = 5.0$ m/s. (a) Case C1 (two centerline shafts, $A = 4$ m²); (b) Case C2 (two diagonal shafts, $A = 4$ m²); (c) Case C3 (two diagonal shafts, $A = 16$ m²).

In the first instance where windcatcher openings are located centrally, allows air to expand tri-directionally, having no streamlined path (dictated by a surface) for the fluid to flow faster under the influence of a negative pressure zone.

In the second instance, we can see that the air has two ways to expand inside the space, and it uses the top and right walls to undergo a Coanda drift. At the end of the Coanda drift path, an outlet windcatcher has been placed on the leeward side, creating a negative pressure zone that sucks out the air at a higher speed, increasing the rate of ventilation. (All this being done passively)

Now the mechanisms of the third and second instances are identical, but the larger cross-sectional area of the windcatchers enables more air volume to be sucked into the outlet, thus a major portion of the room experiences high wind speeds, with it still being a low-pressure zone as the cross-sectional area is still small in relation to the room. From this, we can infer the closer the opening sizes are to the room sizes, the higher will the area of the room that can experience higher wind speeds.

3.2 Methodology & Final Formulation:



Methodology: A wall thickness of 30 cm is preferred for its thermal insulation properties. The carrying over of the cross-sectional area of the inlet and maintaining the size of the air inlet and outlets were preferred from my inferences from the “**terrace effect**”(1.4). Correa’s use of stack effect in the Tube house (Illustration 5) helped formulate P3.

P1. Carrying over the cross-sectional area of the inlet (Maintaining pressure to increase the wind speed)

P2. An outlet that is fairly the same size as the inlet (Pressure maintenance and enabling cross-ventilation)

P3. Coanda suction cups (Combining thermal forces and negative pressure zones to accelerate the loss of hot air from the system) where pressure is homogenized as the cup diameter, void height, and vent opening are of similar dimensions (10 cm cups, 15cm void height, and 10 cm vent size to accelerate the air settled in the void)

All the formulations will be done for a single rectangular room with the optimal 1:1.5 proportions.

Fig.5: The model was done using Fusion 360 and the computational fluid dynamics was studied using the Autodesk CFD software. A CFD for both instances will yield similar fluid behavioral patterns as the use of pressure is the same in both instances. To experience convective cooling over a larger surface area, a larger-sized opening (on the longer side of the room) is ideal.

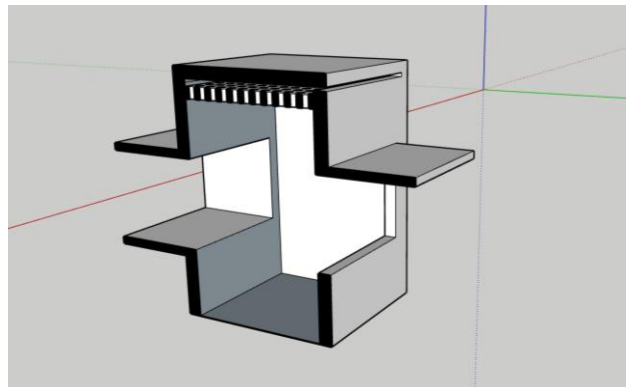
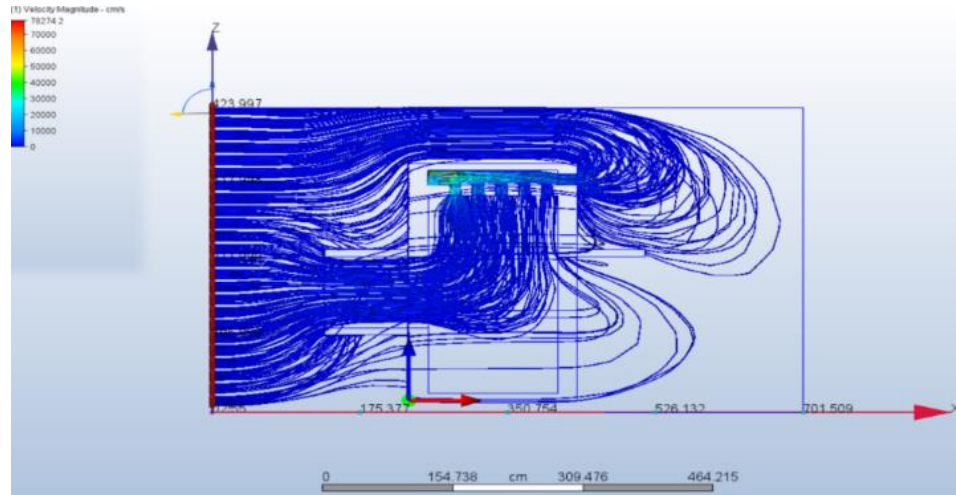


Fig.6: Performance of the solution: The blue lines represent air movement through the module, with the wind speeds represented by the wind speed gradient on the top left.



4 . Observations:

- The imitation of the fuel injection mechanism at the air inlet has worked to yield the desired effect of letting in a higher volume of air and the big opening size makes sure that external air velocity is carried to the interiors with minimal loss.
- The Coanda suction cups create an upward air drift and accelerate the process of convection (as seen in the spike in wind speed), the linear arrangement of the cups all over the slab's perimeter creates upward drifts almost uniformly at all parts of the room (even ones farthest from the windows) as a result of its low pressure and thus increasing the rate of convection and convective cooling.
- The Coanda contraption can serve as a sole outlet in cases of buildings where only inlets can be kept, this can be seen from Fig. 24 as the majority of the air taken in from the inlet exits through the Coanda contraption. But this might vary in rooms where the spans are much larger than the one analyzed, so the more the merrier (from conventional knowledge). This inlet-outlet dynamic can be seen in the Tube House by Correa.
- **Combining pressure and wind can efficiently cut down energy consumption as these themselves provide optimal ventilative functions as observed from the CFD study.**

4.1 Cross-checking with Chennai's psychometric chart:

- From the psychometric chart, the design strategies to be followed in Chennai with the number of hours needed to be covered by different active/passive cooling strategies.
- Dehumidification and cooling take the largest share and it cannot be done passively as of now.
- Sun shading of the windows takes the penultimate priority and this has been achieved by placing pivotable louvers (can act and heat screens and can alter the wind angle) in the opening

of the formulation, the 4 sided sunshade in the inlet provides shading from various sun angles. (Figs.19,22,23 for reference).

- The thermal mass requirements are satisfied by the mud-based brick material chosen.
- Evaporative cooling can be done passively as a one-stage process, but without humidity regulation, evaporative cooling can add to the user's discomfort if the outdoor air temperature is high. Convective cooling can be used as an alternative as it relies on high rates of ventilation for the body to maintain its preferred temperature, which has been achieved in the formulation as seen in the fluid simulation.
- Natural ventilation is achieved in the formulation.

Fig.7: Year-round design guidelines for Chennai from Climate Consultant 6.0

DESIGN GUIDELINES (for the Full Year) ASHRAE Standard 55-2004 using PMV All Design Strategies, User Modified Criteria		LOCATION: CHENNAI, -, IND
		Latitude/Longitude: 13.0° North, 80.18° East, Time Zone from Greenwich 5
		Data Source: IWECC Data 432790 WMO Station Number, Elevation 16 m
Assuming only the Design Strategies that were selected on the Psychrometric Chart, 100.0% of the hours will be Comfortable. This list of Residential Design guidelines applies specifically to this particular climate, starting with the most important first. Click on a Guideline to see a sketch of how this Design Guideline shapes building design (see Help).		
59	In this climate air conditioning will always be needed, but can be greatly reduced if building design minimizes overheating	
68	Traditional passive homes in hot humid climates used light weight construction with openable walls and shaded outdoor porches, raised above ground	
65	Traditional passive homes in warm humid climates used high ceilings and tall operable (French) windows protected by deep overhangs and verandahs	
37	Window overhangs (designed for this latitude) or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning	
57	Orient most of the glass to the north, shaded by vertical fins, in very hot climates, because there are essentially no passive solar needs	
56	Screened porches and patios can provide passive comfort cooling by ventilation in warm weather and can prevent insect problems	
46	High Efficiency air conditioner or heat pump (at least Energy Star) should prove cost effective in this climate	
18	Keep the building small (right-sized) because excessive floor area wastes heating and cooling energy	
35	Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes	
43	Use light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain	
33	Long narrow building floorplan can help maximize cross ventilation in temperate and hot humid climates	
27	If soil is moist, raise the building high above ground to minimize dampness and maximize natural ventilation underneath the building	
25	In wet climates well ventilated attics with pitched roofs work well to shed rain and can be extended to protect entries, porches, verandas, outdoor work areas	
42	On hot days ceiling fans or indoor air motion can make it seem cooler by 5 degrees F (2.8C) or more, thus less air conditioning is needed	
53	Shaded outdoor buffer zones (porch, patio, lanai) oriented to the prevailing breezes can extend living and working areas in warm or humid weather	

- (65) Most people do not have the economic capacity to build high-ceiling buildings, so the formulation uses a Coanda contraption to imitate this effect even in the lowest possible ceiling heights, the air layer in the void of the contraption can reduce the heat gain transmitted by roofs to the interiors.
- (37) 4-sided sunshades in the formulation work for all sun angles and the auxiliary shading device in the fenestration (pivotal louvers) are operable.
- (35) Good natural ventilation has been achieved as seen in the fluid simulation
- (42) Good indoor air movement has been achieved accelerating the rate of convective cooling.

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