Problemática de los sistemas pasivos de climatización en zonas tropicales cálido-húmedas

Problematic of the passive cooling systems in hot-humid tropical zones

Ignacio A. Guzmán-Hernández,[1] Fidel Franco,[2,3,4] Jaime Roset[2,3,5]
Universidad Politécnica de Cataluña
[1]Departamento de Tecnología de la Arquitectura UPC
[2]Departamento de Física UPC
[3]Escola Tècnica Superior d'Arquitectura de Barcelona (ETSAB) UPC
[4]Laboratorio de Innovación y Tecnología en la Arquitectura (LiTA) UPC
[5]Arquitectura, energía i medi ambient (AIEM) UPC

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Resumen

Este artículo se enfoca en expresar algunas problemáticas con las que se encuentra la implementación de algunos sistemas de climatización pasiva para proyectos habitacionales ubicados en zonas climáticas cálido-húmedas, ya que la mayor parte del tiempo las condiciones climáticas son de disconfort térmico. El mayor problema es que las altas temperaturas están acompañadas de altos niveles de humedad, haciendo necesaria la implementación de más de dos estrategias de refrigera- ción, las que siendo efectivas, no logran ser suficientes para mantener niveles de confort la mayor parte del tiempo y hacen necesario el uso de sistemas activos que consumen bastante energía. En el desarrollo del artículo se analizan por separado algunas estrategias de climatización pasiva propues- tas por Givoni en su carta bioclimática (Givoni, 1969) para conocer su grado de efectividad en un caso de estudio propuesto con clima cálido húmedo con lluvias todo el año. Con las estrategias estu- diadas se busca disminuir la temperatura así como la humedad al interior de una habitación estándar.

Palabras clave: clima cálido-húmedo, climatización, confort térmico, sistemas pasivos.

AbstRAct

This article focuses on expressing some problems with the implementation of some passive cooling systems for housing projects located in hot-humid climatic zones, since most of the time the climatic conditions are of thermal discomfort. The biggest problem is that high temperatures are accompanied by high levels of humidity, making it necessary to implement more than two cooling strategies, and although effective, they do not manage to be sufficient to maintain comfort levels most of the time, making necessary the use of active systems that consume a lot of energy. In the

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development of the article, some passive cooling strategies proposed by Givoni in their bioclimatic chart (Givoni, 1969) are analyzed separately to know their degree of effectiveness in a proposed case study with a hot-humid climate with rainfall throughout the year. With the strategies studied, the aim is to reduce the temperature as well as humidity inside a standard room.

Keywords: Cooling, hot-humid climate, passive systems, thermal comfort.

Introduction

Thermal comfort is one of the topics of greatest interest in architecture, since it is directly related to the building's end user satisfaction. It is the duty of all architects not only to design buildings that are aesthetically pleasing but to also seek to satisfy all aspects of the human experience within architecture, both physical and psychological, and the surrounding physical elements. (Figure 1)

Figure 1. Man as a central axis in architecture. (Victor Olgyay, 2015)

Based on the definition of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), which describes thermal comfort as "that condition of the mind that expresses satisfaction with the thermal environment" (ASHRAE, 2004), we can argue that such mental satisfaction depends on many factors, both dependent and independent of the climatic conditions inside buildings, such as different people metabolism, mood, type of clothing and capability to adapt to changes. Although the subject has been widely studied around the world, creating standards for different climatic regions, it is, so far, a poorly documented subject in tropical areas (Djongyang, Tchinda, & Njomo, 2010) owing to the diversity of climates, should be studied in detail, across different locations, each with its own particularities in terms of climate and population.

In warm-humid areas, especially those with year-round rainfall, both temperature and humidity are usually above tolerable levels for human comfort; however, the biggest problem is the high degree of humidity, which does not allow the correct implementation of passive air-conditioning mechanisms to achieve comfort levels. In most cases the implementation of air conditioners and/or dehumidifiers, which consume a considerable amount energy, is necessary. A study conducted in several cities in Chile has analyzed the effect of ventilation as the sole method to reduce such electricity consumption, and in humid areas with maximum temperatures of 30ºC they have achieved energy savings between 12% and 30% depending on the orientation of the house (Palme, Aldunate, & Huerta, 2016). The present paper seeks to explain this problem through examples, and suggest possible solutions for these regions.

Development

For a detailed analysis of the problem, the case study of the city of Villahermosa, Tabasco, in southeastern Mexico, will be carried out. Villahermosa is located at 17º59' north latitude, 92º 56' west longitude with an average altitude of 9 MASL. It is located in a warm-humid area with year-round rainfall and total annual precipitation of approximately 2500 mm (Cervantes *et al.,* 2000). The average temperature is 27ºC, with a maximum temperature of 41ºC and minimum of 17.4ºC .

The highest temperatures have been recorded during the months of April and May between 14:00 and 16:00 hours, while the lowest temperatures are generally between the months of December, January and February, between 6:00 and 8:00 hours. These hours are consistent with the minimum and maximum daily temperatures throughout the year. The relative humidity averages 80%, dropping to an average of 69% in May and a maximum average of 86.5% in August. This makes Villahermosa an interesting case study, because its high temperatures and relative humidity make thermal comfort difficult throughout most of the year, generally having to resort to active cooling mechanisms which account for approximately 18.5% of household electricity expenditure (INEGI, 2016).

On the other hand, even though there is no standard for thermal comfort in Mexico, and even less so in Villahermosa, certain parameters need to be taken into consideration for evaluation purposes. Numerous authors have put forward temperature and humidity ceilings to achieve said comfort and the values depend greatly on the region where their analysis is conducted (Hinz, 1986); for the particular case of tropical climates we can adopt the values proposed by Victor Olgyay, where the temperature should be maintained between 23.3ºC and 26.7ºC and humidity between 30% and 70% (Víctor Olgyay & Frontado, 1998).

If the climatological data compiled in Villahermosa are analyzed in a bioclimatic diagram or in a psychrometric abacus, it can be observed that often times, comfortable levels for most people are not reached, due in many instances to the fact that the relative humidity does not usually fall below 70% and when it does, it is usually accompanied by high temperatures. (Figure 2)

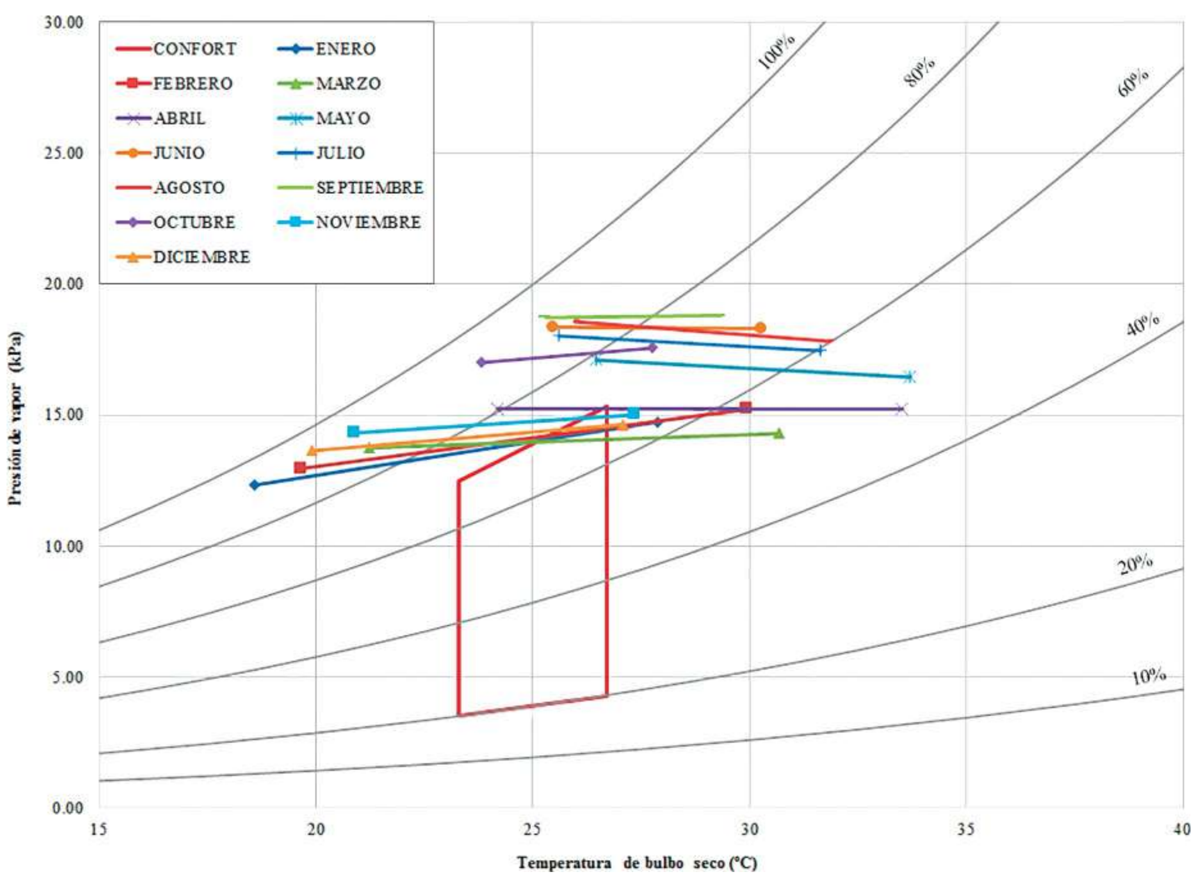

Figure 2. Givoni Bioclimatic chart with data from Villahermosa.

Baruch Givoni, in his book *Man, climate and architecture* (Givoni, 1969), proposes a series of solutions depending on the area outside the thermal comfort in which each data point of the bioclimatic chart is found (Figure 3).

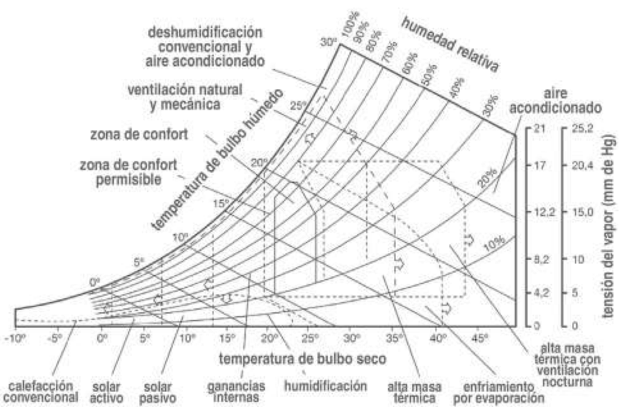

Figure 3. Bioclimatic strategies to achieve comfortable hygrothermal conditions (Givoni, 1969).

For Villahermosa, three techniques would be applied, depending on the season and the time of day: during certain periods in autumn and winter, strategies would be sought to achieve internal gains, and in spring and autumn the strategies used would be conventional dehumidification and the use of air conditioning, however, as mentioned above, the use of these technologies implies a high economic and environmental cost, aside from the noise and aesthetic toll of the devices.

To analyze these strategies and prepare a more detailed study of the associated costs, two archetypal days will be taken from the case study case: the hottest day (May 4, 2017, table 1) and the most humid day (September 10, 2017, table 2) using the following data:

Hour	Temperature (ºc)	Relative Humidity (%)	Total Precipitation (mm)	Total Cloud cover (%)	Sunshine Duration (min)	Short wave Radiation (W/m^2)	Wind Speed at 10 mts (km/H)
00:00	28.56	65	0	0	0	0	11.3
01:00	28.27	66	0	0	0	0	8.47
02:00	27.59	70	0	0	0	0	4.38
03:00	27.02	71	0	0	0	0	1.08
04:00	26.46	73	0	0	0	0	4.55
05:00	25.76	76	0	0	0	0	6.84
06:00	25.19	79	0	0	0	0	7.9
07:00	24.42	83	0	0	17.54	2.67	7.42
08:00	26.72	74	0	0	60	137.06	10.81
09:00	28.88	66	0	0	60	356.89	10.46
10:00	31.44	58	0	0	60	563.37	7.34
11:00	33.36	51	0	0	60	734.25	5.69
12:00	35.11	47	0	0	60	862.41	4.21
13:00	36.59	43	0	0	60	933.61	6.49
14:00	37.72	40	0	10	53.62	911.36	12.4
15:00	38.13	37	0	16	49.79	825.92	25.19
16:00	31.37	60	0	10	53.62	250.98	34.62
17:00	33.34	53	0	10	53.62	495.73	28.02
18:00	31.3	60	0.2	80	8.94	314.17	17.76
19:00	29.7	69	1.7	100	0	46.28	11.49
20:00	28.13	77	2.6	100	0	3.56	18.08
21:00	26.89	80	1.9	100	0	0	17.78
22:00	26.44	82	1.6	100	0	0	17.08
23:00	26.13	84	1.5	100	0	0	16.95

Table 1. Villahermosa climatological data for May 4, 2017, hottest day of the year.

Hour	Temperature (°c)	Relative Humidity (%)	Total Precipitation (mm)	Total Cloud cover (%)	Sunshine Duration (min)	Short wave Radiation (W/m^2)	Wind Speed at 10 mts (km/H)
000:00	24.54	96	1.4	100	0	0	8.79
01:00	24.34	96	0.4	100	0	0	7.42
02:00	24.38	96	0	100	0	0	7.1
03:00	24.28	96	0	100	0	0	7.42
04:00	24.08	96	0	100	0	0	8.91
05:00	23.88	96	0	100	0	0	9.67
06:00	23.76	96	0	100	0	0	9.93
07:00	24.44	98	0	100	0	0	6.49
08:00	25.68	93	0	100	0	77.43	6.57
09:00	25.45	89	0.1	100	0	102.35	8.28
10:00	26.11	88	0	100	0	162.87	10.37
11:00	25.55	90	0	100	0	139.73	11.11
12:00	26.07	90	0	100	0	181.56	11.73
13:00	25.55	92	0	100	0	146.85	11.87
14:00	25.75	92	0	100	0	138.84	11.79
15:00	25.31	93	0	100	0	102.35	11.87
16:00	25.69	92	0	100	0	126.38	11.87
17:00	25.2	93	0	100	0	99.68	11.53
18:00	25.49	92	0	100	0	108.58	11.18
19:00	25.25	92	0	100	0	76.54	9.69
20:00	24.94	93	0	100	0	2.67	8.09
21:00	24.88	94	0	100	0	0	7.75
22:00	24.82	94	0	100	0	0	7.17
23:00	24.75	94	0	100	0	0	6.38

Table 2. Climatological data Villahermosa September 10, 2017, most humid day.

Using these data, we can calculate the apparent temperature, with a mathematical model published by Robert G. Steadman in 1994, which takes into account the impact of temperature, humidity, wind speed and radiation on the heat index of the human body (Steadman, 1994). There are two versions, one that takes into account solar radiation and another that considers an environment in total shade. The apparent temperature is calculated in the following ways:

Version in shaded area

$$AT = Ta + 0.33 \times e - 0.70 \times ws - 4.00 \quad (1)$$

Version under the sun:

$$AT = Ta + 0.348 \times e - 0.70 \times ws + 0.70 \times Q / (ws + 10) - 4.25 \quad (2)$$

Where:

AT = apparent temperature (ºC)
Ta = dry bulb temperature (ºC)
e = humidity (hPa)
ws = wind speed (m/s)
Q = net radiation absorbed per unit of body surface (W)

The water vapor pressure can be calculated with the following equation:

$$e = rh/100 \times 6.105 \times \exp(17.27 \times Ta/ (237.7 + Ta)) \quad (3)$$

Where:

rh = Relative humidity (%)

For the purposes of this analysis, the version of the formula that does not take into account solar radiation and posits that the user in a fully shaded space will be used. Similarly, in order to synthesize and simplify reading of the data, only six data will be taken for each day. (Tables 3 y 4)

As can be seen, the apparent temperature increases considerably with high levels of humidity, which can be reduced or mitigated with the help of the wind, provided extreme levels of relative humidity are not reached, as can be observed during the most humid day of 2017 (Table 4)

Hour	Temperature (ºc)	Relative Humidity (%)	Wind Speed at 10 meters. (km/H)	Wind Direction at 10 meters. (km/H)	Vapor Pressure (HPA)	Apparent Temperature In the shade (ºc)	Difference (ºc)
0:00	28.56	65	11.3	99.16	25.29905809	30.7114669	2.1514669
4:00	26.46	73	4.55	341.57	25.1353181	29.8699328	3.40993275
8:00	26.72	74	10.81	91.91	25.87196531	29.1558041	2.43580411
12:00	35.11	47	4.21	19.98	26.48804676	39.0324443	3.92244432
16:00	31.37	60	34.62	343.07	27.4327035	29.6911255	-1.67887451
20:00	28.13	77	18.08	324.73	29.23148141	30.2608333	2.13083331

Table 3. Apparent temperature in Villahermosa, May 4, 2017.

Hour	Temperature (ºc)	Relative Humidity (%)	Wind Speed at 10 meters. (km/H)	Wind Direction at 10 meters. (km/H)	Vapor Pressure (HPA)	Apparent Temperature In the shade (ºc)	Difference (ºc)
0:00	24.54	96	8.79	235.01	29.4998479	28.5657831	4.02578313
ó4:00	24.08	96	8.91	226.64	28.6994529	27.8183195	3.73831946
8:00	25.68	93	6.57	260.54	30.5813982	30.4943614	4.8143614
12:00	26.07	90	11.73	252.12	30.2848372	29.7831629	3.71316293
16:00	25.69	92	11.87	255.96	30.2704732	29.3712006	3.68120062
20:00	24.94	93	8.09	249.15	29.2674874	29.0252153	4.0852153

Table 4. Apparent temperature in Villahermosa, September 10, 2017.

In this case, the effect of the wind is counterproductive, where the average difference of the apparent temperature compared to the dry-bulb temperature is +3.93ºC, while on the hottest day, the difference was +2.33ºC. Similarly, by plotting the data for both days on a bioclimatic diagram, we can observe in more detail the problem we are facing and the possible solutions (Figure 4).

As can be seen in the bioclimatic chart, both days are outside the comfort zone proposed for the geographical location, and some strategies proposal to improve the apparent temperature conditions can be observed. In the case of the hottest day (May 4) the strategies would be cooling using natural and mechanical ventilation, and also the use of air conditioners during certain times of the day. For September 10, being the hottest day of the year, both natural and mechanical ventilation cooling would have to be combined with conventional dehumidification.

The setback with all these strategies is the energy costs they entail, and as mentioned previously, it is estimated that the implementation of active cooling and/or dehumidification mechanisms represents approximately 18.5% of the electricity expenditure in Mexican households (INEGI, 2016). For both May 4 and September 10, protecting the home from the sun to avoid direct solar radiation on the building, is recommended. The reliability of these mechanisms depends on many factors, such as the amount of radiation, the angle of incidence or the latitude of the location, which is why they must be designed specifically for each building and depending on each geographical location. However, their effectiveness is irrefutable and there are studies that measure the efficiency coefficient of various sun breaker mechanisms and indicate that the lower the shading coefficient, the greater the degree of protection inside the building. (Figure 5)

For the case study under consideration, the sun breaker devices should be placed primarily towards the south, because during the hottest

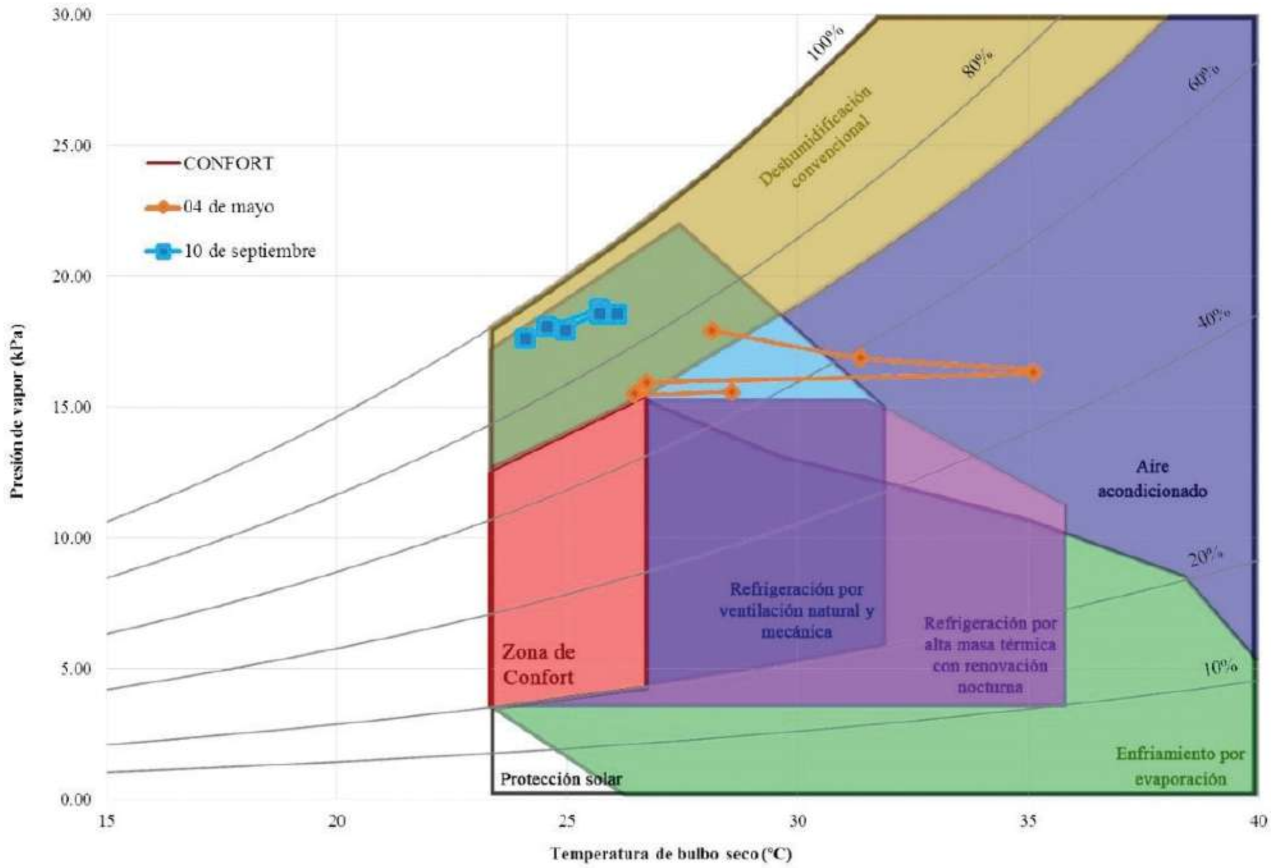

Figure 4. Villahermosa bioclimatic chart,
May 4th and September 10th 2017.

months of the year the sun acquires that inclination, combining them with others with an east and west orientations, therefore it is recommended to place mobile mechanisms which can be adjusted depending on the season of the year and time of the day.

Colling by natural and mechanical ventilation is, as its name suggests, a combination of mechanisms that generate air movement and specific strategies to introduce into the room.

This technique allows the renewal of air inside the building, eliminating stale air, or with excess water vapor and is beneficial precisely in areas with sufficient wind and relative humidity above 20%, as is the case of the present study. Natural ventilation mechanisms for buildings are well known, and can be as simple as generating cross ventilation by making two (or more) openings located on opposite facades

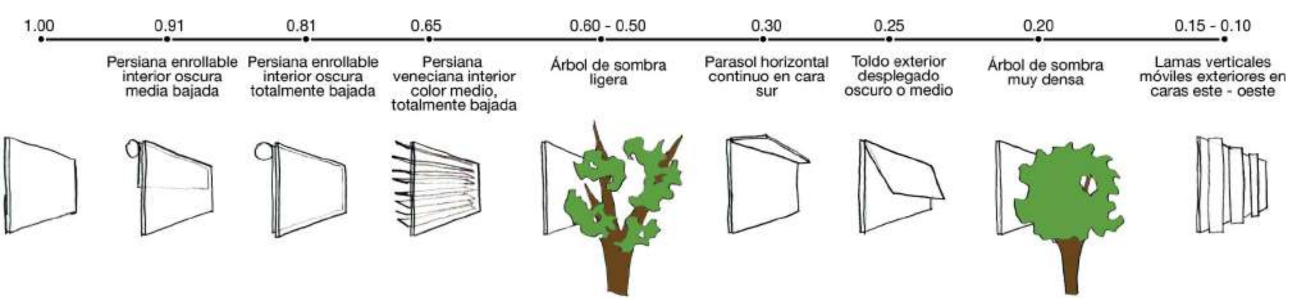

Fig 5. Shading coefficient of sun breaker mechanisms. In-house draft based on data from *Design with Climate*, Victor Olgyay, 2015.

facing outwards, with one of them facing the incoming wind. There are also provisions such as the chimney effect; however, the effectiveness of this system decreases when outside temperatures are very high, as in the case study (Figure 6).

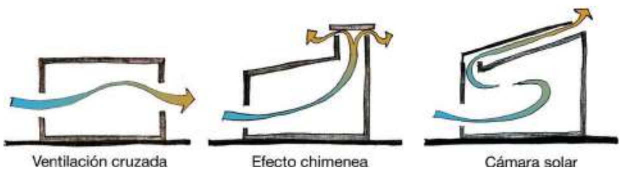

Figure 6. Natural ventilation mechanisms, in-house draft.

Some mechanisms require air thrusters when natural ventilation is not sufficient, such is the case of underground ventilation. This type of ventilation takes advantage of the ground's thermal inertia, passing the air through underground ducts, since starting at a depth of three meters the temperature of the subsoil is quite stable and tends to remain at the average temperature of the location (Figure 7). In the case study the season's weather is 25.34°C; which would help us at certain times of the year, when the temperature exceeds 27°C, but the rest of the time it would be better not to use it.

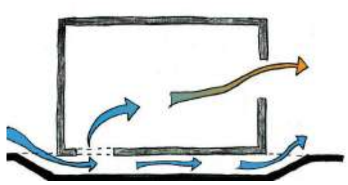

Figure 7. Underground ventilation

For the most humid days, the usual strategy is conventional dehumidification, and it must be combined with other mechanisms to improve the weather conditions. The two best known mechanisms are: desiccant salts and absorbent salt plates.

The former possesses chemical properties that are used to remove moisture from the air while they hydrate, the most commonly used is silica gel, due to its low price. The latter uses precisely these salts and attempt to regenerate themselves, to later return to the interior of the buildings to continue absorbing vapor from the air. The problem with these mechanisms is that very large quantities are needed to dry the rooms, and the rooms would have to be kept completely closed and insulated to keep out moisture from the outside. This would not allow the application of natural ventilation mechanisms and the implementation of air conditioning equipment would be unavoidable. As a sample dehumidification calculation, we can take as a starting point 8:00 pm on September 10, with the following temperature and relative humidity:

$$T = 24.94ºC$$
$$RH = 93\ \%$$

Given an absolute humidity of:

$$\omega = 0.018 \text{ kg water/kg dry air}$$

The aim is to maintain the same temperature and reduce the relative humidity to at least 60%, with a resulting absolute humidity of:

$$\omega_{60\%} = 0.012 \text{ kg water/kg dry air}$$

A formula (Daud, 2001) to determine the total amount of water to be removed per hour is applied as follows:

$$m_w = (\omega - \omega_{60\%})\, m_a \tag{4}$$

Where:

$$m_a = \rho_a * Vol$$

and for analysis purposes we can assign a surface area of 24.3 m^3 to a sample room, as shown below. (Figure 8)

$$m_w = (0.018 \text{ kg water /kg dry air} - 0.012 \text{ kg water /kg dry air})\,(1.2 \text{ kg/m}^3 * 24.3 \text{ m}^3)$$

$$m_w = 0.19 \text{ kg of water}$$

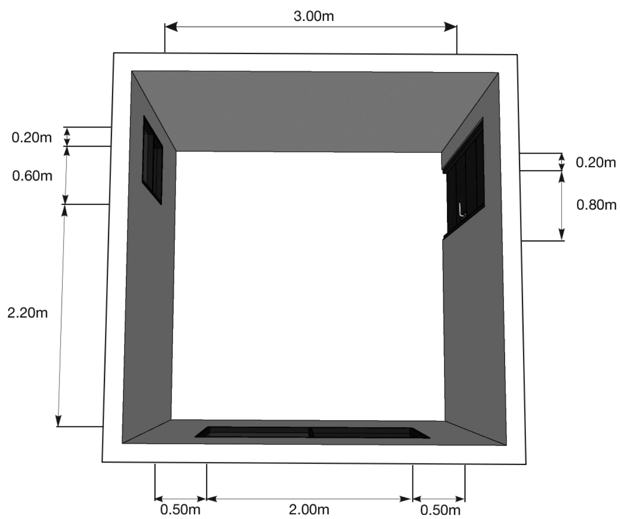

Figure 8. Measurements of the room being analyzed.

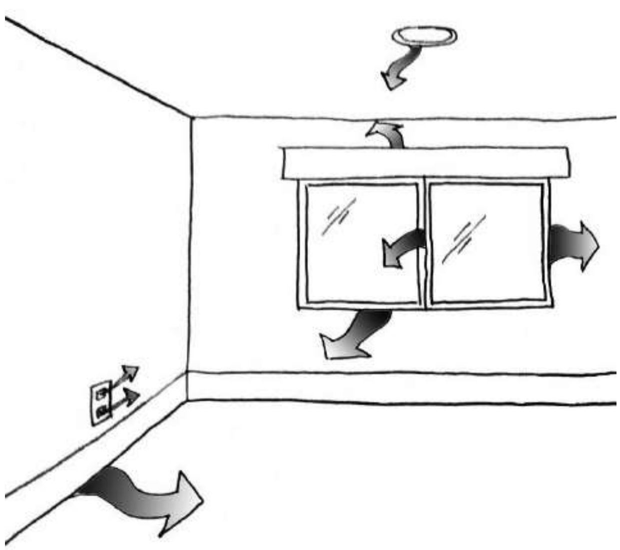

Figure 9. Air infiltration, possible points of entry.

Despite the windows being closed, the infiltration that exists must be considered, which, albeit small, introduces humidity into the room. This infiltration can occur in various places (Figure 10). For practical purposes, 0.1% of the infiltrated air flow that would pass through the window when it is open will be considered as follows:

$$m_w = m_a (\omega - \omega_{60\%}) \tag{5}$$

Where:

$$m_w = V * \rho_a = (1.15\ m^3/hr) * (1.2\ kg/m^3) = 1.34\ kg/hr$$

and therefore formula 5 is as follows:

$$m_w = 1.34\ kg / hr\ (0.018\ kg\ water / kg\ dry\ air - 0.012\ kg\ water /kg\ dry\ air) = 0.0085\ kg/hr$$

If we consider an analysis time of 10 hours, over night the infiltration would account for 0.085 kg of water and if this value is added to the water already inside the room that needs to be removed, we have a total of 0.28 kg of water.

Silica gel has an average absorption rate of 0.3 kg of water/kg of silica, so 0.92 kg of silica gel would be needed. This presents the first problem in terms of the amount of material needed in each room, as well as the amount of energy needed to heat said material to be able to reuse it.

In cases where the implementation of natural and mechanical ventilation is necessary to achieve comfort levels, or if it is impossible, to reduce the consumption of air conditioning, some factors must be taken into consideration. Mainly, for it to work properly, the indoor temperature must be higher than the outdoor temperature, otherwise by introducing natural ventilation in the house, we would be contributing to the thermal gain inside the house. This is possible due to thermal inertia, specifically the delay that exists in the transmission of temperature from the outside to the inside of the house depending on the materials used and their thicknesses, therefore we can control the time of day when the heat from the outside begins to come in. For practical purposes during the analysis, an average of eight hours of lag time was considered, as well as a 10% damping, depending on the materials used. In the analysis of May 4, 2017, from 18:30 hours until 04:30 the inside temperature is higher than the outside temperature, which allows for the use of this cooling mechanism. (Figure 10)

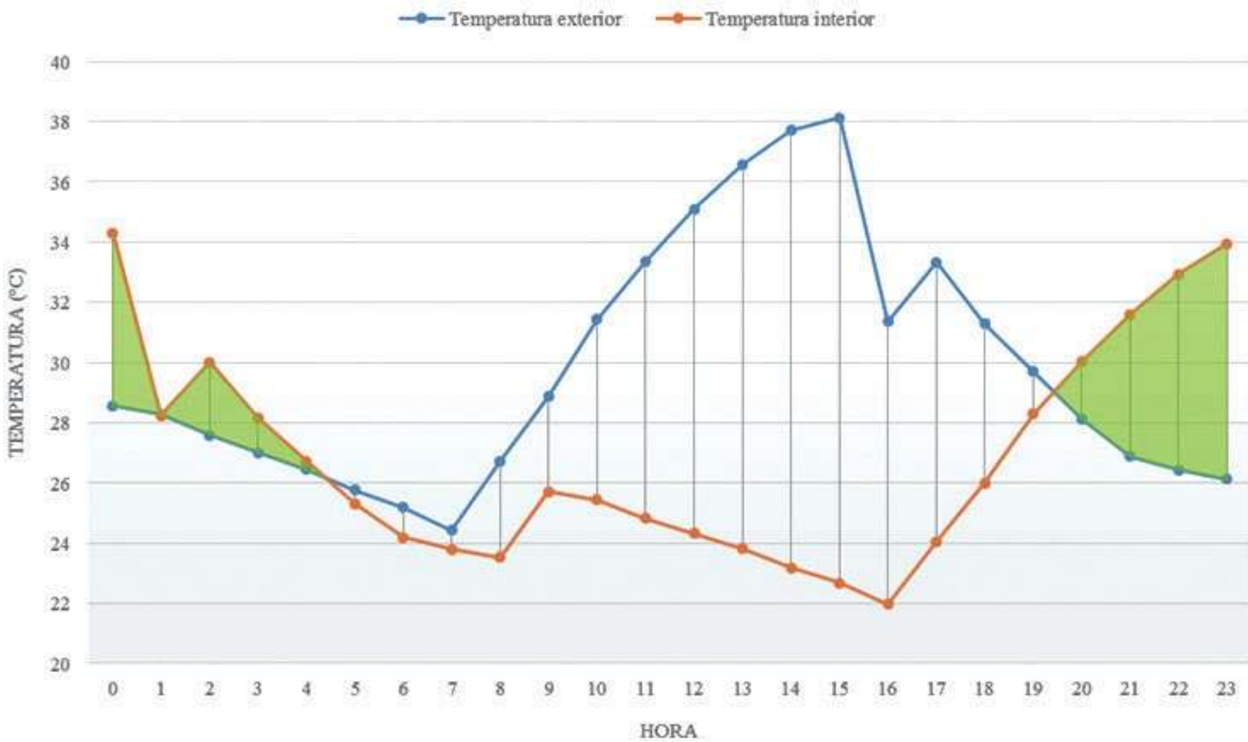

Figure 10. Indoor and outdoor temperature graph. May 4, 2017.

In order to calculate the wind velocity and flow rate entering through the northeast facing window and how the cross ventilation is obtained, some mathematical calculations must be performed. First, an adjustment must be made for roughness and another adjustment for the height of the wind speed, because the data obtained by the meteorological station are at a height of 10 meters in an urban area, the correction is made at 3.5 meters with the following formulas (ASHRAE, 1993):

$$Vref = A_o * V_{met} \quad (6)$$

$$A_o = 1.291 \exp (-0.005214 (\delta - 250) \quad (7)$$

Where:

V_{ref} = estimated reference velocity (m/s)
Vmet = meteorological velocity (m/s)
A_o = roughness coefficient
δ = friction layer or height of the boundary layer (approximate value of 400 meters is set)

The average velocity for the day under study is 12.35 km/h, or 3.53 m/s, thus the velocity Adjusted for roughness is equal to 2.08 m/s and the height adjustment is made using the following equations:

$$VH = k * H^{1/3} \quad (8)$$

Donde:

V_H = wind velocity at height H (m/s)
k = velocity coefficient
H = reference height (weather station)

The velocity coefficient is determined by the following formula:

$$k = V_{ref} / H_{ref}^{1/3} \quad (9)$$

Where:

k = velocity coefficient
Vref = wind velocity (m/s)
Href = reference height

With the data obtained and adjusted for roughness, a wind velocity adjusted to the height of the room to be analyzed (3.5 m) of 1.02 m/s is obtained. Next, the dynamic wind pressure at both windows must be known to subsequently determine the wind flow through the room, using the following formula:

$$\rho w = ½\ p\ *\varsigma^2 \qquad (10)$$

Where:

ρw = dynamic wind pressure (ρa)

ς = ambient air density –exterior- (kg/m^3) [At sea level air density is approximately1.2 kg/m^3]

v = wind velocity (m/s)

Replacing the values in the formula $\rho w = 0.6 * (1.02)^2 = 0.62\ \rho a$ and using approximate pressure coefficients to determine the pressure in each of the windows, the large window points straight ahead in the direction of the wind (Figure 11), therefore an efficiency coefficient of 0.8 is assigned and is known as windward. The wind outlet window takes a coefficient of -0.3 and is known as downwind, leaving the pressures as follows:

Windward window = 0.51 ρa Downwind window = -0.19 ρa

Once the specific pressures are known, the ventilation rate is calculated as follows:

$$Q = 0.827\ A\ (\Delta\rho)0.5 \qquad (11)$$

Where:

Q = ventilation rate (m^3/s)

A = area of the ventilation opening (m^2)

Δp = pressure difference between the two cross ventilation openings (ρa)

Therefore:

$$Q = 0.827 * 1.10\ (0.51-(-0.19)^{0.5} = 0.76\ m^3/s$$

And the wind velocity through the window is defined by the formula:

v = Q/A (12)

v = $0.76\ m^3/s\ /1.10m^2 = 0.69\ m/s$

This result is accurate, since according to Evans (Evans, 1957), it would allow us to achieve a decrease in the user's apparent temperature of approximately 1.2ºC; however, it will not be enough to reach thermal comfort levels throughout, since at various moments, it will still be more than 30ºC inside the dwelling. (Table 5).

Underground ventilation options can also be evaluated, both to lower the temperature and to reduce the humidity of the air, especially on humid days.

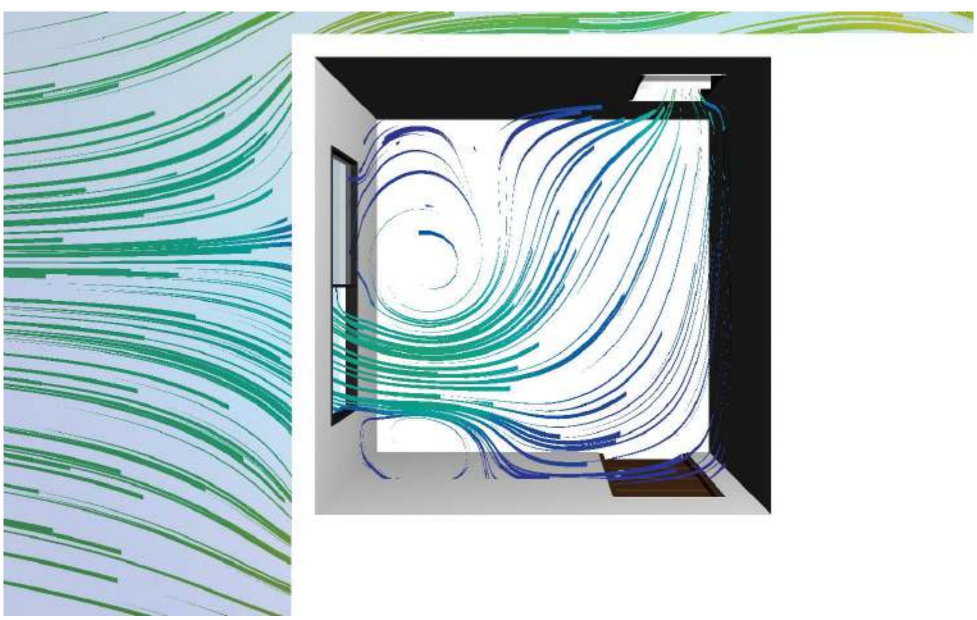

Figure 11. Cross ventilation simulation. Generated using *flow design software.* (AUTODESK, 2019)

Wind velocity (m/s)	Mechanical Effect	Effect on the user	TBS Cooling effect ºc				
			Dry skin				Wet skin
			15°	20°	25°	30°	30°
0.1	Minimal level for household	Suffocation may be felt.	0	0	0	0	0
0.25	Cigar smoke indicates movement.	There is imperceptible movement except at low air temperatures.	2	1.3	0.8	0.7	0.7
0.5	Flaming of a candle.	Feels cool at comfortable temperatures, but uncomfortable at low temperatures.	4	2.7	1.7	1.2	1.2
1	Loose papers can be moved, which is equivalent to the walking speed.	Generally pleasant when the weather is comfortable or warm but causes a noticeable sensation of movement. It is the maximum acceptable level for nighttime comfort.	6.7	4.5	2.8	1.7	2.2
1.5	Too fast for office work. The papers are blown up.	Uncomfortable at comfortable temperatures. Maximum comfort limit for indoor activities.	8.5	5.7	3.5	2	3.3
2	Equivalent to fast walking velocity.	Acceptable only in very hot and humid conditions, when no other environmental relief is available.	10	6.7	4	2.3	4.2

Table 5. Wind velocity in indoor spaces and its effect on users. (Evans, 1957)

Taking September 10 as an example, with an average temperature of 25.01ºC, a relative humidity of 93.37%, and an absolute humidity of 18.10 gr water / Kg dry air, the relative humidity would need to be decreased to 60%, that is 11.63 gr water / kg dry air. However, to achieve this using this technique, the soil temperature would have to be 17.78ºC, which is very different from the 25-27ºC that actually exists. Some options for lowering the soil temperature such as irrigation, shading and placement of gravel layers on the ground have been studied (Derradji & Aiche, 2014; Givoni, 2007) and their effectiveness for the type of climate under consideration should be analyzed.

Conclusions

Based on the analyses carried out, it can be concluded that humidity plays an important role in locations such as Villahermosa, Tabasco, increasing the apparent temperature between 2ºC and 4ºC, making it a priority to reduce these levels to achieve thermal comfort. It is possible to capture the moisture contained in closed rooms through the use of desiccant materials, such as silica gel; however, we ought to look for aesthetic ways of placing it inside the houses, as well as new methods to regenerate it using the least amount of energy possible.

Reducing extreme indoor temperatures is possible through the use natural night ventilation assisted by controlled mechanical ventilation, since constant weather show a potential for wind to help cool the user's apparent temperature by approximately 1.2ºC. The case study revealed that underground ventilation could be useful, provided the ground temperature can be lowered to that found at a depth of approximately 1 to 2 meters, a scenario that should be studied in more detail. Separate analysis of several passive air cooling mechanisms suggested for houses located in warm-humid climates, favorable results are found, but they do not allow for reaching thermal comfort levels inside the whole house; however, they are effective in mitigating the effects and reducing the electrical consumption of active cooling and mechanical ventilation mechanisms. We must also carry out a comprehensive analysis integrating all the strategies in the same case study and performing simulations for several scenarios, adjusting for different combinations of humidity, temperature and ventilation. (table 6)

In tropical locations with hot-humid climates, it is likely that they will continue to be partially dependent on cooling equipment to achieve thermal comfort levels, however, the implementation of passive cooling mechanisms is necessary to reduce electricity consumption.

	Humidity	Temperature	Ventilation
Case #1	High	High	High
Case #2	High	High	Low
Case #3	High	Low	High
Case #4	High	Low	Low
Case #5	Low	High	High
Case #6	Low	High	Low
Case #7	Low	Low	High
Case #8	Low	Low	Low

Table 6. Proposed scenario to be analyzed.

References

ASHRAE. (1993). *Handbook, Fundamentals.*

----. (2004). Thermal environmental conditions for human occupancy (Vol. 55).

Cervantes, J., Barradas, V., Martínez, A., Co*rdova, Q., Ramírez, C., & Tepach, G. (2000). Aspectos del clima urbano de Villahermosa.* Universidad y Ciencia, 16, 10-16. Tabasco, México.

Daud, W. R. W. (2001). *A novel short-cut design method for adsorbers used in gas dryers and dehumidifiers.*

Derradji, M., & Aiche, M. (2014). Modeling the soil sur- face temperature for natural cooling of buildings in hot climates. *Procedia Computer Science, 32,* 615- 621.

Djongyang, N., Tchinda, R., & Njomo, D. (2010). Thermal comfort: A review paper. *Renewable and sustainable energy reviews*, 14(9), 2626-2640.

Evans, B. (1957). Research report 59. *Texas: texas engineering station.*

Givoni, B. (1969). *Man, climate and architecture.* Amsterdam: Elsevier Science.

---- (2007). Cooled soil as a cooling source for buildings. *Solar Energy,* 81(3), 316-328.

Hinz, E. (1986). *Proyecto clima y arquitectura: informe final de la primera etapa del trabajo de in vestigación.Universidad del Zulia.*

INEGI. (2016). *Encuesta nacional de ingresos y gastos de los hogares 2016*. México.

Olgyay, V. (2015). *Design with Climate: Bioclimatic Approach to Architectural Regionalism-New and expanded*. Princeton university press.

Olgyay, V., & Frontado, J. (1998). *Arquitectura y clima: manual de diseño bioclimático para arquitectos y urbanistas*. Barcelona, España: Editorial Gustavo Gili.

Palme, M., Aldunate, C.C., & Huerta, M.A.G. (2016). Estimación del riesgo de sobrecalentamiento y del potencial de refrigeración por ventilación natural de viviendas unifamiliares en ciudades costeras de Chile. *Hábitat Sustentable,* 52-61.

Steadman, R.G. (1994). Norms of apparent temperature in Australia. *Aust. Met. Mag, 43,* 1-16.

Ignacio Alejandro Guzmán-Hernández

Doctoral candidate in architecture, building and urban technology at the Universidad Politécnica de Catalunya, graduated with honors from the master's degree program in architecture technology at the Universidad Nacional Autónoma de México.

Fidel Franco González

Holder of a Bachelors' degree in Physics (1975), Doctor in Physics (1983), Professor at the UPC since 1975. Tenured Professor since 1984.
Areas of research interest: energy saving, thermal comfort, climate change and structural health of the construction.
Activities and publications: participations at 45 congresses, 14 invention patents, 5 book chapters, 2 books and 20 articles.

Jaime Roset

Holder of a bachelor's degree in Physics. School of Physics of the Barcelona University, September 30, 1982. Doctorate in Physics from ETSAB/UPC, July 10, 2006.
Professor (Since 1982 has been Teacher in Charge, Full-time Associate Professor, Tenured Professor and since 2014 Department Head at the Universidad Politecnica de Catalunya)
Activities and publications: author of 20 articles, 2 books, 5 book chapters, participation at 85 congresses (1982-2018). Between 2011 and 2018, 13 articles, 1 book, 4 book chapters. Physics Professor at ETSAVs and ETSAB from 1982 to 2018. Member of the School Board. Academic advisor 2008-2011.