

Software approach towards understanding meteorological data for environmental monitoring and assessment of peninsular Malaysia

Sayed Abulhasan Quadri*, Othman Sidek, Hadi Jafar, Nur Amira binti Amran, Ummi Nurulhaiza bt Zabah and Azizul bin Abdullah

*Collaborative Microelectronic Design Excellence Centre (CEDEC)
Universiti Sains Malaysia, Engineering Campus, Nibong Tebal, Malaysia, 14300*

(Received December 11, 2013, Revised February 23, 2014, Accepted March 11, 2014)

Abstract. The concern for the global environment ensues researchers from various disciplines to work in collaboration to tackle with the issues of sustainability and environmental conservation for well-being of the people. In this study, we have selected and focused on few basic environment-affecting factors such as temperature, humidity, carbon dioxide and oxygen concentration level and referred them as meteorological data. In this paper, we present the development of our own customized hardware setup, environmental monitoring device (EMD) to obtain the data. Utilizing the relationship among these basic parameters, represented in the form of formulas and equations, we tried to encode them using Matlab programming. Data visualization is achieved by plotting the graphs of basic parameters obtained from EMD as well for the derivatives using Matlab programs.

Keywords: meteorological data; temperature; humidity; carbon dioxide; oxygen; software; Matlab; environmental monitoring device

1. Introduction

Climate change is changing our economy, health and communities in diverse ways. Carbon dioxide and other global warming pollutants are collecting in the atmosphere like a thickening blanket, trapping the sun's heat and causing the planet to warm up (IPCC 2007).

The anthropogenic driver of climate change is the increasing concentration of greenhouse gases (GHG) in the atmosphere. Carbon dioxide (CO₂) is the most important anthropogenic GHG, and the global increases in CO₂ concentration are due primarily to fossil fuel use and land use change. The increase in GHG concentrations in the atmosphere affects processes and feedbacks in the climate system. Qualitatively, an increase of atmospheric GHG concentrations will lead to an average increase of the temperature of the surface-troposphere system (Downing 2012).

Although there exist controversies and debates on climate change and global warming issues, scientific research strictly based facts and figures could help in exploring the truth, thus could distinguish exaggerated predictions of natural mechanism and false alarms.

*Corresponding author, Research Associate, E-mail: reachquadri@yahoo.com

Our project has a lengthy procedure that encompasses development of hardware platform by assembling various sensors on microcontroller board; firmware programming to facilitate sensors to obtain data and transmit data wirelessly; Matlab programming utilizes the equations and formula that relates these basic parameters (temperature and humidity), thus presents a calculator that output various derived parameters. The derived parameters are dew point, humidity ratio, vapor pressure, enthalpy, saturation vapor pressure, specific volume density, absolute humidity, wet bulb temperature, mixing ratio, parts per million and water content. Scientific analysis of each derived parameters and its impact on environment, task still in progress.

We start our discussion with the need for the research; as a first task of our study, we assemble all the sensors and deploy it to obtain the basic parameters. Section 3 concisely outlines the hardware and software description. In the next stage, we develop functions and programs to derive various temperature- humidity related parameters. Section 4 briefly discusses the potential of Matlab programming and emphasize how each relations and formulas are translated in Matlab. Finally, we visualize the output obtained from the data by plotting the graphs.

2. Research motivation

Malaysia, being one of the fast developing countries has enjoyed remarkable growth over the last few decades, with industrialization, agriculture and tourism playing leading roles in this success story. But on the other side it faces problems of deforestation, pollution of inland and marine waters, soil and coastal erosion, overfishing and coral reef destruction, along with air pollution, water pollution and the problem of waste disposal. Environmental conservation is not only crucial requirement for well-being of the people but also plays a vital role in sustainable development in the process of nation building.

The temperature trend in Malaysia, due to global warming is addressed by many researchers in the literature (Camerlengo *et al.* 2003, Fong *et al.* 2008, 2009). All studies in this regard certainly affirm mean annual increase of temperature. Thus showing perfect agreement with the report of the IPCC (Houghton *et al.* 2001).

The increasing concentration of ozone is also one of the primary concerns. As the fatal effects of ozone concentration levels are directly related to global warming and climate change, thus the issue is of high prominence. Ozone, a very reactive gas is found in very small quantities in the atmosphere. Its mean concentration can vary from a few to hundreds of parts per billion (ppb) depending on the location and altitude. At the surface layer, ozone is considered a secondary pollutant, which causes oxidant episodes such as haze and smog. In the stratosphere, the layer of ozone reduces harmful ultraviolet radiation reaching the earth's surface. On a global scale, ozone is a greenhouse gas, which contributes to global warming.

To monitor and assess these changes, the Malaysian Meteorological Department (MMD) (www.met.gov.my) began ozone monitoring in 1992 at the MMD headquarters in Petaling Jaya. The ozone-monitoring programme of MMD includes monitoring of vertical ozone profile and total column ozone in the atmosphere.

2.1 Vertical ozone profile

The vertical ozone profile is shown in Fig. 1. The vertical ozone profile is measured by releasing an ozonesonde attached to a balloon into the upper atmosphere. Signals transmitted from

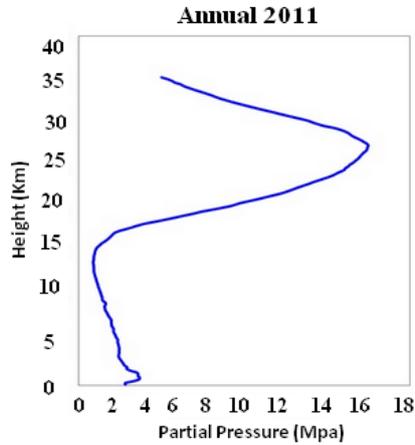


Fig. 1 Vertical ozone profile

the ozonesonde are received by a ground station. The monthly soundings obtained showed that ozone concentrations peak sharply in the stratosphere at a height of about 27 kilometers.

2.2 Total column ozone

Total column ozone observations are made with a Brewer ozone spectrophotometer (BOZ), which measures the relative intensities of selected pairs of ultraviolet wavelengths of light emanating from the sun and zenith sky to determine the amount of ozone in the atmospheric column. Total ozone values measured during the year 2011 varied from 232 to 283 Dobson units, shown in Fig. 2. Dobson unit is the most basic measure used in ozone research. The unit is named after G.M.B. Dobson (1920-1960), one of the first scientists to investigate atmospheric ozone (Schwartz and Warneck 1995).

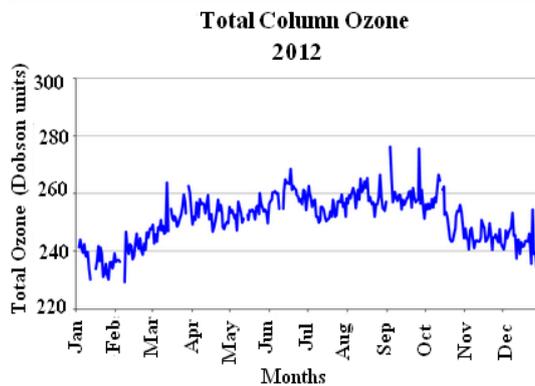


Fig. 2 Total column ozone profile

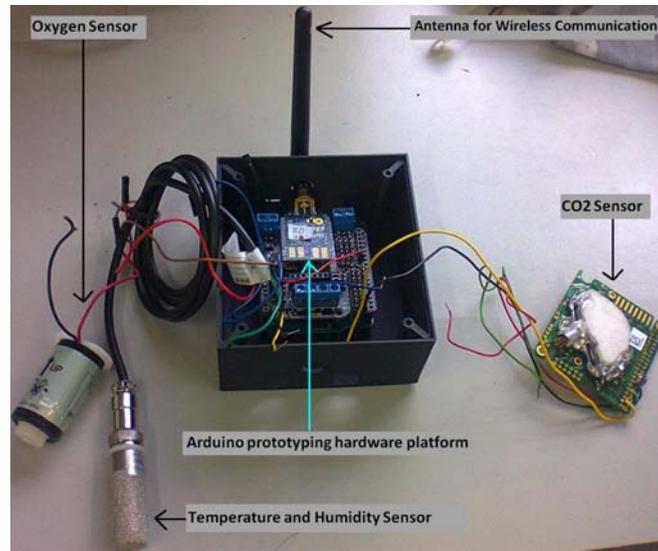


Fig. 3 Hardware setup of environment monitoring device (EMD)

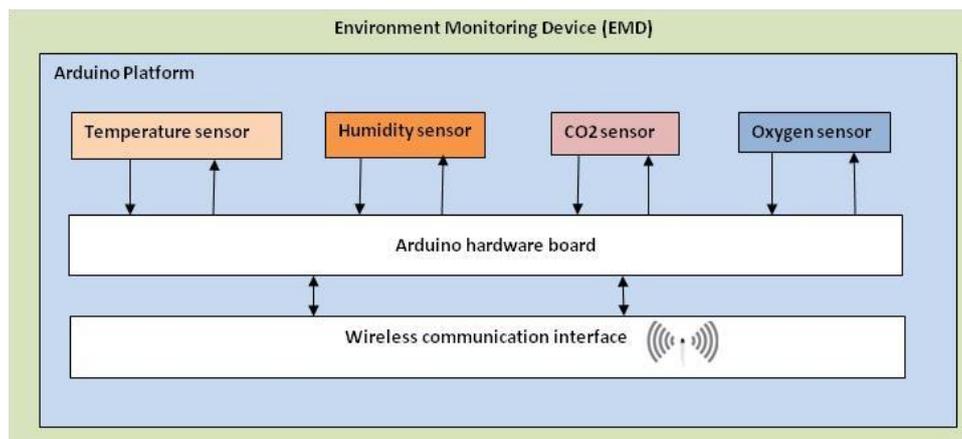


Fig. 4 Functional block diagram of environment monitoring device (EMD)

3. Materials and methods

In this section, we discuss the experimental setup i.e. hardware and software issues involved in obtaining meteorological data.

3.1 Environment Monitoring Device (EMD)

Our project comprises of development of environment monitoring device (EMD), which is an assembly of commercial available sensors fixed on Arduino prototyping hardware platform. The

user-friendly nature of the platform provides us liberty such that any number and any type of sensors could be accommodated on the board. Four different types of sensors, namely carbon dioxide sensor, temperature & humidity sensor and oxygen sensor are fixed on the board. In order to send the output data wirelessly, the board is equipped inbuilt wifi facility. The hardware setup is shown in Fig. 3.

The microcontroller on the board is programmed using the Arduino programming language. Arduino is open-source software. Its flexible and easy-to-use platform provides a means to coordinate hardware components on the board. It is a potential tool for software programmers and hardware designers that facilitate in creating interactive objects or environments for numerous applications (www.arduino.cc). Functional block diagram of EMD is shown in Fig. 4.

Arduino projects can be stand-alone or they can communicate with software running on a computer. In our case, all the sensor output data is wirelessly transmitted to a laptop where we have preinstalled Arduino Software. A graphical user interface displays online current readings, shown in the Fig. 5. The measurements could be easily recorded in comma separated vales (CSV) using data logger facility.

3.2 Sensors and instrumentation issues

As discussed above we have four sensor components, CO₂ sensor (Figaro CDM4161), O₂ sensor (O2-A3), humidity sensor (HIH 4000), and temperature sensor (LM35D). The specification of CDM4161 CO₂ sensors are low power consumption, long life, compact-size, pre-calibrated, low cost and least maintenance is required for this module. The detection range of this sensor is 400 ppm to 8000 ppm with DC 5.0 ± 0.2 V regulated and it require two hours for warming up before it is stable to sensed CO₂ in the atmosphere.

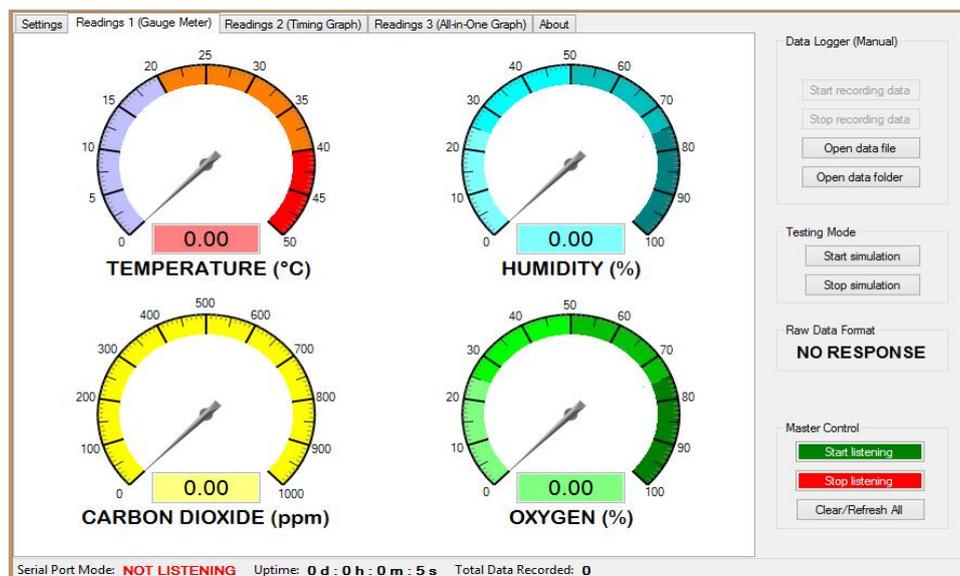


Fig. 5 Graphical user interface display of sensor output

The features of Oxygen sensors (O2-A3) are wide measuring range, compact sized, low power consumption, fail-safe measuring principle, function testing and calibration in ambient air, easy calibration, and lightweight with weight approximately 16 gram.

Humidity sensor, HHH-4000, has the specifications such as ideally suited for low drain, battery operated systems. The sensor also has excellent resistance to most application hazards such as wetting, dust, dirt, oils and common environmental chemicals. This sensor need voltage supply and current supply at range 4-5.8 V DC and 200-500 μ A respectively.

The temperature sensor, LM35D, is a precision integrated-circuit temperature sensor, whose output voltage is linearly proportional to the Celsius temperature. It is characterized with low output impedance, linear output, and precise inherent calibration. This sensor operate from 4 to 30 V and less than 60 μ A current drain which mean the sensor is low power consumption.

On the surface, the procedure of obtaining meteorological data using sensors may appear to be straightforward but the issues related with calibration makes it little complex. Utmost care has to be taken while handling the sensors, in order to achieve maximum accuracy and precision. The accuracy is the degree of closeness of measurements of a quantity to that quantity's actual (true) value. The precision is related to reproducibility and repeatability, is the degree to which repeated measurements under unchanged conditions show the same results.

Inevitable errors may arise from varying sunlight and various atmospheric emissions. Lack of constant power supply to the components may vary their performance. The sensitiveness of sensing material used in sensor is one the major causes affecting the performance. Sometime we have encountered problem of ridiculous and invalid readings, also at some situation we arrive ourselves dealing with, a difference between manufacturer tolerances and process tolerances. The simple solution we adopted was replacement of sensors.

Measurement errors could be caused by errors in transmission system. As we have adopted wireless mode of transmission, there are certain chances of packet loss during transmission. A thorough diagnosis of the whole setup and consultation with experts may reveal inadequacies in the system, and thus can be rectified.

Our two basic parameters of interest such as CO₂ and humidity have a critical role in climate change, the measurement precision requirements are so strict, that relatively minor measurement flaw may produce serious errors (Hengchang *et al.* 2013). The safety and risk levels are defined on these measurements. Thus, makes the issues related with calibration most prominent.

4. Software development approach

The problem of global warming and climate change is massive and complex. In our opinion, collaborative effort is required from various disciplines like environment experts, statisticians, hardware engineers and software programmers. Software programmers could contribute by developing programs for data abstraction, data mining, data processing and data visualization etc., thus providing a better means for indepth scientific data analysis.

In this section, we make an effort to show how Matlab could be used as a prospective tool in meteorological data analysis.

4.1 Matlab programming

Matlab© is a high-level language and interactive environment for numerical computation, visualization, and programming. Matlab (matrix laboratory) is a numerical computing environment

and fourth-generation programming language developed by MathWorks (www.mathworks.com). Using Matlab, one can analyze data, develop algorithms, and create models and applications.

Matlab has wide range of applications, including signal processing and communications, image and video processing, control systems, test and measurement, computational finance, and computational biology.

4.2 Key features of matlab

- High-level language for numerical computation, visualization, and application development.
- Interactive environment for iterative exploration, design, and problem solving.
- Mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, numerical integration, and solving ordinary differential equations.
- Built-in graphics for visualizing data and tools for creating custom plots.
- Development tools for improving code quality and maintainability and maximizing performance.
- Tools for building applications with custom graphical interfaces.
- Functions for integrating Matlab based algorithms with external applications and languages such as C, Java, .NET, and Microsoft ®Excel.
- Elegant, friendly and appealing programming.

4.3 Matlab coding for temperature-humidity derived parameters

The language, tools, and built-in math functions enable us to explore multiple approaches and reach a solution faster than with spreadsheets or traditional programming languages, such as C/C++ or Java ©. In this discussion, various interrelated formulas were utilized to derive these temperature-humidity related factors, for each of these factors, respective functions are written, which are called by the main program during execution.

4.3.1 Saturated vapor pressure

The saturation vapor pressure is the pressure of a vapor when it is in equilibrium with the liquid phase. It is solely dependent on the temperature. As temperature rises, the saturation vapor pressure rises as well. Vapor pressure is a measurement of the amount of moisture in the air. It is technically the pressure of water vapor above a surface of water. When air reaches the saturation vapor pressure, the water vapor in it will be condensed (Bentley 1998, Bob 1998).

The calculation is complex and requires ample knowledge of Algebra. The known parameters are temperature and humidity, obtained from the EMD kit.

We proceed our calculation by using the relation among, actual vapor pressure (e), saturated vapor pressure (pvs) and partial vapor pressure (pvp), expressed in Eqs. (1) and (2) (NWSSR 2008).

$$PVS = 6.112 \times e^{\left(\frac{17.67 \times T}{T + 243.5}\right)} \quad (1)$$

The value of e can be calculated by using the exponential rules in Algebra.

We write a function named (function_pvs) with series of coefficients (a1 to a13 shown in code, see Fig. 6) in order to find the value of PVS. Once, we get the value of PVS we can find PVP by using the relation (NWSSR 2008)

```

function pvs=function_pvs(temp)
%vapor pressure at saturation
a1 = -1.021416462e4;
a2 = -4.89350301;
a3 = -5.37657944e-3;
a4 = 1.92023769e-7;
a5 = 3.55758316e-10;
a6 = -9.03446886e-14;
a7 = 4.1635019;
a8 = -1.044039708e4;
a9 = -1.12946496e1;
a10 = -2.7022355e-2;
a11 = 1.289036e-5;
a12 = -2.478068e-9;
a13 = 6.5459673;
t = temp + 459.67;
if (temp < 32)
    pvs = exp( a1/t+a2+a3*t+a4*t^2+a5*t^3+a6*t^4+a7*log(t));
else
    pvs = exp( a8/t+a9+a10*t+a11*t^2+a12*t^3+a13*log(t));
end
pvs=pvs*2.036021;

```

Fig. 6 Program to calculate saturated vapor pressure

$$PVP = RH \times PVS \quad (2)$$

4.3.2 Dew point temperature

The dew point is the temperature below which the water vapor in air at constant barometric pressure condenses into liquid water at the same rate at which it evaporates. The condensed water is called dew, when it forms on a solid surface. It is a water-to-air saturation temperature. The dew point is associated with relative humidity. A high relative humidity indicates that the dew point is closer to the current air temperature. Relative humidity is at all temperatures and pressures defined as the ratio of the water vapor pressure to the saturation water vapor pressure (over water) at the gas temperature.

Dew point temperature is calculated using the Eq. (3) (Lawrence 2005), equivalent function in Matlab is shown in Fig. 7.

$$DP = \frac{243.5 \times \ln\left(\frac{e}{6.112}\right)}{17.67 - \ln\left(\frac{e}{6.112}\right)} \quad (3)$$

```

function dp=function_dp(pvp)
%Dew point temperature
y = log(pvp*0.491154);
if (pvp < 0.18036)
    dp = 90.12 + (26.142 * y) + (0.8927 * y * y);
else
    dp = 100.45 + (33.193 * y) + (2.319 * y *
y)+0.17074*y^3+1.2063*(pvp*0.491154)^0.1984;
end

```

Fig. 7 Program to calculate dew point

```
%Humidity ratio
hr = 0.622*(pvp/(atm-pvp));
```

Fig. 8 Single line instruction to calculate humidity ratio

4.3.3 Humidity ratio

Humidity Ratio (HR) is expressed as the ratio between the actual mass of water vapor present in moist air to the mass of the dry air. It can also be expressed with the partial pressure of water vapor. The relationship of HR with atmospheric pressure and partial vapor pressure is given below (Lawrence 2005).

$$HR = 0.622 (\text{Partial vapor pressure}) / (\text{Pressure of moist air} - \text{Partial vapor pressure})$$

Thus, we encode the relationship in Matlab as shown in Fig. 8.

4.3.4 Enthalpy

Enthalpy is a measure of the total energy of a thermodynamic system. It includes the system's internal energy, as well as its volume and pressure. It is the preferred expression of system energy changes in many chemical, biological, and physical measurements, because it simplifies certain descriptions of energy transfer. Enthalpy change accounts for energy transferred to the environment at constant pressure through expansion or heating (Wyllen and Sonntag 1986).

Enthalpy is the amount of heat content used or released in a system at constant pressure. Enthalpy is usually expressed as the change in enthalpy. The change in enthalpy is related to a change in internal energy (U) and a change in the volume (V), which is multiplied by the constant pressure of the system. Enthalpy (H) is the sum of the internal energy (U) and the product of pressure and volume (PV) given by the equation (Petrucci *et al.* 2010)

$$H = U + PV \quad (4)$$

When a process occurs at constant pressure, the heat evolved (either released or absorbed) is equal to the change in enthalpy.

Enthalpy is a state function, which depends entirely on the state functions T , P and U . It is usually expressed as the change in enthalpy (ΔH) for a process between initial and final states (Petrucci *et al.* 2010)

$$\Delta H = \Delta U + \Delta PV \quad (5)$$

If temperature and pressure remain constant through the process and the work is limited to pressure-volume work, then the enthalpy change is given by the equation (Petrucci *et al.* 2010)

$$\Delta H = \Delta U + P\Delta V \quad (6)$$

Enthalpy can also be expressed as a molar enthalpy, ΔH_m , by dividing the enthalpy or change in enthalpy by the number of moles. Enthalpy is a state function. This implies that when a system changes from one state to another, the change in enthalpy is independent of the path between two states of a system.

If there is no non-expansion work on the system and the pressure is still constant, then the change in enthalpy will equal the heat consumed or released by the system (q) (Petrucci *et al.* 2010).

$$\Delta H = q \quad (7)$$

This relationship can help to determine whether a reaction is endothermic or exothermic. At constant pressure, an endothermic reaction is when heat is absorbed. This means that the system consumes heat from the surroundings, so q is greater than zero. Therefore, according to the second equation, the ΔH will also be greater than zero. On the other hand, an exothermic reaction at constant pressure is when heat is released. This implies that the system gives off heat to the surroundings, so q is less than zero. Furthermore, ΔH will be less than zero.

When the temperature increases, the amount of molecular interactions also increases. When the number of interactions increase, then the internal energy of the system rises. According to the first equation given, if the internal energy (U) increases then the ΔH increases as temperature rises. We can use the equation for heat capacity and Eq. (7) to derive this relationship (Wagner and Prub 2002).

$$C = q / \Delta T \quad (8)$$

At constant pressure, substitute Eq. (7)

$$C_p = \Delta H / \Delta T \quad (9)$$

Enthalpy can be calculated from mixing ratio equation (Wagner and Prub 2002)

$$h = T \cdot (1.01 + 0.00189X) + 2.5X \text{ (kJ/kg)} \quad (10)$$

where T = Temperature ($^{\circ}\text{C}$) and X = Mixing ratio (g/kg).

The mixing ratio is the mass of water vapor in a particular mass of dry air. The unit is g/kg.

The mixing ratio (mass of water vapor/mass of dry gas) is calculated using relation (Wagner and Prub 2002)

$$X = B \cdot P_w / (P_{tot} - P_w) \quad (11)$$

Where P_w = vapor pressure and P_{tot} = Total ambient pressure.

The value of B depends on the gas. The value 621.9907 g/kg is valid for air (Sirvatka 2013).

$$B = 621.9907 \text{ g/kg}$$

Thus, the equations are first simplified and then encoded in Matlab as shown in Fig. 9.

```
%Enthalpy
enthalpy= ((T*0.24 + (1061 + (0.444*T))*hr) 2.3244) - 17.8125
```

Fig. 9 Code line to calculate enthalpy change

4.3.5 Specific volume

Specific volume of a substance is the ratio of the substance's volume to its mass. It is inversely proportional to density. If the density of a substance doubles, its specific volume, as expressed in the same base units, is cut in half. If the density drops to 1/10 its former value, the specific volume, as expressed in the same base units, increases by a factor of 10.

The density of gases changes with even slight variations in temperature, while densities of liquid and solids, which are generally thought of as incompressible, with change to a very little. Specific volume is the inverse of the density of a substance; therefore, careful consideration must be taken account when dealing with situations that involve gases. Small changes in temperature will have a noticeable effect on specific volumes.

Specific volume for an ideal gas is also equal to the gas constant (R) multiplied by the temperature and then divided by the pressure (Moran and Shapiro 2000).

$$V_h = RT / P \quad (12)$$

The specific gas constant (R) for dry air is 287.058 J/ (kg • K) in SI units (Bentley 1998). Thus, the relation is encoded in Matlab function shown in Fig. 10.

4.3.6 Absolute humidity

Absolute humidity is the ration of mass of water vapor (m_w) per unit volume of total air and water vapor mixture (V_{net}) (Lawrence 2005). The relation is expressed as:

$AH = m_w / V_{net}$; encoded in Matlab as shown in Fig. 11.

4.3.7 Wet-bulb temperature

The wet-bulb temperature is the lowest temperature that can be reached under current ambient conditions by the evaporation of water only; it is the temperature felt when the skin is wet and exposed to moving air. Wet-bulb temperature is largely determined by both actual air temperature (dry-bulb temperature) and humidity, the amount of moisture in the air. The thermodynamic wet-bulb temperature is the minimum temperature, which may be achieved by purely evaporative cooling of a water-wetted ventilated surface (Wylen and Sonntag 1986).

Let us consider the calculation of the thermodynamic wet-bulb temperature, a case, where a stream of air with less than 100% relative humidity is cooled. The heat from cooling that air is used to evaporate some water which increases the humidity of the air. At some point, the water

```
% Function to calculate Specific Volume (vh)
function vh = function_vh(db, hr, atm)
vh = (0.754 * (db + 459.7) * (1 + (7000 * hr / 4360))) / atm;
```

Fig. 10 Function to calculate specific volume

```
%Absolute Humidity
AH = (mw) / (Vnet);
```

Fig. 11 Code line to calculate absolute humidity

vapor in the air becomes saturated (and has cooled to the thermodynamic wet-bulb temperature). In this case, we can write the equations as follows (Petrucci *et al.* 2010)

$$(H_{sat} - H_0).\lambda = (T_0 - T_{sat}).C_s \quad (13)$$

where H_0 is the initial water content of the air on a mass basis, H_{sat} is the saturated water content of the air, λ is the latent heat of water, T_0 is the initial air temperature, T_{sat} is the saturated air temperature and C_s is the heat capacity of the air.

For the case of the wet-bulb thermometer, imagine a drop of water with air of less than 100% relative humidity blowing over it. As long as the vapor pressure of water in the drop is more than the partial pressure of water in the air stream, evaporation will take place. Initially the heat required for the evaporation will come from the drop itself since the fastest moving water molecules are most likely to escape the surface of the drop, so the remaining water molecules will have a lower average speed and therefore a lower temperature (Petrucci *et al.* 2010).

$$P_{sat}(T_{drop}) = P_v \quad (14)$$

Where P_{sat} is the saturation pressure of the water in the drop and is a function of the drop temperature and P_v is the partial pressure of water in the vapor phase. If the air started bone dry and was blowing sufficiently fast then P_v would be 0 and the drop could get infinitely cold. Clearly, this does not happen. It turns out that as the drop cools, convective heat transfer begins to occur between the warmer air and the colder water. In addition, the evaporation does not occur instantly, but instead depends on the rate of convective mass transfer between the water and the air. At a certain point, the water cools to a point where the heat carried away in evaporation is equal to the heat gain through convective heat transfer. At this point, the following is true (Petrucci *et al.* 2010)

$$(H_{sat} - H_0).\lambda.k' = (T_0 - T_{wb}).hc \quad (15)$$

where $(H_{sat} - H_0)$ is now the driving force for mass transfer, k' is the mass transfer coefficient (with English units of $l\ b / (h \cdot ft^2)$), hc is the heat transfer coefficient and $(T_0 - T_{wb})$ is the temperature

```
function wb=wet_bulb(db,dp,h,atm)
% Computes wet bulb temperature
acc=0.0001;
rtb=dp;
dx=db-dp;
for j=1:40
    dx=dx*0.5;
    xmid=rtb+dx;
    psat=function_pvs(xmid);
    wstar=function_w_pvp((atm-psat), psat);
    fmid=function_h_w(xmid, wstar);
    if (h-fmid)>0.0 & abs(dx)>acc
        rtb=xmid;
    end
end
```

Fig. 12 Function to calculate wet-bulb temperature

```

% Computes Parts per million (ppm)
% pw is Water vapor pressure & ptot=Total pressure
ppm = (pw) / (ptot-pw) * exp(6);

```

Fig. 13 Code line to calculate parts per million (ppm)

```

% Single line code to calculate Density (dh)
% We obtain the reciprocal vales of Specific Volume (vh)
dh = (1./vh);

```

Fig. 14 Code line to calculate gas density

```

% Program to derive Enthalpy, Dew point, Saturation Vapor pressure
% Partial vapor pressure and Humidity ratio
% User input
rh = 'Input the RH value ';
rh = input(rh);
db = 'Input the temperature';
db=input(db);
atm=1; % standard atmospheric pressure
atm=atm*29.921; % in Hg
%Vapor pressure at saturation
pvs=function_pvs(db);
%Partial vapor pressure
pvp = rh/100 * pvs; % rh < 1
%Humidity ratio
hr = 0.622*(pvp/(atm-pvp));
%Enthalpy
enthal = enthaleng*2.3244-17.8125;
%Dew point calculation
dpf = function_dp(pvp); % in fahrenheit
dp = (dpf-32)*5/9; % in celsius
vh = function_v(db, hr, atm);
display('Vapor pressure at saturation (pvs)');
display( pvs);
display('Partial vapor pressure(pvp)');
display( pvp);
display('Humidity ratio(hr), units kg/kg ');
display(hr);
display(' Enthalpy (enthal), units,kJ/kg ');
display(enthal);
display('dew point in celsius(dp)');
display(dp);
display('Specific volume (vh) in m3/kg!');
display(vh);
% Saving the Data in Comma separated values (CSV) [.xls or .txt format]
fid=fopen('output-data.txt','w');
fprintf(fid,'%6.6f % 6.6f % 6.6f % 6.6f % 6.6f % 6.6f
',pvs,pvp,hr,enthal,dp);
fclose(fid);

```

Fig. 15 Main program

driving force.

Now if this equation is compared to the thermodynamic wet-bulb equation, we can see that if the quantity $hc / (K'Cs) = 1$; (known as the psychometric ratio) then

$$T_{sat} = T_{wb} \quad (16)$$

Encoding all these equations we write a function namely `wet_bulb` in order to calculate wet-bulb temperature, shown in Fig. 12.

4.3.8 Parts per million (ppm)

Parts per million values are usually given versus the amount of dry air. Below given Eq. (17) (Lawrence 2005) is encoded in Matlab as shown in Fig. 13.

$$PPM_v = \frac{P_w}{P_{tot} - P_w} 10^6 \quad (17)$$

Where, P_w = Water vapor pressure and P_{tot} = Total pressure.

4.3.9 Density

The gas density [mass/ volume unit] is calculated taking into account the mixing ratio of water vapor to dry gas, dry gas molecular weight and the temperature and pressure of the gas. It is inversely proportional to the specific volume. For dry air the molecular weight 28.96443 g/mol is used. For water, the molecular weight 18.015 is used (Bentley 1998).

4.4.0 Main Program

The main program is shown in Fig. 15, it starts requesting the user to input temperature and relative humidity values. The programs thus calling various functions executes and stores all the final values in a file.

5. Results

Graphs are means of visual representation depicting relationship between variables. They are very useful for researchers; facilitate better analysis and understanding that would not come from mere lists of values. In this section, we present graphs of various environmental effecting parameters plotted against time.

5.1 Plotting the graphs

The successful execution of the main program ends up in safely saving the respective output values in a file; in our case, we have named it as 'output-data' file. Simple plot functions are executed to get the graphs; the already saved file (output-data) should be loaded as a prerequisite. Thus, a set all graphs depicting various temperature-humidity parameters are plotted. Fig. 16 shows few lines of code to obtain graph of enthalpy versus time, in the same way we can plot graphs for vapor pressure at saturation (pvs), partial vapor pressure (pvp), humidity ratio (hr), enthalpy (enthal), dew point (dp) and specific volume (vh). All these parameters were plotted

considering the readings for one complete day, thus $24 \text{ hours} \times 60 \text{ minutes}$ makes 1440 values, shown along X-axis. Figs. 17-20 show graphs for basic parameters (temperature, relative humidity, carbon dioxide and oxygen) versus time, Figs. 21-29 illustrate graphs for derived parameters.

```

% Program to Plot the Graph of Enthalpy v/s Time
load output-data;
enthal=output-data();
figure()
plot(enthal,'LineWidth',1.00)
xlabel('Time in Minutes', 'FontWeight','Bold', 'FontSize',12);
ylabel('Enthalpy change in kJ / kg','FontWeight','Bold','FontSize',12);
title('Enthalpy Versus Time ', 'color',[0 0 1]
'FontWeight','Bold','FontSize',14,'Fontname','Arial');
    
```

Fig. 16 Plotting instructions to obtain enthalpy versus time graph

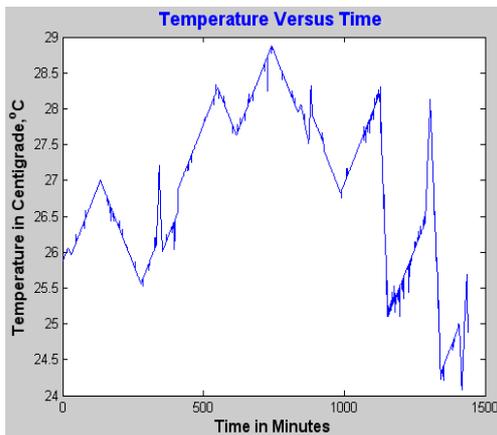


Fig. 17 Graph shows temperature versus time plot

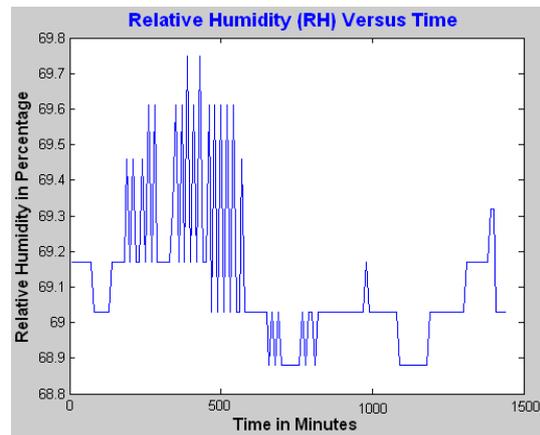


Fig. 18 Graph shows relative humidity versus time plot

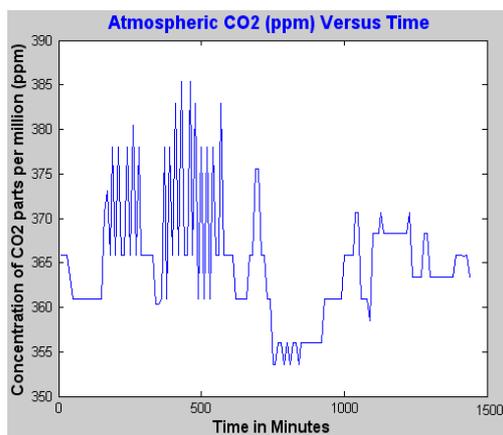


Fig. 19 Graph shows atmospheric carbon dioxide versus time plot

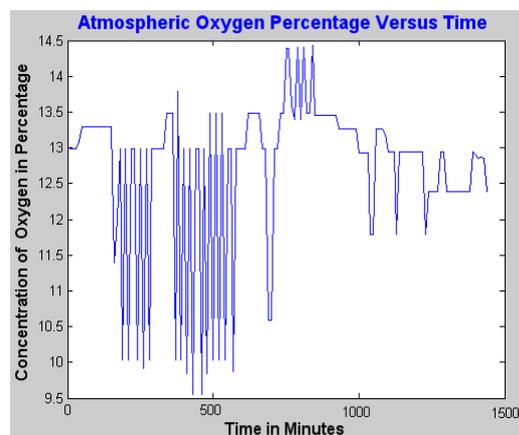


Fig. 20 Graph shows atmospheric oxygen versus time plot

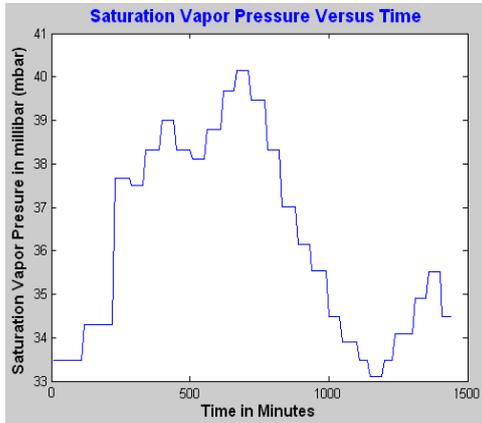


Fig. 21 Graph shows saturation vapor pressure versus time plot

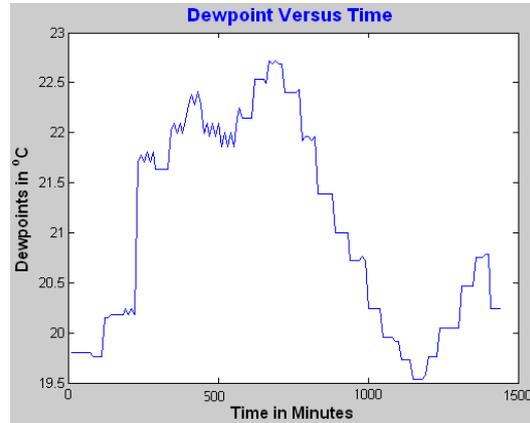


Fig. 22 Graph shows dew point versus time plot

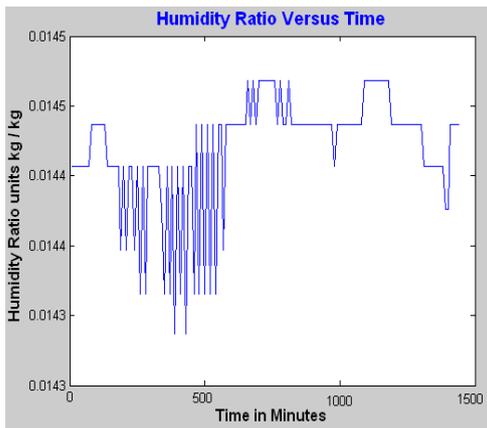


Fig. 23 Graph shows humidity ratio versus time plot

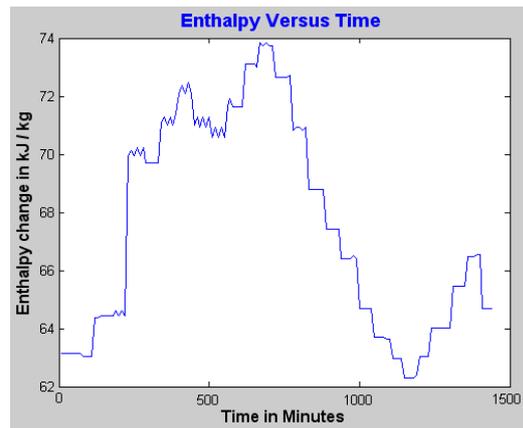


Fig. 24 Graph shows enthalpy change versus time plot

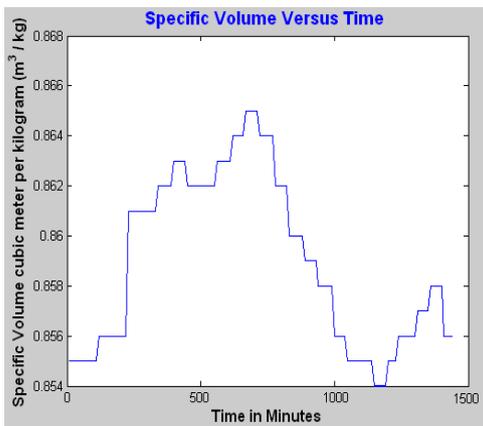


Fig. 25 Graph shows specific volume versus time plot

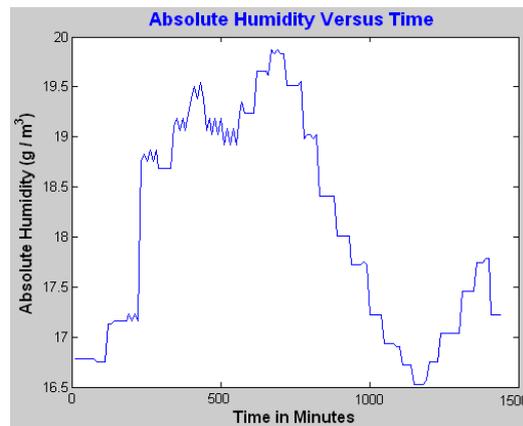


Fig. 26 Graph shows absolute humidity versus time plot

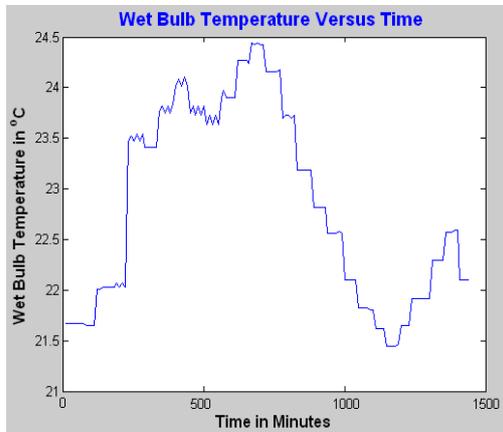


Fig. 27 Graph shows wet bulb temperature versus time plot

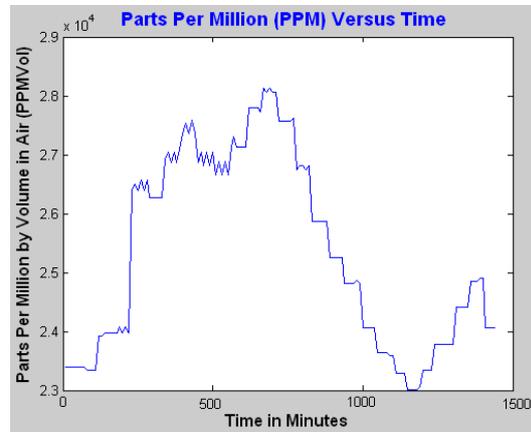


Fig. 28 Graph shows parts per million (ppm) versus time plot

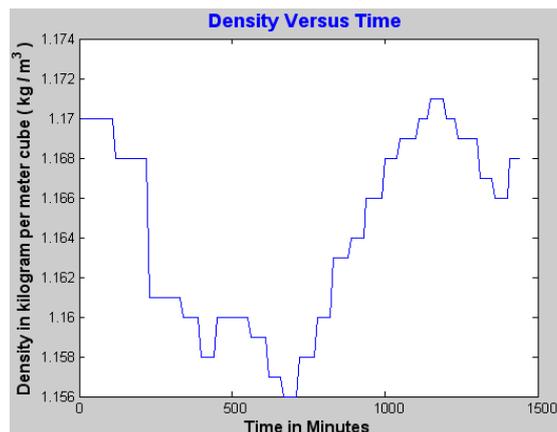


Fig. 29 Graph shows density versus time plot

5.2 Comparison with other online calculators

In order to crosscheck the results, the output obtained from the Matlab scripts is compared with two online available humidity calculators. These are available on websites [<http://www.vaisala.com>] and [<http://easycalculation.com>]. The comparison confirms the output values are almost same. Thus, translation of equations and formulas into Matlab scripts did not sacrifice the accuracy and precision of the derived parameters. As an example to illustrate, we have plotted the graph of dew point versus time taking into account for all three set of output. Let us call the output from [www.vaisala.com] as online calculator 1, shown in red color; output from [www.easycalculation.com] as online calculator 2, shown in black color; Matlab program output is shown in blue color. Fig. 30 shows all the three output lines (values) almost overlapping with each other.

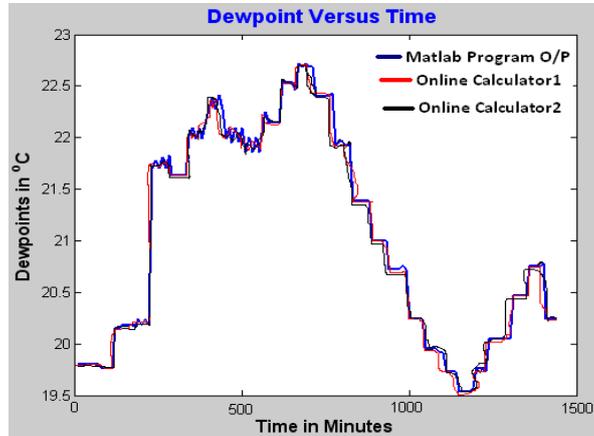


Fig. 30 Graph plotted for dew points obtaining three different set of readings

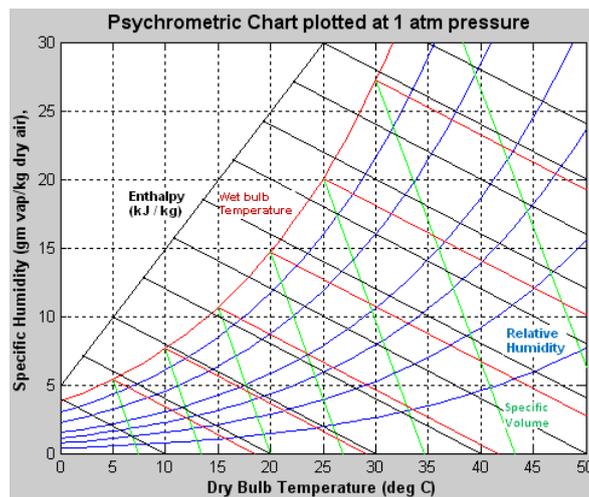


Fig. 31 Psychrometric chart representing temperature-humidity parameters

5.3 Psychrometric chart

Psychrometric charts are graphic representations of the psychrometric properties of the air. By using psychrometric charts environmentalists can graphically analyze different types of psychrometric processes and find solution for many practical problems without having to carry out long and tedious mathematical calculations. The psychrometric chart looks complicated with vast numbers of lines and curves in it, but is easy to understand, once parameters related to temperature and humidity are well understood. Details and tutorials could be found in Ananthanarayanan (2005) and Peralta (2005).

Psychrometric chart representing our meteorological data is presented in Fig. 31. We sincerely acknowledge the source code in Matlab was derived from Urieli (2008), although we have

modified a little as per our convenience.

Dry Bulb Temperature (DBT) indicates the amount of heat in the air and it is directly proportional to the mean kinetic energy of the air molecules. DBT is indeed an important variable in psychrometrics, being the horizontal axis of a psychrometric chart. Relative humidity curves are shown in blue colored lines; specific volume of dry air (cubic m/kg dry air) shown in green color; wet bulb temperature lines are shown in red and enthalpy lines in black color.

6. Conclusions

Synergizing the efforts of multi-disciplinary experts such as hardware engineers, software programmers climatologists, environmentalist and statistical analyzers etc., could form a perspective scientific platform to deal with the issues related with global warming and climate change.

In this project, we developed our own sensor-based kit to obtain the data. Data processing was carried out by software programming, utilizing Matlab platform. In order to achieve comprehensive portrayal of each parameter, the timescale is compressed, with events being measured by the minute rather than by the hour or week. The intricacies related with each of the basic and derived parameters are complex, but would hopefully help in understanding their role in global scenario. Inferences and critical comments on effect of each individual parameter require depth knowledge; this task is still in progress. Issues related to accuracy of sensors, reliability of data transmission, miscalculation, and invalid data processing are kept for the future work.

Acknowledgments

This work has been supported by the Universiti Sains Malaysia (USM) Research University Grant 1001/PCEDEC/854003. The authors would like to thank anonymous reviewers for their valuable comments and constructive suggestions.

References

- Ananthanarayanan (2005), *Basic Refrigeration and Air Conditioning*, Tata McGraw-Hill Education, London, Chapter 17, pp. 233-345.
- Bentley, R.E. (1998), "The theory and practice of thermoelectric thermometry", *Handbook of Temperature Measurement*, **3**(1), 15-20, Springer- Verlag, Singapore.
- Bob, H. (1998), "ITS-90 Formulations for vapor pressure, frost point temperature, dew point temperature, and enhancement factors in the range -100 to +100 C", *Proceedings of the 3rd International Symposium on Humidity & Moisture*, London, **1**, 214-222.
- Camerlengo, A.L., Wahab, A.K., Baharim, H.N., Nasir, K.A.M. and Lim, Y.R. (2003), "Climatologically distribution of certain meteorological parameters in the highland areas and the lowland areas of peninsular Malaysia", *Malay. J. Phys.*, **24**(1), 39-49.
- Downing, T.E. (2012), "Views of the frontiers in climate change adaptation economics", *Wiley Interdisciplinary Reviews: Climate Change*, **3**(2), 161-170.
- Fong, W.K., Matsumoto, H., Ho, C.S. and Lun, Y.F. (2008), "Energy consumption and carbon dioxide emission considerations in the urban planning process in Malaysia", *J. Malay. Inst. Planners*, **6**(1), 101-130.

- Fong, W.K., Matsumoto, H. and Lun, Y.F. (2009), "Application of system dynamics model as decision making tool in urban planning process toward stabilizing carbon dioxide emissions from cities", *Build. Environ.*, **44**(7), 1528-1537.
- Hengchang, B., Kuibo, Y., Xiao, X., Jing, J., Shu, W., Litao, S., Mauricio, T. and Mildred, S. (2013), "Ultrahigh humidity sensitivity of graphene oxide", *Scientific Reports*, **3**, 1-7.
- Houghton, J.T., Ding, D.J., Griggs, M., Noguer, P.J., Linden, V. and Dai, X. (2001), "Climate change 2001: The scientific basis", Contribution of working group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, New York, USA.
- IPCC (2007), Intergovernmental Panel on Climate Change, Fourth Assessment Report on Climate Change, available online, http://www.ipcc.ch/publications_and_data/ar4/wg3/en/contents.html (accessed November 2013)
- Lawrence, M.G. (2005), "The relationship between relative humidity and the dew point temperature in moist air: A simple conversion and applications", *Bulletin of the Am. Meteorol. Soc.*, **86**(2), 225-233.
- Moran, M.J. and Shapiro, H.N. (2000), *Fundamentals of Engineering Thermodynamics*, (4th Edition), John Wiley & Sons, New York, pp. 142-156.
- NWSSRR (2000), "National Weather Service Southern Region report", <http://www.srh.noaa.gov/images/epz/wxcalc/rhTdFromWetBulb.pdf> (accessed November 2013)
- Peralta, P. (2005), "The Psychrometric Chart: Theory and Application", NC State University, available online; <http://www.swst.org/meetings/AM05/peralta.pdf> (accessed Feb 2014)
- Petrucci, R.H., Herring, F.G., Madura, J.D. and Bissonnette, C. (2010), *General Chemistry: Principles and Modern Applications*, (10th Edition), Pearson Prentice Hall, NJ, USA, pp. 312-337.
- Schwartz, S.E. and Warneck, P. (1995), "Units for use in atmospheric chemistry", *Pure Appl. Chem.*, **67**(8-9), 1377-1406.
- Sirvatka, P. (2000), "Introduction to Meteorology", Lecture Notes, College of DuPage, US, available online, <http://weather.cod.edu/> (accessed November 2013)
- Urieli, I. (2008), "Engineering Thermodynamics - A Graphical Approach", Lecture notes, Ohio University, US, available online <http://www.ohio.edu/mechanical/thermo/> (accessed Feb 2014)
- Wagner, W. and Prub, A. (2002), "The IAPWS Formulation 1995 for the Thermodynamic properties of ordinary water substance for general and scientific use", *Journal of Physical and Chemical Reference Data*, **31**(2), 387-535.
- Wylen, G.J.V. and Sonntag, R.E. (1986), *Fundamentals of Classical Thermodynamics*, (3rd Edition), Wiley, UK, pp. 99-112.