Development of a Psychrometric Test Chamber

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Acknowledgments

The design of the Psychrometric Test Chamber was done as a Senior Design Project by undergraduate students Brent Losey and Joseph Stellbrink, under the supervision of Professor Swedish.

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I. Introduction

The purpose of this paper is two-fold:

- To illustrate the incorporation of the capstone design experience into the development of laboratory equipment.

- To describe the capabilities and operation of the psychrometric test chamber.

II. Engineering Design and the Energy Laboratory at the Milwaukee School of Engineering

The Energy Laboratory at MSOE serves undergraduate students in the Mechanical Engineering, Mechanical Engineering Technology, and Architectural Engineering programs. The Lab is a collaborative arrangement between MSOE and Johnson Controls, Inc., which operates a large HVAC system for training purposes.

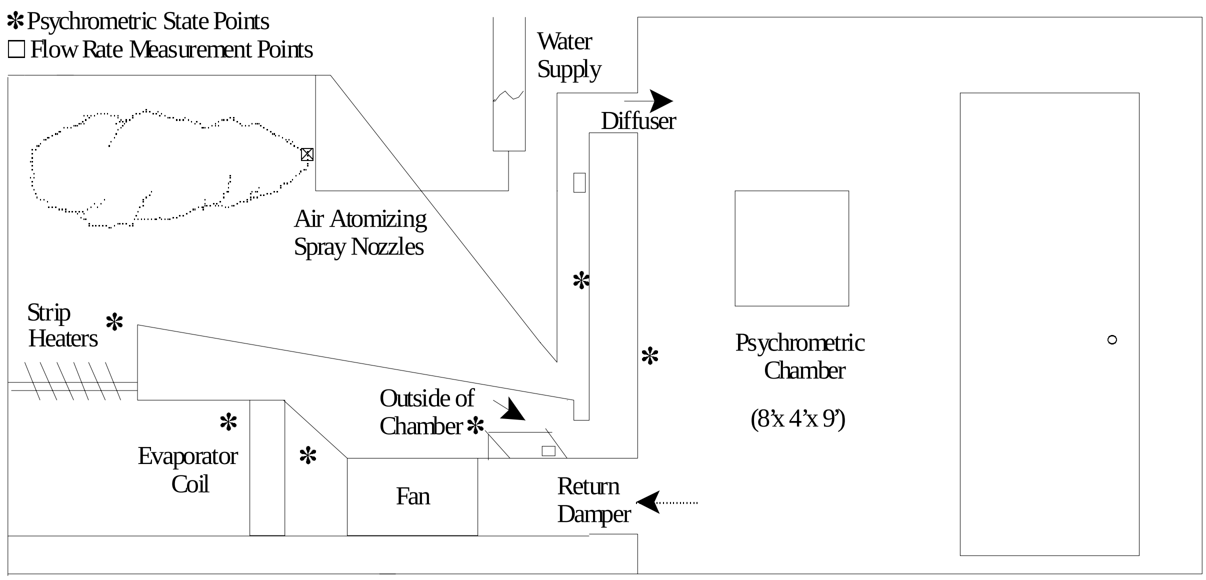
The philosophy behind the continuing development of the Energy Lab is to allow the undergraduate students themselves to design and develop the equipment wherever possible. In this way, the Lab better fulfills its potential as a teaching facility. The primary vehicle for this work is the senior capstone design project. Several pieces of equipment have been designed in this way: a 140 ft/sec wind tunnel, a smoke tunnel for flow visualization, and most recently the psychrometric test chamber.

A team of two students was given the chamber design project. The stated purpose for the chamber was to demonstrate the basic psychrometric processes of heating, cooling, humidification, dehumidification, and mixing. A number of criteria were defined, and a cost target specified. The design report was used as the basis for construction of the chamber, and is on file at the school.

III. System Description

A line drawing of the unit has been included as Figure 1.

Figure 1. Psychrometric Chamber Layout



The apparatus has been designed to fit onto two 8-foot by 4-foot pallets so that it can be relocated within the lab, if necessary. The first pallet holds the chamber itself. The chamber is an 8-foot by 4-foot by 9-foot high "room" built to residential construction standards. The second pallet holds the entire HVAC system for the chamber. Filter, fan, evaporator coil, strip heaters, and sprayers are connected through ductwork to the chamber. Much of the front-facing wall of the ductwork has been constructed of plexiglas, so that the coil, heaters, and sprayers can be viewed from the Lab.

IV. Components and Instrumentation

Fan:

The fan is an in-line centrifugal unit. A maximum air flow of 420 cfm (at about 0.3" wg of static pressure head) and minimum of 180 cfm have been achieved.

Cooling unit:

The size of the cooling unit was set at 1 ton capacity, because this was the smallest size split coil unit that was commercialy available. It is a standard vapor-compression refrigeration system, with Refrigerant-22 as the working fluid.

Heaters:

Two commercially available electric resistance finned strip heaters are used. They were sized for a maximum power input of 12,000 BTU/hr, to match the size of the cooling unit. The power supplied to the heaters can be varied from zero to this maximum value.

Sprayers:

Humidification is accomplished with the use of 3 air-atomizing sprayers. Water is gravity-fed from a tank mounted on the chamber; compressed air is supplied at 20 psig. Median droplet size is about 20 microns diameter.

Instrumentation:

Dry-bulb temperature and relative humidity are measured at five locations within the system, and one location in the Lab. These locations are shown on Figure 1. Also shown in the Figure are two locations where flow velocity can be measured with a hot-wire anemometer, for determination of flow rate. Refrigeration system temperatures and pressures are measured, along with compressor power. Power supplied to the strip heaters is measured. Sprayer water flow rate can be estimated from air pressure and water static head.

V. Unit Operation and Capability

Proper damper adjustment allows for once-through flow through the chamber, complete recirculation, or any percent range of "ventilation" air.

The following operations will be described separately. It is important to bear in mind that any combination of processes can also be used. Dry-bulb temperatures are repeatable to $\pm 1^{o}$ F, and relative humidities to $\pm$ 2%.

Cooling and condensation:

In complete recirculation mode, the cooling unit can be operated to obtain the change in psychrometric state of the air at any location over time. Beginning with relatively dry air, a characteristic constant-specific-humidity line should be traced on the psychrometric chart. This corresponds to cooling only.

Figure 2 shows an example of data obtained with the unit, starting with a dry-bulb temperature of 90°F. The rise in specific humidity seen in the early stages of the cooling process is a characteristic of the unit, and calls for further investigation.

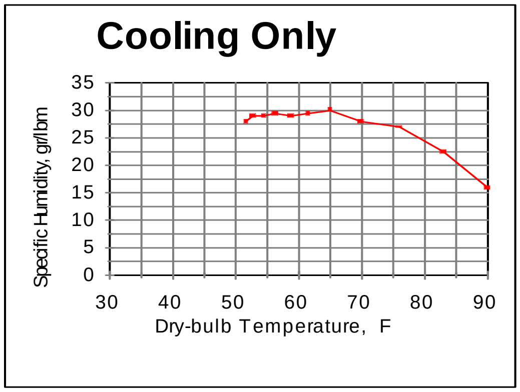


Figure 2.

Beginning with humid air (obtained by operating the sprayers for a period of time), a typical cooling and condensation curve should be traced. That is, if the dry-bulb temperature is dropped low enough, water vapor should begin to condense out of the air mixture. Figure 3 shows data obtained with a starting dry-bulb temperature of 69°F and 50% relative humidity.

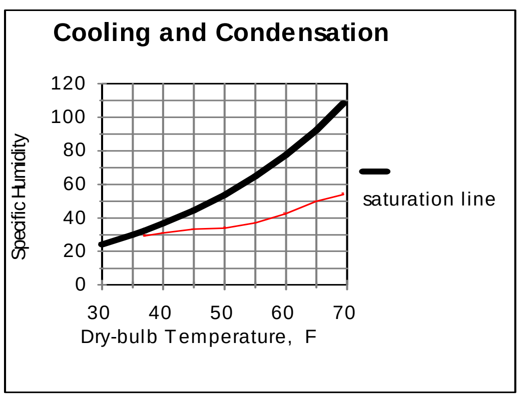


Figure 3.

In complete recirculation, a minimum air temperature of 32°F has been measured at the evaporator coil, corresponding to a chamber temperature of 50°F. In the once-through mode, steady-state conditions across the coil, and in the chamber itself, have been observed. With minimal thermal load in the chamber, a steady-state temperature of 51°F has been achieved there. This corresponds to a coil ΔT of about 27°F.

Heating:

With a range of heating levels from 0 to 12,000 BTU/hr available, the heating process can be examined in detail. Figure 4 shows data for complete recirculation, full heater power, with a starting dry-bulb temperature of 77°F.

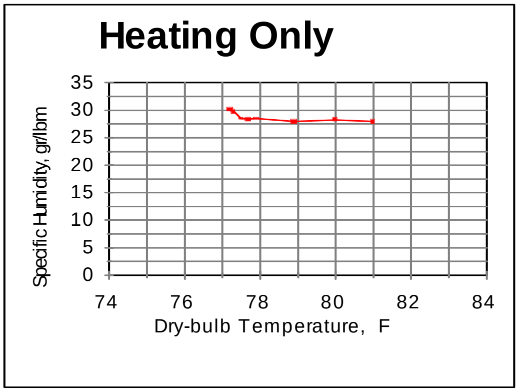


Figure 4.

For complete recirculation, duct air temperatures in excess of 140°F can easily be achieved. A steady-state temperature of 101°F has been achieved in the chamber. In once-through mode, a steady-state temperature of 92°F has been achieved, at a minimum relative humidity of 3%.

Humidification (Evaporative Cooling):

With only the sprayers operating, in complete recirculation mode, the characteristic evaporative cooling process can be shown on the psychrometric chart by plotting the psychrometric state over time as measured at the point in the duct after the sprayers. If the humidification is adiabatic, the process should follow a constant enthalpy line on the psychrometric chart. Figure 5 shows an example of humidification data, starting at a dry-bulb temperature of 99°F. A constant enthalpy line is included for comparison. In this case, the rise in enthalpy in the early stages of the process appears to be a characteristic of the unit.

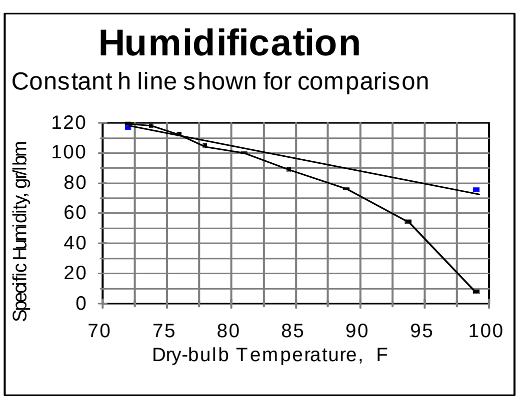


Figure 5.

From normal room conditions, in complete recirculation mode, it takes about 5 minutes to saturate the air. At this point, the formation of fog inside the duct at the sprayers can be clearly observed. Operation of the sprayers together with the heaters in complete recirculation mode should produce the most extreme condition of temperature and humidity in the chamber. In tests of the unit, a psychrometric state of 97^{o}F dry-bulb and 95% relative humidity has been achieved.

Chamber Loading:

The chamber can be set up to place a load on the cooling unit in a number of ways. A high intensity light bulb of known Wattage can be used. An electric resistance space heater can be placed in the chamber, and its power measured. A person can also be placed in the chamber, at rest or at various activity levels, to look at the effect of human loading on both sensible and latent energy.

Energy Balances:

With air flow rates known, energy balances can be performed for the cooling coil and heaters. In fact, energy balances can be performed between any two points in the air flow. For example, energy losses or gains through the uninsulated ductwork can be easily established.

Chamber Environmental Control:

By proper adjustment of dampers, fan speed, sprayers, heaters, and cooling unit, a wide range of psychrometric environments can be created and maintained in the chamber. Conditions of 97^{o}F dry bulb and 95% relative humidity, 97^{o}F dry bulb and 2% relative humidity, 40^{o}F dry bulb and 100% relative humidity, and 48^{o}F dry bulb and 50% relative humidity have been demonstrated.

The chamber has been used to create high-humidity conditions for testing of the hygroscopic characteristics of hydraulic fluids, and used to mimic a Florida climate for small engine testing.

Demonstrations:

Because of the unique design of the unit, certain psychrometric phenomena can be demonstrated. Dehumidification can be shown by passing moist air over the cooling coil and observing droplet formation on the coil surfaces. Coil freeze-up can be shown by passing cold moist air over the coil, and observing the formation of frost. Mixture saturation can be manipulated in the sprayer section by heating or cooling the very moist air and observing the formation and disappearance of fog.

VI. Conclusion

The Psychrometric Chamber as a Teaching Tool

The psychrometric chamber is proving to be a reliable and versatile device for demonstration and experimentation in the fields of thermodynamics, heat transfer, and HVAC processes and design. Its versatility makes it an ideal teaching tool. The data already gathered make clear that there is much to learn about the functioning of this machine. The questions that have arisen from these first experiments will be explored in the future by students, as a part of their laboratory exposure. Development of the psychrometric test chamber will be an ongoing process.

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