# Using the Psychrometric Chart
# in building measurements

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ABSTRACT: This paper centres around the presentation of multiple measured results on a psychrometric chart. The psychrometric chart was programmed in Microsoft Office Excel to accommodate measured results. It was written because existing programs appear not to cater for the researcher wishing to enter results electronically onto the chart. Furthermore, many existing charts are complex and cluttered displaying up to ten attributes, being intended for engineering design, whereas presenting the behaviour of living and working environments is focused on wet and dry bulb temperature and relative humidity. As well as results, users would also like to specify and adjust the 'comfort zone' (a shaded area on the chart) for different 'adaptive' or 'seasonal' conditions. The comfort zone is bounded by lines of constant heat loss from the skin, relative humidity and wet-bulb temperature.

The paper presents various applications of the psychrometric chart for the analysis and reporting of research and discusses the programming of Microsoft Office Excel to generate the chart and display user data.

Keywords: building measurement, building performance, computer modelling

## INTRODUCTION

The authors of this paper have experienced building performance measurement hands on, first, in situ. Continuous measurement of internal and external environmental parameters helps us understand how buildings perform. Yet, the quantity and variety of measured time-series data can be quite overwhelming as well as onerous to decipher and present (Luther & Horan 2009). In pursuit of a continued effort to present data effectively, the electronic plotting of measured or calculated points onto a psychrometric chart is a difficult task for most researchers. Several programs like ECOTECT (Marsh) or ENERGY-10 (Balcomb 1998) take on this task quite well for their own data and results. What is missing is a program that allows the general user to insert their own points.

## 1.    THE PSYCHROMETRIC CHART

### 1.1.  What is the Psychrometric Chart ?
The psychrometric chart tells us about the characteristics of moisture in the air at a particular temperature and pressure. Within the chart itself is a comfort zone defining the properties of the air that 90% of humans clothed at a particular level and doing light office work, would claim as comfortable. ASHRAE defines this comfort zone seasonally as provided by Figure 1.

### 1.2.  Why is the Psychrometric Chart presentation important?
Quite often it is useful to plot a series of collected data points, such as climate data, onto the psychrometric chart to learn where the points lie on the chart relative to the comfort zone. It is also becoming increasingly useful to plot psychrometric processes of untypical air-conditioning procedures and perform their corresponding energy calculations. Simple observation is not sufficient to understand the quality and condition of the air available. The psychrometric chart can help us understand this better and some examples of such are provided in this paper. Whatever the case may be, the psychrometric chart is often necessary in order to understand the differences or similarities between two or more different conditions of air.

### 1.3  How have we used the Psychrometric Chart Recently?
Programs such as ECOTECT (Marsh) plot climatic data points hourly onto a psychrometric chart, showing where they lie relative to the 'comfort zone'. This allows one to identify, often by inspection, the conditioning required to move the environment into the 'comfort zone'. An interesting calculated result of ECOTECT incorporates several passive strategies for the conditioning of external air, and its capability of bringing this air into the comfort zone. Figure 2 shows three of these strategies: (passive solar heating, exposed mass with night-purge ventilation and direct evaporative cooling) applied to the climate of Wodonga, Victoria, Australia. The shaded region highlights all those points external to the comfort zone which can be accommodated and potentially brought into comfort via the passive strategies.
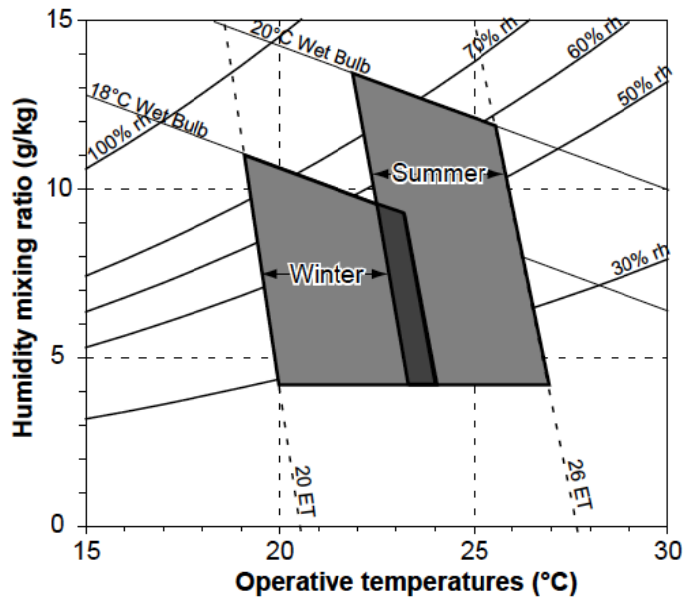
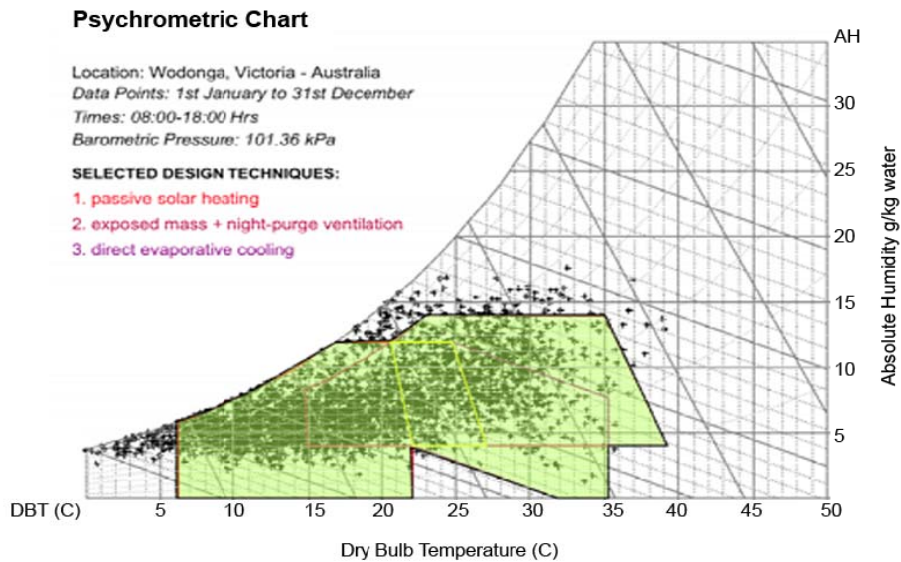**Figure 1: The Comfort Zone (ASHRAE 1992)**



**Figure 2: Plotting Climatic Data Points on the Psychrometric Chart with ECOTECT**

Another program using climatic data and graphing it in several meaningful ways is ENERGY-10 (D. Balcomb 1998). This program provides the user with a separate analysis using 'Weather Maker'. Again, some of the most important outputs provide the user with psychrometric plots of the hourly and monthly weather results. Figure 3 is such a result, providing the user with an indication of each hour of the month plotted on the psychrometric chart. Note that each month is represented by its own colour (not realised in grey-scale). Data such as this is useful in providing the user with a 'range' of the weather to be expected for a particular climate.
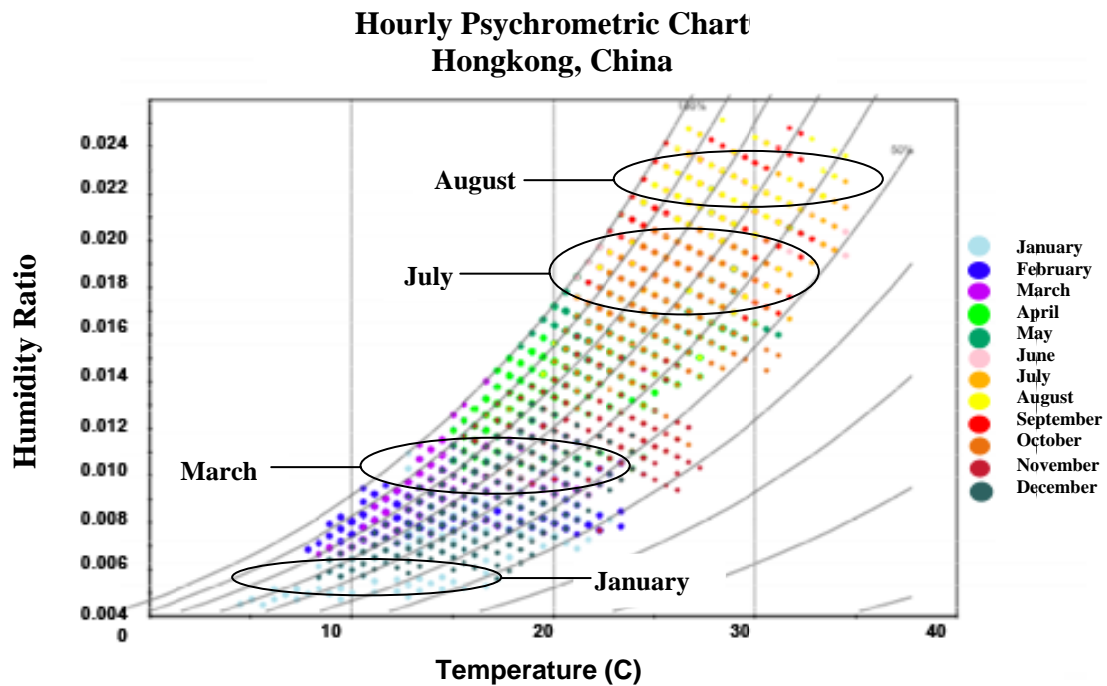
## Hourly Psychrometric Chart
## Hongkong, China



**Figure 3: Plotting Hourly Data Points on the Psychrometric Chart with ENERGY-10**

### 1.4 What uses do researchers wish to make of the psychrometric chart?

We have often wanted to plot our own points (electronically) onto a psychrometric chart. There are several reasons for doing this:

- to see where the quality (humidity and temperature) of air lie in relation to the comfort zone.
- to consider what the energy content of the air is and could be used for.
- to consider what type of conditioning (and energy) is required to bring this air into the comfort zone.
- to consider the application of an economiser cycle (exploiting the enthalpy of the outside air) for ventilation purposes.

An example of the psychrometric chart and its use is illustrated in a recent paper on rammed earth buildings describing the climate as well as interior seasonal temperature conditions (Taylor Fuller and Luther 2008). In this paper the main author found it cumbersome to represent his measured results on the psychrometric chart. In fact, two charts were created in Microsoft Office Excel and these were merged together so that the different comfort zones could be illustrated for the different seasons (Figure 4).
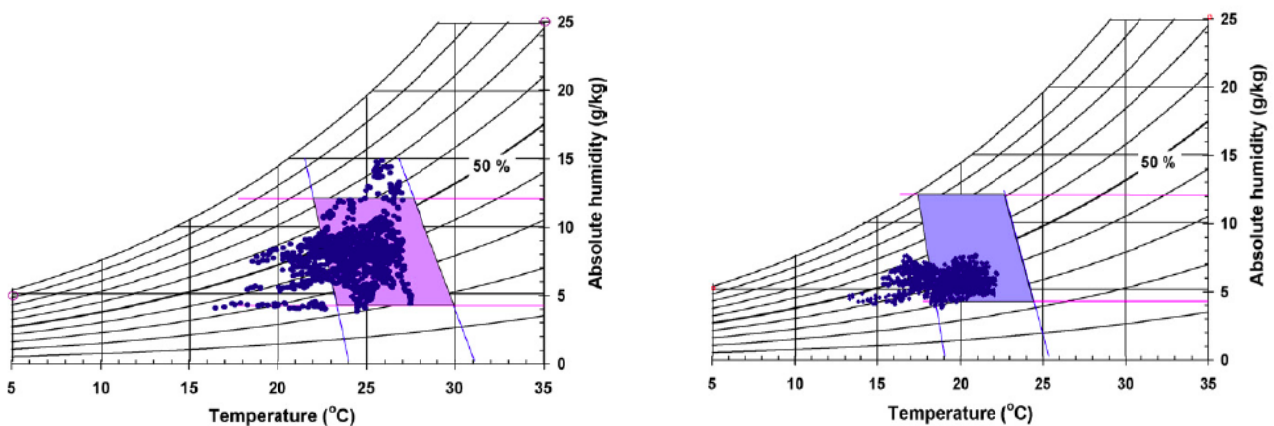


**Figure 4: Plotting the interior conditions of an office space for summer (left) and winter (right) conditions (Taylor Fuller and Luther 2008).**

## 2. PRODUCING THE PROGRAM

### 2.1. What does the program offer?

The authors wanted a simple program to allow the user to plot a set of their measured or calculated points onto a psychrometric chart using the Microsoft Office Excel program.  The chart should be basic and general in its presentation eliminating any of the discreet detail that might 'clutter' the representation of the data. In doing so, it was decided that an indication of summer and winter 'Comfort Zones' would be provided.  Future versions of the program are intended to allow the user to extend and provide their own 'comfort zone' parameters.  It was also decided that a user might want to illustrate differences between two or more sets of data, (for example: exterior and interior data) by using colour or style to distinguish the sets.

At this point in time, the plotting of data points has been kept basic and simple.  There are expected future additions and alterations to the chart sizes and the 'flagging' of specific data points.  We would like to consider this work as an initial step towards further development.  It now may be of interest to the user, presented in the next section, as to how the psychrometric chart is constructed and programmed for the Excel application.

### 2.2. How is the Psychrometric Chart reproduced?

The Psychrometric Chart in common use is a graph of the equation of state for moist air plotted on a sheared coordinate system (Palmatier, 1963). The independent variables are enthalpy plotted as the x-coordinate, and humidity ratio as the y-coordinate. The graph is sheared parallel to the x-axis. As a consequence, lines of constant enthalpy slope downward from left to right and lines of constant humidity ratio are horizontal.

An equation of state is a relationship between state variables. In thermodynamics, it is an equation describing the state of matter, in our case, moist air. Given the state, variables such as pressure, temperature and volume follow. Indeed, the system has two degrees of freedom and any two of these variables determine the state and thus, fix the other quantities. So, a change in one variable is balanced by a change in other variables in the absence of any external influences. The variables change such that the equation of state is satisfied. For example, the ideal gas law ($PV = nRT$) is the equation of state relating pressure (P), volume (V) and absolute temperature (T). If T increases, P or V or both increase to satisfy the law. Note that specifying any two of the variables determines the third.

The gas we are concerned with here is moist air, which is a mixture of dry air and water vapour. As the thermodynamic properties of air and water vapour differ, their combined properties vary according to humidity ratio. This is represented by an extra state variable, the humidity ratio. So, for moist air, its properties are fixed by specifying three state variables, and in the case of the psychrometrics, these are chosen to be pressure, enthalpy and humidity ratio. Enthalpy is useful in engineering applications, because at constant pressure it represents the quantity of heat that flows into or out of a system. In our application, we are concerned with wet- and dry-bulb temperature and humidity.

The Psychrometric Chart is a graph of the thermodynamic properties of moist air at a constant pressure or elevation above sea level; a different chart applies at different pressures. However, although a chart is based on a given air pressure, say, standard pressure at sea level, it is common to use this chart at elevations from sea level up to 600m. As the pressure for a particular chart is fixed, it remains to choose enthalpy and humidity ratio to fix the state.

The chart is drawn using enthalpy and humidity ratio as the independent variables. Equally, one could specify wet- and dry-bulb temperatures or relative humidity and dry-bulb temperature, so fixing the other variables. However, as our purpose is to construct a Psychrometric Chart, we need to work in the underlying coordinate system of enthalpy and humidity ratio which are plotted linearly on two axes. Data to construct the chart are taken from Table 6.2 in (ASHRAE, 2005).

The axes of the chart are linear, but they are not orthogonal. Instead, the graph is sheared horizontally as shown in Figure 5, so that points further above the x-axis are displaced increasingly to the left.  The horizontal shear of the chart is chosen such that the point representing 50°C dry-bulb temperature and 100% relative humidity is vertically above the point representing 50°C dry-bulb temperature and 0% relative humidity. As a result of shearing, a vertical line represents the 50°C dry-bulb, line although it deviates imperceptibly. Lines of lower dry-bulb temperature are also close to vertical, but lean slightly to the left.

From any point on the chart, one can trace six lines: a constant humidity ratio line, an enthalpy line, dry- and wet-bulb temperature lines, a relative humidity line and a constant volume line. By extension, the chart shows the properties of moist air as families of lines of constant humidity ratio, enthalpy, dry bulb temperature, wet bulb temperature, relative humidity and density. The humidity ratio and the enthalpy lines are the only straight lines on the chart. The wet- and dry-bulb temperature lines are almost straight and the relative humidity lines are distinctively curved.

Tracing along a particular line, one crosses the other lines. For example, tracing along a humidity ratio line, one crosses lines of enthalpy, dry and wet bulb temperatures, relative humidity and density. One can see that as the enthalpy increases, so do the dry- and wet-bulb temperature, but the relative humidity and air density decrease.

The ASHRAE Psychrometric Chart No. 1 shows all six families of lines. However, in our applications, we are mainly concerned with four families: the constant humidity ratio family, dry- and wet-bulb temperature families and the relative humidity family. Also shown on the chart are the summer and winter comfort zones.
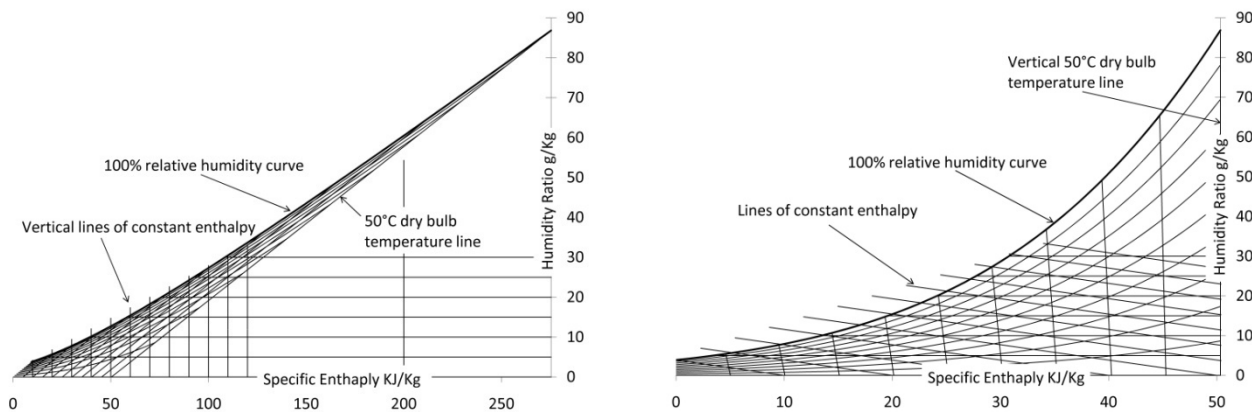


**Figure 5: The psychrometric chart before and after shearing**

The program uses either pairs of dry- and wet-bulb temperatures or pairs of dry-bulb temperature and humidity ratio as a table of data on a worksheet. These are converted to enthalpy and humidity ratio by lookup and interpolation from Table 6.2 in ASHRAE (2005). The values are then sheared and plotted on the chart.

Plotting points on the chart is a two-step computation. The first step is to determine the enthalpy and humidity ratio from the given parameters and the second is to apply the shear to these values to locate the point on the graph. For example, given dry-bulb temperature of 20°C and relative humidity of 40%, the enthalpy is 35.09kJ/kg$_{da}$ and humidity ratio is 5.9g$_w$/kg$_{da}$. (These quantities are relative to the mass of dry air, kg$_{da}$, involved). These figures are determined by interpolation from Table 6.2 in (ASHRAE 2005). In the second step, the humidity ratio can be plotted using this value as the y coordinate, but the enthalpy value needs to be reduced in proportion to the humidity ratio to give the x coordinate. We wish to ensure that the temperature-enthalpy point 50°C, 275.343kJ/kg$_{da}$ which is fully saturated and carrying 86.858g/kg moisture is plotted vertically above the dry air point 50°C, 50.326kJ/kg$_{da}$. The x-coordinate is calculated from:

$$x = h - -h_s - h_{da}w/w_s$$  1.

where

$h_s = 275.343\text{kJ/kg}_{da}$ – enthalpy of moist air at 50°C per kg of dry air
$h_{da} = 50.326\text{kJ/kg}_{da}$ – enthalpy of dry air at 50°C per kg of dry air
$w_s = 86.858\text{g}_w/\text{kg}_{da}$ – moisture content of fully saturated air at 50°C per kg of dry air

## 3.    A CASE STUDY USING THE DATA

A case study is presented here to illustrate a few applications of how collected data points can be combined on the psychrometric chart.

### 3.1  Comparing with different set of data
In the example of Figure 6 below several points of exterior temperature are compared with those of internal air temperature in an ice-rink.  The interesting point here is that the interior temperatures contain the same amount of water (moisture) or absolute humidity as the external air temperatures.  This implies that only a sensible heating (one not requiring a change in water content) is required to bring the outside air to the internal condition.

The next graph is one taken at a totally different location in the building (Figure 7).  This graph shows the interior air under a different set of conditions where there is a difference between the moisture content (absolute humidity) and the external air.  In this case, both the external and internal air temperature may be unsuitable for the desired interior conditions.  Heating and humidification of the internal and external air may be necessary to make the internal conditions suitable: not too dry when heated and with a reasonable humidity.
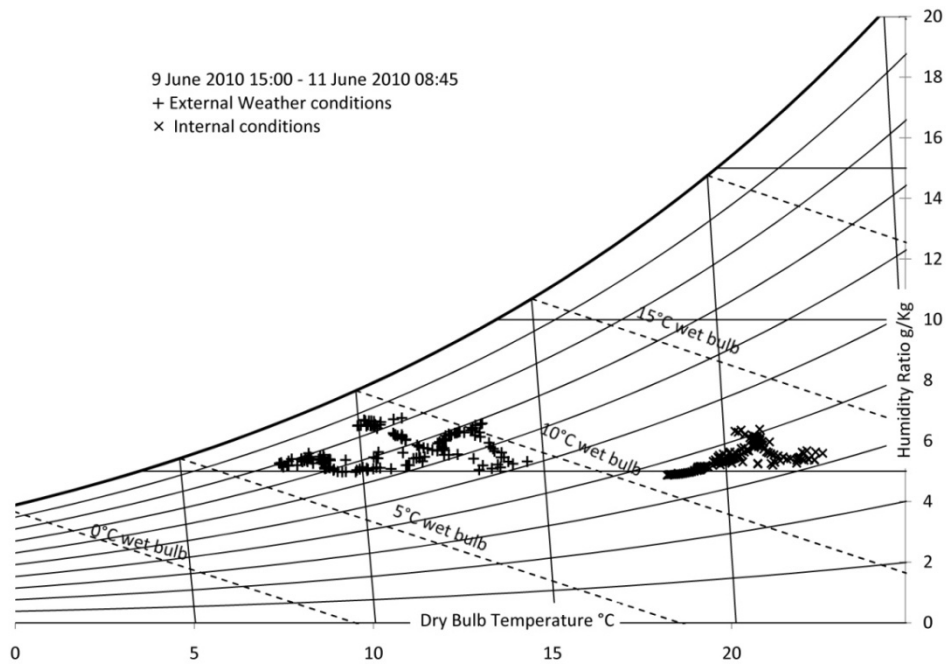
**Figure 6  Plotting a set of external vs. internal points on the psychrometric chart**
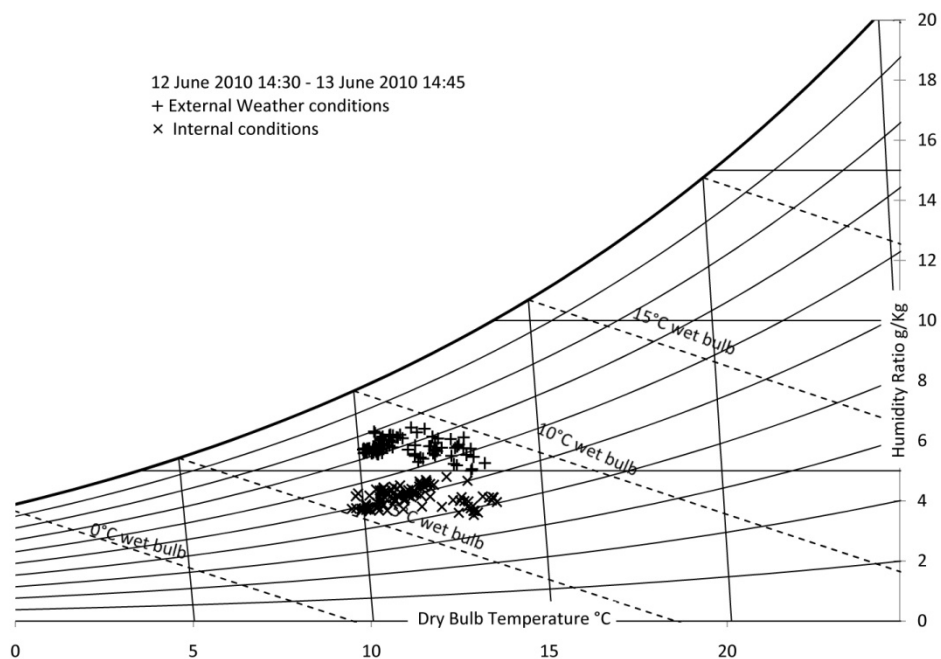


**Figure 7  Interior and exterior data points plotted with different absolute humidity**

Comparing the two plots in Figures 6 and 7 shows that the external weather conditions are similar, but the internal conditions differ at different places in the building. On the psychrometric chart, the differences in air quality (moisture content and temperature) are immediately evident. Furthermore, the comparison shows different conditioning strategies need to be used at different locations in the same building.

### 3.2 Plotting selective points or locations
One of the problems with the psychrometric chart is that it does not show time.  In this case, a series of points within the building are shown as in Figure 8.  For a specific time period the points are plotted on the chart.   The location of these points needs to be associated with a section and plan to appreciate the data point fully. Several points are provided within the space as well as externally, indicating quite a range of variability within the interior air itself.  The conditioning requirements of the external air may not be needed in order to obtain the internal requirements of some locations.
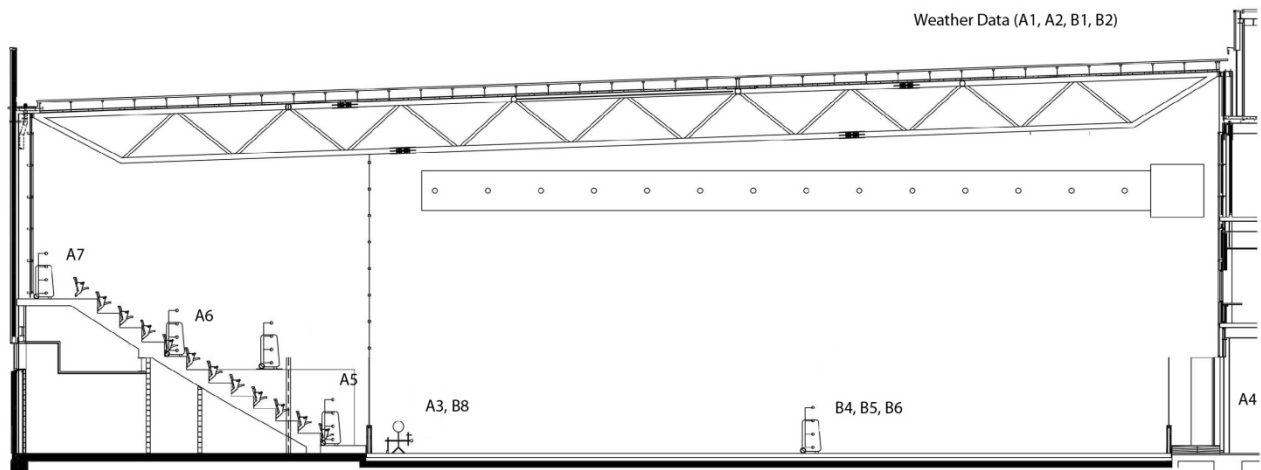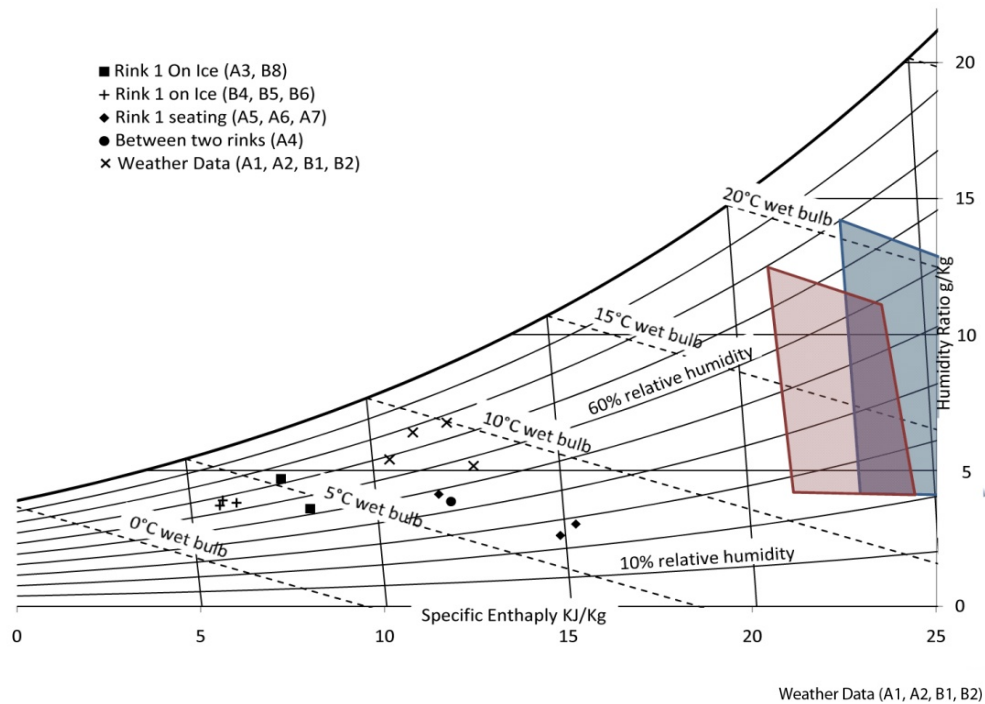
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**Figure 8 Plotting individual exterior and interior points around a specific time period**

## CONCLUSION

The psychrometric chart and its usefulness is becoming increasingly forgotten among the architecture profession. It is appropriate that students of architecture, in a period of environmental hybrid conditioning of buildings realise how helpful and important the chart is in helping them to understand what potentials there are to conditioning their buildings. The plotting of psychrometric data of a particular climate is the first step in becoming aware of the design conditions or constraints. It should be a precursor to any design approach and could even become a design concept generator when an understanding of our external climatic conditions is fully understood and appreciated.

The authors of this paper felt that there is a need among architecture researchers to take single or multiple points and plot them onto the psychrometric chart. A niche has perhaps been filled to provide users with a simple tool for plotting data points and the comfort zone onto a psychrometric chart. Future work is expected to make the program more flexible to the user, allowing for variable 'comfort zone' and chart ranges, as mentioned in this paper.

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