Laboratory Instruction
on
Air Conditioning Unit

Introduction

Air conditioning deals with the thermodynamic properties of moist air and used these properties to analyze conditions and processes involving moist air. It controls the temperature, moisture, cleanliness, and movement of indoor air. It cools the air when the weather is hot. It warms the air when the weather is cold. Comfort depends partly on humidity, and air conditioning removes moisture from the air or adds it as needed. This laboratory unit illustrates the application of the principles of thermodynamics in the field of air conditioning. The unit is self contained, mobile and specially designed for teaching purposes, providing results over a wide range of operating conditions.

Objectives:

- To develop fundamental understanding of refrigeration and air conditioning systems;
- To prepare the students to design air conditioning systems;
- To lay the groundwork for professional career in air conditioning area;
- To enhance knowledge of energy conservation and management as applicable to air conditioning systems;

Theory

The thermodynamic analysis and design of refrigeration and air conditioning systems are studied. This covers psychrometric processes; theory of the Psychrometer; air conditioning systems and vapor compression system.
A psychrometric chart graphically represents the thermodynamic properties of moist air. The chart may be obtained through ASHRAE. This chart can be used to solve numerous process problems with moist air. Typical air conditioning processes are moist air sensible heating or cooling, moist air cooling and dehumidification, adiabatic mixing of two moist airstreams and adiabatic mixing of water injected into moist air.

Moist air sensible heating or cooling

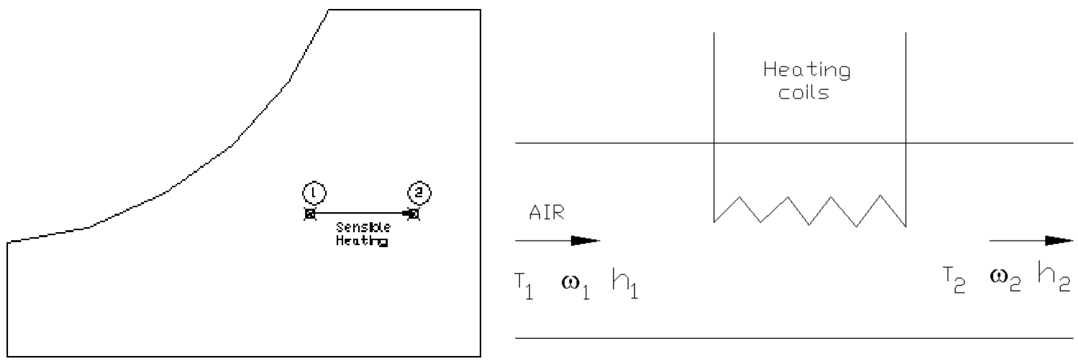


Fig. 1 Schematic for heating moist air

The process of adding heat alone or removing heat alone from moist air is represented by a horizontal line on the psychrometric chart, since the humidity ratio remains unchanged. Figure 1 shows a device that adds heat to a stream of moist air. For steady flow conditions, the required rate of heat addition is

$$q_{12} = \dot{m}_{da} (h_2 - h_1)$$

Note: $\dot{m}_{da}$ = air flow rate / specific volume per unit mass of dry air = $\dot{Q}/\nu$

Adiabatic mixing of water injected into moist air

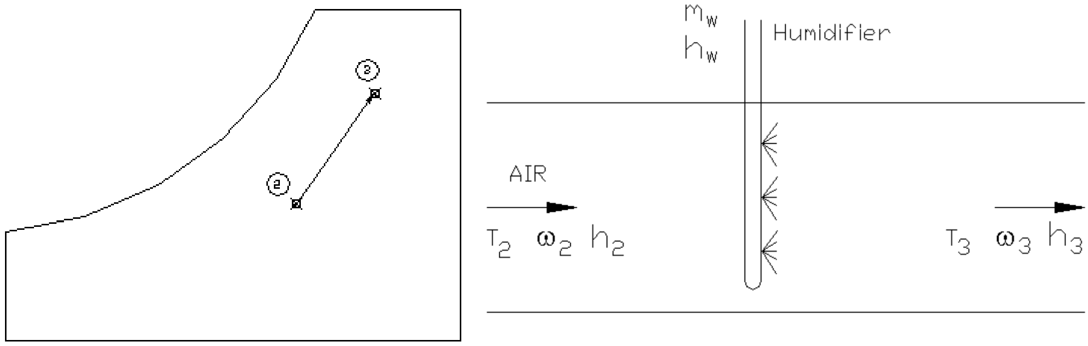


Fig. 2 Schematic for injection of water into moist air

Steam or liquid water can be injected into a moist airsteam to raise its humidity. Figure 2 represents a diagram of this common air conditioning process. If the mixing is adiabatic, the following equations apply:

$$\dot{m}_{da} h_2 + \dot{m}_w h_w = \dot{m}_{da} h_3$$

$$\dot{m}_{da} \omega_2 + \dot{m}_w = \dot{m}_{da} \omega_3$$

Therefore, $$\frac{h_3 - h_2}{\omega_3 - \omega_2} = \frac{\Delta h}{\Delta \omega} = h_w$$

according to which, on the psychrometric chart, the final state point of the moist air lies on a straight line which direction is fixed by the specific enthalpy of the injected water, drawn through the initial state point of the moist air.

Moist air cooling and dehumidification

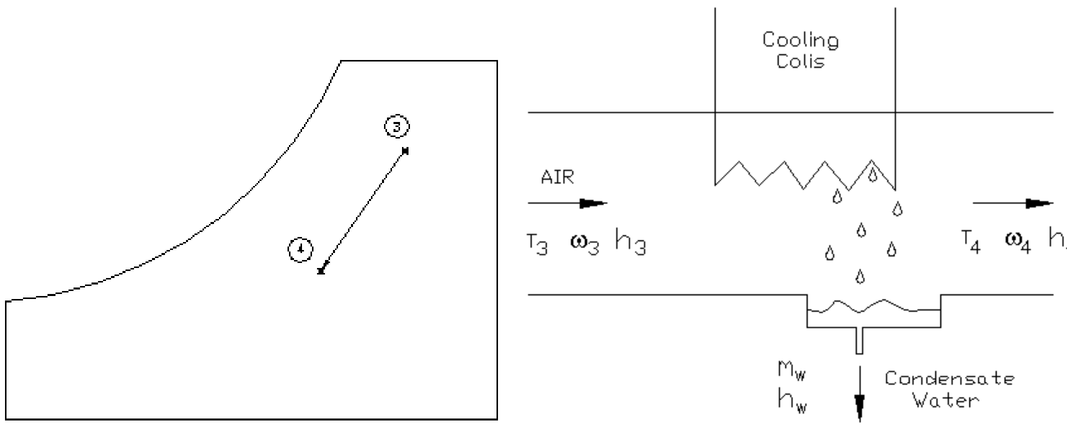


Fig. 3 Schematic for cooling moist air

Moisture condensation occurs when moist air is cooled to a temperature below its initial dew point. Figure 3 shows a schematic cooling coil where moist air is assumed to be uniformly processed. Although water can be removed at various temperatures ranging from the initial dew point to the final saturation temperature, it is assumed that condensed water is cooled to the final air temperature T_4 before it drains from the system.

For the system of the steady flow, energy and mass of water balance equations are

$$\dot{m}_{da} h_3 = q_{34} + \dot{m}_w h_{w4} + \dot{m}_{da} h_4$$

$$\dot{m}_{da} \omega_3 = \dot{m}_w + \dot{m}_{da} \omega_4$$

Thus, $\dot{m}_w = \dot{m}_{da} (\omega_3 - \omega_4)$

$q_{34} = \dot{m}_{da} [(h_3 - h_4) - (\omega_3 - \omega_4) h_{w4}]$

Adiabatic mixing of two moist airstreams

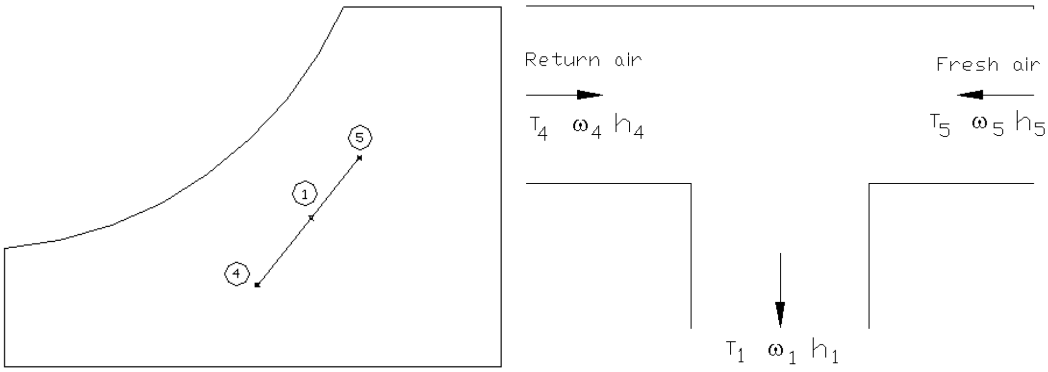


Fig. 4 Schematic for adiabatic mixing of two moist airstreams

A common process in air conditioning system is the adiabatic mixing of two moist airstreams. Figure 4 schematically shows the problem. Adiabatic mixing is governed by three equations:

$\dot{m}_{da4} h_4 + \dot{m}_{da5} h_5 = \dot{m}_{da1} h_{w1}$

$\dot{m}_{da4} + \dot{m}_{da5} = \dot{m}_{da1}$

$\dot{m}_{da4} \omega_4 + \dot{m}_{da5} \omega_5 = \dot{m}_{da1} \omega_1$

Eliminating $\dot{m}_{da1}$ gives $\frac{h_5 - h_1}{h_1 - h_4} = \frac{\omega_5 - \omega_1}{\omega_1 - \omega_4} = \frac{\dot{m}_{da4}}{\dot{m}_{da5}}$

according to which, on the psychrometric chart, the state point of the resulting mixtures lies on the straight line connecting the state points of the two streams being mixed, and divides the line into two segments, in the same ratio as the masses of dry air in the two steams.

Description of the equipment

Air conditioning unit comprising ducting system, variable delivery fan unit for air flow, inlet air heating and humidification, air cooling with condensate removal and measurement and air reheated. The line diagram of the unit is shown in Figure 5. Main components are:

1. Refrigeration capacity is 1.77 kW (6,000 BTU per hour). It uses refrigerant-134a as the working fluid. Design evaporator temperature at 8°C and condenser temperature at 45°C (with 5°C degree of superheated). A hermetric compressor of scroll type is used. The compressor unit and refrigerant condenser are air-cooled.
2. A variable delivery axial-flow fan unit supplies metered air to a pre-treatment plenum chamber where it can be heated and humidified to a variable and measured extent.
3. Air intake flow measurement is taken by a vane-anemometer and air flow rates between 0.03 - 0.09 m^3/s can be used.
4. Pairs of thermometers are provided at different points on the air flow path in order to read wet and dry-bulb temperatures.
5. A boiler with a set of heater 3.5 kW (0.5 kW, 1 kW and 2 kW each) injects steam into a moist air to raise its humidity.
6. A set of heater 2kW (0.5 kW × 2 and 1kW) is provided for sensible heating process.

7. A damper at the exit of the unit is used to control and mix outdoor and return air.

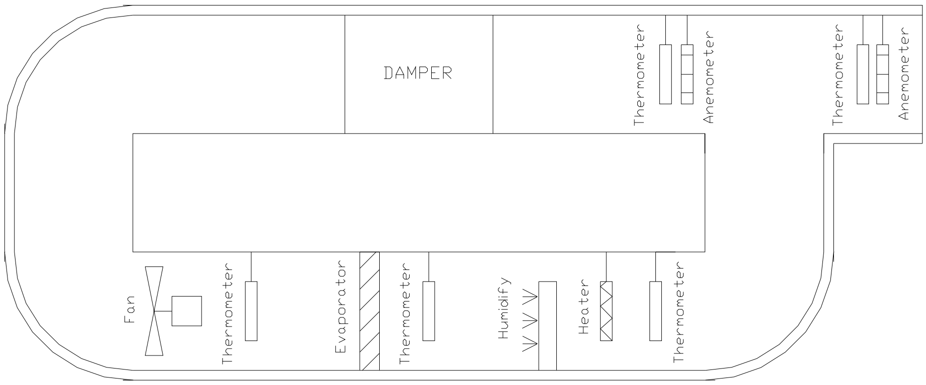
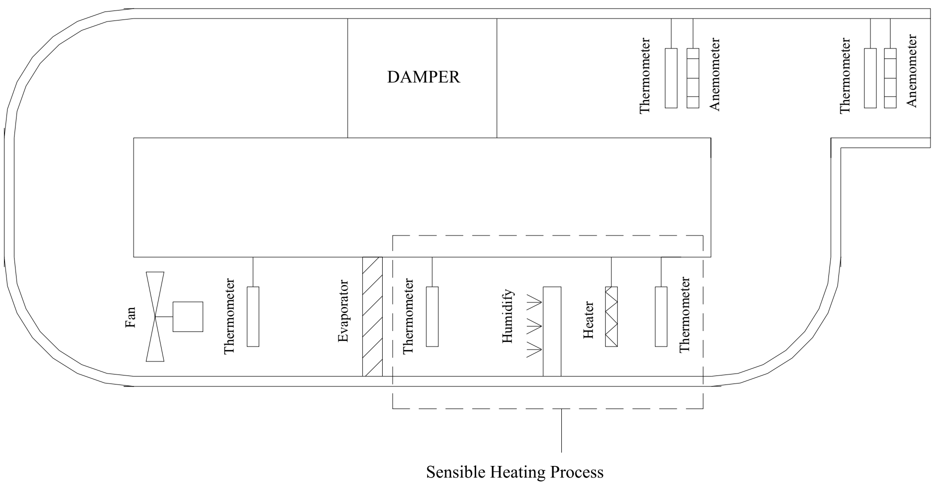


Fig. 5 Line Diagram of Air-Conditioning Unit

Test Procedure

1. Fill up every water tube of the wet-bulb thermometer.
2. Fill up the water tanks of the boiler nearly full (about 5-10 cm. from top).
3. At the boiler, close the steam outlet valve to the system (in order to prevent the steam into the system) and open the water inlet valve from the water supply tank.
4. At the switch panel, make sure that all the switches are at off position. Connect power supply and turn on the main switch.
5. Adjust the damper to 0% return air. Turn on the fan switch and set the fan speed to maximum velocity by adjusting the fan speed controller knob. Wait until the temperature reading at each point is steady then start the following testing processes. For the air flow rate measurement using anemometer see note 1.
6. Test should be run at:

   6.1 **Sensible heat process:**



   6.1.1 Measure the air flow rate by using anemometer.

   6.1.2 Turn on the heater to 0.5 kW.

   6.1.3 Wait until the temperature readings at the point before and after the heater are steady then record the data (power supply to the heater by voltmeter and ammeter).

   6.1.4 Increase the heater power (e.g. 1 kW and 1.5 kW) and/or adjust to another air flow rate value.

Note: Before start the testing point in 6.1.4, one should circulate air in the system until the temperature reading is approximately equal to the ambient temperature.

6.2 **Heating and humidifying process:**
(Using the same testing section as the sensible heating process)

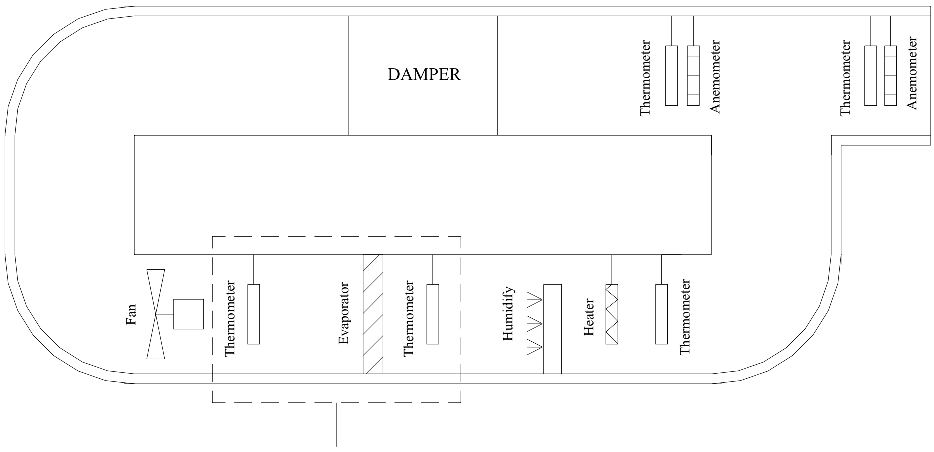
6.2.1 At the boiler, open the steam outlet valve to the system and turn on the heater to 3.5 kW wait until the water temperature at 100°C then switch the heater to 0.5 kW.

6.2.2 Measure the air flow rate by using anemometer.

6.2.3 Wait until the temperature readings at the point before and after the testing section are steady then record the data (power supply to the heater by voltmeter and ammeter).

6.2.4 Adjust to other air flow rate values.

6.3 **Cooling and dehumidifying process:**



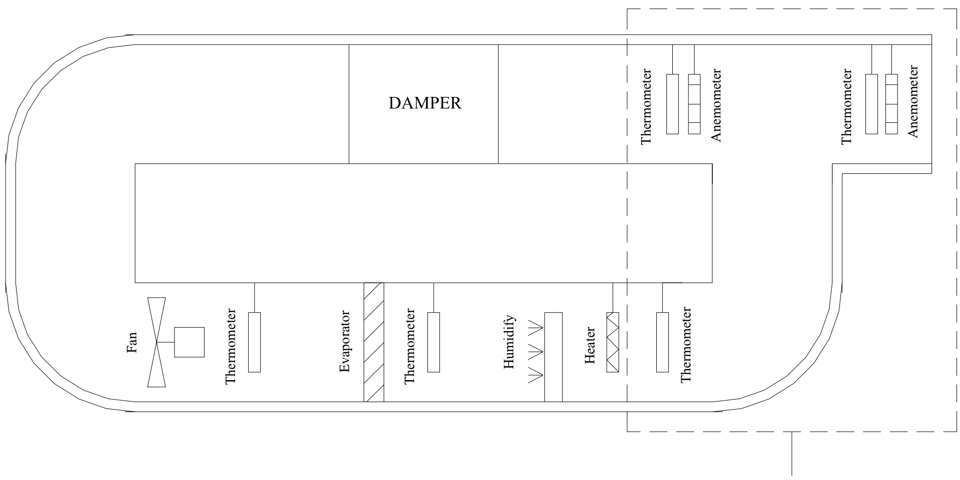
Cooling and Dehumidifying Process

6.3.1 Turn on the refrigeration unit and measure the air flow rate by using anemometer.

6.3.2 Wait until the temperature readings at the point before and after the testing section are steady then record the data (power supply to the compressor by voltmeter and ammeter).

6.3.3 Adjust to other air flow rate values.

6.4 **Adiabatic mixing process:**



Adiabatic Mixing Process

6.4.1 Turn on the refrigeration unit. Adjust the damper to 40% return air and measure the air flow rate by using anemometer.

6.4.2 Wait until the temperature readings at the point before and after the mixing section are steady then record the data.
6.4.3 Adjust to other air flow rate values and/or damper positions.

Note 1 : the air flow rate measurement using anemometer

The anemometer used is the Testco 435 vane type measuring range value 0.6 - 40.0 m/s (120.0 - 8000.00 fpm) with the resolution of ±0.01 fpm [0.0-4000.00 fpm], ±0.1 fpm [4000.1-8000.00 fpm]. The air flow rate through the duct can be measured as follow.

1. Connect the probe cord to the measuring unit Testco 435 and press <I/O> button to turn on the unit.
2. Insert the probe head to the measured location.
3. The measured velocity will show on the unit screen. When it is steady press <2nd function> and <HOLD> buttons to lock the value. Press <HOLD> button the second time to show the maximum and press <HOLD> button again to show the minimum value since the machine has turn on.
4. The average value can be measured by pressing <2nd function> and <MEAN> buttons. The message "MEAN" and "00:00" will show on the unit screen.
5. Insert the probe head to the measured location.
6. Press <START> to record the data. Wait for about 10 seconds the measured value will show on the unit screen then press <STOP> to stop the record.
7. Move the probe head to another measured location and repeat step (6) unit all the measured locations are recorded.
8. Press <MEAN> button to show the mean value of the record data.

Note 2 : Once you finish testing the air-conditioning unit, do the followings.

1. Turn off all switches except the main and fan switches.
2. Circulate the air in the system until all the reading temperatures in the unit are steady and approximately equal to ambient temperature.
3. Turn off the fan and the main switches.
4. Fill up every water tube of the wet-bulb thermometer.
5. Fill up the water tanks of the boiler nearly full (about 5-10 cm. from top).
6. At the boiler, close the steam outlet valve to the system and open the water inlet valve from the water supply tank.

Calculation

1. Determine and analyze sensible heating, heating & humidifying, cooling & dehumidifying and adiabatic mixing processes of an air-conditioning system.
2. Mark the processes on the psychrometric chart and compare the result to those of the theory.
3. Compare the measured result (e.g. q) with the benchmark experiment data. Discuss their uncertainty and the comparison.

References

1. ASHRAE, (2009): "ASHRAE Fundamentals Handbook (SI)", American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
2. Cengel, Y.A. and Boles, M.A., (2007):"Thermodynamics: an engineering approach", 6th edition, McGraw-Hill Higher Education

Data sheet on air-condition unit

Date.. Group...................
Test by...

No	$\bar{V}$ (m/s)	Q (m^3/s)	$\dot{m}$ (kg/s)	Heater		q_{theory} (kW)	T_{inlet} (°C)		h_{inlet} (kJ/kg)	ω_{inlet} (g moist /kg)	T_{outlet} (°C)		h_{outlet} (kJ/kg)	ω_{outlet} (g moist /kg)	q_{cal} (kW)	Note
				Volt	Amp		T_{db}	T_{wb}			T_{db}	T_{wb}				