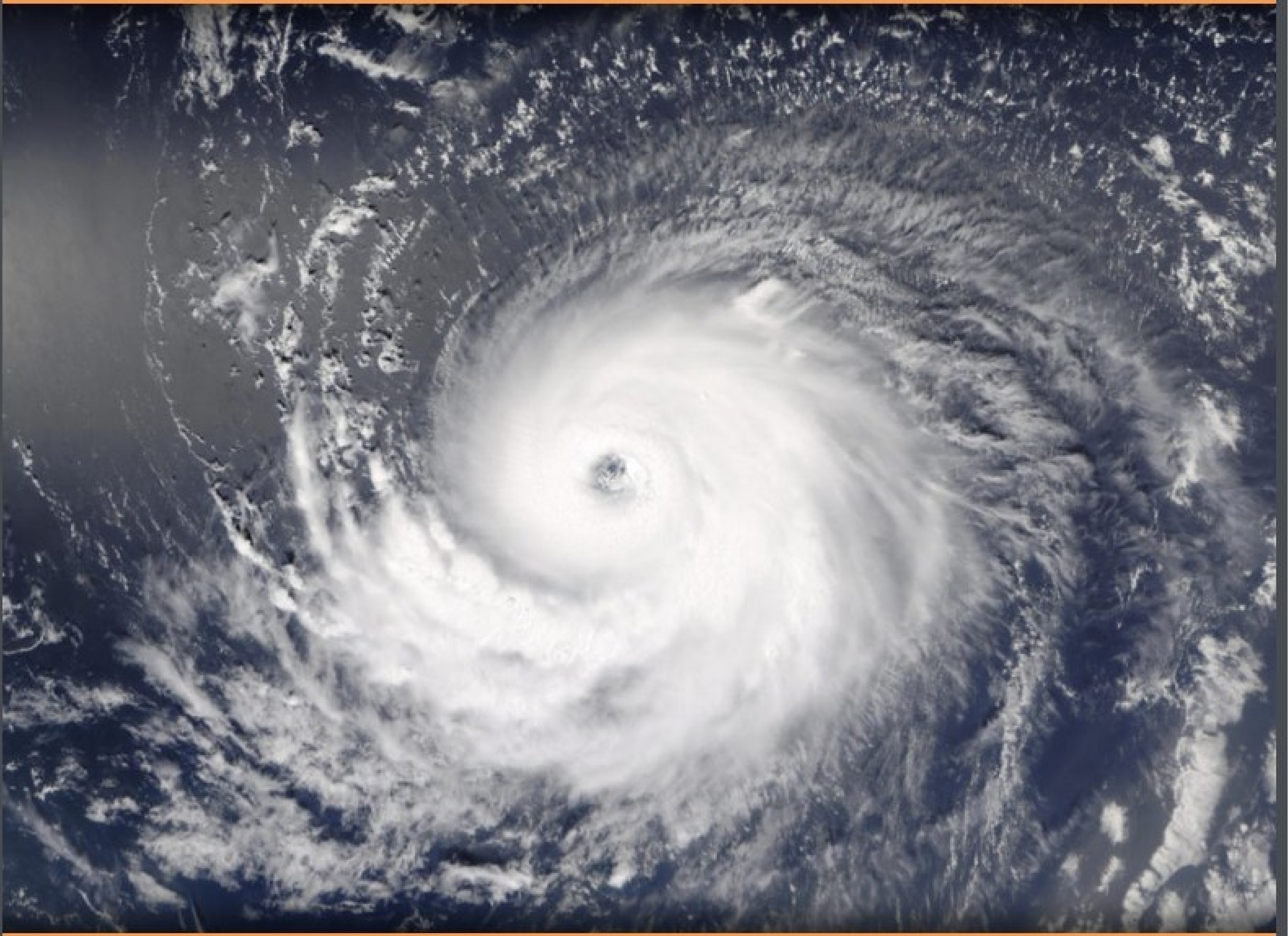
bookboon.com

A Wet Look At Climate Change

Hurricanes to House Mites

Dr. Peter Moir



Dr. Peter Moir

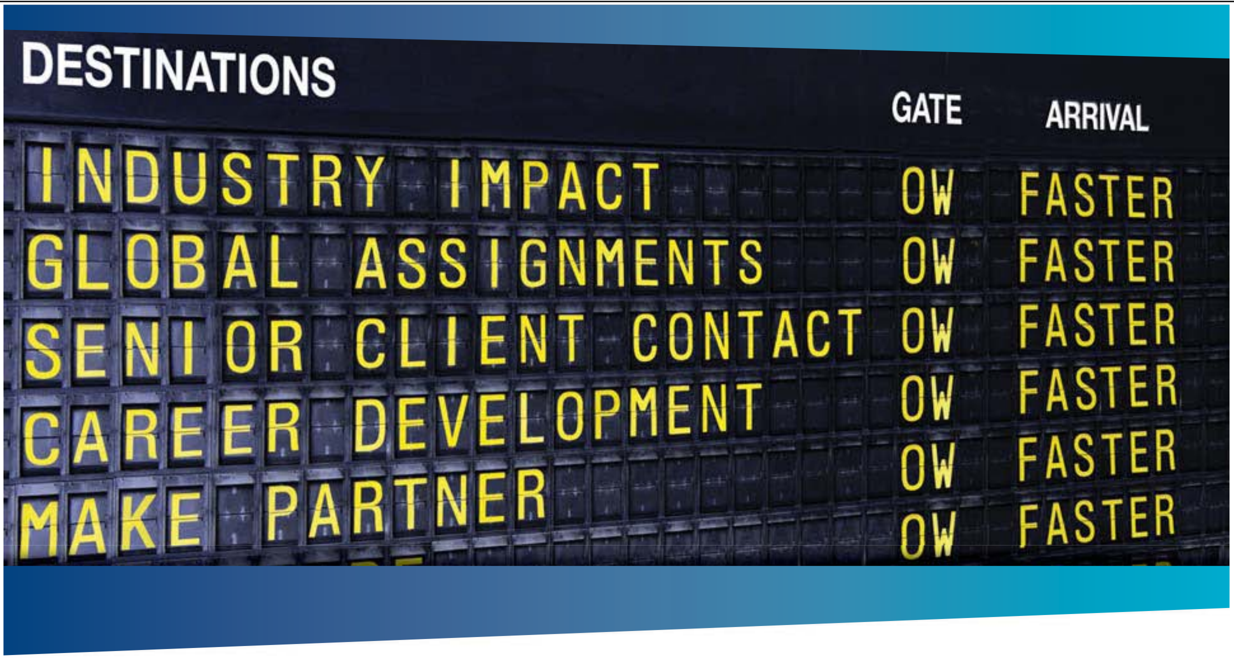
A Wet Look At Climate Change

Hurricanes to House Mites

A Wet Look At Climate Change: Hurricanes to House Mites

ISBN 978-87-403-0063-5

Contents


DESTINATIONS
GATE
ARRIVAL
INDUSTRY IMPACT OW FASTER
GLOBAL ASSIGNMENTS OW FASTER
SENIOR CLIENT CONTACT OW FASTER
CAREER DEVELOPMENT OW FASTER
MAKE PARTNER OW FASTER

Acknowledgments

Cover design by Yellow Branding and Digital Media Ltd. - www.yellowdesign.tv
Cartoons by Máirin Grant – mairingrant@yahoo.com
Matt Cartoons, The Daily Telegraph

My friends and close associates Andrew Lake, Larry Glick and Stuart Allcock who in that order suggested I write a book. I thank you greatly as I did not really think I would get this collection of thoughts, ideas and experiences together.

This book is for people who like me struggle with maths but appreciate why we must use it. I have done my best to keep most of the complex equations out of this book and present the more difficult concepts in a readable form. I only achieved this by trying out different approaches in front of classes of secondary level students for which I thank Mike O'Sullivan of St. Augustine's College who made it possible and even invited me back.

To Sarah, who has no mean task having to live with my obsession.

Introduction

I do not want to mislead you into thinking this book is about global warming and its part in climate change. My hope is that I can talk to you using mostly simple terms and common experiences about certain properties of water, how these are affecting us all, and where climate change has a role in ongoing problems.

I will describe and explain some properties of water that you need to know to understand how water and air interact in a predictable way. Using this knowledge, you can gain an understanding of not only why and how global warming is affecting climate, but also be able to explain many other things you will have seen in daily life and probably never really thought about.

At this point, I should issue a warning that this subject can become a bit obsessive. You could find yourself wandering around saying to yourself, "so what's happening to the moisture here and why's it doing that?" Over more than ten years I've been asking myself that question and it's led me into all sorts of areas. Literally, from hurricanes to house mites, such is the diversity of the subject and all explained on some fundamental properties of water.

I suppose it's only natural that as our bodies are largely made up of water and it is essential for life on our planet, there is a lot going on with water in our everyday lives, most of which we fail to appreciate or begin to understand. We are all of course familiar with the destructive force of water in floods, but there are unseen forces involving water vapour that influence our well being, both positively and negatively.

After having lived a career in science and related subjects, I have kept my interest in science not just in my own work areas but in science generally. Along the way I have picked up useful tips and thought processes and have tried to pass these on by building some of them into the chapters as they progress.

This is not a traditional text book. It is more about looking at things differently and that includes the silly cartoons. I hope you enjoy this trip into the world of moisture.

1 Relative Humidity

In the context of this book, the most important property for us to grasp is what it really means when we use the term ‘Relative Humidity’. The best way here is to deconstruct the two terms starting with ‘Humidity’.

Humidity

Our common experience of humidity is based on climate. Depending on where you live and the local climate, or if you have been lucky enough to have gone somewhere warm on holiday, you have most probably at some point said or heard somebody say “it’s humid”. If it gets more humid than is comfortable, we hear this described as “muggy”. These terms describing the climate are our perception of a key property of water. Whether we can see it or not, the air contains water.

How much water there is in the air depends on one very important factor and that is temperature. However, our common experience of warm or hot days that are not humid, tells us that it is not simply an increase in temperature that leads to muggy weather. As we will explore in this chapter it is not simply the temperature or the amount of water that is the answer. What we need to consider is how much water the air can hold and that is totally dependent on the temperature. When thinking about humidity, and I cannot state this strongly enough, **you must always consider the temperature!**

My first dramatic experience of a humid climate that went way beyond ‘muggy’ was in August 1987 when I was sent by the company I was working for at the time to an international conference at Cold Spring Harbor on Long Island. I arrived at JFK airport, hired a car and drove to the conference. Arriving in the car park I stepped out of the air conditioned car at Cold Spring Harbor and was blasted by a wave of heat. A truly unforgettable first for me. My colleagues had warned me, “August, Cold Spring Harbor, the humidity should be fun”. The daily 4pm thunderstorms were quite fun as well, as was the sweating all night in the accommodation without air conditioning.

An experience like this brings home to you the close association between temperature and moisture. Also, the thunderstorms tell you that there is a lot of energy being generated and moved around in the air. Walk into a sauna and feel the heat, then throw some water on the hot stones and you will quickly learn about ‘heat transference’.

So, the ‘Humidity’ part of “Relative Humidity” has to do with the amount of water in the air. This can be referred to as ‘moisture’ or, to be more precise, ‘water vapour’. We are all familiar with water vapour in many ways; two common experiences are steam from boiling water in a kettle, and clouds, either up where they usually are or down here at ground level as mist.

The term ‘Humidity’ is used loosely on weather forecasts where often the ‘Relative’ part is dropped. If humidity describes the amount of moisture in the air then what has the ‘Relative’ bit got to do with it and where does temperature fit in? This is where it gets a bit more tricky but it is absolutely essential to understand why ‘Relative’.

You will hear and see on weather reports that humidity is given as a percentage (%). This is where the ‘Relative’ part comes from. One scientific fact that you must know first, and please commit this to memory, **air can only hold a certain amount of water vapour**.

Common experience tells us that when clouds have built up, and keep building up, at some point it rains. That is, the air cannot hold any more water vapour and droplets are formed that are heavier than air and fall to earth.

The maximum amount of water vapour that can be held by air is called 'Saturation'. This is covered in more detail in the next chapter. To understand how saturation influences humidity, imagine you are in a room 5 x 5 x 5 metres in size and the temperature is 21°C. The air in the room could hold about 9kg of water vapour and would be saturated. If that amount of water vapour was present, you would soon be damp and feel uncomfortable. Let us now half the amount of water to 4.5kg and this would give 4.5/9.0 resulting in a 'Relative' amount of water equivalent to half, or 50% as a percentage, to what it would be at the saturation level. Now you are sitting in this room at 21°C and 50% Relative Humidity (or 50% RH), a much more comfortable environment.

Relative Humidity

So, 'Relative Humidity' is a measure of the *actual* amount of water compared to the amount of water there would be at saturation and expressed as percentage:

$$\%RH = \frac{\text{actual amount of water vapour}}{\text{maximum possible amount of water vapour}} \times 100\ \%$$

Unfortunately, as with so many things, it's not that simple. Remember? **You must always consider the temperature!**

Here is the tricky bit I mentioned; a scientific fact is that **the amount of water vapour that air can hold at saturation is strictly dependent on the temperature.** As temperature increases the amount of water vapour air can hold also increases. This ties in nicely with our experience of being in a humid climate. It has to be warm and there has to be a source of water, such as the sea, a lake, rain or any combination of these.

Air and Humidity

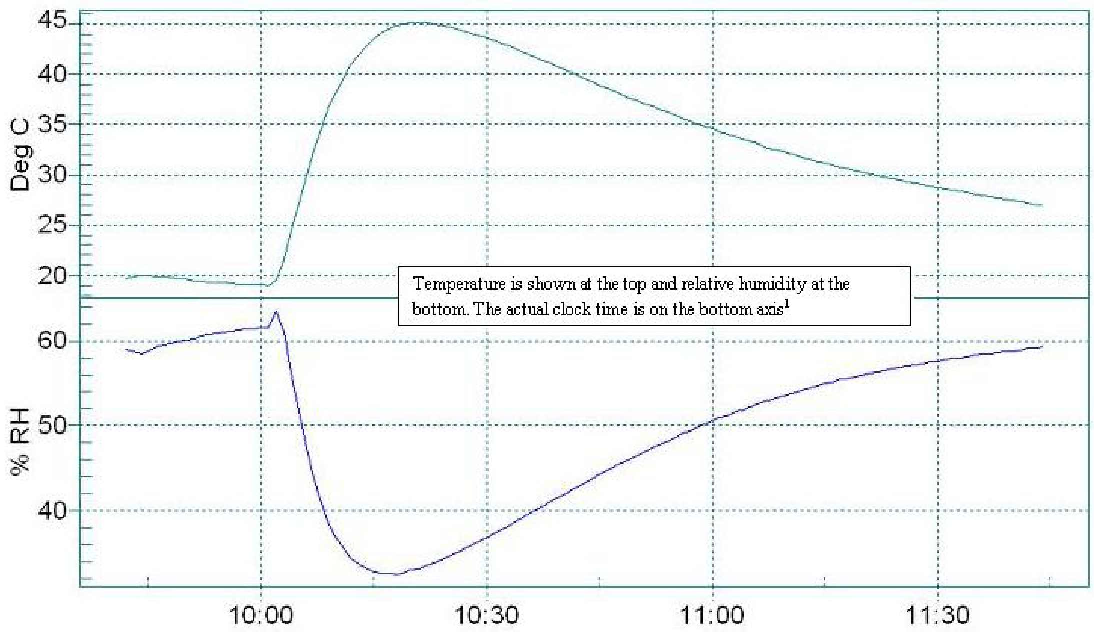
Now there is a further rule of nature that has to be obeyed; **warm air holds more water than cold air!** Quite a simple rule but it explains so much. A simple example, to get you started on exploring the world from the perspective of humidity, is where you get a rain shadow on one side of a mountain. The NASA satellite picture below of the Tibetan plateau appears on a Wikipedia page as an example of a rain shadow:

At the top is the Tibetan plateau which is arid. This is because the Himalayas mountain range, running across the picture, causes the rain to fall on the side of the mountain at the bottom of the picture. We are told that this occurs because the moist warm air is pushed up by the mountains and the water condenses as it cools with altitude causing rain to fall. This explanation tells you how and where the rain shadow occurs but not why.

Using your new knowledge of water vapour you can complete the story be saying that as the air cools it cannot hold as much water (because of the above rule) and this results in condensation and rain. The point where no more water can be held by the air is the 'Saturation Point'. Since the Himalayas are so high, the drop in temperature lowers the saturation point so much that little water is retained and dry air of low relative humidity flows over the top of the mountain depriving the leeward side of rain.

It is easy to demonstrate the strong relationship between temperature and humidity by measuring relative humidity and then heating the air. I first publicly performed such a demonstration during a talk I give to local schools entitled "What is Science?" where I decided to give a series of these talks on an ongoing basis to encourage students to go on and take science subjects.

I use a closed container with a built-in temperature/humidity probe (measuring device) that displays via a laptop the actual temperature and relative humidity of the inside of the container. By applying a small amount of heat to raise the internal temperature by a few degrees the response is an immediate change in the relative humidity and this is what you see:



Temperature is shown at the top and relative humidity at the bottom. The actual clock time is on the bottom axis[1]

At the start the temperature is about 20°C and relative humidity is around 60%. I applied external heat and of course, the temperature, the top line on the graph, can be seen to rise. The %RH immediately begins to fall. As part of my talk, I let the demonstration run for a few minutes and ask the students to explain why the relative humidity drops as the temperature increases. In the graph above I have shown what happens when you let the test run until the temperature and humidity return to about where they started.

Armed with the information above you should be able to work out why in the graph you see almost a perfect symmetry. Have a go and see if you agree with my explanation that follows:

---

[1] Moir, Peter D. A New Approach to Equilibrium Relative Humidity Testing for Moisture Sorption Studies in Pharmaceutical Product Stability. Tablets and Capsules May 2007; 5(4): 18-25.

Three key bits of information are required; a) warm air holds more water than cold air, b) as temperature increases the amount of water vapour air can hold increases and c) Relative Humidity is a measure of the actual amount of water compared to the amount of water there would be at the saturation point.

The key to understanding the symmetry of the graph is remembering that the amount of water does not change inside the container. So, as the temperature changes and consequently changes the saturation point, the amount of water relative (as a percentage or ratio) to what **could be** held at saturation must also change up or down depending on whether the temperature goes up or down.

A fuller explanation: As we heat the container the internal air warms up and because warm air can hold more water vapour it has a higher saturation point. Since the amount of water in the closed container does not change, then the amount of water vapour **relative** to the saturation point must decrease as the saturation point increases. Just as with the clouds rising up the mountains, as the temperature drops the saturation level decreases and the relative humidity must increase. At the point the temperature starts to decrease the opposite happens and the relative humidity increases.

In fact, if we continued to cool the container, the relative humidity can be increased to the saturation point and we would get condensation inside the container.

Immediately some common experiences come to mind; condensation on windows and walls on a cold night, condensation on surfaces in a kitchen where steam comes in direct contact with a surface, kitchen and bathroom windows getting steamed up. These observations can all be explained using the above properties of water.

We recently had a bathroom tiled from floor to ceiling and fitted with a new toilet. I almost called the plumber back in to fix a leak from the new toilet as we had water collecting on the floor. As I discovered, water vapour from showering was condensing on the cistern of the toilet and running down around the soil pipe and onto the floor behind the toilet. The toilet is against an outside wall and was also attracting condensation and this led to a pool of water on the tiled floor.

Two compounding factors led to the problem; this started in winter where cold water from the storage tank was filling the cistern and because it was cold outside the bathroom windows were closed. In other words, we had a box full of water vapour and some cold surfaces. The air above the cold surface cooled and this increased the humidity to saturation, causing the water to condense onto the cistern and tiles. I talk more about houses and humidity in the next chapter.

Exactly the same principles apply on the large scale and are the reason why the international community is so worried about global warming. As the Earth's atmosphere warms up, as you now know, it is capable of holding more water due to the temperature affect on the water vapour saturation level. This means that the air around the globe has a higher capacity for holding water and moving it around from one place to another. Vast amounts of water are involved and this is causing changes to the landscape, creating and expanding lakes and rivers and at the same time causing drought in other areas.

In this chapter I have used the term 'saturation' and in the next chapter I explain its importance for understanding more about some common experiences.

2 Saturation

If you have ever been caught in a downpour or had to walk a distance in the rain you say “I’m soaked through” or “I’m saturated”. In this state, your clothes cannot hold any more water and you have water dripping off you. The same thing happens with air when there is so much water vapour that water droplets are formed. This is the ‘saturation point’ of air and what happens next largely depends on temperature.

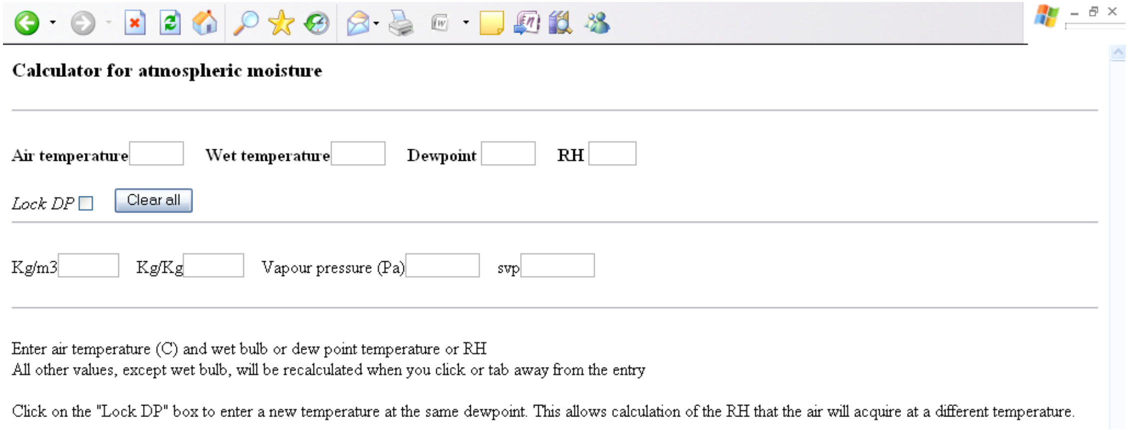
It is not within the scope of this book to discuss all the different events that could occur in this situation. Plenty of information is available on reputable internet sites and in television documentaries. The BBC did an excellent documentary “Rain” (April 2009) that explained some of the science, well worth a look.

The scientific term used for saturation is the ‘dew point’ and is expressed as a temperature. At the time of writing, my local weather conditions are 11°C, 82% RH and a dew point of 8°C. If the temperature was to drop, as you now know, the relative humidity will increase and when the temperature reaches 8°C it will be 100% RH (dew point), the air will be saturated and water droplets will form.

This is exactly what has happened when you see dew on the grass.

The cool surface of the ground has caused the air above the ground to reach its dew point and water droplets have condensed onto a convenient surface, the blades of grass. Lifting of the dew from the grass is the reverse and requires an increase in temperature that is large enough to reduce the relative humidity of the air above the ground. This raises the saturation point and allows water vapour to enter the air by evaporation.

A dew point can be calculated for any combination of %RH and temperature and there are on-line calculators freely available for download that will give you the dew point if you input temperature and relative humidity values. The one I have used for many years is a simple calculator created by Tim Padfield.



Calculator for atmospheric moisture

Enter air temperature (C) and wet bulb or dew point temperature or RH
All other values, except wet bulb, will be recalculated when you click or tab away from the entry

Click on the "Lock DP" box to enter a new temperature at the same dewpoint. This allows calculation of the RH that the air will acquire at a different temperature.

There is a great line in one of Tim's articles,

"Humans are not good at estimating atmospheric water vapour"[2]

---

[2] The potential and limits for passive air conditioning of museums, stores and archives, Padfield, T., Poul Klenz Larsen, Lars Aasbjerg Jensen and Morten Ryhl-Svendsen 2007.

This was prompted by a person who was responsible for looking after archived military material and decided at certain times of the year to open the windows to reduce the humidity. Unfortunately, the outside humidity was higher than the archive room!

I will stick with the concept of 'saturation' rather than use the term dew point. I think it is easier to apply our new knowledge to every day situations since saturation (being saturated) comes from common experience. Here is a very common example; how do

you in winter decide whether or not to hang your clothes out to dry? One approach is to say to yourself "Doesn't look like rain" and then hope it doesn't.

One day you hang the washing out in the morning, it does not rain as you hoped but you come home to find that it is just as wet as when it was hung out. The following day, the weather forecast is better, but the day does not look much different. However, rather than increase your carbon profile by using the tumble dryer, you hang the washing out again. This time when you get home, your clothes are not completely dry but good enough to air off in the house. So, what is the difference?

Before providing you with a possible explanation, I have to admit to having a weather station in the garden fitted with a remote temperature and humidity sensor. As I said in the introduction, this world of humidity can get a bit obsessive. The first thing we do before hanging out washing is check the outside relative humidity reading and see if there is a chance of any sunshine. If we see low temperature with high humidity and no chance of sun, we say "snowball's", not that we would be expecting snow (a rare enough event in this part of Ireland) but that, to get the washing dry, stands a "snowball's chance in hell"!

"Clouds are having a fun day out"

Let us say on the first day in the example above we have 7°C and 95% RH in the morning. This level of humidity is very close to saturation (100% RH) and in fact is less than 1°C above the dew point. You would not put your clothes somewhere wet to dry, obviously, and, as explained above, the air at 95% RH is nearly full of moisture. If the daytime temperature drops slightly or stays the same your clothes are simply not going to dry.

On the second day, the daytime temperature increases by 2-3°C and, although it is still overcast and not feeling pleasant, the humidity has dropped to 70-80% RH and this allows some drying to occur, particularly if there is a very slight breeze. A slight breeze, every now and then, displaces the near saturated air above the wet clothes and allows evaporation of the water in the clothes into the air above. These small differences on the second day you may not notice because, as far as you perceive from the atmospheric conditions, it is not a nice day, a bit chilly and certainly not "a good drying day", but these small changes make all the difference.

The problem with cold weather is that it takes very much less water vapour to push the humidity way up. Using a moisture calculator such as the one above produced by Tim Padfield, the actual amount of water vapour can be calculated. This allows us to compare the amount of water in the air for different conditions of temperature and humidity.

Taking 90% RH as an example, I compared my local temperature of 11°C to Orlando, Florida, 22°C, on the day of writing. Using Tim Padfield's calculator I put in 90% RH and 11°C, noted the "Absolute Humidity", and did the same for 22°C. The table below shows the absolute humidity converted to the amount of water in grams per cubic metre. The right hand column of the table shows the difference as a ratio (17.37/8.98) of the two conditions compared to my home location:

Location	Amount of Water at 90% RH (g/m3)	Ratio
Dungarvan, Ireland	8.98	-
Orlando, Florida	17.37	1.93

You can see that you need to have nearly twice as much water in the air at 22°C to reach the same humidity as at 11°C. Or, to look at it the other way round, if your washing was hanging out at 11°C and 90% RH, it will not dry, but if the sun came out and shot the temperature up to 22°C, this would reduce the humidity to 45% RH and you would have no problem getting your clothes dry.

This works even though it is the same amount of water vapour in the air! Interesting observation do you not think? Take a few moments to understand why this is and if you are stuck, the answer is in Chapter 3 where I talk about Equilibrium Relative Humidity, something you will not hear about on the weather forecasts.

Now that you have seen that temperature has a big affect on humidity, and have had a look at some common experiences, hopefully you are beginning to get a few new insights. Let us consider an application that you will know about, but I want us to look at it from a different perspective. Imagine you have never heard of 'air conditioning', in fact, let us imagine it has not yet been invented but you have this idea. Your idea is based on the fact that people are feeling uncomfortable in humid weather and you are going to invent a machine to turn warm moist air into cooler, drier air and make your fortune.

Using your knowledge of temperature and humidity, or from the simple observation of clouds travelling up and over mountains causing rain because of condensation, you have at the heart of your new machine a thing called a 'condenser'. Simply pass the warm moist air through the condenser where it is cooled and releases water to give drier cooler air for everybody to enjoy. We will not worry about what to do with the condensed water for now but take out the patent, put your feet up and retire happy.

Unfortunately, it is never that easy. Instead of people singing your praises your customers are complaining that they are getting skin complaints and having to use large amounts of moisturiser. This is because we, as biological entities, have a very close relationship with humidity. Personally I am quite happy on a sunny day at 25 -30°C with middle of the scale humidity. I am definitely uncomfortable with these temperatures at 85% RH or higher. This is the 'muggy' weather I talked about earlier. Living on the coast in Ireland I do not have too many days of the latter to worry about and would like a good few more of the former!

At the other end of the humidity scale, I have seen people in offices and in pharmaceutical facilities that have dry, sometimes flaky, skin because the humidity must be kept low to protect the drugs during manufacture. An air-conditioned, low humidity working environment may not necessarily feel uncomfortable but there are consequences for continuously losing moisture from our bodies. I talk more on the subject of humidity and human health in Chapter 5.

The breath that we breathe out is saturated with water vapour, so we lose water on every breath. You only commonly see this on cold days because, as you now know, at low temperatures the saturation point of the water vapour is much lower. As you breathe out, the air carrying water vapour out of your body cools rapidly. This, of course, causes condensation and we temporarily 'see our breath' before the 'mini-cloud' is diffused into the mass of air around us and becomes part of the atmospheric water vapour.

Saturation Vapour Pressure

I have put in this small section, and the section following, into separate blocks because the subject matter is much more technical. These two sections do not contain any new concepts or rules that you necessarily need to know about, but it may be useful to be familiar with the terms and their meaning. If you look up information for humidity in books or on the internet you will most certainly come across these terms.

This section on Saturation Vapour Pressure (SVP) contains an equation for calculating the SVP, which clearly shows that the only variable is temperature. According to the Ideal Gas Law, all gases, because they are composed of molecules that have a mass, exert a pressure that can be measured. A common experience of gas exerting pressure is the mass of air around and above us that is called atmospheric pressure and reported on weather forecasts usually in millibars (mbar). The traditional type 'aneroid' barometer that you see hanging on walls uses this pressure to push on a diaphragm that is connected to a mechanism to give a reading.

Fortunately for us looking at the properties of humidity in terms of vapour pressure, water vapour behaves as an 'Ideal Gas'. This means we can reproducibly predict and calculate certain parameters. SVP, just as the term describes, is the pressure exerted by water vapour in air at the saturation point.

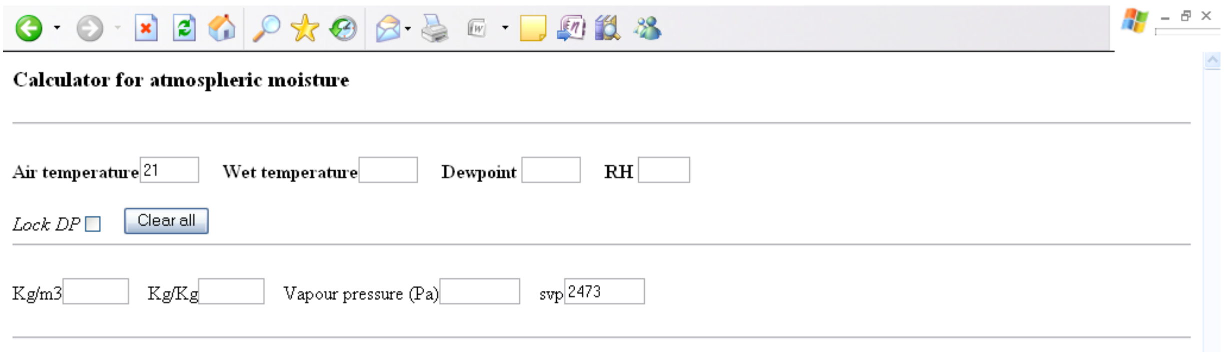
Here is an equation for calculating the SVP. You can see that the only variable is "TEMP". :

SVP = 610.78*EXP(TEMP/(TEMP+238.3)*17.2694)

Remember? **You must always consider the temperature!**

I have written the equation in this form so you can copy it into a spreadsheet and substitute TEMP for a target cell. Enter a temperature in degrees Celsius to get the result for the SVP.

If you use an on-line calculator that displays the SVP, you often see that the SVP is calculated as soon as a temperature value is added as shown in thea picture below. The units of pressure in the example below are 'Pascals', named after a brilliant French scientist Blaise Pascal (1623 – 1661). Dividing Pascals by 100 converts the pressure to mbar (millibar) which gives the SVP at 21°C of 2473 Pa a value of about 25 mbar. Compare this to 'normal' atmospheric pressure of 1013 mbar.



Calculator for atmospheric moisture

Air temperature 21

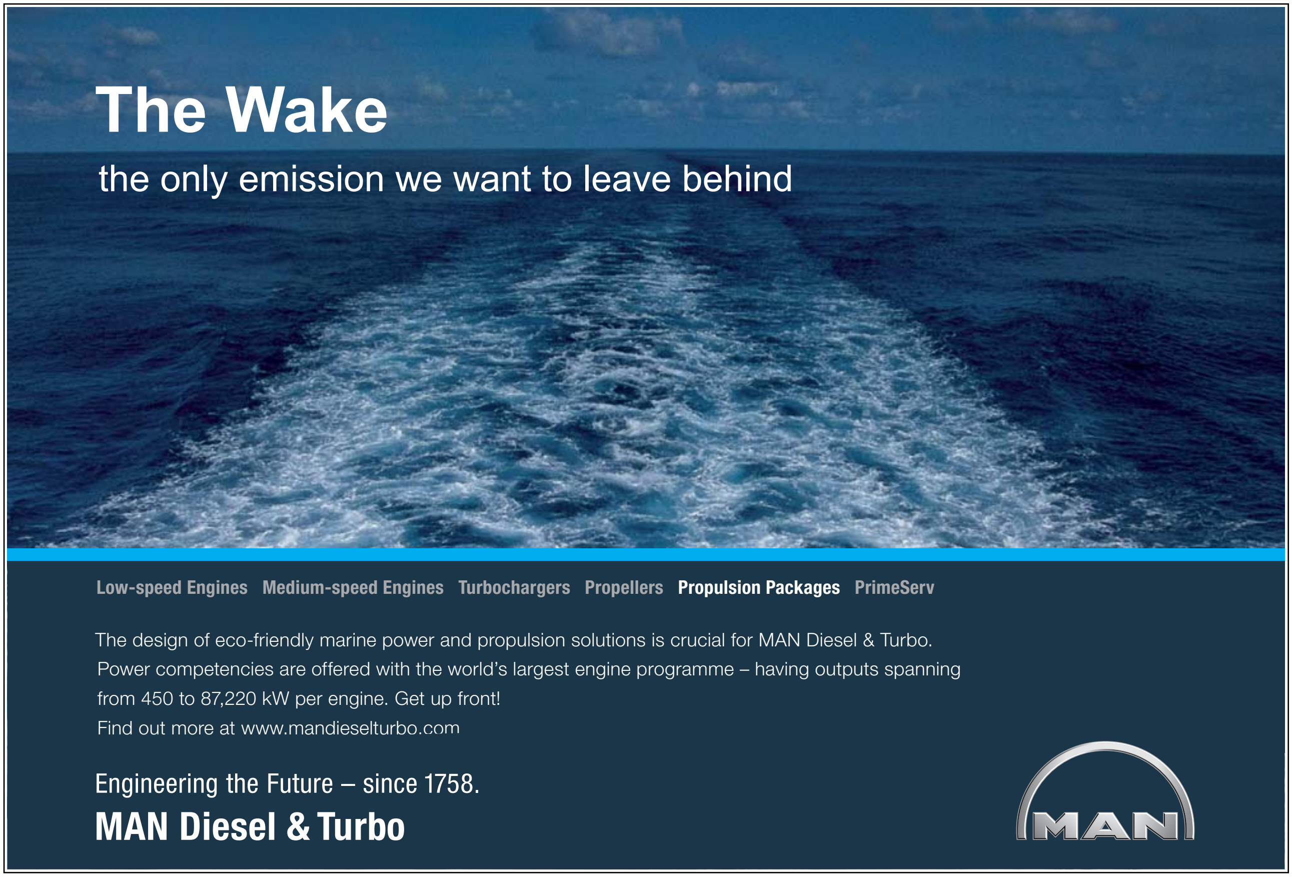
svp 2473

This difference in pressure can be thought of as the difference in the amount of water compared to the air. If you wanted to increase pressure on something you would push harder, "put your weight behind it", or if you wanted to flatten a piece of paper you could put a weight on top. Weight is mass (an amount of something) acted upon by gravity. The pressure or 'weight' of a gas can be thought of in the same way, the only difference being that a gas pushes in all directions at the same time.

Because we have such a large difference between atmospheric pressure and water vapour at the saturation point means that only a small fraction of water is required to saturate air. Every time I think about this I find it fantastic; our planet is just the right distance from the sun (the so called Goldilocks Zone) to allow liquid water to exist; water has properties that means only a small amount can be held in the atmosphere relative to the amount of air. Otherwise, given that about 80% of the Earth's surface is water and it easily evaporates, we would not be human beings breathing air, we would be something akin to fish!

It is this relationship of water and air that drives our climate. Generally, on the global scale, the warm moist air above the sea at the equator moves towards the cooler poles, forms clouds that return the water by way of rain back to the sea. On a more local scale, evaporation from sea, lakes and land redistributes water. This is called the 'Hydrologic Cycle'.

You can perhaps now see a big consequence of global warming. As the temperature increases and pushes up the SVP, we are not short of water to supply the atmosphere and hence the warnings in the media about climate change and to expect warmer, wetter and more extreme weather. The sea will hold onto water more than fresh water because of the salt content, something I cover in Chapter 3 on Equilibrium Relative Humidity. However, there is plenty of fresh water locked up on land around the South Pole, about 85% of the Earth's fresh water, and as we hear regularly on the news, the ice caps are melting.



To finish the section and to show how all things I have talked about so far are interrelated, here is an equation that tells you the same thing as the equation in Chapter 1:

$$\%RH = \frac{\text{VP of water vapour}}{\text{SVP of water vapour}} \times 100\%$$

VP is the **actual** vapour pressure of water and so relative humidity is the actual pressure of an amount of water **relative** to the pressure it would be at the saturation point.

Moving the terms around by simple algebra we can calculate the actual vapour pressure from knowing the temperature, which gives us the SVP and the relative humidity:

$$VP = SVP \times \%RH$$

Having calculated the VP, the actual amount of water present can be calculated. This is not a simple formula so I will not reproduce it here, but this is how the amounts of water were calculated for the table shown in the previous section where I compared my local conditions to Florida. I used Tim Padfield's calculator, of course, and you can see the terms 'Vapour Pressure' and 'Kg/m^3 in the calculator above. I simply entered the temperature and relative humidity values and multiplied the amount of water given in Kg/m^3 by 1000 to turn the value into grams per cubic metre.

Psychrometry

Before the days of digital technology and calculators, in order to work out what was happening in situations where moisture was involved, people had to be familiar with 'psychrometry'. This is not to be confused with the entirely different and modern practice of "psychometry".

There are two aspects of psychrometry that I want to mention. One brings in two new terms that you will come across if you look into humidity in any detail. The other aspect involves the science behind what happens when going from one climatic condition to another.

The Wet Bulb and Dry Bulb

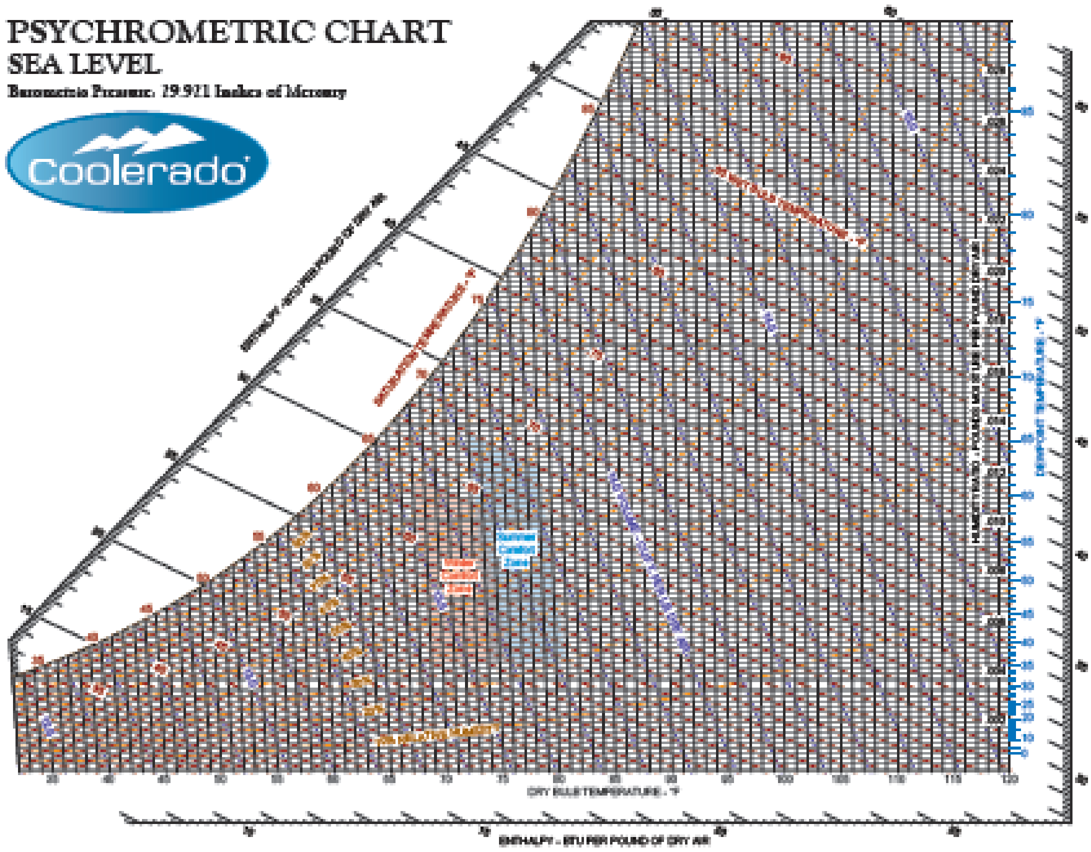
The terms 'Wet Bulb' and 'Dry Bulb' come from the original, and reportedly, the most accurate method of measuring humidity. The 'Bulb' part is the bulb at the end of a thermometer that holds the reservoir of mercury. Two thermometers are used in the measuring device, called a 'psychrometer', where they are fixed side-by-side. One of the thermometers has a thin piece of muslin wrapped around the bulb, which is wet with pure (distilled or deionised) water, hence, the term 'Wet'.

The psychrometer is waved in the air which causes the water on the wet bulb to evaporate. The amount of water that leaves the wet bulb is directly related to the humidity of the air. At saturation, no water will evaporate from the wet bulb, whereas in dry air, water vapour leaves the wet bulb very quickly.

Just as water evaporating from our bodies cools us down, each water molecule leaving the wet bulb takes a little bit of heat with it and cools the bulb of the thermometer. After waving the psychrometer around for about 20 seconds, the reading from each of the two thermometers is recorded. The Dry Bulb is the actual air temperature that, as you now know from our calculator, can be used to work out the SVP. The Wet Bulb is used to calculate the VP. From these two parameters the %RH is easily calculated as shown above in the section on SVP.

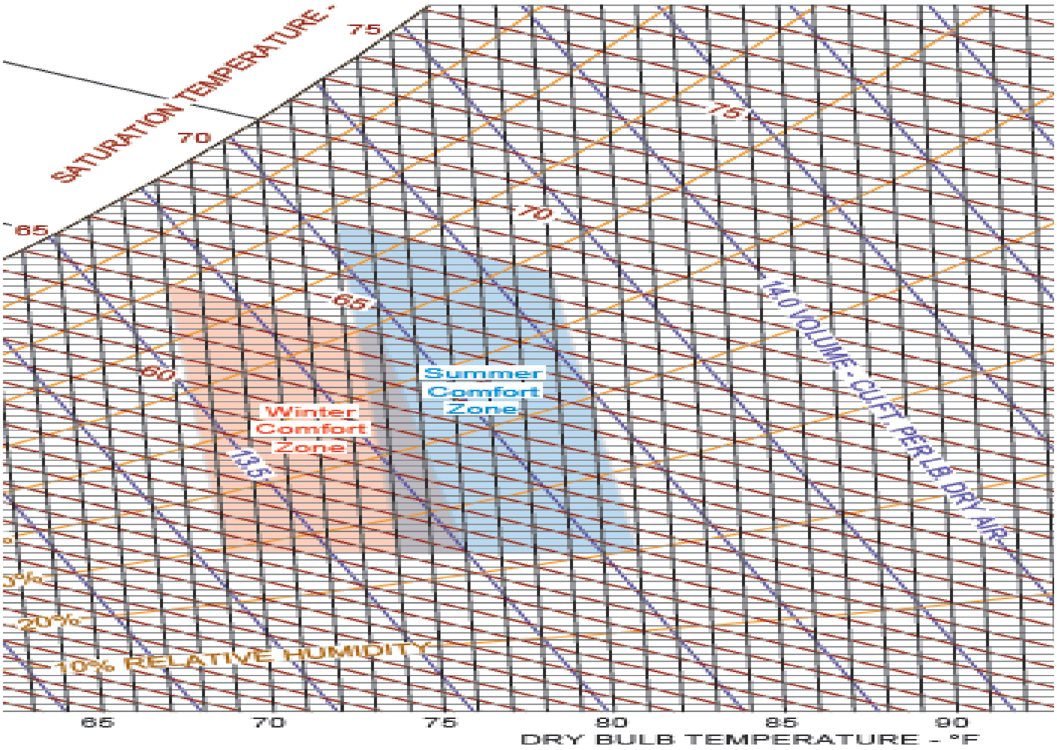
Psychrometric Charts

Psychrometry is used to work out different properties of moisture in air. A tool used for many years by heating engineers is to refer to 'Psychrometric Charts'. A typical application may be to work out what happens when air of a particular temperature and humidity from one part of an air conditioning system mixes with air from another part that has a different moisture content. There are loads of these charts available for download off the internet, as well as online calculators to save having to manipulate charts by hand. I've reproduced the chart below supplied by an air conditioning company as it highlights some important points.



You would not think, by the look of them, that these charts make it easy for people working with moisture parameters. This perhaps gives you an indication of the complexity of the physical chemistry and mathematics of the subject. Note that the title in the top left hand corner includes "Sea Level". Depending on what you are working out, a different set of chart data may be required depending on the altitude as this affects parameters such the actual amount of moisture in a volume of air (purple diagonal line going upwards from the right).

I have expanded a part of the chart, shown below, so you can see the sections labelled “Winter Comfort Zone” and “Summer Comfort Zone”. These zones cover the range of temperature and relative humidity set out in guidelines from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) for air quality within building and homes for human comfort. Although not included in the ASHRAE title, engineers also have to consider ventilation for larger buildings (HVAC) and for designing homes. Of course, the external temperature and humidity have a massive influence on the challenges faced to maintain a satisfactory living and working environment.



The final point I want to illustrate from this chart uses the reddish brown line running upwards and left. If you pick a temperature, say 84°F, let us follow the reddish brown line going left until you reach the “10% RELATIVE HUMIDITY” line as indicated by the white arrows, drop a vertical line down and you can read (approximately) that the temperature is 76°F. Back up again and keep following the reddish brown until you reach the “20%” line and drop down again. The temperature is 70°F. This shows graphically what we learned earlier, that as the temperature decreases the humidity goes up.

Note that on the psychrometric chart we have the terms Dry Bulb and Saturation being used for which you should now have a better understanding.

Remember? Y**ou must always consider the temperature!**

The first time I came across a psychrometric chart in real life was working on a proposal for mapping temperature and humidity around a warehouse. The engineer produced a chart to work out changes to the humidity as a result of a change in temperature. I discovered a new concept from this engineer that a humidity ‘statistic’, or profile, can be calculated for a building based on its size, shape, materials of construction and location.

In Ireland, and particularly on the west coast, buildings are in the front line of moist air driving in off the Atlantic in the prevailing Westerlies. These buildings are at least twice as challenged by humidity than buildings in central England.

If the force of humidity can be measured and quantified to this extent, it makes me wonder about all the new houses built during the last economic boom. Have they been built to deal with only current climatic conditions in mind and will they cope with a greater external humidity challenge brought about by global warming?

An interesting new approach is to build "intelligent buildings" that will monitor the internal relative humidity and adjust the level to within a defined range. This is now possible by the development of accurate and more precise digital humidity measurement that can function to feed back to a humidity controlling device. (Intelligent buildings maybe but remember the archivist with a liking for fresh air!)

I introduce in the next chapter the last concept you will need before we go on to look at how the properties of water vapour influence the world around us.

3 Equilibrium Relative Humidity

This is the most difficult piece of your new knowledge on humidity for me to explain from common experiences. How Equilibrium Relative Humidity (ERH) works is obvious in one way but quite subtle when trying to apply the concept to real life situations. To begin with, you will have to imagine invisible water molecules moving around in the air. In the previous chapter I talked about "seeing your breath" in cold weather, but obviously water leaves your body in every breath and most of the time it is invisible.

The next important point is a fact:

Most materials absorb water to a greater or lesser extent.

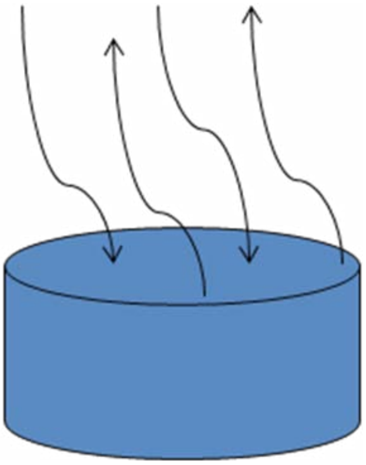
The next step in the logic is that the water molecules you are imagining moving around in the air will come into contact with materials. We will think about two things that can happen:

The water sits on the surface of the material.

The water at the surface penetrates into the material.

Assume that there is insufficient water at the surface to cause condensation and that we are still thinking about the invisible water molecules. The water on the surface can evaporate back into the air or it can move into the material. If it penetrates into the material, this is known as 'absorption'. Water that has already penetrated into the material can stay there, or move back to the surface and evaporate into the air. Where the water is lost into the surrounding air, this is known as 'desorption'.

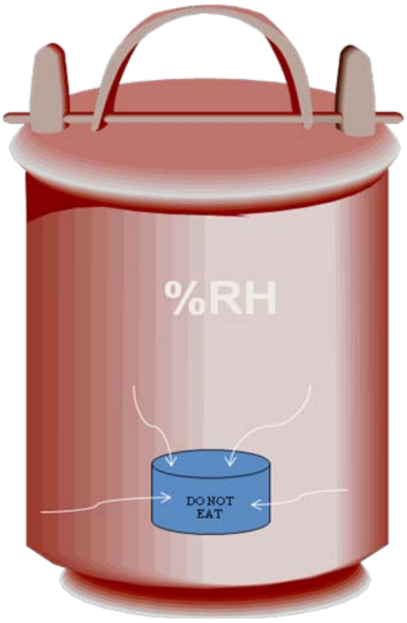
See this process of absorption and desorption as continually active (or dynamic) with water molecules entering and leaving the material. At some point, the amount of water entering and leaving the material will be the same (balanced) and we have an 'equilibrium'.



When the amount of water vapour entering and leaving is the same, an equilibrium exists.

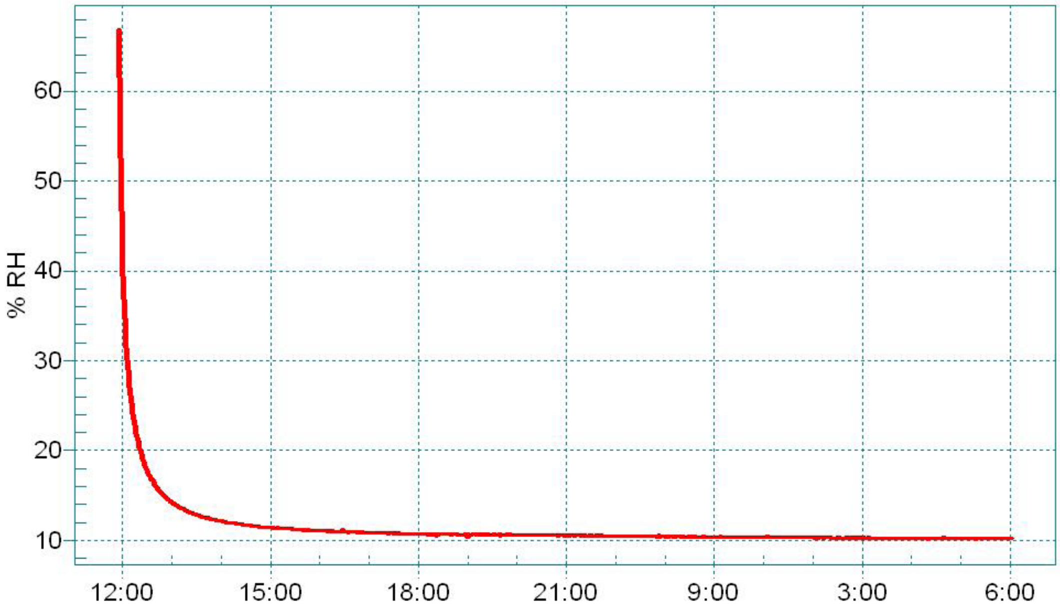
So there we have the "E" of ERH explained. Now we use our knowledge of relative humidity from the previous chapters.

As you know, relative humidity is a way of measuring the amount of water vapour in the air. Imagine we have a container that is filled with air containing moisture. We can measure the level of moisture in this container and we call it the %RH. Imagine that we now place a very dry material in the container, for example, a desiccant such as silica gel. You know the ones: the little silica gel sachets you get with some things that have "DO NOT EAT" on them. Assuming you have not eaten the sachet and you place it in the container and tightly close the lid (see picture below), what happens next?



Naturally, as you would expect, the silica gel starts to take the water out of the air by the process of absorption. Because the air now holds less water vapour, the % RH will fall and we have 'dehumidified' the air, which of course is the function of the desiccant. However, this absorption **will not** continue to zero %RH, as you may have expected, but will stop at a particular point. The %RH at this point occurs when we have absorption and desorption at equilibrium. The %RH value achieved is the "Equilibrium Relative Humidity", which for silica gel is usually around 10% to 25% RH. This means the desiccated air in the container is being held at 10% to 25% RH.

The graph below shows silica gel desiccant coming to its ERH. The shape of the curve is typical of a material coming to equilibrium and in this case the %RH dropped rapidly to below 20% in about 20 minutes and then took several hours to finally reach equilibrium. This shows the function and purpose of using desiccants to protect moisture sensitive materials from the atmospheric water vapour when the relative humidity is above a level that would cause damage.



Some of the modern desiccants we use today started development as products around the time of World War II for use by the military to protect equipment from rusting in the humid Pacific region.

So here we have ERH defined as the relative humidity value measured for the air surrounding a material that is interacting with water vapour. By necessity, this has to be done in a closed container to prevent the air surrounding the material from mixing with the atmospheric air, which would add to, or reduce, the available moisture.

Before going into the subtleties of using ERH, at this point I will tell you about how my interest, and some would say my obsession, in the whole humidity area started. I had just started at a company as their Product Development Manager and was presented with a problem that was up to me to sort out. They had recently developed an amoxicillin tablet and were about to market the product. Unfortunately, recent batches were failing to meet the required level for one of the analytical tests and the product could not be released onto the market. My task was to find out why and fix it.

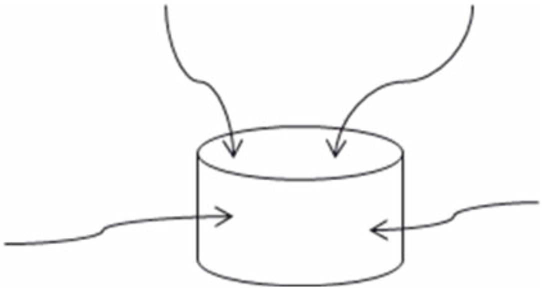
Our problem was brought about by a change in the 'monograph'. This is a list of tests that the company has to pass before placing the product on the market. The test for water content of these tablets had changed from 7.5% to 6.0%, and although the tablets made during product development passed, the most recent tablets were just above 6%. After an extensive investigation, and to keep the story short, we discovered that the product development batches of tablets, just by chance, had been made during one of the driest weeks of the year. This we discovered from the relative humidity records.

You might think "problem solved"? However, after dehumidifying the tablet production area, we were still getting inconsistencies in water content. Now we discovered that we also had a problem with the water test. The method used for this test requires a number of tablets to be ground up into powder and accurately weighed samples of this powder are used in the test apparatus. Each powder sample would usually be taken about 10-15 minutes apart by the time you perform one test and set up a repeat test. An average result of the two tests is taken, as long as the results agree within set limits. It was that last bit about limits that alerted us to another problem. The amoxicillin tablet powder was absorbing water from the atmosphere so quickly that if the analyst did not run the two samples in quick succession the result for the water content of the second sample was much higher than the first. This also meant you could not grind the tablets to a powder and leave it sitting for any length of time.

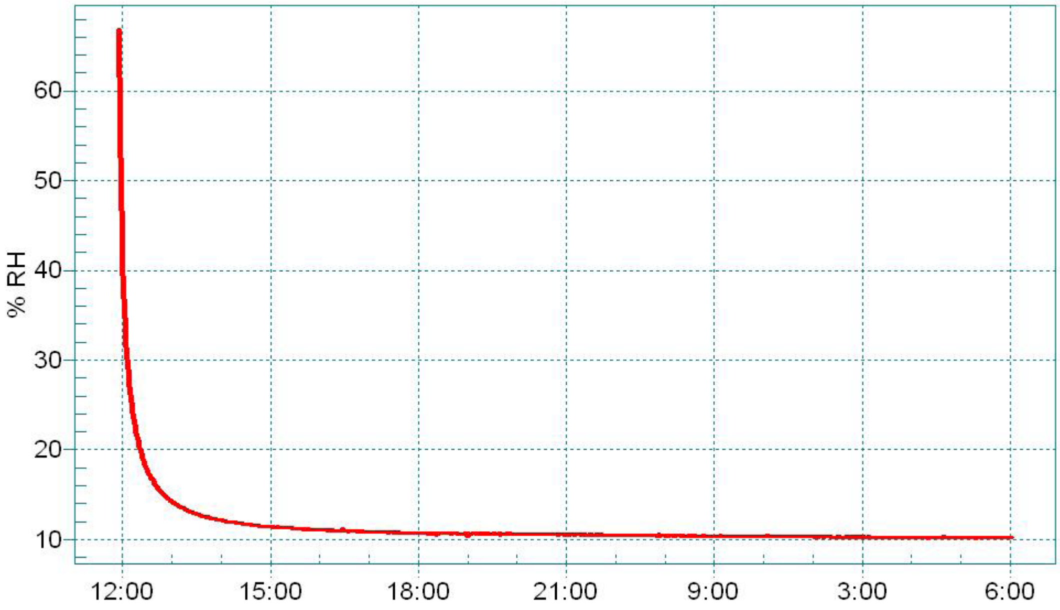
Many years later, I was presenting a talk on ERH at a pharmaceutical conference in Vienna and one of the other speakers, who gave a presentation before me, produced data on a problem they were having in the assay for their amoxicillin product. This is where the content of the drug is determined from an accurately weighed sample. They were observing the weight of the sample changed due to moisture absorption. Naturally, in my talk that followed, I suggested that they measure the ERH of their product and the humidity in the laboratory and determine if, and when, it is possible to safely test their product.

So what was going on with these samples? Here is another rule:

A material placed in relative humidity above its ERH will absorb water vapour from the surrounding air.



Here is the graph again of the silica gel absorbing moisture.



You can see from the graph the point where the moisture uptake levels out. This is the equilibrium point and defines the ERH of this sample of silica gel. As explained above, the value of the ERH is the %RH at equilibrium and so, for this sample, the ERH is 10%. You can also see from the graph that the relative humidity of the air in the container at the start was about 66% RH. Since the humidity of the surrounding air was higher than the ERH of the silica gel, moisture was absorbed by the silica gel and this continued until the humidity of the air reached its ERH.

Back to the amoxicillin samples. I hope now you can see what was happening with the amoxicillin tablets. During manufacture and testing in the laboratory, the humidity of the surrounding air at the time (also known as the 'ambient' humidity) was higher than the ERH of the amoxicillin. All the time the product was exposed to the air, moisture was being absorbed and this was happening fast enough to upset the test results.

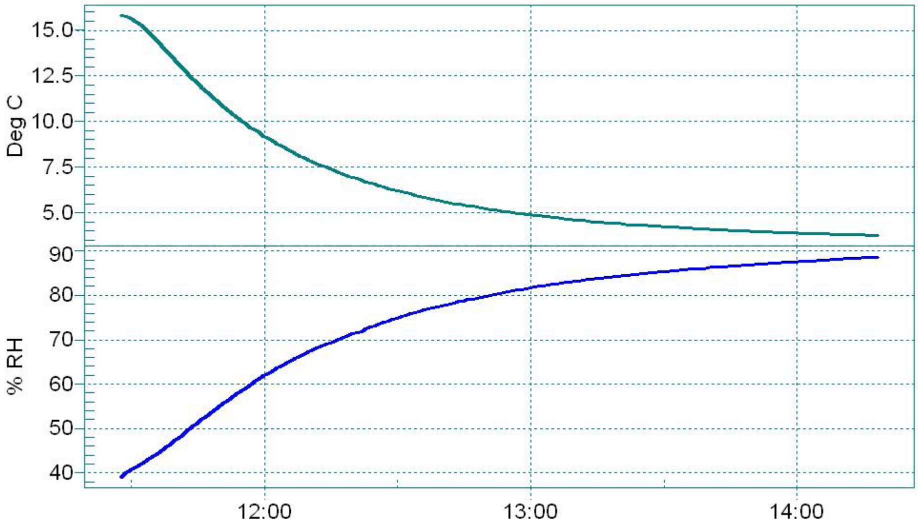
To complicate matters even more, whether or not this sort of thing is a problem depends on your geography and, as we found out, the time of year. Thanks to the Atlantic Ocean, there is a year round supply of moisture in Ireland, it is not called the "Emerald Isle" for nothing! The other speaker at the Vienna conference with the amoxicillin problem was from Malta, a small island in the middle of the Mediterranean. In both cases we have the necessary ingredient for trouble, a source of water vapour.

It is very important at this stage to understand that at the ERH point, absorption and desorption has not stopped, and this is a true balanced system at equilibrium.

To prove that we have a balanced system at ERH is very easy. Remember? **You must always consider the temperature!**

This is one of the subtleties of working with ERH that can take people a while to appreciate. Again you need to use your new knowledge of relative humidity. You know from Chapter 2 what happens to the humidity within a close container when the temperature is increased. To remind you, a decrease in relative humidity occurs because the saturation point (SVP) directly increases with temperature.

Also, we know that the reverse is true and the humidity increases if the temperature is reduced. This gives us a mechanism we can use where, by changing the temperature, we can adjust the internal humidity of a container. The graph below shows what happens:



Closed container placed in a fridge

In this case we have lowered the temperature and, as predicted by the rules of humidity, we see the % RH increase. When the system stabilises at the new lower temperature we get, as expected, a new % RH in the empty container.

Consider what would happen to a material that was present in the container. As the % RH increases to adjust to the drop in temperature, the material will start to absorb moisture when the humidity goes above its ERH.

Perhaps you can now see how cold and dampness are closely linked. These changes in humidity happen instantaneously. There is no hurdle for the water vapour to overcome to get moving. We are dealing with a dynamic system that, when the environment is cold, moisture is driven into materials.

The opposite to the above is also true:

A material placed in relative humidity <u>below</u> its ERH will <u>not</u> absorb water vapour from the surrounding air.

We also have to add to this rule that if the material contains water that has already been absorbed, then at a relative humidity below the ERH of the material it will lose water to the surrounding air. An example of this happening taken from common experience is shown in Chapter 6.

In these first three chapters, we now have enough tools to explore our world of moisture. In the next chapter, we look at hurricanes and use what we have learnt on water vapour and its relationship with temperature.

4 Hurricanes, Typhoons and Cyclones

These three names describe one of the most powerful forces of nature. Which term is used depends on the part of the globe they are located. In the Atlantic they are hurricanes, in the Pacific they are typhoons, whereas in the Indian Ocean they are cyclones.

I mentioned the role of water vapour in the Earth's weather systems in Chapter 2. We have warm moist air rising from the seas around the equator and travelling towards the poles. Factors such as sea temperature, the Earth's rotation and prevailing winds affect the movement of this moist air. If a particular set of factors come together over the oceans at the equator, vast amounts of warm moist air accumulates and this builds into the extremely powerful storms we call hurricanes, typhoons or cyclones.

One essential fact from my basic research into why these massive storms begin is that the sea temperature must be at least 26°C. I cannot explain why this temperature is so critical. My guess is that by observation of the sea area around the origin of hurricanes the one factor that always contributed was this minimum sea temperature. Using what we know about temperature and moisture it is easy to work out that the air above the warm sea gets heated and vast amounts of water evaporates due to the capacity of warm air to hold this moisture. This mass of warm moist air rises rapidly, begins to cool and as it does so, forms clouds.

A consequence of the rising moist air is that because it is rising very quickly it creates an area of low pressure at, and above, sea level. Here are a couple of common experiences that may help explain why this happens: When you drink a liquid through a straw the common expression is that you are "sucking" up the liquid. There is no actual force of "sucking", what you are doing is creating negative pressure from the top of the straw and it is air pressure that pushes down onto the surface of the liquid and forces it up the straw towards the negative pressure.

As a living organism on the Earth's surface, we have evolved under the force of atmospheric pressure and are not normally aware of it as we go through our daily lives.

On occasions we do have to become very aware of it, as you will understand from this second common experience: On rail station platforms that have high speed trains passing through, there are warnings to stand back from the edge of the platform as there is a high speed train approaching and often there is a line for you to keep behind. The reason is that although most people think that they might be "sucked" on to the track if they are too close, the high speed train is moving so fast that a large amount of air is being pushed in front of the train and this creates an area of higher pressure in front and lower pressure along the side of the train. A partial vacuum runs along the side of the train.

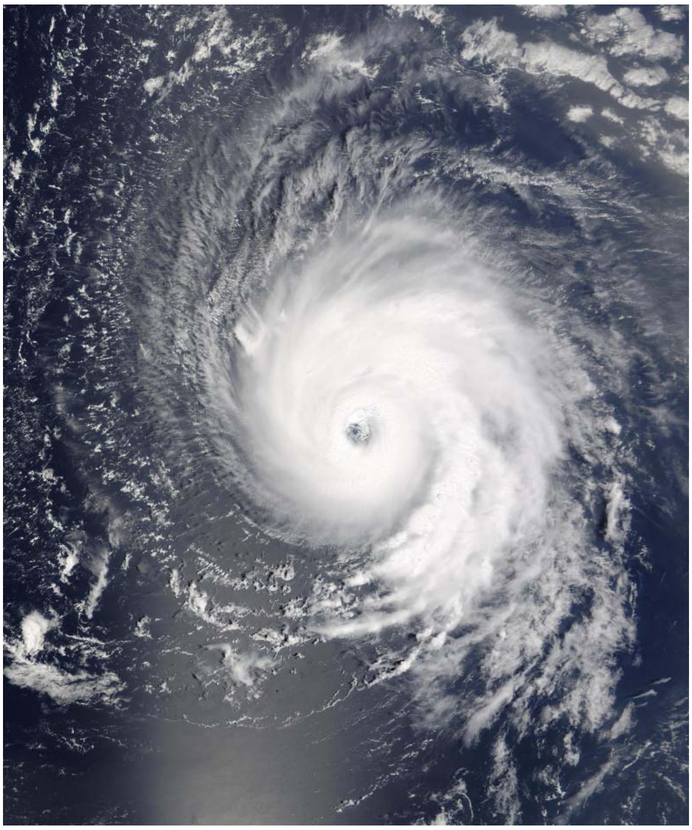
The laws of physics dictate that these areas of high and low pressure cannot exist beside each other and air has to move from the higher pressure to the lower pressure to equalise the overall pressure. The faster the train moves the greater the difference in the pressure and the faster the air moves into the low pressure area. Pressure from this movement of air by a high speed train is easily enough to dislodge a human body from the standing position, and of course you will head in the direction of the low pressure area on the track. By the way, the same applies to trucks flying past you on a motorway so be aware of this also if you have to stop on the hard shoulder.

"I think it was a bad case of wind"

Back to the hurricane where we have a mass of moist air travelling at high speed upwards, with low pressure underneath. Now you can see that due to air pressure, the surrounding air must rush into the low pressure area and this is drawn across the sea towards the centre of the newly forming hurricane. This air becomes heated and loaded with moisture and heads upwards. As you now know, this moist air will cool as it rises causing the water vapour to condense, form clouds and, as the mass of cloud accumulates, at some point we have rain.

The clouds and rain are pushed outwards by the rising air around the middle of the hurricane and the cooler air that has lost its moisture falls back to earth away from the middle. This falling, cooler air assists in pushing more air at sea level in towards the centre of the hurricane. So we have a cloud generating cycle that will continue so long as there is a source of warm moist air at the centre.

Other key factors come into play now. Rotation of the Earth and driving prevailing winds cause the mass of rising, warm, moist air to spin and move across the sea. The one common experience that comes to mind is water going down a plughole: gravity is a force that pulls things straight downwards, but water does not simply disappear straight down the plughole. The fluid water is affected by the rotation of the Earth and this causes it to 'spin' down the plughole. The situation is very similar with the mass of rising moist air, and that is why hurricanes and cyclones spin anticlockwise in the northern hemisphere and typhoons in the southern hemisphere spin the other way round. You can see the anticlockwise spin of a hurricane in the NASA satellite picture below.



Hurricane Isabel

There is no upwards movement of air in the 'eye' of the hurricane and clouds do no form here. The rising, warm, moist air forms the wall of the eye as the high winds, known for their destructive force, spin around the outside.

So, the basic driving force for hurricanes, typhoons and cyclones is water vapour. As long as these storms are travelling across sea water, they have a source of water vapour that sustains them and has the potential for increasing their force. I remember a few occasions hearing on the news that a hurricane has weakened a bit when hitting the Caribbean Islands or Mexico and then travelled into the Gulf only to increase in strength before hitting Florida or the other southern United States.

When the storms hit land, their source of energy is cut off and they weaken as their cloud generating cycle is cut off. Unfortunately for those individuals caught in the storm's path, not only are they battered by strong winds, but the storm also dumps its water vapour as rain and this could amount to several billion tons of liquid within a short period of time as you'll see in Chapter 9.

Will global warming increase the frequency and strength of these storms? I do not think anybody really knows for certain. The occurrence of storms depends on many different factors such that they cannot be predicted. Therefore, we can only hope that a temperature increase alone may not lead to an increased frequency. However, using what you now know about temperature and humidity, it is easy to see that a warming of the sea surface will heat the air above it to a higher degree and, of course, the air can then hold even more water.

Since it is this water vapour that is the source of power for storms, it is easily imagined that we are going to see larger and, consequently, more violent hurricanes, typhoons and cyclones. Watch this space…

5 Health

This is one of those subjects that raises more questions that can be answered at this stage of our understanding.

Let us start with what can be put into the category of "old wives' tales". I am sure many of you will have heard somebody talking about the weather affecting their 'rheumatics' or 'arthritis'. People living in cold and damp conditions are, without question, worse affected. I remember my granny sitting quietly then suddenly jumping, holding her hand saying "bad weather's on its way".

So how can forthcoming bad weather cause sudden pain to shoot through your hand, down your arm, up your neck (that one from my mum), or across any other part of your body? Medical science is now looking at 'Rheumatoid Arthritis' as an autoimmune disease. This on the one hand (excuse the pun) makes it even more bizarre that the weather could affect your immune system in some way. But, on the other hand, common experience tells us, and your GP knows, that people are more susceptible to ailments in the winter months.

It is a health statistic that more people visit their GPs during these months and more deaths occur at this time of year, particularly in the very young and elderly. Our immune system is at a developing stage through our early years and works less efficiently when we are older.

I do not personally know anyone who has gone to warmer climes to fend off rheumatic attacks, but GPs will tell you that it can give some relief from symptoms. You hear of retired people spending the entire winter months in the Mediterranean and some even relocating completely to a warmer and drier climate. Some medical studies have been undertaken but no actual mechanism or clinical factor between damp conditions and rheumatics has been found.

The closest 'causal' relationship appears to be that a drop in body temperature is not good news in the elderly. However any possible role of relative humidity is still not understood. Part of the problem with these types of studies is the same issue that I talked about in Chapter 2, which is that controlling relative humidity can be very difficult in a real life situation.

My own experience of humidity and health goes way back to my teenage years in Edinburgh. Every winter I would get sinusitis and had to have some treatment or another. It became such a problem that I had two operations to drain my sinuses. This settled things down for a while, but the trouble started again when I moved to Nottingham. Briefly, in terms of the geography, Nottingham is a city with surrounding suburbs and towns all sitting in the Trent Valley. There is a notable landmark called the Radcliffe Power Station. The power station is located on an elevation to the south-west of Nottingham and its eight cooling towers can be seen for miles across the valley.

On warm summer days you can see the steam billowing from the towers and then it disappears as the water vapour evaporates into the surrounding atmosphere. You should know from Chapter 1 why this happens. A different sight is seen on damp days and especially on cold, damp, winter days. The steam still billows out but, instead of disappearing, it usually heads eastwards and out over the valley. I have seen clear winter days where the low-lying sun was completely blocked out by the cloud of steam above the cooling towers. Again, applying the reverse of the argument to the disappearing steam, you should now know why this cloud persists on a clear winter day.

Radcliffe is, not surprisingly being in Nottinghamshire, a coal fired station. Next to the cooling towers are the chimneys for the coal-fired boilers. So, not only do we have all this extra moisture drifting across the valley, but mixed in are the exhaust gases from burning coal. By EU law these gases must be cleaned before release but there will still be a residual level of pollutants.

Back to my health issue. The local GPs at my time in Nottingham referred to sinusitis and related problems as ‘Trend Valley Blight’. During my childhood and teenage years in Edinburgh, I would have been exposed to the same type of air quality. Being on the east coast of Scotland, we got cold damp air blasting in off the North Sea.

Edinburgh also used to get bad fog and often gets a sea fog called a “Haar” in winter. I also remember the coal lorries doing the rounds and our bunker in the back ‘green’ was filled from coal sacks humped by the coalmen round from the street. I was obviously susceptible to sinus problems and the combination of water vapour and coal fire pollutants was not good news.

Incidentally, the current thinking is that the increase in asthma and allergic rhinitis (hay fever type reactions) in the UK may be related to pollutants. I would think that it must be of great concern that a general increase in humidity due to climate change is going to lead to an even further increase in these problems. I have not been able to work out if climate change is going to make the people of the Trent Valley worse or not.

The situation in winter I would think will be much the same. Will an increase in summer temperature compensate for a humidity increase (Remember? **You must always consider the temperature!)** so that the millions of tons of water vapour from Radcliffe station will still evaporate away? I think I need a climatologist for that one.

At this point I should add a disclaimer: as far as I am aware there is no proven clinical link between Radcliffe power station and health problems in the Trent Valley region. I hope that keeps the lawyers at bay.

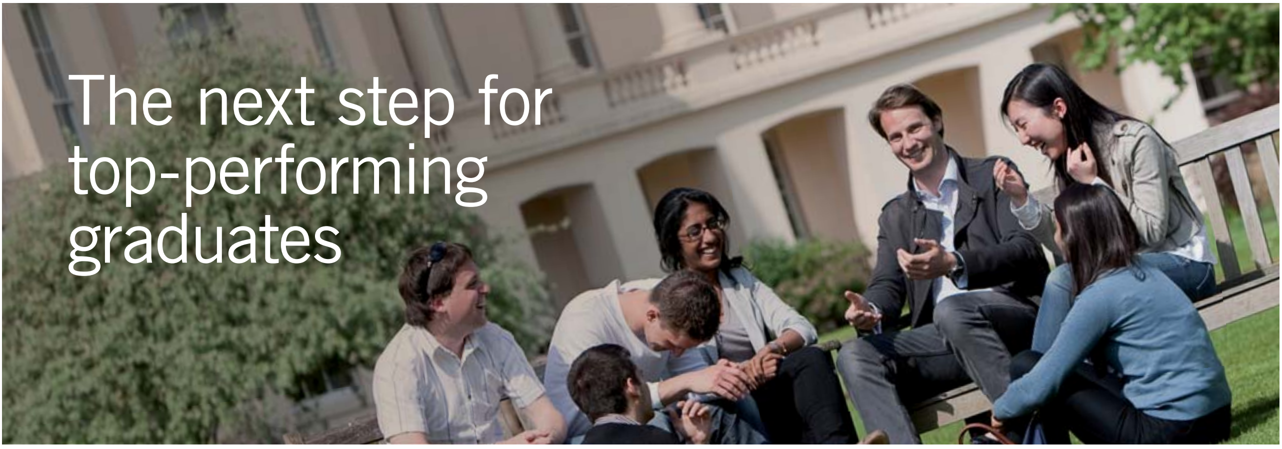
“Pete’s sauna came free with 2000 megawatts of electricity”

To finish off my own personal experience related to this story, apart from sometimes being stuffed-up following a cold and some mild seasonal hay fever, I have not had any sinus problems since leaving Nottingham and coming to Ireland in 1993. However, looking out my window as I type this, and seeing the grey sky and puddles, I am now thinking Mediterranean!

There is one situation where there is a direct causal link between health and humidity. In a hot, humid climate, people need to be aware of its affect. Not only in this situation do we have a direct link to health but we can use our new knowledge to gain an understanding of the problem. The situation results in 'heat exhaustion' due the human body overheating.

As warm-blooded mammals, we have to regulate our body temperature to within quite narrow limits. Most people generally know that this is around 37°C. You also will have heard of "hypothermia" where the body temperature drops by more than a few degrees and progressively shuts down organs to maintain supply of blood to the brain for as long as possible. When body temperature is raised by a few degrees, this causes stress on our respiratory system and is particularly dangerous as the onset of effects are more sudden and can quickly lead to fatalities in people with heart conditions.

Perspiration is our in-built system for cooling down. This relies on water vapour in our sweat evaporating from the skin. As I mentioned in Chapter 2, as the water evaporates it takes some heat away and cools the surface it left. A problem arises at high relative humidity where the ERH of our sweat is lower than the relative humidity of the surrounding air, as we have in a humid climate. In this situation no water vapour evaporates and therefore no cooling takes place. We do of course keep sweating more and more as our body attempts to cool itself and maintain "homeostasis" due to our in-built thermostat.



The ERH of pure water is 100% which means there is no relative humidity below saturation where water will not evaporate. We do not sweat pure water because if we did we would soon dehydrate as our body pumped out sweat to replace the loss through evaporation. Our sweat contains salt and this lowers the ERH to about 75% if it was simply pure water and salt (see later in Chapter 8). This means that if the surrounding air has a relative humidity above 75%, water will not evaporate from our sweat. As the surrounding temperature increases, as you now know, the relative humidity drops and when we get 'hot' and sweaty the water in our sweat will evaporate off into the air because it has a lower relative humidity than the ERH of our sweat. In a humid climate where the relative humidity is high this mechanism for cooling our body cannot function efficiently as water vapour will not move from our sweat to the surrounding air with a higher relative humidity than the ERH.

As long as you stay in the hot, humid conditions you will of course keep on sweating and the sweat will run off or soak into your clothes. Losing sweat this way does not cool you because evaporation is not occurring and all that happens is you stay hot and become dehydrated. Unless you do something to cool yourself and replace the water loss, the consequence will be heat exhaustion.

Directly linked with our health is the food we eat. I discuss the consequences of climate change on our food supply in the next chapter.

6 Food

The amount of literature on the role of humidity in the subject of food is huge. This reflects both its importance and that the subject has been studied for over 50 years. This short chapter sets out, as with the previous chapters, to give you a little bit more information, but also more than that. My aim is to show you how the ideas and principles around relative humidity can be applied for you to come to your own understanding of this very important area.

Climate change and its impact on our worldwide and local food supply is a serious threat to our civilised progress. It has in the past and, for sure, will in the future, have random and devastating socio-economical consequences for people in all communities. In the first chapter I talked about how global warming causes shifts in movement of water in the atmosphere due to its increased capacity for holding water vapour.

Images of failed crops and displaced people, "climate refugees", are there in front of us to see in newspapers and on television. We also see and hear about the problems farmers have in bad weather when they cannot grow or harvest their crops. Of course, we also pay for these natural events in the form of higher food prices. Hidden from sight, and not so easy to comprehend, is the subtle and potentially lethal world of microorganisms in our food that are totally dependent on humidity and change their growth according to ERH.

Like it or not, our food is not sterile and just like us, comes naturally covered in a range of bacteria and fungi. You will know this intuitively even if you have not, or choose not, to think about it, as you can only keep fresh food for a certain length of time before it 'goes off' and acquires a different smell, along with cultivating various fungi.

In 1957 W.J. Scott published a scientific paper, "Water relations of food spoilage microorganisms", reporting that he had found out that it is not the absolute amount of water present in food that resulted in microbial growth, but it is the amount of water that is available to the microorganism. This is 'free-water' as opposed to 'bound-water' and the free-water is measured as *Water Activity*. The alternative term I have been using for this property is Equilibrium Relative Humidity (ERH). This was a highly significant finding for the food industry. It meant for the first time a measurement of the food could be performed to determine if microorganisms will grow on it or not. In fact, it was even better than that, as Scott published a list of different species and the water activity, or ERH, that must be present for each to grow. It turns out that the ERH is critical for these organisms and very precise in that they simply do not grow if the ERH is one or two percent below their critical level for growth.

I cannot imagine the size of the impact on the safety of our food that this one discovery must have had over the past 52 years. Below is a table of ERH values and various microorganisms. Some names you will have heard on the news as outbreaks and in adverts on food safety, especially around Christmas about washing turkeys. Familiar organisms are Escherichia coli (E. coli) and Salmonella which have a similar ERH.

Micro-organism	ERH required for growth (%)
Pseudomonas spp.	97
Escherichia coli	96
Bacillus subtilis	95
Clostridium botulinum, types A and B	94
Candida utilis	94
Botrytis cinerea	93
Most spoilage bacteria	90
Most spoilage yeasts	88
Penicillium patulum	81
Most spoilage molds	80
Aspergillus conicus	70
Aspergillus echinulatus	64
Zgosaccharomyces rouxii	62
Xeromyces bisporus	61

From: Jay, J.M. 1992. Modern Food Microbiology Chapman & Hall, International Thomson Publishing. New York

So where does climate change come into this story? If we are going to get wetter and warmer weather this, as you now know, will push up relative humidity for longer periods. However, microorganisms do not suddenly get up and start growing madly. They have a growth lag period to overcome first and then the right conditions for growth in their surrounding environment has to be maintained for them to continue growing. Maintaining high humidity provides these conditions for growth.

A common experience of this is fungi growing in autumn. In autumn, the temperature drops (Remember? **You must always consider the temperature!**) and the humidity is pushed up for longer periods. This allows growth of the fungi's 'mycelium', the organic growth phase of fungi that takes place in the ground or inside decaying vegetation. The fungus then, in the appropriate conditions for its species, starts the sexual phase of growth and we see the part we call mushrooms and toadstools

Of course fungi can grow at any time of year as long as there is moisture. Carefully inspect the underside of a decaying piece of a log, where moisture has been trapped between the ground and log, to see the fungi performing its natural function. Then replace the log back into the position you found it to let nature carry on as normal.

Here is one of my favourites that regularly appears in my garden:

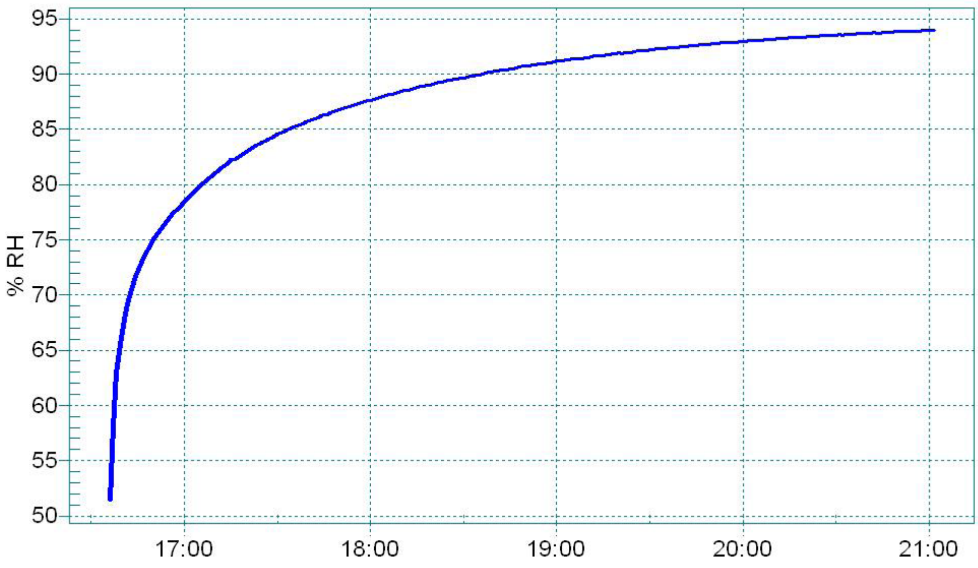
For reasons I cannot fathom it grows along an edge of a concrete slab under the stones that you can see and in the middle of a path. Unfortunately, this year I kicked it over by mistake and I hoped that as this is only its sexual organ, that there was mycelium or spores still in the ground for it to come up the following year, it did.

So back to food. You may now have easily made the connection to problems that will be caused by climate change. As the environment changes, different species of microorganisms will take advantage and they are very good at adapting. Generally, wetter and warmer conditions are ideal for faster growth of the microorganisms that cause concern. Some can tolerate cooler temperatures but they all need the levels of humidity shown in the above table of microorganisms. Different strains within a species may become more prevalent and the longer a microorganism is growing the greater the chance that a new strain can arise through mutation.

Let us approach this from a more familiar and practical point of view. Say for the sake of argument, you do a weekly shop for some food and you place the vegetables in the very handy compartment that the manufacturers provide at the bottom of your fridge. If you have bought your vegetables packed, do you unwrap them, or leave them wrapped, before placing them in the vegetable compartment of your fridge?

I will leave you to work out what is the effect of bringing a closed pack from the ambient conditions of the shop, to a car, house and then into the fridge. Also, remember that vegetables contain water and moisture enters a fridge when the door is opened. Whether or not the vegetables are wrapped, they end up in a high humidity environment. As you are probably well aware, unless you are scrupulous in both fridge cleaning and management of your food stock levels, the cold temperature does not stop those black and green cultures from co-habiting.

Here is the result of a test I did on a fresh loaf of bread



It is a shame I cannot show this in real time as the moisture 'pours' out of the bread.

By the way, if you are wondering by now how I do these tests, I could not find a test system suitable for the type of tests I wanted to perform. So, the only option in these circumstances, of course, is to build one! I won't go into the details here but decided that it needed a name and came up with "**RELEQUA**" derived from **Rel**ative humidity coming to **Equ**ilibrium.

You do not need to understand the test system to work out what I am leading to next.

Fresh bread is moist, bread dries out. When you pack a fresh loaf of bread in a sealed polythene bag, its moisture is rapidly released and you have the potential for a very high humidity environment as shown in the graph above. Look up the ERH in the table above and you will see that it is easily above the ERH for growth of fungi.

We do not eat a lot of bread and can have a loaf sitting around for a few days. Unless there is absolutely no other choice, I never buy a loaf packed in a polythene bag and always go for the waxed paper packaging. The latter type of packaging does not of course prevent fungal growth but it does let out moisture and lowers the humidity of the air around the bread, assuming that the humidity of the room where the loaf is kept is not too high.

Sometimes bread on the supermarket's shelf is cool and, not surprisingly, condensation has appeared on the inside of the polythene bag. This could be due to deliberate refrigeration or through early morning delivery and storage when temperatures are cool. Either way it is not the best packaging and not necessary in my opinion. There, I have got that one off my chest.

On a very much more serious note, the problems I see with climate change for food are in the supply chain. For thousands of years human beings have worked with, and battled against, nature to cultivate food crops. Plants that make up the bottom of our food chain are open to attack by weather, disease and animal pests. The one I want to briefly focus on here is disease.

Just as in the area of food spoilage organisms, plant diseases are numerous and their causes multi-fold. Crops with better resistance to disease have been development by selective breeding and crop management techniques have provided us with a means of growing the vast quantities of food that are required to support the human population. Climate change shifts the balance of our control and microrgansims can quickly take advantage. This threat to our food supply is constantly monitored at control centres around the world so that action can be taken where possible. One of the key factors in plant health is the amount of rain and relative humidity levels. Too much ground water and high humidity is not good for our grain crops and leads to fungal attack on the growing plants and serious problems for harvesting and storage. Other key crops such as maize and potatoes are also badly affected.

It is not just a case of economics or a nuisance factor, fungal attack has serious health consequences in some cases. There is a fungus that attacks coffee beans after the outside husk has been removed. Suppliers of this product should monitor the humidity levels during shipping and storage to avoid processing beans that are infected with this fungus. The fungus produces chemicals that are carcinogenic so it is best to avoid these getting into the coffee that ends up on the market.

In the next chapter I have picked one example of a food crop where climate change has had disastrous consequences.

7 Potato Blight

I could have put this short chapter quite easily as a section in the previous chapter. My reasons for including a separate chapter on potato blight are two fold really; one is that I am living in Ireland and was here for the 150th anniversary of the "Great Irish Famine" and second, it is an example of a wake-up call of how climate change can have devastating consequences on our health and communities.

In my chapter on Food, I mentioned the problems that are seen with microorganisms exploiting changes in moisture levels, allowing them to grow and attack our food chain. The great famine in Ireland was a consequence of such an attack. The potato was introduced into Ireland in the 17th century and does grow very well in the Irish soil and climate. By the 1800s, most of the Irish population depended on the potato crop, both for income and as the main food for consumption.

In the early1840s a new "malady" appeared in potato crops that mycologists at the time thought was a fungus. The "fungus" caused blackening and then defoliation of the potato plant leaves, turning the plants to mush, as well as making the tubers inedible. It spread rapidly during a couple of seasons of bad weather.

Estimates vary, but the Irish population of about 6-8 million nearly halved between 1845 to 1849. A minimum of 500,000 people died, with some estimates as high as 1 million. Another million people were forced to emigrate. Ireland has not since recovered its population back to pre-famine levels.

We are quite familiar with wet weather here in Ireland and obviously bad seasons had occurred previously to 1845. Politics aside, different factors came together to lead to this disaster. First, a new strain of potato pathogen had evolved or gained an advantage. Remember in Chapter 6, I talked about the ability of microorganisms to grow to large populations allowing new strains to come through. Next, the potato crop was a single variety of potato and this lack of species variation meant that the blight could propagate freely from plant to plant without resistance. Also, the farming practice was to use the previous season's tubers to start to next years crop and since the "fungus" also attacks the plant tubers, the disease was propagated into the following season by infected tubers. Finally, a change in the climate resulted in high persistent moisture levels.

The microorganism causing the problem is called *Phytophthora infestans*. I put "fungus" in inverted commas because we now know that it is not a true fungus, although you will still see it described as the 'potato blight fungus'. All the reasons why it is not a fungus are not necessary in the scope of this discussion, but if you are interested in the story of this organism it is described in detail by experts in this area. I came across a very readable article by Gareth Griffith from a highly respected source, The Institute of Biological Science at the University of Wales Aberystwyth. The article is called "Phytophthora: a blight on Ireland", published in Microbiology Today in February 2007 and is available for download from the internet.

Phytophthora infestans is well adapted to wreak the havoc that it does. It produces spores that, like fungi, can be transported across large distances by the wind. When the spores find a potato plant they germinate on the leaves, but unlike fungi, they produce an organism that has appendages called flagella. Equipped with flagella the 'zoospores', helped by rain, are able to "swim" and infect other parts of the plant including the potato tubers.

The driver of the infection process is the weather. As you know from Chapter 6 on Food, an ERH of at least 60% is required for microbial growth. In the case of *Phytophthora infestans*, a humidity of 75%RH or more, has to be maintained, along with a minimum temperature of 10°C for about 2 days for growth to begin. Wet conditions in the soil are also needed to produce a film of water around the soil particles for the organism to swim through and reach the tubers.

Knowing the conditions required for growth, meteorological data are now monitored in blight susceptible areas and warnings issued to farmers to treat their crop with fungicide to control this disease. In Ireland, the Meteorological Service do not issue warnings before June as the disease rarely appears before that month. As you know from Chapter 1, I monitor daily the temperature and humidity in my garden and can confirm for this year that the minimum temperature certainly did not hold above 10°C for more than 2 days in a row until June.

Here is one of the little synchronicities in life: Austin Bourke (1913 -1995) who became Ireland's expert on potato blight was born and educated in Dungarvan and Waterford City. I am writing this book from my home in Dungarvan. Dr. Bourke did his Ph.D. thesis on potato blight and became Director of the Irish Meteorological Service in 1964 and, before that, he was President of the Commission for Agricultural Meteorology of the World Meteorological Organisation.

In 1953 he developed a protocol, or model, for predicting outbreaks of potato blight in Ireland based on meteorological data, This model is still use today. During his distinguished career he made significant contributions to the study of Agrometeorology and the influence of climate on crops disease.

Agrometeorology is a multidisciplinary science that studies the affects of climate on the biosphere. If there are any budding scientists reading this, unsure in which direction to go with their studies, have a look at Agrometeorology. This is a varied and very interesting subject area that is going to become more important as we live through the anticipated climate change over the next 50 years and beyond.

After working a bit of ground in our garden in early spring of 2009, I planted three different types of potato, all blight resistant but not immune. I was concerned while starting to write this chapter in July of that year that I perceived the weather to be very wet, it gave the impression of generally being a "bad" month. I also measure daily rainfall and saw that there were only 5 days without rain at some point during the day.

However, applying Dr. Bourke's model, which in brief, requires a run of 16 days above 90%RH or 12 days above 90%RH if it rains on all days, I need not have worried. In fact, it was only on July 1st, when we had 30mm rainfall, that the humidity stayed above 90% for 2 days. On 18 days in July the humidity dropped to less than 70%, and as low as 41% on one day, and only on 5 days did the humidity remain above 90%.

I could see that the soil had been damp for most of the month and was not really drying out much, hence the reason for my concern. Since we generally rely on our senses, we must be careful about our subjective perceptions of the weather and we really need good data on which to base any actions, something I talk about in Chapter 9.

At the very end of that July**,** Met Éireann, the Irish meteorological service, issued a potato blight warning. I checked my early potato plants and my main crop, which were showing ominous dark patches on a few leaves. I removed these leaves and disposed of them in the organic bin. Also, at the same time, a tomato blight warning for the East Coast in USA and Western Europe was issued. Clearly a good summer for microorganisms!

There are Agrometeorology stations in countries around the world collecting data to monitor climate and any changes to crops. The public does not hear much about these activities but we should all be thankful for the scientists working to protect our food supplies.

I hope by now that you can see that any increase in moisture levels is potentially very serious. Microorganisms are very opportunistic and quickly adapt. It is not easy to stay one step ahead of them and often is impossible.

July 2009 ended up very wet indeed, in fact, the early summer was the wettest in England and Wales since records began more than 240 years ago. County Kerry in Ireland had the wettest July since records began there in 1866 with the temperatures holding up about average or slightly higher.

It is an ironic fact of life that apparently due to the "credit crunch" followed by recession, more people have taken to growing their own fruit and vegetables. Ironic, why?

Due to the wet weather over the summer in 2009, there was concern that blight would spread to people's gardens and allotments and could be spreading from there into the farmers crops. This additional human activity propagates the opportunistic spread of the disease and increases the cost to the farmer for disease control and through lower yields. Consequently, supply and demand results in higher cost to the consumer.

Obviously I am not against people growing their own fruit and vegetables as I have done so myself for several years. However, a level of awareness to local affects of climate change is useful for being alert to potential problems.

Here is an example of opportunism in these wet times. Fungi, as I explained in Chapter 6, generally show up in the autumn because of the climatic conditions. The photo below shows a fungus that grew in the month of July on a pile of wood chippings. These wood chippings are courtesy of our local tree man and we use them as a mulch for weed control and increasing the organic content of our garden soil.

The fungus was growing under an overhanging plant. No other growth of this fungus, or any other type of fungus, appeared anywhere else on the large pile of wood chippings.

The surface of the wood chippings were dry, but, due to a large amount of rain and the moisture retention properties of wood, just under the dry surface, the wood chippings were wet.

My interpretation of this scene, through the eye of my obsession with moisture, is that the wood chippings pile was continuously losing water vapour because the ERH of the wood will be quite high and generally the atmospheric humidity, as described above, was low on most days allowing the moisture to escape. However, the space under the vegetative growth had trapped some of the moisture being released by the wood chippings and this localised microenvironment maintained a high enough humidity to allow the fungi to enter into its sexual phase and produce the fruiting bodies shown in the photograph.

This is the same wet environment opportunism that you see when black mould appears in corners of rooms, particularly in bathrooms, where water vapour is trapped.

Fortunately for us, the high humidity requirements for *Phytophthora infestans* are quite stringent for it to be quickly opportunistic. However, in Gareth Griffiths article, he says there are over 60 different species of *Phytophthora* and no doubt many more are to be found. On top of this, there are thousands of species of bacteria and fungi. In a world of increasing temperature and humidity, it is only a matter of time before more virulent strains come through.

In the next chapter, I show how our new knowledge is really an evolution into a new understanding of something we have known about for a very long time.

8 Salt

I was in two minds whether or not to include a chapter on salt. The subject certainly has its place in a discussion on relative humidity and ERH, but I did not want to get into chemistry or too detailed technical information. I decided in the end to include a very short chapter because a common experience came to mind that you may have seen that is worthwhile discussing.

Nowadays little paper packets of salt are everywhere in cafes and restaurants but, prior to this, salt sellers were left on the tables. I remember specifically during summer days seeing little droplets of water around the holes of the salt sellers in cafes. I do not see this at home because I have not sprinkled table salt on my food since my teenage years and when we use salt for cooking it comes out of a big jar or we use sea salt from a mill.

The little droplets on top of the salt seller are due to three things. One is a property of salt called 'liquefaction'. This is a process where the salt keeps absorbing more and more moisture from the air until it turns into a solution of salt by dissolving into the moisture that it has taken from the air. Substances do not normally do this as they only absorb a certain amount of moisture and at most become damp. The second factor is the ERH of table salt which is around 75%. Thirdly, you know from your new knowledge that the relative humidity of the surrounding air must be above 75% for the salt to absorb moisture from the air.

You can see the moisture uptake in the graph for a sample of table salt shown below.

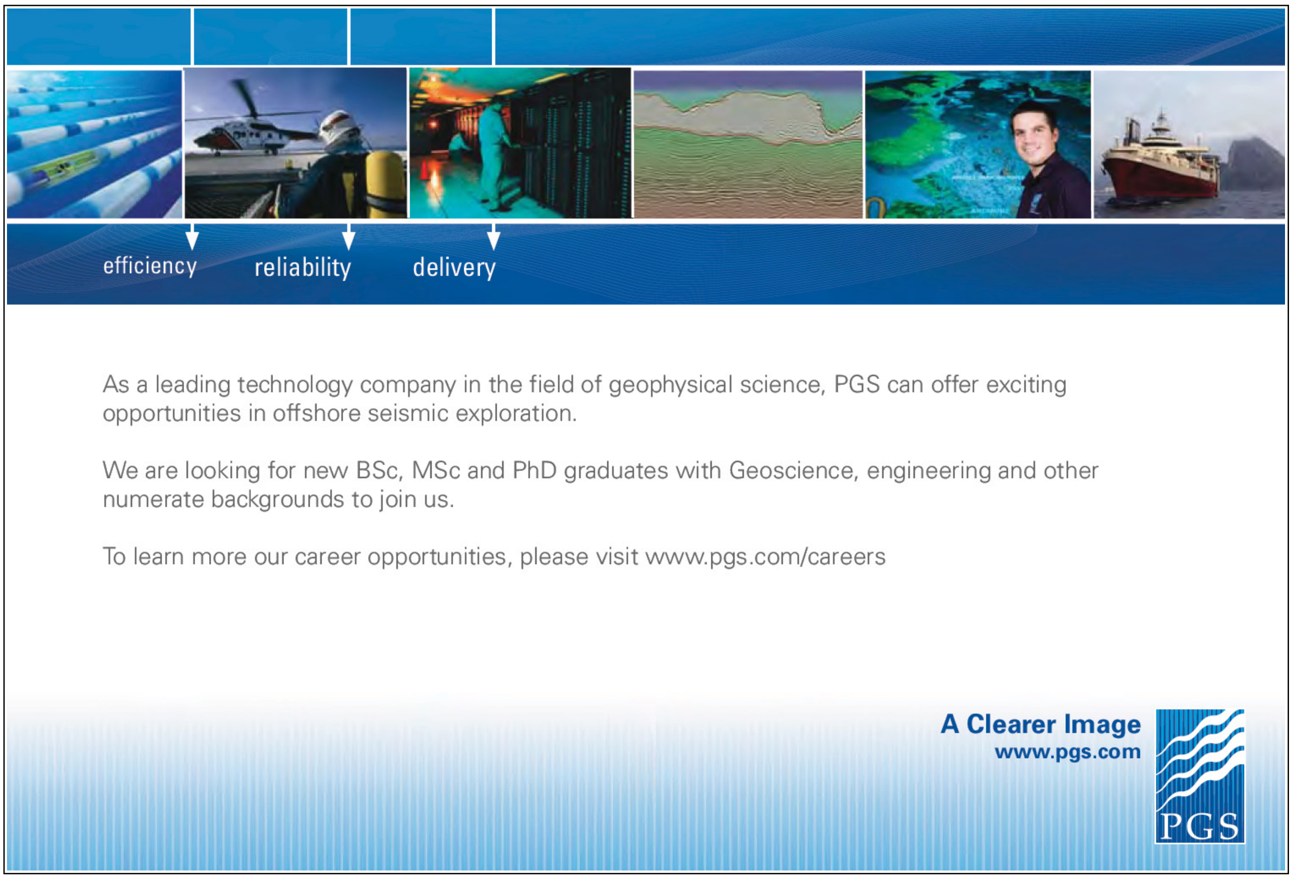
Salts behave differently from most other materials that absorb moisture. The ERH of many materials depends on both the type of material **and** its moisture content. This usually means that as more moisture is added the ERH increases. Imagine that within the material there are a limited number of sites that water molecules can sit, and as you add more water it is difficult for the material to hold onto the water as the molecules move between the available sites. Salt on the other hand just keeps absorbing more and more water until it dissolves, but uniquely, up until that point of *liquefaction*, salt has the same capacity for interacting with the surrounding air and the ERH is always 75%.

In fact this property of salt is used to generate a relative humidity of a known value. For example if you wanted to calibrate a humidity probe at 75% you would need to place the probe in air at 75%RH and adjust its reading accordingly. If you prepare a saturated solution of pure table salt, chemically sodium chloride (NaCl), by adding the salt to water until no more salt dissolves and the solution is 'saturated', the air above that solution will have a relative humidity of 75%.

The sample of salt used to generate the above ERH graph is nowhere near saturated but still results in an ERH of 75%. This is possible with a salt because a little amount of water added to the salt still generates the same humidity as if it was saturated.

Back to the cafe and you now know that on the days I saw the droplets of water, or a short time before, the relative humidity must have been above 75% for long enough for the crystals of salt left around the holes of the salt seller to have absorbed moisture and dissolve into little droplets.

I like to include a little bit of basic science every now and then, so let me tell you about some other salts you may have heard of and their ERH values. Different salts generate different ERH values and you can pick salts to go from less than 10% to over 90%. We have covered NaCl at 75%. As a bit of background to its chemical name, the Na comes from Latin for **Na**trium and Cl from **Chl**orum.



Other salts you will see listed as ingredients in food include potassium chloride, chemically KCl, the K from **K**alium, This has an ERH of 84%. KCl is a constituent of Sea Salt and an important salt in our diet. And then there is Magnesium chloride, $MgCl_2$, ERH of 33%, used in baby formula and as a dietary supplement. The Mg from the similar Latin Magnesia (do you remember Milk of Magnesia?). The subscript "2" after the chloride shows that there is two parts chloride to one of magnesium that form the salt. Just as in H_2O, two hydrogens to one oxygen. Chemistry lesson over.

Why these salts have a special and specific relationship with water is difficult to explain without a scientific knowledge of atoms and molecules. However, human beings have realised this relationship and used it for hundreds of centuries without the scientific knowledge we have now. Salt has been used for preserving and adding taste to food since ancient times. Its preserving properties are all to do with the interaction with water and the effect this has on the ERH.

Referring back to Chapter 6 and the table listing the ERH values that allow microbial growth, it was not until 1957 that this relationship was discovered even though mankind had exploited this physical property of salt for thousands of years. So you can see in this simple example how scientific discoveries provide us with new knowledge and using that new understanding we can begin to gain some control over the world we inhabit.

In the next chapter, we see that to take advantage of our new understanding we need data.

9 ERH Revisited

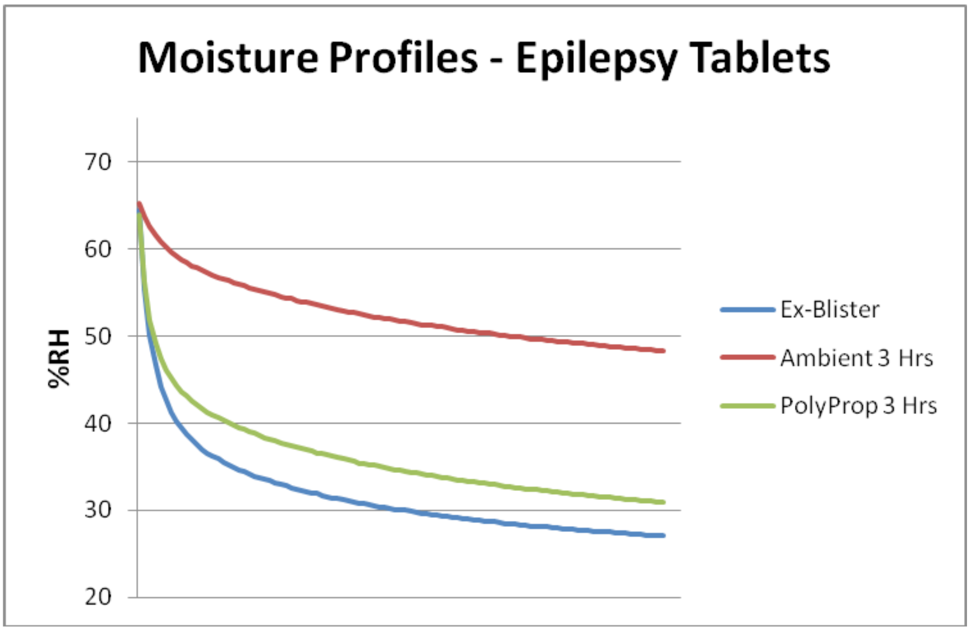
I thought now that you have read about some real life examples of where the ERH phenomenon is important, I would add a very short chapter on looking at ERH in a different way.

In the last three chapters the references to ERH have been from an "investigational" aspect. That is, let us look at something and, using our new knowledge, provide an explanation. Generally, the more we know about something the more it leads to a greater understanding of the subject. The next step in science is can we use what we know "prospectively"?

Here is a prospective study of something you may have seen or are familiar with form your own experience or that of a family member. A recent initiative in pharmacies to improve patient compliance, particularly in the elderly, is re-packing supplies of medicines so that the patient has their daily requirements individually dispensed.

This study involved investigating re-packing of a well known brand of epilepsy tablets into polypropylene type sachets. The intention was to include these tablets that are taken once or twice a day, along with the other daily medication required by the patient. A pharmacist was concerned that because the tablets are supplied in a blister pack with thick aluminium foil forming the blister pockets, protection from moisture may be important.

An initial moisture profile was performed on the tablets taken directly from the blisters. Tablets from the blister left were exposed open to ambient (room) conditions, as well as being placed in a good quality polypropylene zip-lock bag to simulate the re-packing conditions. After 3 hours, moisture profiles were run of the exposed and re-packed tablets. The initial part of the moisture profiles, which contain the most significant comparative information in this case, are shown in the graph below.



The tablets taken directly from the blister pack have a low ERH that was measured as about 24% RH and, as you now know, will interact with atmospheric moisture at any humidity level above this value. This low ERH means that the tablets must be protected from atmospheric moisture using a good moisture barrier such as the aluminium blister material in which they are supplied by the pharmaceutical manufacturer.

Exposure to the ambient conditions, which were 60-70% RH, caused a change in the moisture profiles after only 3 hours. The ERH had increased showing that moisture uptake had occurred. Naturally, the more exposed tablets absorbed moisture more rapidly than the packed tablets. The polypropylene bag gave some protection but insufficient to prevent moisture uptake by the tablets.

For the sake of simplicity, only the data from the first 3 hours are shown on the graph above, however, the prospective study was continued for 3 days and then stopped because of the condition of the tablets. These tablets are manufactured with a film coat around them and after 3 days of ambient exposure the film coat had cracked at the sides due to swelling of the tablet matrix. Tablets within the polypropylene bag had continued to take up moisture and had an ERH of 48% after 3 days.

It was concluded from this study that these tablets must not be re-packed in polypropylene sachets as physical damage will occur and that, based on knowledge of moisture interaction with drugs, could also result in chemical changes putting the patient at risk.

This study is a good example of what I love about science. You start with an observation that materials absorb and lose moisture until they come to an equilibrium. You gain new knowledge about this property of materials. A real life situation presents itself. You devise a plan of investigation. You execute the study and observe data. You come to a conclusion, which in this case has averted a potentially serious problem occurring.

How does this tie in with A Wet Look At Climate Change? The tablets are another example of everyday items that you may be using. As is the case with most materials that absorb or lose moisture, some are more sensitive than others. It is important to know which are sensitive and be aware of the climatic conditions to which they are exposed. Of course, these conditions do change as a matter of climate, or through our own handling of materials. Sometimes this can have disastrous consequences,

In the next chapter, you will see that having gained all this knowledge and applying tools of investigation, it pays to *actually* remember to use what you know!

10 How Much Water?

A question that struck me when thinking about ERH and running moisture profiles, was how much water is actually moving between the air and the material I am testing? I will come back to this specific question later in this chapter.

There is a much bigger question that is important when considering climate change and how much water. We are all familiar with, and probably at some time experienced what happens when a lot of rain falls in one area over a short time, we get "flash flooding". In the past couple years we have seen devastating flooding in Devon in the South West of England following torrential rain and in April 2011 a month's worth of rain, 5 inches, fell in 48 hours in Western Scotland.

This was followed in June by large amounts of rain across an area stretching from north-east Wales through the north Midlands, Lincolnshire and Yorkshire that sadly resulted in three deaths.

But how much water is 5 inches of rain? To appreciated the massive amount of water this measurement of 5 inches represents we need to relate this to something more familiar and easier to grasp. A mental picture and story often helps and here is my story of how much water.

Ireland, as you may have heard if you live in the Western World, is not in a good financial state. In order to squeeze more money out of the general public a water tax is most certainly going to be introduced. We have a water meter that I only discovered fairly recently when one day I went to turn off the mains water to fix a leaking garden tap. The local council had re-surfaced the road along the front of our property and had sneaked in a water meter at the same time.

We had been considering a while to set up a butt to collect rain water. As you know from the earlier chapters we have a garden and grow our own vegetables. So now there was a financial incentive and rain water must be better for plants than chemically treated tap water. I bought a water butt, going for a 110 litre slimline type as I thought it would look better than the more rotund 210 litre size as it was to be located at the corner of the house.

The plan was to use a downpipe that did not drain in to a drainage pipe but emptied directly onto an area of the garden that was prone to flooding. Thus achieving two objectives at once, collecting rain water for the plants and alleviating an area of flooding.

I removed the bottom section of the downpipe, offered up the water butt and cut a section of downpipe to end just above the lid of the butt. Applying simple mathematics, and using two 45° angle connector sections inserted into each other, I reversed the 45° angle so that the direction of the pipe was returned to 180° downwards but now a few inches out from the wall. Using one of the connectors as a template I cut a tight fitting hole in the lid of the but. Guessing that the butt was made of thermoplastic polypropylene or something similar, I used a heat gun to soften the plastic around the hole that I had cut and pushed in one of the downpipe 45° angle connectors to make a secure fit.

After connecting the downpipe I stood back and feeling really quite proud of my ingenuity and efforts resulting in a tidy job, and I took a photograph:

Have you heard the saying "pride comes before a fall", well in my case it was "pride before a rainfall". The climate in Ireland has definitely changed over the past couple of years. We have less of the Irish "soft days" of mist and drizzle and are seeing more heavy downpours sometimes just lasting a few minutes and then a short break followed by another downpour.

It was two days after setting up the water butt that three downpours arrived in quick succession lasting only a few minutes each. Naturally, and like an excited child, I went out to see how much water I had collected. The butt was overflowing!

Please click the advert

Going up in the world…

You'll be going up in the world after graduating from Nottingham Trent University. We are one of the best universities in England for graduate employment with over 97 % of our students employed or in further study within six months of graduating.*

- Consistently ranked as one of the leading modern universities in *The Independent Good University Guide*.
- Courses informed by businesses and industry – strong commercial partnerships with over 6,000 companies globally.
- Many courses include professional accreditation and / or the opportunity to undertake a work placement. This gives our graduates a competitive edge when entering the job market.
- An exciting student city in the middle of England. Ideally located for travel across the UK and with direct flights to destinations across Europe from East Midlands Airport.
- Investing £130 million across our three campuses to create an inspiring learning environment.
- In the most recent QAA institutional review, the University received the highest commendation for its consistent commitment to supporting students and their learning.

If you would like any guidance on applying to Nottingham Trent University please contact Laura Vella, our International Officer for Europe, on

Tel: +44 (0)115 848 8180
Email: laura.vella@ntu.ac.uk
www.ntu.ac.uk/book

NOTTINGHAM
TRENT UNIVERSITY

5365/07/09

* HESA DHLE 2006–07

Despite all my scientific training, years in project management, working as a consultant telling clients that we must have data, to plan the next step and be in a position to start drawing conclusions, did I at any stage think to calculate how much water would be expected from rainfall – no! I cannot explain this oversight. I can only say that I took the dangerous path of "assuming" that the suppliers of water butts make them at a size that would collect a reasonable amount of water over a reasonable period of average rainfall.

To be fair on the water butt manufacturer they do supply a diverter for standard round downpipes. The diverter is attached to the downpipe and diverts water to the butt. When the butt is full, the excess water simply flows down the pipe into the drainage system as usual.

So let us now do the calculations that I should have done in the first place. This will show you the importance of collecting good data and the useful insights that can result before embarking on an experiment or project.

Area of roof = Length of guttering x distance to apex

Note: Take angle of rainfall as vertical hence roof area is its two-dimension profile and not based on the hypotenuse of the triangle

Area of roof = 7m x 7m

Area of roof = 49 sq. m

The amount of water in 25mm (1 inch) of rain is defined as 25 litres per square metre.

Amount of rainfall from 3 downpours = 5mm (actual measurement by a standard rain gauge in my garden)

Amount of water falling on roof area = 5/25mm x 49 sq. m x 25 litres

Total amount of water = 245 litres

So, there is the proof, in just over an hour, enough rain fell to fill the water butt more than twice. Now I have to "work the problem".

The aesthetics are out the proverbial window and a 210 litre butt is to be purchased. Both butts will be connected using the 210 litre butt as an overflow container and I also have an idea to attach a perforated garden hose. This hose is to be run along to irrigate a boarder that sits sheltered under the roof soffit and has usually to be watered manually even if it has been raining.

Time for a “sanity check”. This is not what has probably come immediately to mind and you are thinking that this man with a fixation on all things water should go and talk to someone. This is a check on my calculations. If you can find an alternative way of calculating the maths to give you the same result or a “ballpark” figure, this gives better assurance that your approach is correct and you can rely on the result.

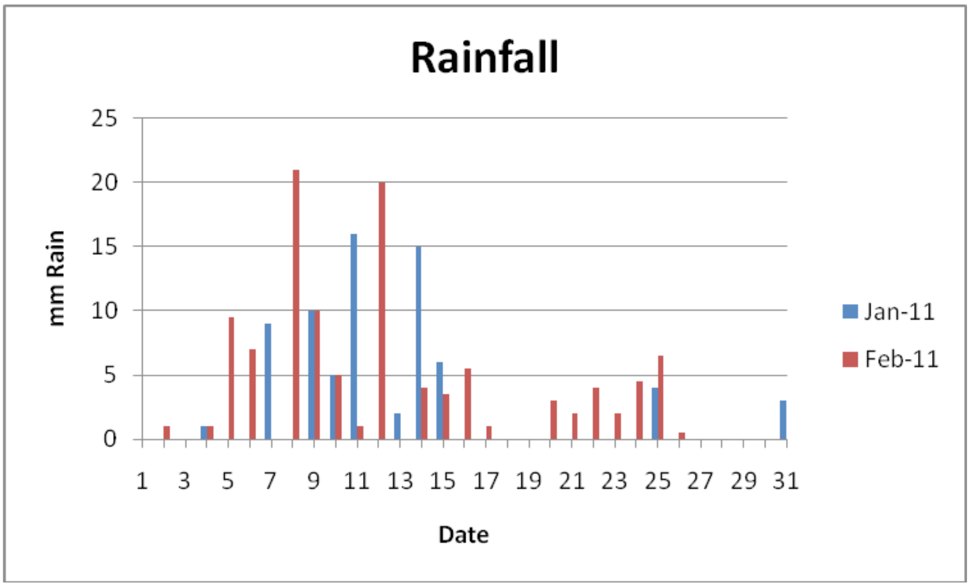
The key premise in my “how much water” calculation is the definition of 25mm (1 inch) of rain is 25 litres per square metre and the assumption that my water gauge is calibrated on this basis. So, it would be good practice to check this assumption:

Sanity Check:
Diameter of water gauge = 8cm
Area of water gauge = πr^2 = 3.14 x 4 x 4 =50.3 cm^2
Volume of a cylinder = $\pi r^2 h$ = Area of water gauge x height of water
Volume of 5mm in water gauge = 50.3 x 0.5 cm = 25.1 cm^3

Area of roof divided by area of water gauge = 49 m^2 /50.3 cm^2
1 square meter = 10 000 square centimeters
Ratio of area of roof to water gauge = 490,000/50.3 = 9,741.6
Volume of water in 5mm rain on roof area = 9,741.6 x 25.1 cm^3
= 244,514.1 cm^3
1 litre = 0.001 cubic centimeters
Total amount of water = 244.5 litres

The mathematicians amongst you will immediately see that the "how much water" calculations above can be reduced to 490,000 x 0.5 /1000 to give 245 litres' but the sanity check calculation shows that the water gauge is calibrated properly. Also, it demonstrates in a practical way how rainfall is measured as a volume of water over a defined area. In fact, you can use any small container to collect rainwater and knowing the surface area and accurately measure the volume collected, then you can convert this to mm or inches of rain and have you own homemade rain gauge.

Just to show you that the troublesome downpours were not a freakish event, in the graph below I have included my own rainfall data for January and February 2011. These data tells us that there were 7 days in January and 13 days in February where the 110 litre butt would have filled to overflowing.



Having added the "how much water" calculation to my armoury, interesting and valuable insights start to become revealed. I mention above the problem of flooding in the area of the garden where the downpipe used to discharge until my recent diversion to the water butt. Looking at the rainfall from the 8th-12th of February we can calculate that on the 8th, a vast 1029 litres of water was dumped onto that part of the garden. In addition of course, the area of ground will have received directly 21/25mm x 25 litres or 21 litres of water per sq. metre. The area that floods is about 40 sq. metres, given a total of over 2000 litres of water. That was followed by about 1000 litres the following day, 500 litres on the next day, a bit of a rest bite of only 100 litres on the 11th and then another big dump of 2000 litres the following day. Hardly surprising then, that the ground flooded.

Another factor is the atmospheric conditions at that time year.

Remember? You must always consider the temperature! The daily temperatures were 4.3, 2.8, 4.5, -0.1 and 4.4°C, respectively. Applying your new knowledge of the relationship between temperature and humidity, you can see that the air will have been quickly saturated and there would be no scope for evaporation to remove water between downpours. Of course, it is also likely that it just rained continuously.

Let us now go back to 5 inches of rain and try to imagine what that would be like. We can do the maths and we get 125/25mm x 25 litres or 125 litres of water per sq. metre. Those of you astute enough will have notice that the sum is 1litre per 1mm of rain, but as they said in school, you must show your workings.

So, a whacking 125 litres on each square metre. I am looking at a tiled floor and a metre squared is about 3 tiles up by 3 tiles across and trying to imagine the entire contents my lovely slimline water butt, plus a bit more, poured onto the square. Then multiply by 4 then by 3 and we have a room under 5 inches of water.

On a bigger scale, let us take as an example the pitch size at the new Aviva stadium Lansdowne Road in Dublin. I chose this because I was on the pitch on the 25th June this year at a Neil Diamond concert and perhaps because it is all enclosed, it is a large area that I can conceive in reality and visualize to try and get a mental picture. In fact the pitch is 105 metres in length and 68 metres in width.

Actually, this was the first concert that I have ever attended where there was people with Zimmer frames and couples, presumably still sober at that time of the evening, supporting each other to get along the road, with and without walking sticks. It was a bit surreal. I forget that in my head I'm still about 24, forgetting that I remember Neil Diamond from the sixties, as did all the pensioners!

Anyway, back to the maths. Thankfully, with it being an open air concert, there was no rain that evening, but if we had 5 inches, this would be:

Amount of water falling on the pitch = 125/25mm x 105 x 68 sq. m x 25 litres

Total amount of water = 892500 litres

Nearly 900,000 litres or the combined capacity of 30-40 large petrol tankers.

We have reached August 2012 and just had another very wet July month that included some sudden very heavy downpours. Over the past 12 months in different parts of the British Isles there has been devastating flooding. This extreme weather has been attributed to a band of high altitude air that flows from west to east around the globe in the northern hemisphere and is called the jet stream. The jet stream is running further south for reasons nobody can explain, but the consequence is that it pulls cold and wet air from the Arctic over the British Isles.

The reality for us at ground level is that we are having terrible summers and the pattern of rainfall is resulting in the soil not getting a chance to dry out and each heavy downpour is quickly saturating the ground and causing flooding. When the sun does appear for its occasional visits, the radiated heat begins evaporating the sodden earth and, as you now know, the humidity shoots up with all its consequences.

If we scale our 5 inches of water calculation to a city that has very much been on our television screens recently for hosting the Olympics, and do the calculation for the Greater London Area, we get an enormous 217,500,000,000 litres of water.

Would this amount of water ever fall on Londoners? The UK Met Office has a page on its web site www.metoffice.gov.uk showing extremes of weather and the rainfall page shows that Hampstead in Greater London got 169mm, nearly 7 inches, of rain over 155 minutes on the 14th August 1975. So yes, a lot of wet Londoners.

'Look, the Shard'

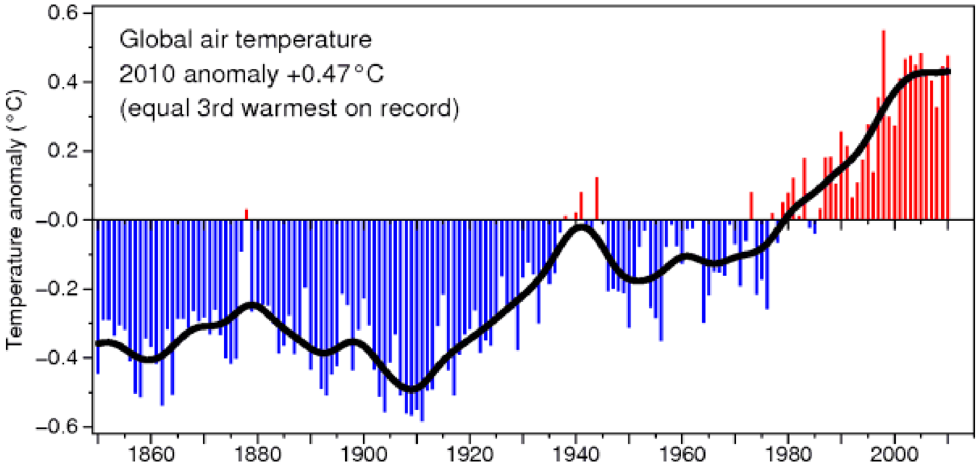
Reproduced with permission from Telegraph Media Group - Matt Cartoon © Telegraph Media Group

In chapter 4, I briefly covered tropical storms and talked about their power and size but did not relate their destructive potential to events at ground level. Now you have added the "how much water" calculation to your new knowledge you can appreciate, even be in awe, of what the scene must have been like in Harris County, Texas in the USA on June 5th-9th 2001 which was hit by one of the most devastating storms in US history .

Harris County with an area of 1778 square miles is about 3 times the size of Greater London. During tropical storm Allison almost two-thirds of Harris County received over 12 inches of rain in 14 hours, with rainfall amounts exceeding 19 inches at several locations on the first two days of the storm (Tropical Storm Allison and its impact on Harris County, Binbin Chen, December 9, 2006).

I am not a "gloom and doom" merchant so I will not recount here the devastation that affected over half the population of 4 million people, but just imagine, or work out for yourself, the enormous amount of water that fell in a couple of days.

Applying your new knowledge of the relationship between temperature and humidity, you may begin to get a feel for the consequences of global warming. The chart below form the Climate Research Unit, School of Environmental Sciences, University of East Anglia, shows a graphical representation of a calculation that is performed using air temperature data from around the world.



The study of weather and climatic differences is a complicated science and certainly not within my expertise or the scope of this book. Clearly, over the last 30 years we have entered a phase of slightly increased global air temperatures. I do not have sufficient knowledge to comment on the significance this has in global warming and climate change, but, I can say with confidence that any increase in air temperature adds to the total amount of water that can be held in the air. Even where the temperature increase is only a small percentage, a small percentage of a very large amount of water is still a very large amount of water!Next, let us go from very, very large movements of water to very, very small movements.

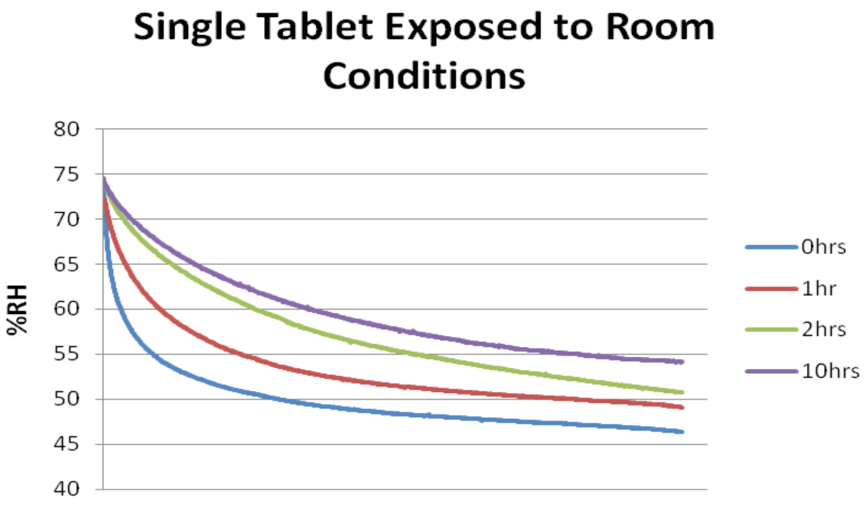
Next, let us go from very, very large movements of water to very, very small movements.

ERH and Water Vapour

When working with moisture profiles and measuring the ERH of materials, often I ask myself, "how much water" is actually moving in or out of the material. Another related question is "how fast". These are not easy questions to answer because of the complexity of working with relative humidity. I can see this section of this chapter continuously expanding maybe into a chapter of its own as my own knowledge and experience grows in this area.

I will begin with a simple experiment. During demonstrations of moisture profiling with my Relequa unit I use a pack of tablets as my test material as tablets are a convenient form for transporting around. These tablets have a low ERH, stored in the presence of desiccant and therefore very useful in demonstrations as they will always absorb moisture rapidly at %RH values around 50-60% or higher.

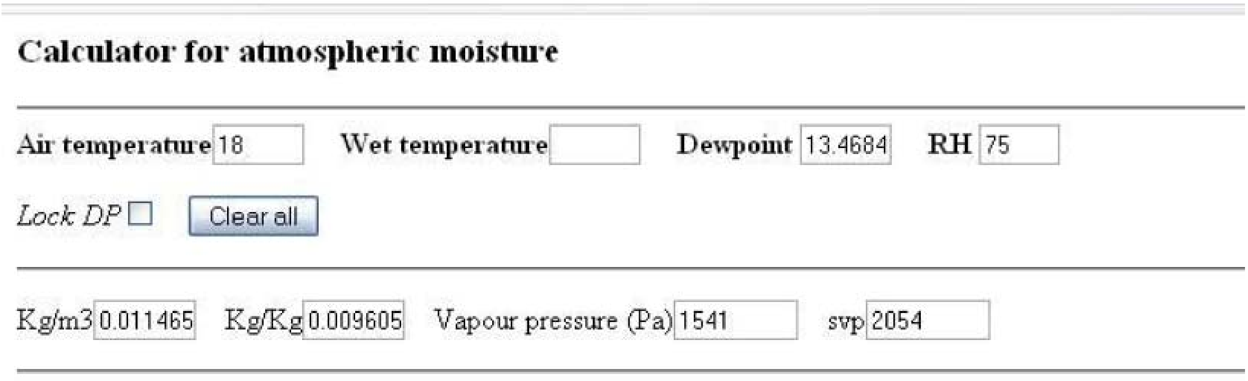
In November 2007 I presented a talk entitled 'Equilibrium Relative Humidity – Active Moisture Sorption by Pharmaceutical Products' at a conference on stability testing in pharmaceuticals. One of my slides showed what happens when a tablet is left exposed to the atmosphere. To collect the data for the slide I simply took one of my demonstration tablets out of the pack, ran its moisture profile and then left the same tablet openly exposed on a table. The ambient humidity was about 75%RH and the temperature about 18°C.After an hour the tablet moisture profile was run again and this was repeated at 2 hours and then after 10 hours. The graph below shows that the tablet straight out of the pack (0hrs) quickly takes up moisture and lowers the %RH within the Relequa test chamber. After exposure to a humidity above its ERH (1, 2 and 10hrs) the tablet continues to take up moisture and the moisture profile curve changes.



We see two changes in that the curve becomes more shallow suggesting the rate of moisture uptake decreases as the ERH increases.

As far as my presentation at the conference was concerned the only point I wanted to make was that ERH is a good indicator that physical changes in drugs may have occurred due to moisture interactions. The same data in the context of this chapter demonstrates that materials easily take up moisture given the right conditions. The next question was of course "how much water"?

Now we get into the very small. The tablet weighs about 120 milligrams and was tested in a chamber with a volume of 35 millilitres. Using Tim Padfield's humidity calculator that I intorduced in Chapter 2, we can calculate how much water there is in air at 18°C and 75%RH.



Calculator for atmospheric moisture

Air temperature 18
Wet temperature
Dewpoint 13.4684
RH 75

Lock DP ☐

Kg/m3 0.011465
Kg/Kg 0.009605
Vapour pressure (Pa) 1541
svp 2054

The figure we will use is seen in the Kg/m^3 box. This number is the actual weight of water in one cubic metre of air and is known as the "Absolute Humidity".

Please click the advert

Technical training on
WHAT you need, *WHEN* you need it

At IDC Technologies we can tailor our technical and engineering training workshops to suit your needs. We have extensive experience in training technical and engineering staff and have trained people in organisations such as General Motors, Shell, Siemens, BHP and Honeywell to name a few.

Our onsite training is cost effective, convenient and completely customisable to the technical and engineering areas you want covered. Our workshops are all comprehensive hands-on learning experiences with ample time given to practical sessions and demonstrations. We communicate well to ensure that workshop content and timing match the knowledge, skills, and abilities of the participants.

We run onsite training all year round and hold the workshops on your premises or a venue of your choice for your convenience.

For a no obligation proposal, contact us today at training@idc-online.com or visit our website for more information: www.idc-online.com/onsite/

OIL & GAS ENGINEERING
ELECTRONICS
AUTOMATION & PROCESS CONTROL
MECHANICAL ENGINEERING
INDUSTRIAL DATA COMMS
ELECTRICAL POWER

Phone: +61 8 9321 1702
Email: training@idc-online.com
Website: www.idc-online.com

IDC TECHNOLOGIES

Download free ebooks at bookboon.com

In Tim Padfield's calculator, the absolute humidity has an inbuilt assumption in order to maintain simplicity. You will see a note in the screenshot of his calculator in Chapter 2 that states "natural climate near sea level" which means an atmospheric pressure of 1 Atmosphere or 1013 mbar (101300 Pa). This assumption, for our purposes here, makes very little difference to the outcome. I checked this using another humidity calculator available from a company called Viasala who make a range of humidity measuring equipment. Viasala seem to have some very knowledgeable people and have produced a number of technical webinars covering various topics associated with understanding humidity and its measurement.

Using the Viasala calculator, I took one of the highest and one of the lowest air pressure measurements from my weather station, 1032 and 997 mbar, and calculated the absolute humidity for 18°C and 75%RH at these two pressures. The result at each pressure is less than 2% different from normal atmospheric pressure and is the same difference as 1032 and 997 mbar from 1013 mbar, showing that we are looking at a straight mathematical calculation that has a factor for air pressure included.

Having checked and confirmed that our absolute humidity figure is not overly sensitive to small pressure changes, we can proceed. We see from the calculator that, at our chosen temperature and %RH, there is 0.011465 Kg/m^3, or converted to grams and rounded, 11.5 g/m^3 of water in the air. The test chamber is 35mL so the amount of water in the chamber is:

Amount of water in the air = 11.5 g/m^3
Volume of chamber converted to m^3 = $35 \times (1 \times 10^{-6})$
Amount of water in chamber = $11.5 \times 35 \times 10^{-6}$

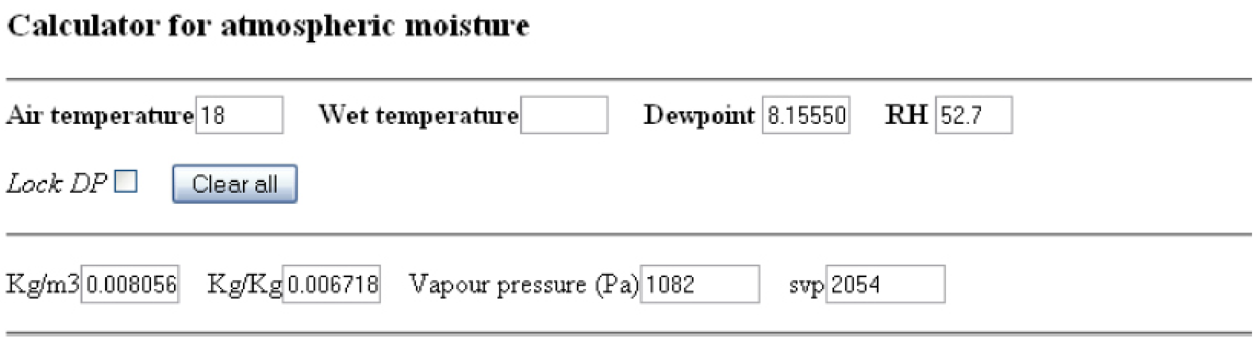
= 0.0004025 g

If we take it that 1 millilitre of water weighs 1 gram, the above "how much water" calculation tells us that the amount of water in the Relequa test chamber at our chosen temperature and %RH would be 0.4 thousandths of a mL, or just under half of one millionth of a litre!

This is tiny amount of water and so small you would need special equipment to measure out this amount.

But, we can go even smaller. Looking at the graph of the exposed tablet, we see in the moisture profiles that the drop in %RH begins quickly and then gets slower and slower until they reach the ERH point. Logically, the drop in %RH is water vapour being absorbed by the tablet and the difference between the starting %RH and the final %RH at the ERH point represents an amount of water taken up by the tablet.

So, "how much water" has moved from the air to the tablet? We know from the humidity calculator that the air started with is 11.5 g/m^3 and is the actual amount of water in the air at 18°C and 75%RH. Let us take the 10hr exposed tablet moisture profile where the ERH was 52.7%. Using the humidity calculator for 18°C and 52.7%RH:



Calculator for atmospheric moisture

Air temperature 18 Wet temperature Dewpoint 8.15550 RH 52.7

Lock DP ☐

Kg/m3 0.008056 Kg/Kg 0.006718 Vapour pressure (Pa) 1082 svp 2054

We see that the amount of water in the air has dropped from 11.5 g/m^3 to 8.1 g/m^3 giving a difference of 3.4 g/m^3. Calculating this difference for the 35mL chamber we get 0.000119g, just over one tenth of a millionth of a litre absorbed by the tablet. As percentage, the tablet absorbed 0.099% of its weight.

By performing some simple calculations, we have gained some further insights into ERH. As well as knowing in what atmospheric conditions a material will take up or lose moisture, we can work out how much moisture is involved. Knowing over what period of time the movement of moisture occurred, we can work out a rate of moisture uptake and loss.

These measurements show the power in having a deeper understanding of ERH as a fundamental property of materials. To investigate moisture uptake directly by measuring such a small weight gain in the tablet, we would need to use a very accurate and very expensive analytical balance.

The reality of what I have just demonstrated is that by applying a bit of knowledge we can sometimes take simple measurements in science and deduce facts about systems that are working at a micro level.

As my own knowledge has grown in this area, I no longer think in terms of changes in %RH, instead I think of water vapour and vapour pressure. I see moisture uptake and loss as movement of water molecules driven by different forces and interacting with materials in different ways. In this light, moisture profiles are very interesting.

In this chapter I included some number crunching, keeping it as simple as I could. The reason was to show you that we have to measure things in science, and in life generally.

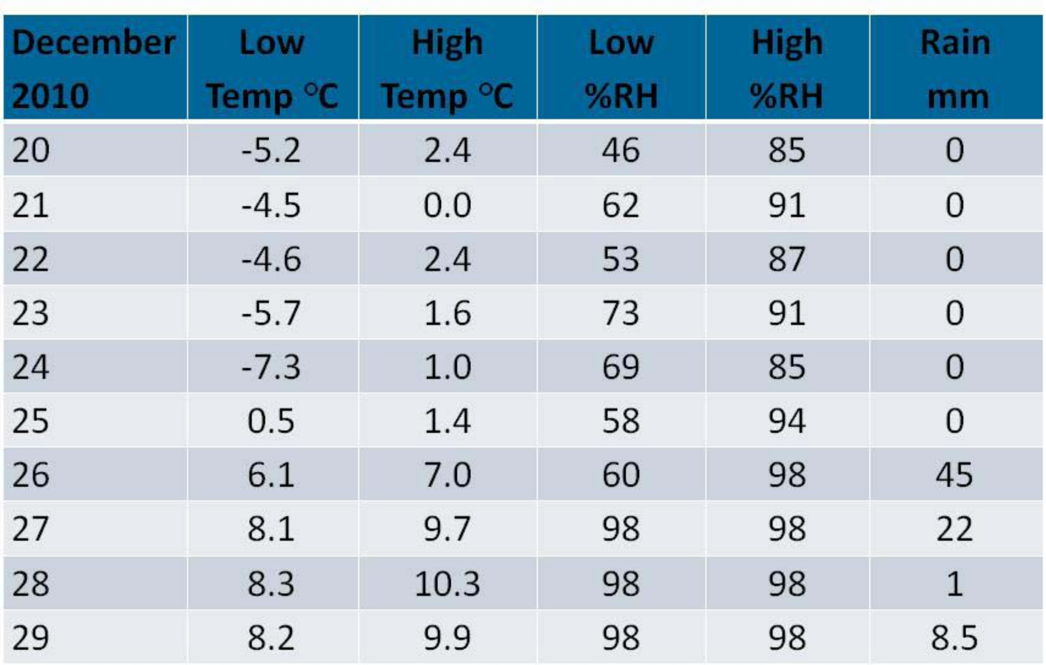
Gordon Bethune in his book “From Worst To First” explains how he turned around a struggling Continental Airlines to be one of America’s top airlines, He includes a chapter called “What Gets Measured Gets Managed”. Basically they measured everything to find out where improvements could be made. Without the data, the management team were working in the dark. I have adopted this approach into my own thinking, turning it into the words I say to people faced with a problem “that you can only manage what you can measure”.

Learn the skills of measurement, practice and keep an eye on detail. These are valuable if not essential skills for students of science and technology, perhaps also everybody else.

In the next chapter, we start with measurement but sometimes the problem is not within your power to manage.

11 Oh Poor Olive Tree!

I gave a talk at a training course in February 2011 and presented some of my own data to show that local climate can, and does, change dramatically in a short space of time. The data I chose came from ten days in December 2010 and is shown in the table below.



December 2010	Low Temp °C	High Temp °C	Low %RH	High %RH	Rain mm
20	-5.2	2.4	46	85	0
21	-4.5	0.0	62	91	0
22	-4.6	2.4	53	87	0
23	-5.7	1.6	73	91	0
24	-7.3	1.0	69	85	0
25	0.5	1.4	58	94	0
26	6.1	7.0	60	98	45
27	8.1	9.7	98	98	22
28	8.3	10.3	98	98	1
29	8.2	9.9	98	98	8.5

I used these data to emphasise some points about the relationship between temperature and humidity, something that you now know about from your new knowledge. There is no real benefit in going over the same points here as I have covered these in the earlier chapters.

Observe though, the dramatic change from Christmas Eve, through Christmas Day into St. Stephen's Day (as it is called in Ireland). This sequence of ten days started with another dramatic change from mild weather to the wintery scene in the picture below.

Remember in Chapter 2 I referred to snow in our part of Ireland as "rare enough event" and even put in a cartoon to make a bit of a joke of having enough snow to make snowballs. Well, that chapter was written in summer, or what we laughingly referred to as summer, in that very wet year of 2009.

I also used this picture in my talk to discuss possible problems caused by long term cycles in climate change. According to acquaintances from the Dungarvan area, the last time this amount of snow fell was in the early 80s. Nearly thirty years of fairly consistent weather with mild winters, then in 2009 there were signs of change where we had a couple of spells of very cold and frosty days with a sprinkling of snow. This was followed a year later by the coldest and snowiest weather that I had experienced in 17 years on this island.

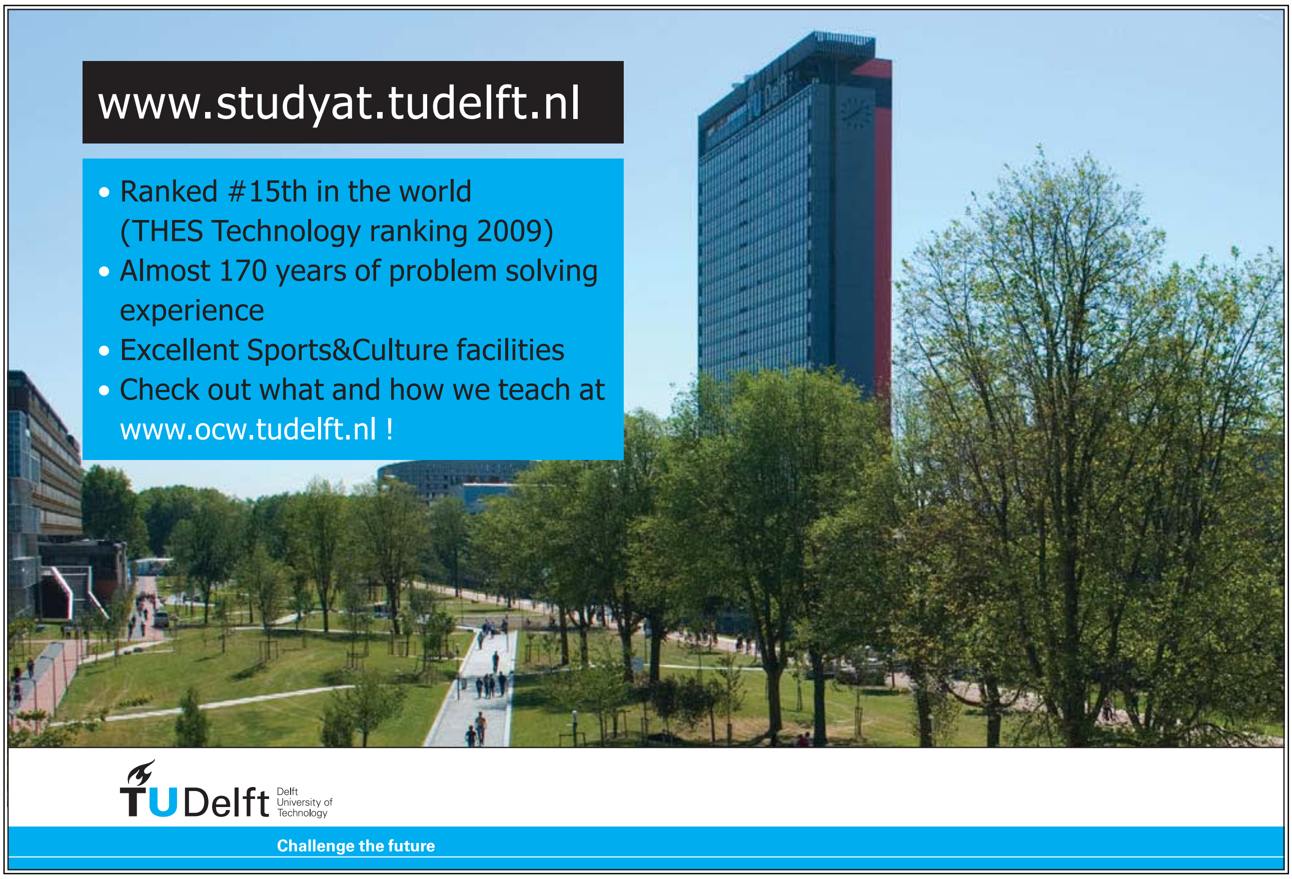
The tree in the picture, as you may have guessed from the title of this chapter, is an olive tree. I actually only found out recently that this is an olive tree. On a visit to the UK, I went to the annual open day at **Wisley Garden in Surrey**, the flagship **garden** of the Royal Horticultural Society. On the way out, walking around the rows of plants for sale, I saw a tree that I immediately recognized.

I had lived with this tree for nine years without knowing what it was. The way it grows held a fascination for me in that the young branches grow very quickly and the leaves are small 'pinnate' and 'opposite' similar to a fern. When the branches mature the leaves change to the characteristic oval shape of the olive tree. Pruning off branches causes the tree to sprout multiple new branches, a characteristic that presumably makes olive trees good for orchid management.

The single tree in the Wisley garden centre had been managed in this way, and that is how I spotted the characteristic features of the new growth. A helpful assistant, who was clearly very knowledgeable about their tree, told me it was an olive.

You will see in the picture above that the tree has leaves. This unfortunately was the last time our poor olive tree had leaves. There is now no sign of any life at the top of the tree. Ironically, we had only just the previous summer put wooden edging around the tree in an approximation to an octagon shape as a feature. So now we have as a garden feature, a trunk!

My little anecdote about our poor olive tree is an example of signs that can be found in nature that are indicators of climate change. Our olive tree is fighting back! Over the summer new shoots have appeared low down coming out of the trunk.



In the right hand picture you can see the distinctive leaves I recognised on the tree at Wisley. Look up pictures of olive trees and you will see how different the mature leaves are in shape and colour.

Fergal, our tree man who lops our bigger trees every three to four years, said he would cut down our poor olive tree to a stump and we can put a plant pot on top. However, if our tree is willing to fight back we have to give it a chance. Besides, my scientific curiosity has kicked in and I am wondering whether it will survive this winter. What happens when the new growth gets bigger? Do we end up with an ‘olive bush’ or a complete mess?

Moving on and taking the risk that you may think this is turning into a gardening book, I have another story from the garden that brings us back to the world of moisture.

Over the spring and summer of that very wet year 2009, we grew courgettes. Having eaten courgettes with nearly every meal for about a month and frozen lots of portions of ratatouille, we decided that despite the weather, courgettes were a big success and we would repeat the process the following year.

In the spring and summer of 2010 the weather pattern was quite different with several days of very little or no rain and the occasional heavy downpour, A pattern that has continued into this year, 2011. The courgette plants were planted out in May, just as the year before. They grew quite well until late June when everyone of the large leaves got covered in powdery mildew.

Only two out of six of the plants survived with the others succumbing to the fungal infection. Reviewing my own climate data showed that, even though there had not been rain, the evening relative humidity rose above 90%RH and close to saturation on most days in June and July. At the end of June the day time temperatures were at least 19°C and up to 23°C on a few days. The night time temperatures were lower, but held up around 15 -16°C.

These were obviously ideal conditions for the powdery mildew fungus, warm with the relative humidity above its require ERH for growth over a significant portion of the day. I think I contributed to the problem by making a mistake. Because the air contained a high level of moisture, the soil around the courgette plants looked damp most of the time. Assuming that the intermittent rain we had was sufficient for the plants, they were not watered frequently. Although the plants seemed to be growing well, they were probably stressed due to lack of water and this reduces their immunity to fungal attack.

My whole approach to this situation was unscientific and too ‘subjective’. Just consider my language in the previous paragraph that shows the weakness in my thinking. The words “looked”, “assuming” and “seemed” have not to be used at all, or used with caution and qualification, in analysing problems. In science, you aim to be ‘objective’ as possible.

Applying objectivity to find a solution is not always easy and you have to first ‘define the problem’. As you may have perceived, we have not fully defined the problem in this case as we do not ‘know’ exactly why the courgettes were attacked by mildew. So we have to go to the next level, which is our ‘best guess’. On this basis, to prevent stressing the plants and retain soil moisture, we decided that for the next year’s courgettes a wood chip mulch would be put around the base of the plants and generally over the growing patch. You may remember from Chapter 7 that we have plenty of wood chippings available thanks to our local tree man.

This is not a complete solution as it is still only our ‘best guess’. To get control of the problem we have to apply the maxim from the previous chapter, “What Gets Measured Gets Managed”. The unknown parameter in our best guess is soil moisture. What happens to soil moisture when a woodchip mulch is placed on top of the soil? Since the mulch will be around the base of the plants, will the courgettes get enough water from rainfall?

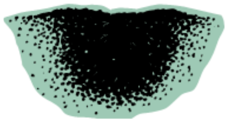
Obviously, and logically, we need to measure soil moisture. The most common and cheapest soil moisture meters have a scale that shows “wet”, “damp” and “dry”. This is not good enough for our purpose in this case. We need better accuracy and that means we need numbers to give us data. I purchased a digital soil moisture meter that gives readings as a percentage of moisture level.

I picked a dry day in mid-June and armed with my new measuring device headed into the garden. Comparative data is always useful, so as a working procedure, I decided to measure soil moisture of some exposed earth next to the courgette patch as well as within the patch itself. Consistency in executing procedures is also good, so I applied three key elements to the procedure that I considered important:

1. Testing the same patch of exposed earth and the same (first three) courgette plants closest to the exposed earth.
2. The moisture probe that is inserted into the soil is graduated along its length, so the probe was to be inserted to the same depth for each measurement.
3. Taking measurements at the same three locations in the exposed earth and at the base of each of the courgette plants stem.

Here are the range of results from the dry day:

EXPOSED EARTH



24% -27%

BASE OF PLANT

29% -32%

The woodchip mulch appears to be having the desired affect with the underlying soil around the plants retaining a slightly higher amount of water.

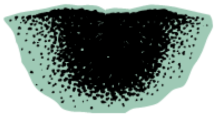
Courgettes were watered and left overnight and there was no rain:

24% - 25%

33% - 35%

The exposed soil has dried a little and there is a significantly higher moisture level around the plants from watering the previous evening. I do not show the data here but this level of moisture persisted throughout the dry day.

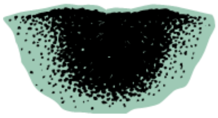
Focussing now on my concern about what happens when it rains, the change in the weather pattern to more frequent heavy downpours gave the opportunity to measure the effect of rain on soil moisture in one afternoon. Here are the range of results from two downpours in quick succession, totalling 5mm:



44% - 45%

37% - 39%

Followed by another two downpours in quick succession resulting in a total of 10mm in a couple of hours:



46% - 47%

45% - 46%

The exposed earth in the vegetable growing area of ground is deeply dug and drains well so does not easily become saturated. In comparison, the soil moisture of the earth in one of the flower boarders that is only disturbed at the surface when weeded, was 80 - 90 %. The significant result is the difference between the exposed earth and the soil around the courgette plants.

Between the first and second measurements, the moisture content of the exposed earth does not change significantly, perhaps being slightly wetter. In contrast, it is not until after the second downpour that the soil around the courgettes reaches the moisture level of the exposed earth. My conclusion from this short investigation is that the woodchip mulch can prevent rain reaching the plants and you cannot 'assume' that on a day of moderate rain that the plants do not need to be watered.

After two dry days, we were back to where we started:

24% - 25%

29% - 30%

I hope this example has shown you that by adopting a simply thought, “What Gets Measured Gets Managed”, you have a powerful tool for dealing with problems. Also, where there is a change in a system, such as climate, we need to measure and generate data in order to give us any chance of drawing the best conclusion.

In case you are wondering, this year we have six out of six beautiful courgette plants, pictured below. In the immediate foreground you will see the exposed earth where I took the soil moisture measurements and in the rest of the picture the woodchip mulch.

I am finishing off this chapter with a third indicator and consequence of climate change. In the top left hand corner of the picture above is a buddleia, also known as the butterfly tree. We have a few buddleias around the garden and every year we get lots of butterflies coming to visit, mainly Red Admirals, Painted Lady's and Peacocks.

Here is a Red Admiral feeding:

Except this year, when there have only been one or two butterflies in the garden, and it may be the same one flying around as far as I know. Concerned about this I contacted a very helpful chap called Michael on the Waterford Wildlife website and this is the reply quoted from his email "this is not a good butterfly year. It seems that the month of May was too good and many butterflies thought it much later, bred, laid eggs that hatched into larvae that could not find enough to eat as the larval food plants were not advanced enough. So, populations are down this year."

Michael assured me that the butterflies will return. I certainly hope so, because as a different type of present last Christmas, I asked for, and got, a Butterfly Hibernation Box- it's kind of redundant at the moment.

In the next chapter we come back to ERH in a surprise observation.

12 Oil + Water = ?

In the last three chapters we have looked at how in science we can go beyond simple observation and accumulation of knowledge into applications. My first degree in science was in Applied Chemistry and I think the applied aspect has defined my whole approach to science from that point onwards.

Using real life situations and problems, I hope to have shown you the importance of "**observation**" and how it is linked to "**measurement**" to give us the "**data**" we need to "**interpret**" a situation to "**understand**" the "**how**" and "**why**" giving us new "**knowledge**" to solve a problem and/or lead to the next hypothesis.

The key words highlighted in bold in the above paragraph are the fundamentals of the analytical scientific approach known as "reductionism". They are also the fundamentals behind "what gets measured gets managed". This forensic approach has been tried and tested over thousands of years by us humans, and it works.

However, it is not the only way science works.

Our fascination with the world is that it is full of surprises. Just when we think we know everything there is worthwhile knowing, something new and interesting comes along. Knowing this simple rule of life, I try as much as possible to keep an open mind and often ask myself "now why did that happen?", the implication of course is that I did not expect that particular thing to occur.

This chapter is about one of those little surprises that took me into an area of "new knowledge".

You probably have heard sayings around oil and water; that "they do not mix", or, "pouring oil on troubled water"; the former usually about two people that do not get on and the latter in a situation where things need calming down. The basis of these sayings is that it is commonly thought that oil and water are so different as to be opposites. Very basic chemistry texts tell you that oil is hydrophobic and will not mix with water.

I think sayings can be useful in particular circumstances and, as you may have noticed, I have my favourites; " **you can only manage what you can measure**" (my version); "**if it works use it**" and the related "**if it ain't broke don't fix it**" (engineer's saying); we can solve this problem "**with a bit of luck and a fair wind**" (positive thinking).

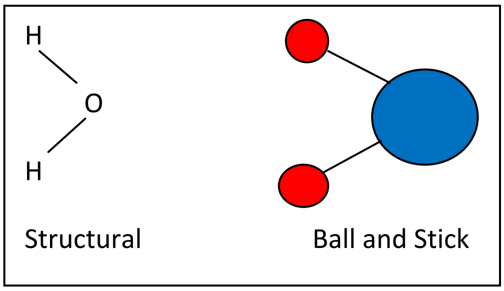
The concept of oil and water not mixing is very pervasive in human culture. You are probably well familiar from common experience of situations where you know that they do not mix. In order to mop up oil spills and wash a surface clean we use 'surfactant' materials, such as, soaps and detergents, that can interact between the oil and water. Where we have forced oil and water to mix in a suspension we use 'emulsifiers' that will stabilise the mixture as an emulsion for a while, but these often eventually "split" back into the component parts.

The point of this preamble into sayings and oil and water is that the concept was firmly implanted in my own mind. One of the dangerous aspects of sayings is that they can easily become embedded in our thinking that we play them back like a recording without really thinking about the situation. Consequently, it came as a bit of a surprise when I stumbled upon a situation where water was actively mixing with oil without any human interference.

This gives me an opportunity to say a bit more about the main character of this book –Water.

We are all familiar with the name H_2O, which is a representation meaning there are two hydrogen atoms to one oxygen atom in each molecule of water. This is the 'formula' of water and the notation, H_2O, is a convenient way to work with molecules in chemistry.

Other ways are use to represent molecules and you will be familiar with these as are they are commonly used. Here are two more ways of representing the water molecule:



In reality, the atoms are not connected by solid structures as shown in the structural formula and the ball and stick model. The chemical bonds holding the atoms together are a space occupied by two electrons. These negatively charged entities move around in the space between the positively charged nuclei forming the molecular bond.

The two electrons that form the bond are not always shared equally between the nuclei. This is the case with water, where the oxygen nucleus attracts the electrons more strongly than the hydrogen nucleus. This imbalance of sharing results in there being overall a slightly negative charge on the oxygen and slightly positive charge on the hydrogen.

A term for separation of charge is 'polar', as in a magnet. or the North and South Poles on Earth. In the water molecule, the small separation of charge in the chemical bond, making it slightly positive at one end and slightly negative at the other, is called a dipole. Substances that mix well with water tend also to have polarity and contain charged atoms or molecules.

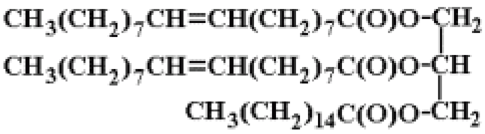
Most of the common oils we come across in everyday life are hydrocarbons. These oils are chains of carbon atoms with hydrogen atoms bonded to the individual carbons in the chain. The structure can range from simple chains to branched chains and combination of chains connected in special ways.

Unlike water, the hydrocarbons are non-polar, and because they do not contain charged atoms, they do not mix readily with water. Hence, the origin of the saying "oil and water don't mix" is based on good chemical grounds.

My justification for running through this basic chemistry is to establish with you my belief beyond any reasonable doubt that water and oil do not mix.

I had reason to investigate olive oil using my Relequa test system. An explanation why I was doing this may be forthcoming in a future update of this chapter if the study works out well, but for now just go with the flow.

Here is the structure of olive oil:



$$\begin{array}{r}
CH_3(CH_2)_7CH{=}CH(CH_2)_7C(O)O\text{-}CH_2 \\
| \\
CH_3(CH_2)_7CH{=}CH(CH_2)_7C(O)O\text{-}CH \\
| \\
CH_3(CH_2)_{14}C(O)O\text{-}CH_2
\end{array}$$

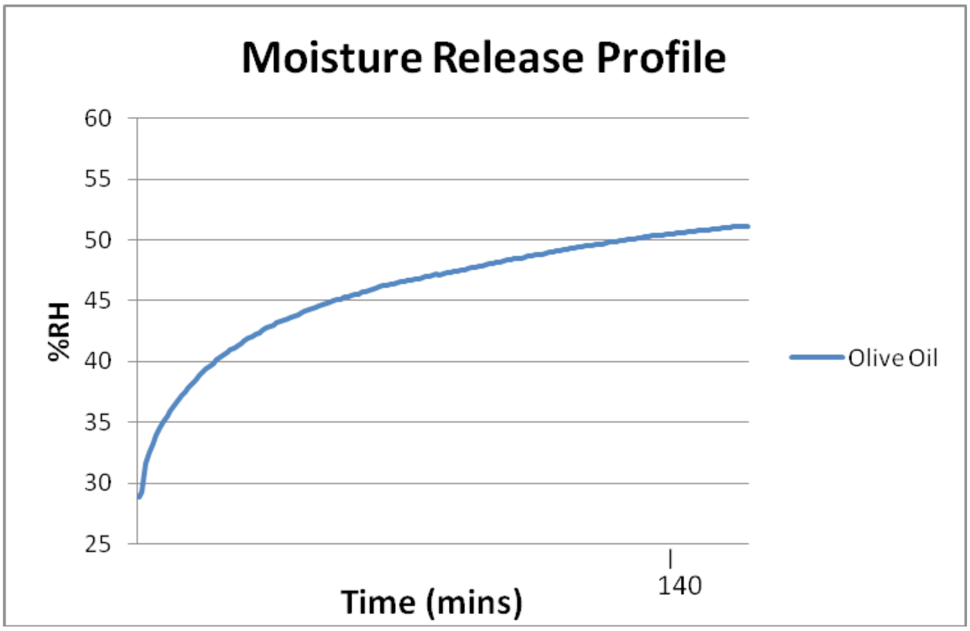
The molecule is nineteen times bigger in its molecular weight than water. The right hand side part with the oxygen atoms is glycerol, which is attached to three fatty acids forming a molecule that is in the general class called, 'triglycerides'. Two of the fatty acid chains are Oleic Acid which has an "unsaturated" bond (double bond) in the middle of two chains of carbon atoms either side. The other fatty acid is Palmitic Acid, a saturated fatty acid, which has a straight run of 15 carbon atoms all bonded to and surrounded by hydrogens.

Any potential polarity from O – H bonds originally present in the glycerol part, or in the acid part of the fatty acids, was lost when the olive oil molecule was formed.

Two substances, water and olive oil, both liquids at room temperature but chemically very different.

I took a bottle of olive oil from the kitchen cabinet and ran a sample in my Relequa unit in just the same way as I had done with bread in Chapter 6.

Here is what happened:



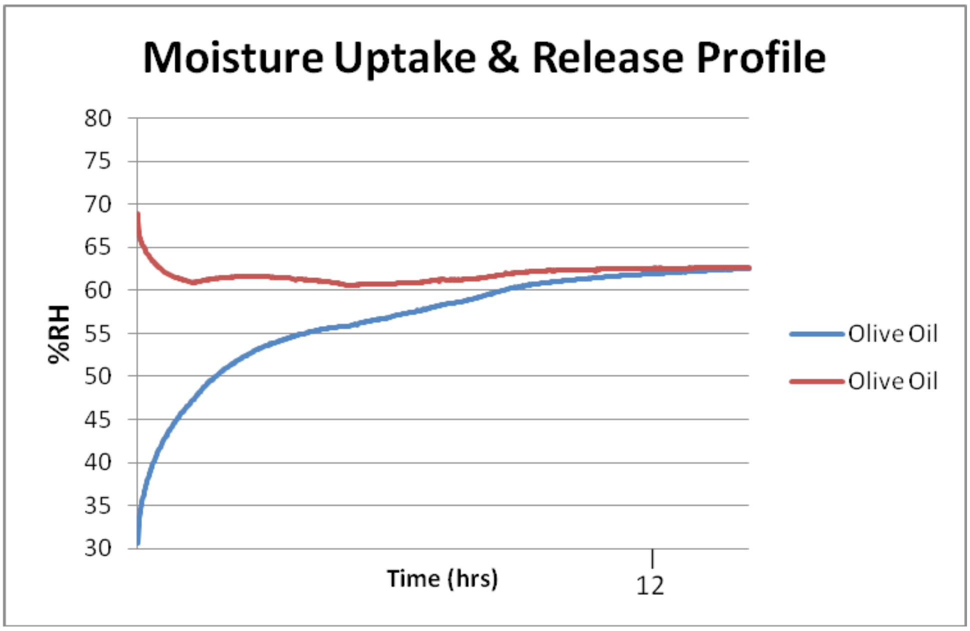
A surprise “**observation**” that the olive oil appeared to be releasing moisture. At the time I was probably expecting nothing much to happen. I thought the oil would just sit there minding its own business.

Concerned that this may be some sort of artefact, I moved to the next stage of “**measurement**”. First, I repeated the test and got the same result, essential to know that it was repeatable. Next, I took an unopened bottle of olive oil, which happened to be from a different manufacturer, and again got a similar release of moisture.

Curiosity riding high and into the fun part of science, I took a trip the supermarket and bought old and new lots of olive oil from the same manufacturer based on the best before dates. This is not statistically sound because I only ran one lot of each, but the new lot did have a lower ERH than the older lot and it was also the lowest ERH of all the oils I tested. This also was repeatable.

If the older oil had gained moisture over time and was this driven by humidity, did this mean that olive oil displays a true moisture equilibrium in the same way as solid materials? The implications are that if we measure the ERH it will obey the same rules for moisture uptake and loss as described in Chapter 3.

Of course, this is easily measured and the result is shown below:



Now I was really starting to get some useful "**data**" and it was telling me, despite my ingrained belief that water and oil do not mix. Here was evidence that an oil had a capacity to hold water to the extent that moisture release can be detected. This was further supported by observing actual moisture uptake. Both of these activities continued until the same equilibrium point was reached and we can "**interpret**" these data as the oil showing the characteristics of ERH.

Having collected some data and proved to myself by repeated analysis that olive oil has an ERH, the next step was to start a process that could lead me to "**understand**" the science behind the observations.

There is a golden rule in problem solving which says, "**first define the problem**".

Using the data I had generated, I could see that I needed to search for information on what is known about "interactions" of oil and water. If you simply search on the internet for "oil and water" you get a lot stuff about them not mixing and lava lamps and so on.

Using my knowledge of water vapour and vapour pressure, I was able to focus on physical interactions and discovered Henry's Law. If we covered this in my chemistry degree, I had forgotten to the extent that I would swear that I had never heard of Henry's Law. However, the law is briefly mentioned in my copy of Linus Pauling's General Chemistry book, which I occasionally use as a reference text. This law, apparently, is generally applicable to materials and in 1803 William Henry taught us that:

At a constant temperature, the partial pressure of the gas phase of one component of a solution is, at equilibrium, proportional to the concentration of the component in the solution.

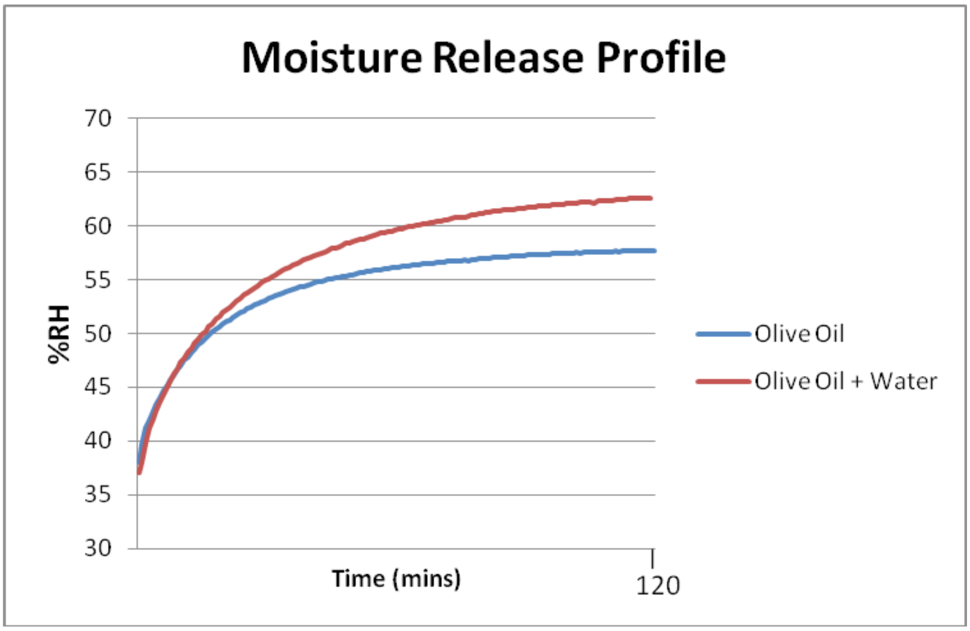
To my mind, and I hope you agree, this precisely describes the above observation of olive oil and its ERH, where water is the component in the gas phase.

The driving force for a gas to enter a solution is the pressure of the gas above the liquid. This is exactly how fizzy drinks are made, the fizz (CO_2), is release when you reduce the pressure by opening the can or bottle. In the olive oil ERH graph above, the pressure is seen as %RH (see Chapter 2 and SVP). The %RH decreases as the oil interacts with, and takes up water molecules (upper profile). Conversely, %RH increases as the vapour pressure of the water present in the oil drives water molecules into the air (lower profile).

Now that we have established the "**how**" we should test this by experiment. Henry's Law also tells us that if we change the concentration of the dissolved gas the partial pressure will also change.

I took 20 ml of the 'new' olive oil and added a few drops of water. Shook the mixture and let the emulsion that formed settled so that I had oil with a small amount of water sitting in the bottom. Taking care to sample the oil from just below the liquid's surface, and well away from the water, I ran its moisture release profile along with the starting oil as a control.

The release profiles are shown in the graph below:



By simple observation of the graph you can see that the ERH is definitely influenced by having additional water present. A reasonable conclusion is that the amount of water "dissolved" in the oil has increased resulting in a higher vapour pressure, and hence, a higher equilibrium point as determined by %RH is reached. This is in complete agreement with Henry's Law.

Now we come to what is always the most difficult question, "**why**". To provide a comprehensive answer we would need to know why two quite physically diverse substances interact in the way they do as shown above.

The disappointing outcome of this chapter for you, but of immense interest for me, is that I simply do not know the "**why**".

In the context of this book, one top line outcome is that olive oil is another substance that freely interacts with water vapour. Local climate changes where olive oil is being produce and handled potentially could affect the quality of the oil. My ongoing investigations show that olive is not alone in this behaviour and water interaction occurs with other types of oil.

Perhaps in the next update of this book the "**why**" might tell us that moisture interaction with oils is to be expected and instances where it does not occur, will be become the interesting ones.

In the next chapter, we will look at how interactions of materials with water vapour has been exploited in the natural world.

13 House Mites

Like it or not, we all share our lives with these little darlings shown in the picture below. They may look like some sort of alien armoured vehicle from a sci-fi video game, but they are ideally evolved to share homes with us in a very special way.

Again, this is another chapter that is interrelated with others and could very well be fitted in as a section in the chapter on Human Health. The faeces and carcasses of house mites cause allergic reactions in people leading to asthma attacks who are sensitive. Why include these microscopic creatures in a chapter of their own? The answer is that they possess a special feature that is the epitome of the principles that I hope you have learned throughout this book, "our new knowledge", as I referred to it in the previous chapters. So, if you've jumped to this chapter, you need to read Chapters 1, 3 and 8 to understand what is coming next.

Species that need to wait until a particular set of conditions come along, as described for potato blight in chapter 7, or are waiting for a particular host to pass by, have to adopt a strategy that involves a dormant phase. An easy one to understand, and familiar to most people, is fungi that form resistant spores that protect it against unfavourable conditions.

Fleas and ticks enter a low metabolic dormant phase and it is known for people to pick up fleas from houses that have not had occupants for many years. Fleas and ticks, once they have found their host, obtain their water requirements by drinking blood from their host. House mites on the other hand are not parasites but feed off dead skin shed from our bodies. So how do they get water? They cannot just go and drink some, and dead skin is extremely dry.

Millions of years ago the ancestors of house mites evolved a special gland that uses salts to absorb moisture from the atmosphere. This gland known as the 'supracoxal' produces a concentrated solution of the salts KCl and NaCl. As you know from Chapter 8, the ERH of these two salts are 84% and 75 % respectively. This means that when the relative humidity of the air is 75% and above, the salt solution will absorb moisture and this is how the house mite "drinks". A canal that carries the salt solution runs from the supracoxal gland to the mite's gut where the water is absorbed from the salt solution.

Why this salt solution contains both KCl and NaCl is probably not known. My guess is a mite evolved that cohabited with early mammals in a warm humid climate and had evolved a mechanism for absorbing moisture based on KCl. When early humans migrated northwards and adapted to seasonal changes the mite had to adapt also to be able to scavenge moisture in a climate that is not humid most of the time. One simple way for the mite to do this is to produce KCl solution containing another salt with a lower ERH. As you know from Chapter 8, NaCl has an ERH of 75% and since NaCl is a common salt in biological systems, using this salt is a logical way for the mite to have evolved to pick up moisture at a lower humidity. Also, the house mite has a ready source of NaCl from its diet of dried skin that will have an amount of NaCl on it from human sweat.

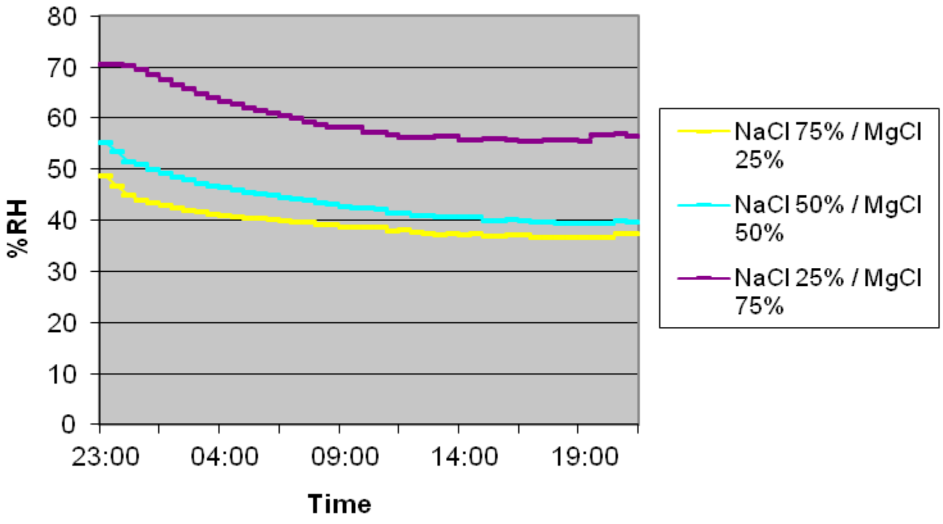
My simple explanation cannot be the whole story because that means house mites would need at least 75% humidity to grow. All reports I have found state that house mites need a humidity of 65 -70% and some as low as 60%. Even allowing for an inaccuracy in measuring % RH, this does seem a bit low. There may be some other factor or substances involved, such as, a protein or possibly sugars combined with a proteins known as 'glycoproteins' that may be lowering the ERH of the secreted solution from the supracoxal gland.

I have not written this explanation to provide an answer to the relationship of the house mite and humidity. It is to show you how, by using your new knowledge on humidity and a applying a bit of thought and imagination, you can come up with ideas and theories on how things may be working in all sorts of situations. This could lead you to all sorts of new discoveries.

When we are having to tackle the problems brought about by climate change we should look towards nature for possible answers. After all, millions of plants and animals have been adapting to climate change for millennia before we appeared on Earth.

Let us take as an example the house mite mechanism for picking up moisture and use the observation that the solution from the supracoxal gland contains a mixture of salts.

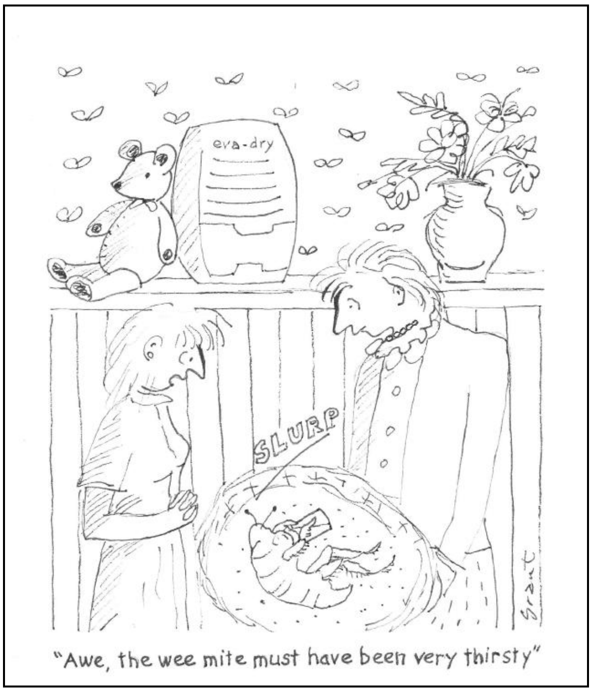
So what does happen when you mix a salt of lower ERH with a one of a higher ERH? The moisture profiles below show the result of combining NaCl (ERH 75%) with MgCl (ERH 33%) in different proportions (75:25, 50:50, and 25:75, respectively).



The answer is that the resulting ERH is somewhere between the ERH values of the individual salts and depends on the relative amounts of each one present. This demonstrates one of the fundamental properties of Equilibrium Relative Humidity, that the observed value depends on the composition of the material in addition to its physical properties for interaction with water vapour.

Thinking along these lines takes you one step further and it is easy to see how you can generate almost any relative humidity you want by mixing salts and adding some water. Just as in the case of the house mite, you would use salts with common atoms, or to use the chemical term, "ions", to prevent chemical reactions. In the graph above, both of the salts used contain chloride ions, as does the salt solution from the supracoxal gland.

One way of controlling house mites is to lower the relative humidity to less than 50%. At this moisture level the mites cannot absorb water as it is below the ERH of the KCl/NaCl salt solution and some reports claim that the mites may dehydrate. This does not get rid of them completely as a proportion of the mite population will enter a dormant phase until the relative humidity increases to 65-70%, allowing the mites to thrive again.



"Awe, the wee mite must have been very thirsty"

I saw one report on the internet that climate change will lead to an 80 fold increase in house mites as the climate becomes wetter and warmer. Actually, the temperature aspect I have not covered here, but there is an optimum temperature for house mites of 25°C. This is fortunate because, as you now know, it is possible to get high humidity in cold weather just as a function of the low temperature (Remember? **You must always consider the temperature!).** In fact some people get 'seasonal allergic rhinitis', just like hay fever, but instead from pollen, this is due to house mite populations increasing as we enter into the warmer spring to summer season.

Returning to looking at the natural world for new ideas, as I was writing this chapter another little synchronicity cropped up. I subscribe to an engineering website called Globalspec that I have set up so I receive email alerts to new developments in measuring humidity. Literally, I was just starting one of the paragraphs above on observing nature for solving moisture problems, when an alert came in and one of the headings was "Drinking Water from Air Humidity".

Researchers at the Fraunhofer Institute for Interfacial Engineering and Biotechnology announced a process for extracting moisture from air based on "hygroscopic brine". The idea is have salt solution running down a tower absorbing moisture as is does so and then evaporate the trapped water under a partial vacuum. Just in case you do not know, you can 'boil' water at room temperature by lowering the surrounding pressure.

I used to do this using a syringe with a little water in the barrel, putting my finger over the end and pulling the plunger. You can see the water bubble and the 'steam' condense on the inside of the barrel. In the Fraunhofer system, they heat the salt solution to some extent to help evaporation. When the absorbed water has evaporated off for condensing to drinking water, the salt solution is recycled to the top of the tower. The system is driven by a solar powered pump.

The article describing this system states that the average humidity of the Negev desert in Israel is 64% and each cubic metre of air contains 11.5ml of water. Guess what they did not remember to include? As you should know by now, **the temperature**. They should have also stated an average temperature of about 21°C. If you managed to download a humidity calculator, you can check this; 64%RH gives 0.0117 kg/m^3 water vapour at 21°C (assumes sea level). Take 1ml weighs 1g and multiply by 1000 gives you 11.7ml of water per cubic metre.

I really like this innovative thinking and I wish the Fraunhofer Institute every success in their new development. I contacted the institute to find out what salt or combination of salts they are using, but as the project is in a very early stage, they quite rightly did not want to release any more details.

My imagination got going and I could see a scaled down version of this moisture capture system for houses to lower the humidity where house mites and condensation is a problem. This can be done already with dehumidifiers, but these use mains electricity whereas, the Fraunhofer system is solar powered. I can also see batteries of the moisture capture towers along the side of a reservoir taking moisture out of the air and toping up water levels.

I have no idea how practical these ideas may be, but included them just to show how a spark of innovation in this area of humidity, along with an understanding of ERH, may lead to all sorts of exciting and essential new developments.

Looking towards nature for answers to tackle the consequences of climate change seems a very good place to start.

14 A Challenge

Time now to apply your new knowledge. Imagine the following scene:

A south facing garden somewhere in Ireland. It is winter and there is a cloudless sky. To the west the garden has a wooden fence, a stone wall to the south and a metal fence to the east. There is no wind, not even a slight breeze. The time is 10am and you look out of a window and see steam rising from the wooden fence and from the stone wall. After 30 minutes you look out again, the wooden fence looks damp and there is still steam rising. The steam from the stone wall has stopped. The metal fence is covered in frost. The lawn is white in places and covered in dew everywhere else.

Using your new knowledge, or re-read the pertinent parts from the chapters of this book, and come up with an explanation of the above scene.

To construct a more comprehensive answer, you will need an understanding of at least three other pieces of information that I have not covered:

- The electromagnetic spectrum and transparency in air
- The electron shell structure of metals
- Mechanisms of heat transference

Good luck and farewell for now!