International Journal of Innovation and Sustainability, 2 (2018) 34-40
Journal Homepage: www.erjournals.com
ISSN: 0184-7937

PSYCHROMETRIC ANALYSIS OF AN AIR-CONDITIONING SYSTEM OPERATING UNDER GIVEN AMBIENT CONDITIONS

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ABSTRACT
When air passes over a cooling coil whose effective surface temperature is below the dew point temperature of entering air, condensation of the moisture takes place. This separation of the moisture results in fall in the specific humidity or humidity ratio. Thus, both dehumidification and cooling can be obtained with a cooling coil effective surface temperature lower than the dew point temperature of the entering air. In this paper, a psychrometric analysis of an air-conditioning system operating under given ambient conditions was undertaken. Working with the outdoor characteristics of 35 ^{o}C db, and 24 ^{o}C wb; and indoor variables of 18 ^{o}C db, the analysis yielded a sensible heat ratio of 0.6966, and cooling capacity of 440 W. For calculation of psychrometric properties, the end points are important irrespective of the path followed. Altering the ambient parameters will, no doubt, either increase or decrease the operation of the air-conditioning system. Therefore, it becomes expedient to put into perspectives these factors that affect the overall performance of the system.

KEYWORDS: Air-Conditioning System, Psychrometric Analysis, Ambient Conditions, Cooling Capacity, Degree of Saturation.

INTRODUCTION

Psychrometry is that branch which deals with the study of moist air, i.e. dry air mixed with water vapour or humidity. It also includes the study of the behaviour of dry air and water vapour mixture under various sets of conditions. Though the earth's atmosphere is a mixture of gases including nitrogen (N_2), oxygen (O_2), argon (Ar), and carbon-dioxide (CO_2), yet for the purpose of psychrometry, it is considered to be a mixture of dry air and water vapour only. There are many psychrometric terms; however, the following are important from the subject point of view (Khurmi and Gupta 2008).

How to cite this article: Madu; K. E. (2018). Psychrometric Analysis of an Air-Conditioning System Operating Under Given Ambient Conditions. *International Journal of Innovation and Sustainability*, 2: 34-40.

Dry Air. The pure dry air is a mixture of number of gases such as nitrogen, oxygen, carbon-dioxide, hydrogen, argon, neon, helium etc. But the nitrogen and oxygen have the major portion of the combination. The dry air is considered to have the composition as given in table 1. The molecular mass of dry air is taken as 28.966, and the gas constant for air (R_o) is equal to 0.287 kJ/KgK.

Table 1: Composition of Dry Air

S/N	Constituent	By Volume	By Mass
1.	Nitrogen (N_2)	78.03%	75.47%
2.	Oxygen (O_2)	20.99%	23.19%
3.	Argon (Ar)	0.94%	1.29%
4.	Carbon-dioxide (CO_2)	0.03%	0.05%
5.	Hydrogen (H_2)	0.01%	-

Moist Air. It is a mixture of dry air and water vapour. The amount of water vapour present in the air, depends upon the absolute pressure and temperature of the mixture.

Saturated Air. It is a mixture of dry air and water vapour when the air has diffused the maximum amount of water vapour into it. The water vapours, usually occur in the form of superheated steam, as an invisible gas. However, when the saturated air is cooled, the water vapour in the air starts condensing, and the same way may be visible in the form of moist, fog, or condensation on cold surfaces.

Degree of Saturation. It is the ratio of actual mass of water vapour in a unit mass of dry air to the mass of water vapour in the same mass and pressure of dry air when it is saturated as the same temperature.

Humidity. It is the mass of water vapour present in 1 Kg of dry air, and is generally expressed in terms of gm per kg of dry air. It is also called specific humidity or humidity ratio.

Absolute Humidity. It is mass of water vapour present in 1 m^3 of dry air, and is generally expressed in terms of gm per cubic metre of dry air. It is also expressed in terms of grains per cubic metre of dry air. Mathematically, 1 Kg of water vapour is equal to 15,430 grains.

Relative Humidity. It is the ratio of actual mass of water vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure.

Dry Bulb Temperature. It is the temperature of air recorded by a thermometer, when it is not affected by the moisture present in the air. The dry bulb temperature is generally denoted by t_d or t_{db}.

Wet Bulb Temperature. It is the temperature of air recorded by the thermometer, when its bulb is surrounded by a wet cloth exposed to the air. The wet bulb temperature is generally denoted by t_w or t_{wb}.

Wet Bulb Depression. It is the difference between dry bulb temperature and wet bulb temperature at any point. The wet bulb depression indicates the relative humidity of the air.

Dew Point Temperature. It is the temperature of air recorded by a thermometer, when the moisture (water vapour) present in it begins to condense. In other words, the dew point temperature is the saturation temperature (t_{sat}) corresponding to the partial pressure of water vapour (P_v). It is usually denoted by t_{dp}.

Dew Point Depression. It is the difference between the dry bulb temperature and dew point temperature of air.

Psychrometer. There are many types of psychrometers, but the *sling psychrometer*, is widely used. It consists of a dry bulb thermometer and a wet bulb thermometer mounted side by side in a protective casing that is attached to a handle by a swivel connection; so that the casing can be easily rotated. The dry bulb thermometer is directly exposes to air and measures the actual temperature of the air. The bulb of the wet bulb thermometer is covered by a wick thoroughly wetted by distilled water. The temperature measured by this wick-covered-bulb of thermometer, is the temperature of liquid water in the wick, and is called wet bulb temperature. The sling psychrometer is rotated in the air for approximately one minute after which the readings from both the thermometers are taken. This process is repeated several times to ensure that the lowest possible wet bulb temperature is recorded.

The state of the atmospheric air at a specified pressure is usually given by two independent intensive properties. The sizing of a typical air-conditioning system, involves numerous calculations, which may eventually get on the nerves of even the most patient engineer. Therefore, there is a clear motivation to computerize calculations or to do these calculations once, and to present the data in the form of easily readable charts. Such charts are called *psychrometric charts*, and they are used extensively in air-conditioning applications (Yunus and Michael, 2011). A psychrometric chart for a pressure of 1 atm (101.325 kPa), is given in Appendix 1, in SI units. The psychrometric chart also serves as a valuable aid in visualizing the air-conditioning processes. An ordinary heating or cooling process, for example, appear as a horizontal line on this chart if no humidification or dehumidification is involved (i.e. specific humidity = constant). Any deviation from a horizontal line indicates that moisture is added or removed from the air during the process.

Maintaining a living space at a desired temperature and humidity requires some processes called air-conditioning processes. These processes, in Nigeria context, include simple cooling (lowering of temperature) and dehumidification (removing moisture). Cooling can be accomplished by passing air over some coils through which is contained a refrigerant or chilled water (Madu, 2018). During simple cooling, the specific humidity remains constant, but relative humidity increases. The comfort of the human body depends primarily on three factors: the dry bulb temperature, relative humidity, and air motion. The temperature of the environment is the single most important index of comfort. Most people feel comfortable when the temperature of the air-conditioned space is between 22 and 27 ^oC (Wane and Nagdeve, 2012; Thornley, Partner, Roger and Partners, 1969**).** The relative humidity, also, has a considerable effect on comfort, since it affects the amount of heat a body can dissipate through evaporation. Relative humidity is a measure of air's ability to absorb more moisture. High relative humidity slows down heat rejection by evaporation, and low relative humidity speeds it up. Most people prefer a relative humidity of 40 to 60 % (ASHRAE, 1997). Air motion, also, plays an important role in human comfort. It removes the warm, moist air that builds up around the body and replaces it with fresh air. Therefore, air motion improves heat rejection by both convection and evaporation. Air motion should be strong enough to remove heat and moisture from the vicinity of the body, but gentle enough to be unnoticed. Most people feel comfortable at an air-speed of about 15 m/min (Fountain and Arens, 1993). Very-high-speed air motion causes discomfort, instead of comfort.

MATERIAL AND METHOD

A faculty of engineering seminar of Chukwuemeka Odumegwu Ojukwu University, is scheduled for 2014/2015 doctoral candidates of the department of Mechanical Engineering, on August 26, 2018. The students' nominal roll is 10. Expected in the seminar are: the Dean of the Faculty, the Faculty Officer, 4 Heads of Departments, 2 Professors in the faculty, and 8 other senior lecturers of the faculty. It is required to air-condition the annexed Faculty Conference Hall to take care of the comfort of the occupants. The hall is to be maintained at 18 ^oC db and 50 % RH. Outdoor air of 35 % proportion, at a temperature of 35 ^oC db and 24 ^oC wb mixes with the indoor air. The air circulation in the hall is estimated at 2.5 m^3/hr/occupant. The estimated total heat gain in the hall (exclusive of infiltration) is 180,000 kJ/hr, of which 30 % appears as latent heat. Assuming a barometric pressure of 1.01325 bar, and an air-off coil of 14 ^oC db. Design the system on psychrometric chart, showing all conditions, and determine;

- Dry Bulb Temperatures of the Mixture
- Humidity Ratio of Indoor Air (analytically)
- Dew Point Temperature of the Indoor Air
- Degree of Saturation of Air in the Hall
- Mass Flow Rate of Air Entering the Hall
- Sensible Heat Gain Due to Infiltration
- Latent Heat Gain Due to Infiltration
- Sensible Heat Ratio of the Hall
- Water Condensation Rate from the System
- Cooling Capacity of the System

RESULTS AND DISCUSSION

Expected number of people to be seated in the hall = 26

Indoor Data: Temperature = 18 ^oC db;
Relative Humidity = 50 %

Outdoor Data: Proportion of Air = 35 %; Temperature = 35 ^oC db, and 24 ^oC wb

Air Circulation in the Hall per Occupant = 2.5 m^3/hr = 0.000694 m^3/s

Air Circulation in the Hall for 26 Occupants = 65 m^3/hr = 0.018 m^3/s

Total Heat Gain in the Hall (exclusive of infiltration) = 180,000 kJ/hr

Latent Heat = 30 %

Barometric Pressure = 1.01325 bar

Air-Off-Coil = 12 ^oC db

Analysis 1: Determination of the Dry and Wet Bulb Temperatures of the Mixture

Outdoor Condition: 0.35 x 35 = 12.25 ^oC

Indoor Condition: 0.65 x 18 = 11.7 ^oC

Therefore, Mixing Condition: 12.25 ^oC + 11.7 ^oC = 23.95 ^oC. The mixing temperature is the dry-bulb temperature of the mixing air. From analysis 1, we proceed to determine the values of enthalpy, ***h***, from point 1 to point 5. Also, the values of humidity ratio, ***w***, in the earlier mentioned points were determined. The results from the psychrometric chart, are tabulated as in Table 2, below.

Table 2: Psychrometric Results of Enthalpies and Humidity Ration from Points 1-5

Enthalpy, H	Values	Humidity Ratio, W	Values
Enthalpy, h_1	72 kJ/Kg	Humidity Ratio, $\mathbf{w_1}$	0.0143 $Kg_{Water}/Kg_{Dry\ Air}$
Enthalpy, h_2	34 kJ/Kg	Humidity Ratio, $\mathbf{w_2}$	0.0065 $Kg_{Water}/Kg_{Dry\ Air}$
Enthalpy, h_3	49 kJ/Kg	Humidity Ratio, $\mathbf{w_3}$	0.0095 $Kg_{Water}/Kg_{Dry\ Air}$
Enthalpy, h_4	52 kJ/Kg	Humidity Ratio, $\mathbf{w_4}$	0.0065 $Kg_{Water}/Kg_{Dry\ Air}$
Enthalpy, h_5	27 kJ/Kg	Humidity Ratio, $\mathbf{w_5}$	0.0005 $Kg_{Water}/Kg_{Dry\ Air}$

Analysis 2: Determination of the Humidity Ratio of Indoor Air

This is usually determined through mathematical analysis and interpolations. The humidity ratio is a function of partial pressure and saturation pressure, as in the relation;

$$w = \frac{0.622\,P_a}{P - P_s}$$

Recall that Relative Humidity, $\emptyset = \frac{P_a}{P_s} = \frac{Partial\ \ Pressure}{Saturation\ \ Pressure}$

And from Saturated Water – Temperature Table; P_s @ 18 °C equals,

$$\frac{T_{20} - T_{15}}{T_{18} - T_{15}} = \frac{P_{S_{20}} - P_{S_{15}}}{P_{S_{18}} - P_{S_{15}}}$$

$$\frac{20-15}{18-15} = \frac{2.3392-1.7057}{P_{S_{18}} - 1.7057}$$

$P_{S_{18}}$ = 2.0838 kPa = 0.020838 mPa

$$\therefore 0.5 = \frac{P_a}{0.020838}$$

P_a = 0.010419 mPa

We proceed to calculate the humidity ratio, w, thus;

$$w = \frac{0.622x0.010419}{1.01325 - 0.020838}$$

= 6.53 x 10^{-3} kJ/Kg

Analysis 3: Determination of the Dew Point Temperature of the Indoor Air

According to Carrier's equation, the partial pressure of water vapour equals;

$$P_v = P_w - \frac{(P_b - P_w)(t_d - t_w)}{1544 - 1.44 t_w};$$

Where P_v = Partial pressure of water vapour

P_w = Saturation pressure corresponding to wet bulb temp.(from steam table)

P_b = Barometric pressure

t_d = Dry bulb temperature

t_w = Wet bulb temperature

From steam tables (saturated water-temperature table), after interpolation (between 25 °C and 20 °C), we find that the saturation pressure corresponding to wet bulb of 24 °C is

P_w = 0.0300368 bar

Therefore, $P_v = 0.0300368 - \frac{(1.01325 - 0.0300368)(35-24)}{1544 - (1.44\ x\ 24)}$

$P_v = 0.02287$ bar

Since the dew point temperature is the saturation temperature corresponding to the partial pressure of water vapour (P_v), therefore, from the steam table (saturated water-pressure table), corresponding to 0.02 bar, dew point temperature equals **17.50 ^oC**

That is, 0.02 bar ≡ **17.50 ^oC**

Analysis 4: Determination of the Degree of Saturation of Air in the Hall

This is the same as the percentage of saturation of the in-door air, $\boldsymbol{\varphi}$; and is usually computed using the following mathematical relation;

$$\boldsymbol{\varphi} = \emptyset \frac{P - P_s}{P - P_a} = 0.5 \text{ x } \frac{1.01325 - 0.020838}{1.01325 - 0.010419} = 0.4948$$

where P in the relation equals barometric pressure

Analysis 5: Determination of the Mass Flow Rate of Air Entering the Hall

Volumetric Flow Rate for 26 Persons, V = 0.018 m^3/s

Specific Volume, v, at Point 1 = 0.893

$\therefore \dot{m} = \frac{0.018}{0.893} = 0.02$ Kg/s

Analysis 6: Determination of the Sensible Heat Gain due to Infiltration

$Q_{S_{inf}} = \dot{m}(h_4 - h_2)$

$= 0.02\ (52 - 34) = 0.36$ kJ/s

Analysis 7: Determination of the Latent Heat Gain due to Infiltration

$Q_{L_{inf}} = \dot{m}\ (h_1 - h_4)$

$= 0.02\ (72 - 52) = 0.40$ kJ/s

Analysis 8: Determination of Sensible Heat Ratio, SHR

Infiltration in the hall could be attributed to gaps and cracks in the wall; and, sometimes, due to tiny openings in the doors and windows.

Total Heat Gain, Q_T = 180,000 kJ/hr

Latent Heat, Q_L = 0.3 x 180,000 = 54,000 kJ/hr = 15 kJ/sec

Sensible Heat, Q_S = 0.7 X 180,000 = 126000 kJ/hr = 35 kJ/sec

$Q_{ST} = Q_S + Q_{S_{inf}}$

$= 35 + 0.36 = 35.36$ kJ/sec

$Q_{LT} = Q_L + Q_{L_{inf}}$

$= 15 + 0.4 = 15.4$ kJ/sec

Sensible Heat Ratio, SHR, is calculated thus;

$$\text{SHR} = \frac{Q_{ST}}{Q_{ST} + Q_{LT}} = \frac{35.36}{35.36 + 15.4}$$

= 0.6966

Analysis 9: Determination of Water Condensation Rate from the System

The water condensation rate from the system is dependent on humidity ratios at points 3 and 5; and usually calculated using the equation

$w_r = \dot{m}\ (w_3 - w_5)$

$w_r = 0.02(0.0095 - 0.0005) = 1.8 \text{ x } 10^{-4}$ Kg/s

Analysis 10: Determination of the Cooling Capacity of the System

The cooling capacity, Q_C of the plant equals;

$Q_C = \dot{m}\ (h_3 - h_5)$

$Q_C = 0.02(49 - 27) = 440$ W

The heating of air without any change in specific humidity, is known as *sensible heating*. The process of sensible heating, on the psychrometric chart, is shown by a horizontal line, extending from left to right. The heat absorbed by air during sensible heating may be obtained from the psychrometric chart by the enthalpy differences; for instance $h_2 - h_1$. It may be noted that the specific humidity during the sensible heating remains constant (i.e. $w_1 - w_2$). Similarly, the dry bulb temperature increases, and the relative humidity decreases.

CONCLUSION

The pure dry air does not, ordinarily, exit in nature because it always contains some water vapour. The term air, wherever used in this paper, means dry air containing moisture in the vapour form. Both dry air and water vapour can be considered as perfect gases because both exist in the atmosphere at low pressure. The density of dry air is taken as 1.293 Kg/m^3 at pressure 1.0135 bar or 101.35 kN/m^2 and at temperature 0 ^oC (273 K).

REFERENCES

Khurmi, R. S. and Gupta J. K. (2008). *A Textbook of Thermal Engineering*. New Delhi: S.Chand, pp.798-800.

Yunus, A. and Michael, A. B. (2011). *Thermodynamics: An Engineering Approach*. New-York: McGraw Hills, p.736.

ASHRAE Psychrometric Chart, No 1.

Madu, K. E. (2018). Adaptation of an Air-Conditioning System for use in a 100-Seater Capacity Auditorium, in Nigeria. *Equatorial Journal of Engineering*, 1-8

Wane, S. S. and Nagdeve, M. B. (2012). Design of Air Cooling System for College Auditorium, *Journal of Environmental Research and Development*, 6, 3.

Thornley, D. L., Partner, F. I. H. V. E., Roger, P. J. and Partners (1969). Consulting Engineers Air-conditioning System Design for Buildings, 256.

ASHRAE Handbook of Fundamentals, (1997)..

Fountain, M. & Arens, E. A. (1993). Air Movement and Thermal Comfort, *ASHRAE Journal*, 35(8), 1-6

APPENDIX 1

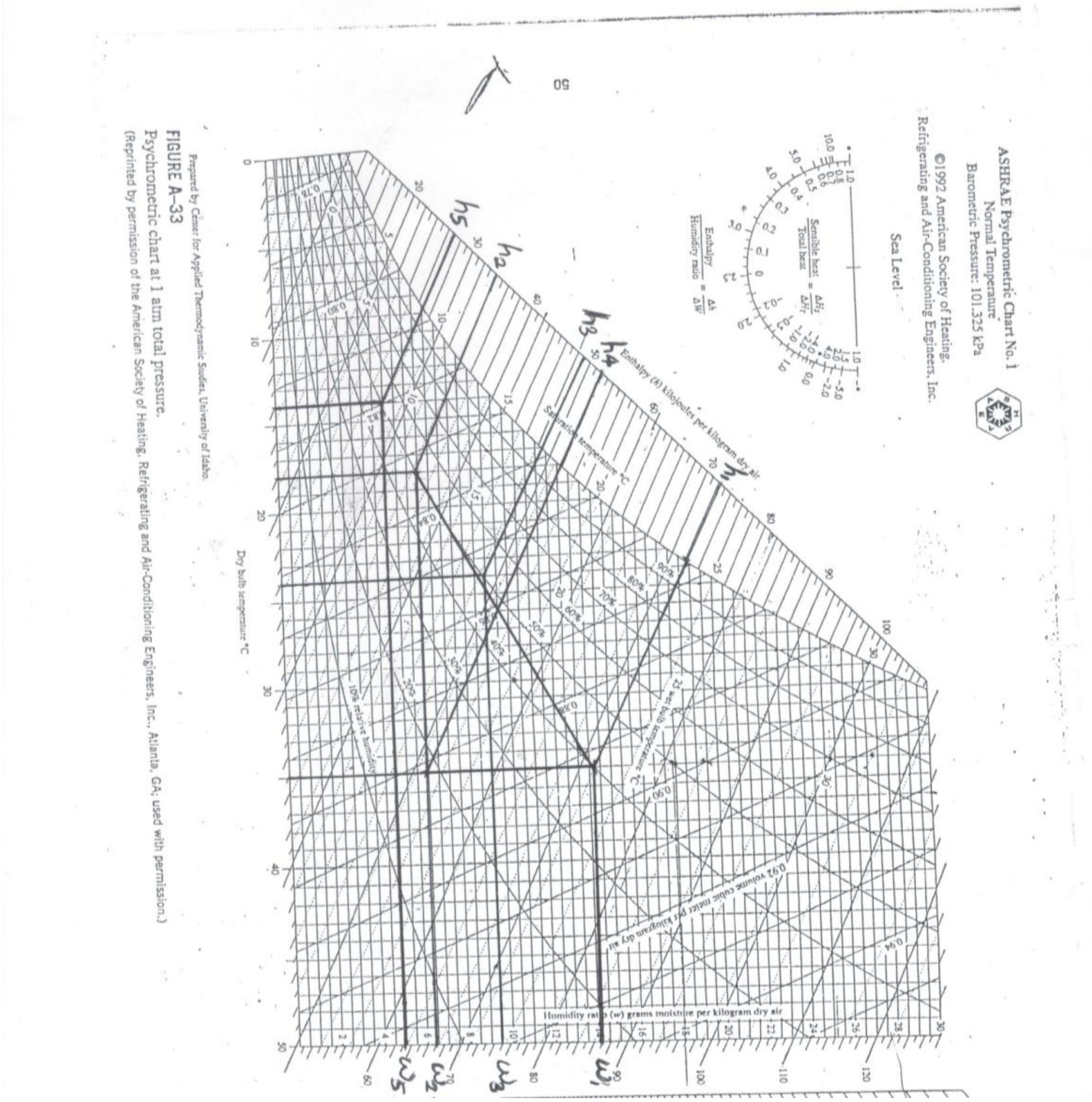

FIGURE A–33
Psychrometric chart at 1 atm total pressure.
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