Reconceptualization of Climate Classifications and Climate Analysis Tools to Support Evaporative Building Cooling Strategies in the Hot Humid Tropics

Claudio Aurelio Diaz[1], Steve King[2], Paul Osmond[3]
[1-3] *University of New South Wales, Sydney, Australia, [1]claudio.diaz@student.unsw.edu.au, [2]stevek@unsw.edu.au, [3]p.osmond@unsw.edu.au*

1. Introduction

Evaporative Cooling (EC) is increasingly regarded as a powerful and effective method for building cooling, mitigation of Urban Heat Islands (UHI) and for urban adaptation to climate change (Kitano *et al.*, 2011; Saneinejad *et al.*, 2014). As this cooling technique depends on the adequate supply of water, it is notable that most research gives little attention to local water availability, and also that the research community largely ignores the Hot Humid Tropics, despite these being regions with significant water surplus. Evaporative Cooling is still generally omitted in the theory and practice of building and urban cooling for the Hot Humid Tropics, even though diverse experiments and practical applications have confirmed that it can be effective even in hot humid climates (Kitano *et al.*, 2011).

This paper argues that the problem of marginalization and stigmatization of EC techniques as unsuitable for these regions is rooted in an incomplete understanding of the nature of hot humid climates and their variations, which has historically permeated approaches to building cooling. The authors propose the need for a reconceptualization of climate classifications and climate analysis tools for architectural applications, which would allow a more detailed differentiation of hot humid climates than what is usually seen in conventional classifications. This finer grained differentiation is essential to overcome the problems referred to above, and to reconsider promising passive and low energy solutions for buildings and cities for the majority of the hot humid areas of the world, particularly those with less developed economies.

2. Issues of Climate Classifications in Architecture

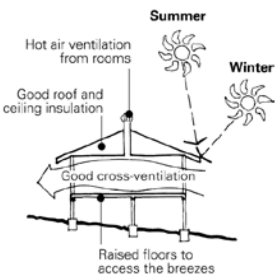
One of the reasons for the disregard of EC as a suitable cooling strategy for buildings in hot humid climates (especially in the wet tropics) is the lack of an appropriate differentiation of their variants, particularly in relation to moisture saturation and water availability. This is an issue that is present in all climate classifications prevalent in architecture, which in general can be sorted into three types:

1. Simple classification in 4 major groups: Cold, Temperate, Hot Dry and Warm-Humid (e.g. Drysdale, 1959).
2. Classifications with further subdivision of the 4 major groups (e.g. Atkinson, 1953; Lee, 1953; which give specific attention to hot climates).
3. Detailed grouping based on temperature and precipitation criteria, but not on humidity (Köppen classification)

All these classifications arrange climates according to similarities on particular criteria, indicating certain general "truths" or conditions, and illustrating some general principles applicable to each different climatic group (Lee, 1953; Givoni, 1976). However, these classifications prioritize particular characteristics and make some generalizations, because is not possible to include every variation of climate. Additionally, they are delimited around a level of simplicity in order to remain of practical use. All of these generalizations and simplifications provide any classification with limitations that, as remarked by Lee (1953), **all users must take into consideration**. Unfortunately these limitations are usually overlooked.

A consequence of the oversimplification of classifications is that all locations labelled as warm-humid, hot-humid, warm-wet, and so forth, are put indiscriminately in one "box", even if there are significant differences between them. This has caused the emergence of a hot-humid 'architectural stereotype' (the low mass, raised, naturally ventilated building, Fig. 1) which, rather than serve only as rough guide for design, has become a routine architectural response according to the hot humid label (Szokolay, 1990). Thus, the complex reality of a hot humid location is usually addressed by oversimplified architectural or mechanical solutions.

a)



b)

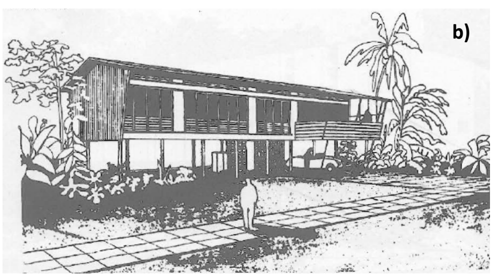


Fig. 1.- a) Typical concept for hot humid climates [from Your Home – Australia's Guide to Environmentally Sustainable Homes 4th ed.]
b) Example of the architectural stereotype for hot humid climates [from Koenigsberger et al., 1974]

Usually, the diversity in the spectrum of Hot Humid climates is not shown in depth. Traditionally these have been described in ways that are too vague (Relative Humidity (RH) between 55% and 100%, Precipitation above 1000mm). This is illustrated by the disparities found in the architectural literature for hot humid climates (Table 1):

No.	Reference	High Humidity (monthly and daily averages)	Abundant Precipitation (annual total rainfall)
1	Drysdale, 1959	High RH day and night 70 to 80%	Heavy summer rainfall
2	Givoni, 1976	A frequent RH of 90% and above	High rainfall
3	Koenigsberger et al., 1974	RH about 75% for most of the time	Rainfall from 2000 to 5000mm
4	Evans, 1980	RH above 60% and commonly around 100%	High rainfall, in excess of 1000mm

Table 1.- Typical descriptions of high humidity and abundant precipitation of hot humid climates.

Such a wide range of RH (a variance of 45%) represents different mixtures of hot humid conditions and levels of air saturation, which imply significant differences for the performance of EC. This range is wider if hourly variations are considered (e.g. RH down to 30%). On the other hand, there are major differences in amounts and distributions of rainfall which have implications in the sustainability of EC (for instance, annual rainfalls of 2000 mm may be distributed in 4, 6 or 12 months, Fig. 2). Thus, hot humid conditions can be very different even between locations which are relatively close or which have common characteristics, and therefore, it is not possible to understand the diverse spectrum of hot humid climates only with annual and monthly averages.

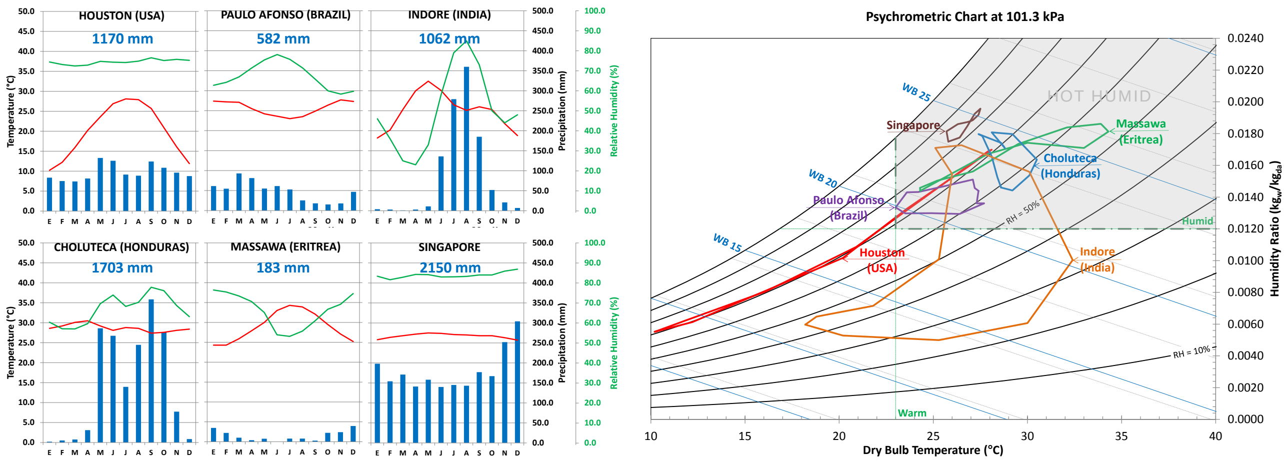


Fig. 2.- Comparison of climatic profiles of locations with permanent or seasonal hot humid climates.

The above confirms that hot humid climates need to be studied and contrasted in more detail, exploring their whole range of temperatures, saturations and precipitation patterns, in order to be better understood. It is here where climate classifications remain relevant, not as a source of generalizations and principles but as **a tool for contrasting**; to highlight relevant differences and observe relevant aspects which may help inform design. However, there is still a lack of suitable means for the integral analysis of hot humid climates for architectural purposes, particularly to explore applications of EC for building cooling and thermal comfort.

3. Issues of Climate Analysis Tools

Conventional climate analysis tools for thermal comfort in buildings, like the bioclimatic chart (BBCC) (e.g. Givoni, 1998), suggest the approximate limits within which passive building strategies can achieve comfort conditions before resorting to the use of mechanical means. When the conditions of hot humid climates are plotted in these charts, most are located distant from the main and extended comfort zones for the passive cooling techniques for buildings (Fig. 3). Consequently, the whole region of high hot humid conditions is usually dismissed as **intractable for passive and low energy strategies in architecture**. Therefore, the automatic conclusion is that the only alternative left to improve comfort conditions is through conventional air conditioning and dehumidification.

The above is the result of the existing misconceptions about hot humid climates and insufficient understanding of non-conventional cooling techniques like EC. Additionally, the uncritical use of the BBCC brings other limitations which impede the development and implementation of solutions different to the conventional strategies:

a) Strategies tend to be valued only if they achieve ideal comfort conditions on their own. Partial contributions to comfort conditions are discarded even if they are significant for heat gain reductions and energy savings.
b) There is a bias towards indoor air temperature and humidity. Techniques are analysed focusing on how they improve these two variables. Improvements in other variables for thermal comfort are less regarded or cannot be easily expressed by the BBCC, e.g. reductions in Mean Radiant Temperature (MRT).
c) The BBCC cannot clearly express how a combination of techniques would perform or how one strategy could be potentiated by another, e.g. shade plus thermal mass cooling.

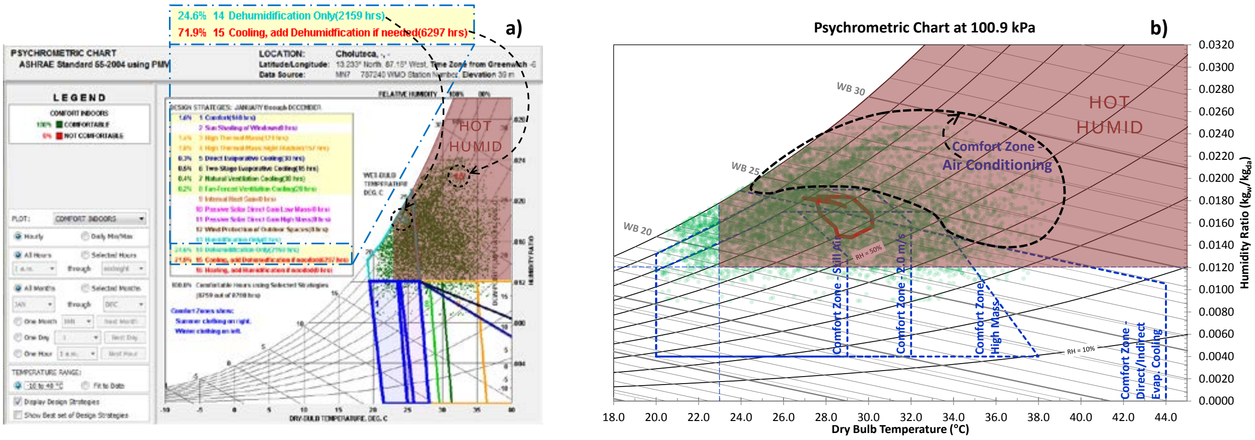


Fig. 3.- Strategies for hot humid conditions, suggested by a) Climate Consultant 6.0, b) BBCC (Givoni, 1998)

The comfort boundaries of the BBCC were originally defined from research conducted in USA, Europe and Israel. Alternative limits for developing countries were suggested later, derived from **subjective evaluation** of research data and from some assumptions made from field experience. Little subsequent research has contributed with new elements to test or enrich these suggestions. Thus, in many cases there is a mechanical use of the BBCC and other tools, which is contributing to the stagnation of ideas and to overshadow new alternatives of passive strategies for hot humid climates.
The BBCC and other climate analysis tools do not integrate all the required information to carry out an analysis of hot humid climates for applications of EC. Therefore, is necessary to think how these could be adapted or if new tools could be created for this purpose. For this, one must first distinguish some critical aspects for the application of EC in buildings which are necessary to remove the “mental crutch” of climate classifications (Szokolay, 1990) and other misleading ideas that are preventing us from taking opportunities for innovative solutions.

4. Critical Disregarded Aspects

A more complete framework for analysis of hot humid climates in architecture has to consider some aspects which are relevant to identify overlooked variables for classification and analysis, and to inform a better understanding of these climates in relation to EC. These critical but generally disregarded aspects are:

a) Indirect Influences on Human Thermal Comfort, b) Time Scale and c) Expression of Humidity Conditions

4.1. Indirect Influences on Human Comfort

A drawback of climate classifications for architecture is that they only focus on the climatic factors which have direct influence over human thermal comfort (Lee, 1953; Evans, 1980), particularly air temperature and humidity. Climatic conditions are analyzed as if they impact the individuals directly, without any influence or modification from the building. This is a key misconception that leads us to disregard one relevant climatic factor: *Precipitation*.
Any building will necessarily alter the prevailing outdoor climatic conditions. Building envelopes usually prevent the direct impact of solar radiation, rainfall and wind to the indoors, and they also convey these impacts with altered magnitude and time. So not all climatic variables will affect human thermal comfort through direct contact and/or in their original condition. If this is pondered, it is possible to see that precipitation can influence human thermal comfort indirectly through the building envelope, especially by means of EC. Building envelopes wetted by precipitation may have significant reductions of their outdoor surface temperatures, which consequently influence the indoor environment in positive ways. Lower surface temperatures contribute to lower indoor air temperatures and especially to lower MRT; two variables which directly influence the comfort conditions of the occupants.

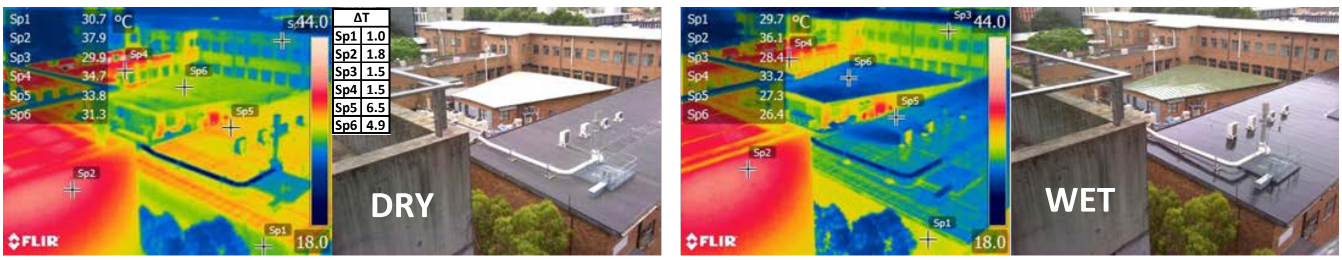


Fig. 4 Reductions of building surfaces temperatures after incidence of light showers (30 minutes difference).

Additionally, precipitation is a main source of water which can be stored and used to prolong the wet conditions over building envelopes through artificial means (e.g. a spray system). Hence, the amount of precipitation and its distribution in time are important aspects to consider in the analysis of hot humid climates in relation to EC.

4.2. Time Scale for analysis

Most climate classifications and some climate analyses are based on annual and monthly mean values of climatic variables. This approach is appropriate for certain purposes of building design and energy analysis, but it does not provide sufficient information for analysis and design related to thermal comfort and EC.

Although annual or monthly averages give a rough idea of general environmental conditions, they do not provide information about transition of conditions nor about extreme conditions. These last two are relevant aspects for thermal comfort as well as for EC. For instance, a monthly average of 28.8°C and 68% RH does no reflect how a person may feel or how evaporative cooling performs during a specific time within the month with parameters of 33.0°C and 53% RH. These are very hot humid conditions, mostly uncomfortable but with high opportunity for EC.

EC performs better when heat conditions are extreme, even in hot humid climates, because they are favorable to evaporation rates. Thus, around midday or under extreme weather (e.g. heat waves) the level of saturation significantly decreases (going as low as 30%) and EC improves. However, the real potential of EC in these cases cannot be seen without detailed description of the climate. For this reason, small time scales (e.g. hourly averages) are necessary to describe and analyze hot humid climates in relation to EC.

4.3. Expression of Humidity Conditions

Another issue precluding appropriate understanding of hot humid climates and their variations is the way to express humidity levels. In architecture and thermal comfort applications three expressions of humidity are typically used: Relative Humidity (RH), Vapor Pressure (VP) and Humidity Ratio (HR).

RH is the most conventional expression of humidity despite its many drawbacks. RH can be sometimes misleading (Givoni, 1976), because it does not measure the moisture content in the air but its level of saturation (see Section 5.2). Additionally, RH is highly volatile due to its dependence on air temperature. Thus, an amount of moisture in the air will be expressed by a wide range of RH if there are marked temperature changes.

Vapor Pressure (VP) and Humidity Ratio (HR) are more authentic expressions of humidity, because they relate to the amount of water molecules mixed with the air. The former is used in some climate classifications (Atkinson, 1953; Lee, 1953), and the latter is found in thermal comfort applications. However, these also have drawbacks: they are barely known to users, few climatic data are reported in these terms, and there is disparity in the use of units for VP (milibar, Pascals, N/m²) and appellations for HR (also called absolute humidity or mixing ratio).

Dew Point Temperature (DPT), another expression of humidity, is rarely seen in architecture applications. However, DPT integrates many advantages which make it more appropriate for climate analysis in architecture, because it has direct relation to the other humidity expressions and to Dry Bulb Temperature (DBT). For example:

a) DPT uses the same scale as DBT (°C or °F) and both have the same value when the air is fully saturated.
b) DPT is related to RH because it represents the temperature of saturation (100% RH).
c) DPT is a stable expression of moisture levels like VP and HR, and it can be directly converted to these two.
d) In hot humid climates, DPT resembles Wet Bulb Temperature (WBT) patterns.

Thus, DPT has the capacity to express humidity levels, refer to saturation levels and to provide an idea of the cooling potential through evaporation. For these reasons it can be argued that DPT should be the primary expression of humidity conditions for climate classifications and analysis in architecture.

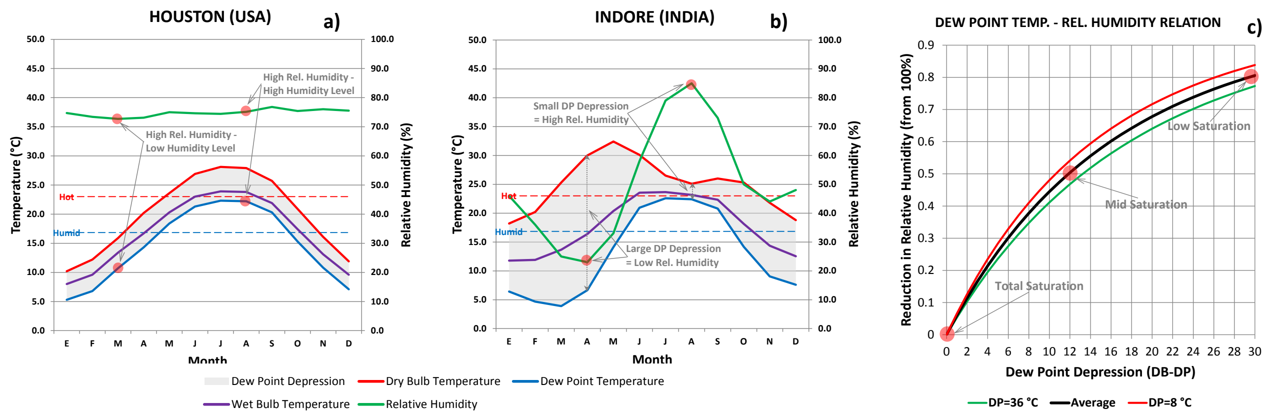


Fig. 5- DPT as expression of humidity levels and examples of its direct relation to other variables (DBT, RH, WBT)

5. Key Elements for Categorization

The application of EC requires a more detailed disaggregation of hot humid climates than what is commonly found in traditional classifications. To avoid overgeneralization and the vagueness seen in section 2, is important to observe the complete ranges of the climatic variables, distinguish the duration and magnitude of the hot humid conditions (permanent or temporary, extreme or average); and identify their capacity to sustain EC strategies. Thus, three criteria, additional to temperature and humidity, are identified as convenient to differentiate hot humid climates in detail: *a) Seasonality, Variability and Intensity, b) Saturation, c) Water Availability (Precipitation).*

5.1. Seasonality, Variability and Intensity

These three concepts are important to properly identify the context of any climate analyzed. They allow us to:

a) Differentiate between locations conventionally labelled as hot humid but which have very different patterns,

b) Recognize the potential preferences of a population for hot or cold conditions, according to how they adapt to their local climate, in order to guide interpretations and conclusions for building design; and

c) Consider the feasibility of implementing specific EC strategies, particularly for cases with issues related to fluctuating conditions between hot and cold (seasonal hot humid climates).

Seasonality distinguishes the duration of the hot season and its phasing with the rainy season to identify where EC is feasible (Fig. 7). Variability indicates how the saturation levels of the location fluctuate around the year and is expressed by the peak to peak amplitude of the annual RH (see section 5.2). Intensity shows the magnitude of the extreme (hourly) conditions of temperature, humidity and saturation of the location.

More than a labeling system, these criteria are relevant for **relative comparison** among climates of different locations, associating ranges, amplitude and peak conditions (Fig. 6).

5.2. Saturation

In classification and analysis of climates for architecture is not common to talk about saturation, despite that RH is one of the climatic variables which is commonly observed. Is important to highlight this concept because of two issues commonly seen in architectural applications:

1. RH tends to be associated with humidity levels instead of saturation levels. For example, 75% RH is usually regarded as high humidity although this might not necessarily be so (See Fig. 5a).

2. While making assumptions or conclusions about the RH (saturation) of an environment, no discrimination is made whether such an environment is closed or open, even though this has significant repercussions in the performance of EC techniques for buildings.

The first issue makes it clear that RH must not be the main expression of humidity, but instead the expression of saturation for architectural purposes (see section 4.3).As such, it informs about the potential for EC.
For the second issue, it is important to discern the differences in environments. Indoor spaces tend to be closed systems, with a limited volume of air which can be saturated easily. On the other hand, outdoor environments are open systems, unlikely to saturate due to the immense volume of air constantly circulating. Also, more factors influence evaporation rates outdoors e.g. solar radiation, wind speeds, etc. Hence the same level of saturation in each of these environments does not imply the same potential for EC, due to the different influences and effects.

Talking about saturation also provides a new angle from which climate profiles can be better understood. For instance, the monthly averages loop of most climates follows the trends of saturation instead of the direction of temperatures and humidity. Thus, in a more refined differentiation of climates for EC applications, a categorization based on saturation is more practical than one based in temperature and humidity (Fig. 2 & 6).

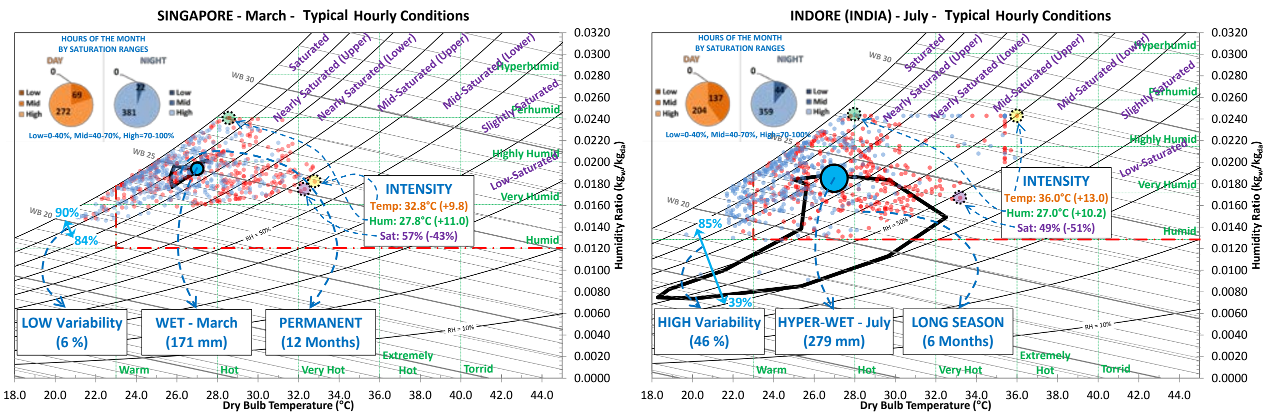


Fig. 6.- Integral analysis and contrasting of hot humid climates applying the proposed analysis criteria.

5.3 Water Availability (Precipitation)

The significance of precipitation is poorly understood in climate classifications and analysis for architecture, especially in the case of the hot humid tropics and subtropics. The attention to this factor is usually focused on the need to protect buildings against water ingress. This is reflected in the literature on buildings in hot humid climates which interprets the effects of precipitation as benchmarks for waterproofing and heavy rain problems, challenges to the integrity of buildings, and so forth. However, there are two other aspects in the interaction of buildings and precipitation which, despite being relevant, receive less attention in the literature for hot humid climates, namely:

1. Precipitation as a primary source of water for human use at building scale (rainwater harvesting), and
2. Precipitation as a resource for passive and low energy building and urban cooling (passive EC).

These two aspects reveal that there is a major opportunity in the hot humid tropics due to their abundant availability of water. Yet, to appreciate this, it is required to understand precipitation as a resource favorable for the building and not only as a detrimental factor. The second aspect particularly validates precipitation as a relevant variable for climate classifications in architecture and for thermal comfort. Although this is usually overlooked, there are cases in which this opportunity is recognized. For instance, Givoni (1976) refers to the use of EC in places where water availability during the cooling season is 0.3-0.5 m^3 of water per day per dwelling unit.

In brief, precipitation is a main source of water with a considerable cooling effect over the building fabric, which should be better regarded in climate analysis related to building design, especially for the Hot Humid Tropics.

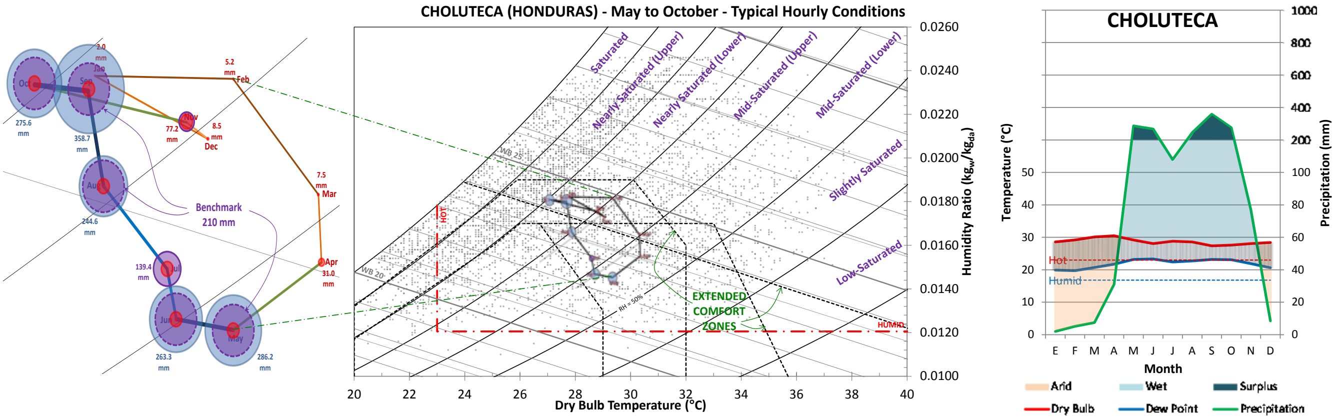


Fig. 7 Examples of conventional climate analysis tools integrating precipitation with temperature and humidity.

6. Conclusion

The aim of this work is to discern critical aspects and variables usually absent in the systematic ordering and analysis of hot humid climates for architecture, which are relevant to properly understand the actual performance of EC in hot humid climates. This deficiency limits the scope of climate classifications and climate analysis tools and is a key problem which has caused the marginalization of EC techniques for buildings in hot humid climates. To overcome this problem, the authors propose a new categorization and analysis framework for a finer grained differentiation of hot humid climates, which is summarized in Fig. 8 and illustrated in Fig. 6.

Through this reconceptualization of climate classifications and climate analysis tools, it is expected that their users, novice or experienced, will be able to better understand and describe the diversity of hot humid climates. Such better understanding will expand the awareness of alternative building cooling techniques for these environments, beyond the typical natural ventilation, air-conditioning or dehumidification responses.

With the analysis framework proposed here, researchers, designers, and planners may open their minds to a new gamut of creative solutions for the hot humid tropics based on or potentiated by evaporative cooling principles, in which buildings and cities take advantage of the natural cycles of abundant water in the hot humid tropics, in a practical and responsible manner.

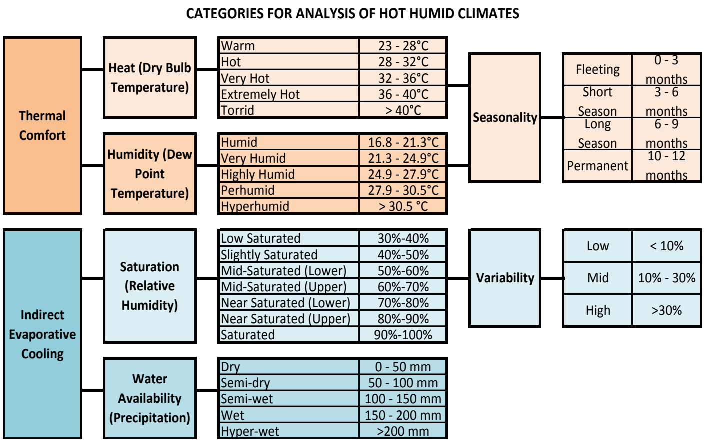


Fig. 8. Categorization criteria proposed for hot humid climates

References

Atkinson, G.A., 1953: An Introduction to Tropical Building Design. *Architectural Design*, xxiii No. 10, pp. 268–271.

Drysdale, J.W., 1959: *Designing houses for Australian climates,* 2 ed. Commonwealth Experimental Building Station, Sydney

Evans, J.M., 1980: *Housing, climate, and comfort*. The Architectural Press; London.

Givoni, B., 1976: *Man, climate and architecture*, 2 ed. Applied Science Publishers, London.

Givoni, B., 1998: *Climate considerations in building and urban design*. Van Nostrand Reinhold, New York.

Kitano, Y., et al., 2011: Evaporative cooling technologies that use the water supply system to improve the urban environment. In: *The 4th IWA-ASPIRE conference and exhibition: Towards Sustainable Water Supply and Recycling System,* Tokyo.

Koenigsberger, O.H.; et al., 1974: *Manual of tropical housing and building: Part 1: Climatic Design*. Longman, London.

Lee, D.H.K., 1953: *Physiological objectives in hot weather housing.* U.S. Housing and Home Finance Agency, Washington.

Saneinejad, S.; et al, 2014: Comparative assessment of heat island mitigation measures. *Build Environ*, Vol.73, pp. 162–170.

Szokolay, S.V., 1990: Design and research issues: passive control in the tropics. In: *Energy and the Environment: Into the 1990's*, 1st World Renewable Energy Congress, *Reading, UK,* pp. 2337–2344.