CHAPTER 2

EXPERIMENTAL APPARATUS AND PROCEDURE

2.1 PURPOSE

An experimental apparatus was designed and constructed in order to measure the moisture transfer through common building materials. The main purpose of this apparatus was to measure the moisture flux rate as a result of temperature and humidity gradients through materials. The original apparatus was designed and constructed by Crimm (1992). A series of modifications have been made later by Mosier (1994), Chevrier (1996), and during the present research. These modifications were implemented to extend the operational parameters of the apparatus.

2.2 DESCRIPTION OF THE APPARATUS

2.2.0 Overview

The apparatus is composed of a pair of individually controlled environmental chambers on both sides of the test material. A general schematic of the chamber and its environmental controls is shown in Fig. 2.1. The temperature and the relative humidity within each chamber are controlled separately. The environmental systems rely upon the circulation of air through the chambers. The temperature within the chamber is controlled by forced air flow through heat exchangers set at a predetermined point.

In order to maintain the desired relative humidity in a chamber, airflow is diverted prior to entering the chamber through either a tube filled with distilled water or a granular desiccant. Air bubbles through distilled water to increase its relative humidity, or passes through the desiccant tube to decrease it. A more detailed explanation of both of these systems is given in later sections.

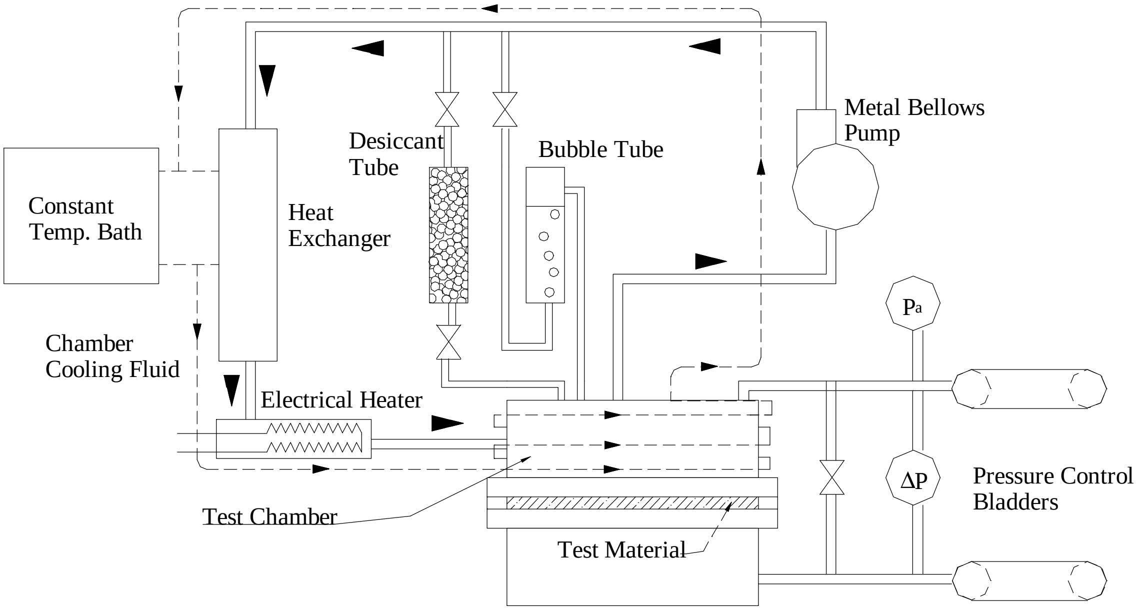

Figure 2.1 Schematic of the environmental chamber and control systems.

2.2.1 Test Specimen

The specimen used in this experiment is oriented strand board, denoted “OSB”, a typical material in the construction industry. The specimen is a circular OSB piece 431.8 mm (17 inches) in diameter and 6.35 mm (0.250 inches) thick. The sample is mounted in an acrylic ring, as shown in Fig. 2.2, which in turn is sandwiched between the two chambers. The acrylic ring has an inner diameter of 431.8 mm (17.00 inches) and a thickness of 12.7mm (0.5 inches). A special type of wax secures the sample material to the acrylic ring. The wax as described by the ASTM (ASTM,1990), allows the specimen to expand and contract, resulting from changes in both moisture content and temperature. This special property of the wax prevents any possible physical alterations to the sample.

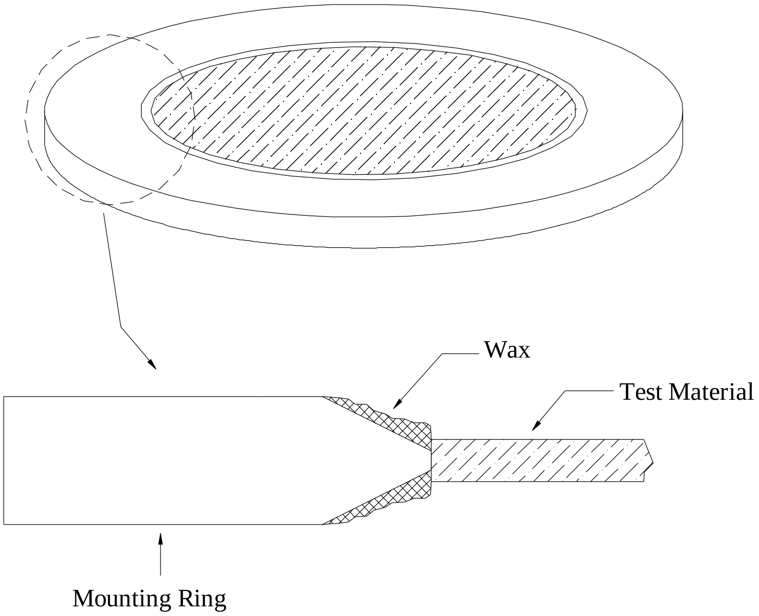

Figure 2.2 Test specimen assembly.

2.2.2 Environmental Conditioning

The environmental chambers have undergone an evolutionary process since the initial design by Crimm (1992). A schematic of the assembled chambers is depicted in Fig. 2.3. After several tests with various materials such as acrylic and brass, the current material for the chambers was chosen to be aluminum. The aluminum sheet used to construct the end cap and flange of the chamber is 12.70 mm (0.5 in.) in thickness, while the side wall is 1.58 mm (1/16 in.) thick.

In order to prevent leakage, a polymeric gasket of Nitride™ rubber is placed at both faces of the acrylic ring holding the specimen, and then it is secured between the chamber flanges with 16 equally spaced bolts.

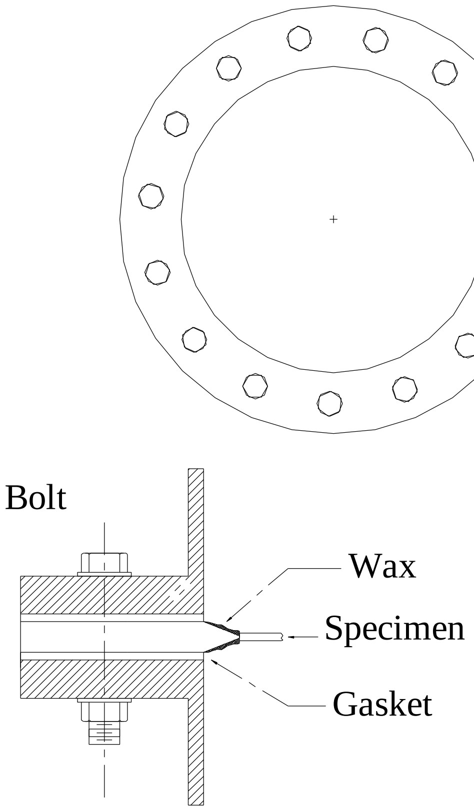

Figure 2.3 Environmental chamber assembly.

2.2.3 Chamber Air Circulation

A critical part of the correct operation of this apparatus is to maintain uniform and constant temperature and relative humidity conditions within the chambers. An induced air mixing arrangement is used to accomplish this objective. Another objective of the forced airflow is to minimize the moisture transfer resistance associated with a stagnant or low velocity convective coefficient at the surface of the specimen. The mixing in the chambers is generated by airflow through a small aperture at the end of a copper tube. Each chamber has two of these tubes placed directly opposite to each other. Figure 2.4 is an illustration of the copper tubes and the chamber. The spiraling flow generated by these tubes enhances the uniformity within the chambers and minimizes the surface resistance.

A metal-bellows type pump (Parker Metal Bellows MB-602) is used to circulate air in the environmental systems. This pump was selected due to its minimum leakage characteristic. Its dual head design allows air to be pumped to the chambers independently, therefore only one pump is needed for the entire system

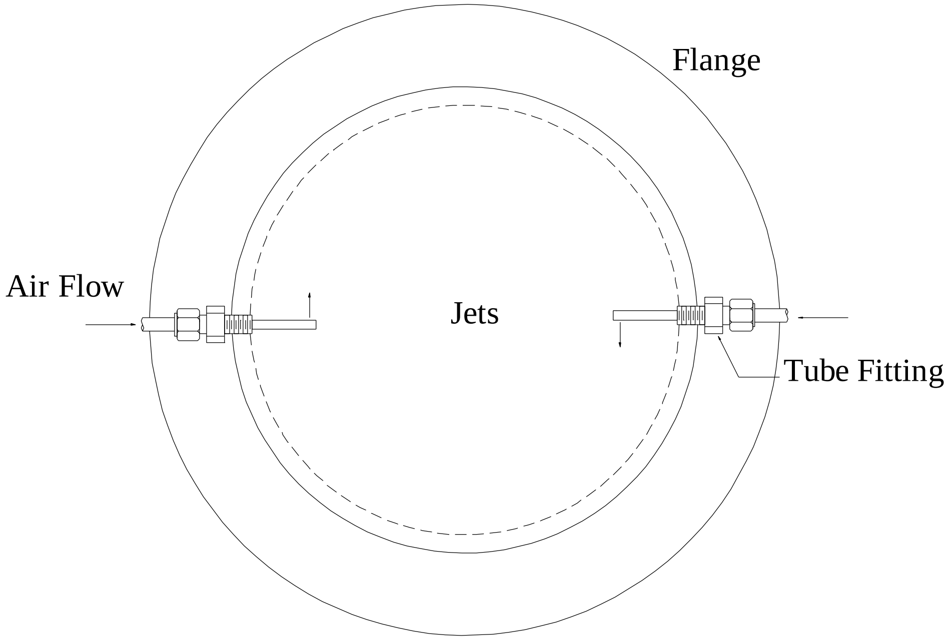

Figure 2.4 Environmental chamber conditioning and air circulation.

2.2.4 Instrumentation

The experiments required accurate measurement of temperature, relative humidity, and pressure. Temperature and relative humidity within each chamber are recorded during the run of the experiment to guarantee steady conditions. The data acquisition system used is a Hewlett Packard model 3582A data acquisition and control unit. This unit reads analog voltages from different instruments including a type *T* thermocouple to measure temperature. A control function of this unit is to open and close the solenoid valves by using a general-purpose switchboard within it. The data acquisition unit is controlled by a program written in GW-BASIC™ and run on an IBM compatible personal computer.

The relative humidity, temperature and static pressure of the apparatus are controlled by separate and independent control systems. Detail descriptions of these control systems are given in the following sections.

2.3 CONTROL SYSTEMS

2.3.1 Temperature Control

One of the objectives of this apparatus is to maintain a temperature difference across the test specimen. This difference is accomplished by controlling the temperature within each chamber separately, but in the same manner. This control system is shown in Fig. 2.5.

Temperature control is accomplished by a heat exchanger and a resistance heater. The first of these parts cools the recirculatory flow by using a concentric counterflow heat exchanger. This heat exchanger consists of two concentric tubes through which the fluids flow. The warmer airflow passes through the annular space, while the cooling liquid, a mixture of ethylene glycol and water, flows through the inner tube. The coolant fluid is pumped from a constant-temperature reservoir. The inner tube of this heat exchanger is made of copper. Its outer surface has been specially modified to enhance the heat exchange capabilities. This process maintains the temperature of the airflow approximately 5 °C lower than the desired chamber temperature. Once this temperature level has been accomplished, an electrical resistance heater, powered by a Eurotherm™ control system, heats the airflow. The temperature is controlled by a Eurotherm™ model 810 PID analogue temperature controller. This unit monitors the temperature constantly by means of a type *T* thermocouple and compares it to the set point temperature.

Appropriate adjustments are made through the electric resistance heater. This control system reads a type *T* thermocouple inside the chamber, compares it to the set point, and regulates the power into the heater from its readings.

In order to minimize the heat exchange between the chambers and the ambient, the chambers are covered by foam insulation one-inch thick with an approximate thermal resistance value of 0.096 W/m-K (0.0166 Btu/h-ft-°F). An ethylene glycol-water mixture flowing through 6.35 mm (0.25 inches) OD, aluminum tubing wrapped around the chambers also decreases the effect of the ambient and helps maintain a constant temperature within the chambers.

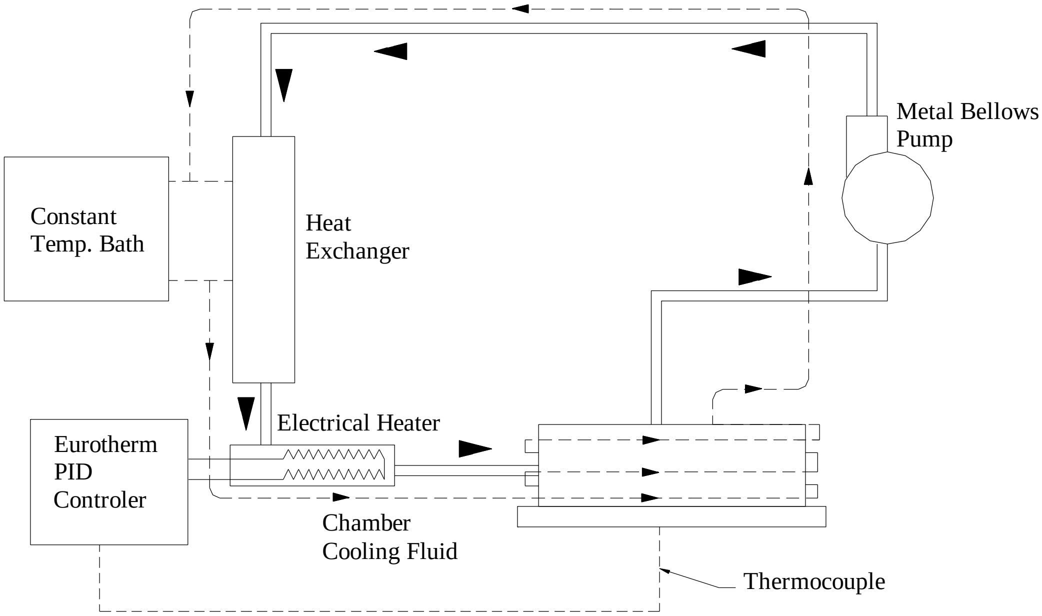

Figure 2.5 Temperature control schematic.

2.3.2 Relative Humidity Control

The relative humidity control systems for the separate chambers are identical. The schematic of one of these controls systems is shown in Fig. 2.6. Relative humidity and temperature are measured in each chamber by a Vaisala model HMP230 sensor. The Vaisala instrument is capable of measuring with an accuracy of ±1% for relative humidity over the tested range, and ±0.2 °C for temperature.

A computer program controls the amount of moisture added to or removed from the airflow based upon the desired and the actual conditions within the chambers. The computer determines the relative humidity by using the RH and temperature sensor. These values are then analyzed to determine how much to open or close the valves to the conditioning tubes. These valves are operated directly by stepper motors. If the value read by the computer is lower than the set point, then the control program will incrementally open the valve to the bubble tube, hence increasing the relative humidity. On the other hand, the program will incrementally open the valve to the desiccant tube to decrease the relative humidity. In order to avoid premature saturation of the desiccant material, however the program only allows flow through one conditioning tube at a time. A solenoid valve prevents the back flow of moisture to the desiccant when it is not in use.

The flow through the entire system is separated into two stream paths. The largest of these streams flows through the temperature control system, while the remainder goes to the relative humidity control loop.

Automated Relative Humidity Control

In order to maintain a steady relative humidity within each chamber, an automated digital feedback control system is used. This control system is composed of a computer and a data acquisition unit. The computer records the signals emitted by the RH sensor inside the chambers by using the data acquisition unit. Based upon the readings taken by the acquisition unit, the computer algorithm then regulates the stepper motors and the solenoid valves to maintain the desired level. The logic protocol followed by the computer program is depicted in Fig. 2.7.

The relative humidity measured is compared each time to the set value. Depending upon this result, the computer will adjust the corresponding valve to compensate and eventually reach the set point. The adjustment of the valves is controlled by program named CONTROL, written in GW-BASIC™. This program utilizes proportional, integral, and derivative control. The gains for these controls were determined by Moiser (1994) to be 18 steps/volt, 15, and 15 respectively, where 400 steps rotate the valve one turn (360°). The calculation for the step size for a valve adjustment is as follows:

$$N = K_p\left[E_1 + E\left(K_i - 1\right) + K_d\left(E_1 - E\right)\right] + 0.5 \tag{2.1}$$

where E_1 is the previous difference between the measured RH and the desired value, E is the actual error, and K_p, K_i, K_d are the corresponding gains.

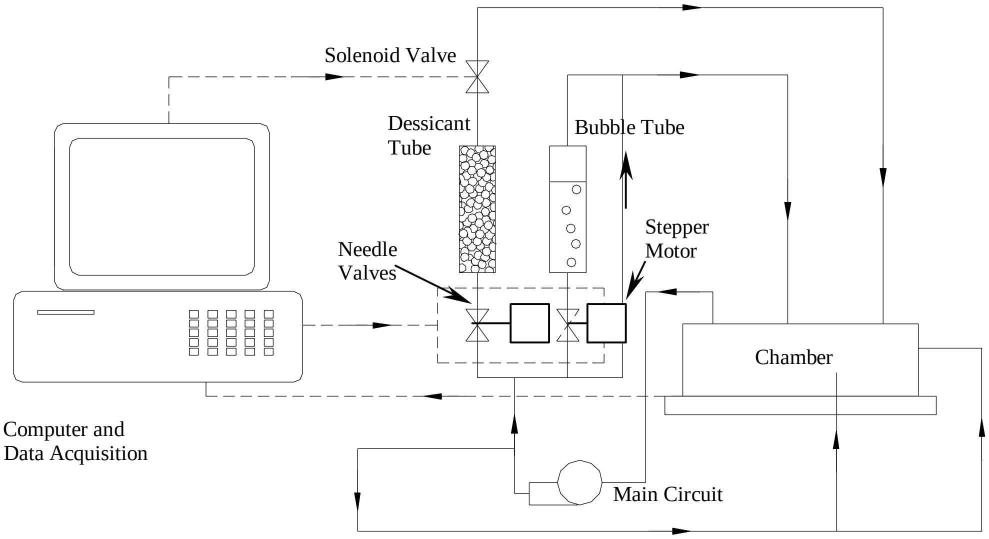

Figure 2.6 Relative humidity control system schematic.

Conditioning Tubes

The task of the conditioning tubes is to add or remove the necessary moisture from the airflow to maintain the desired relative humidity. The tubes are made from acrylic, 254 mm (10 inches) long, 31.7 mm (1.25 inches) outside diameter, and 25.4 mm (1.0 inches) inside diameter. The total weight of each filled tube is to be kept under the maximum capacity of 400 g for the Mettler™ balance.

Each chamber has assigned a set of conditioning tubes, desiccant and bubble. The bubble tubes are filled with distilled water, and are fitted with 1.58 mm (1/16 in.) tubing to supply air directly into the water. The desiccant tube uses a drying agent known as synthetic silico aluminate zeolite (Davidson Chemical Molecular Sieve). This agent consists of a mixture of moisture-absorbing and indicator beads. The indicator beads facilitate the visual detection of the moisture level of the desiccant agent.

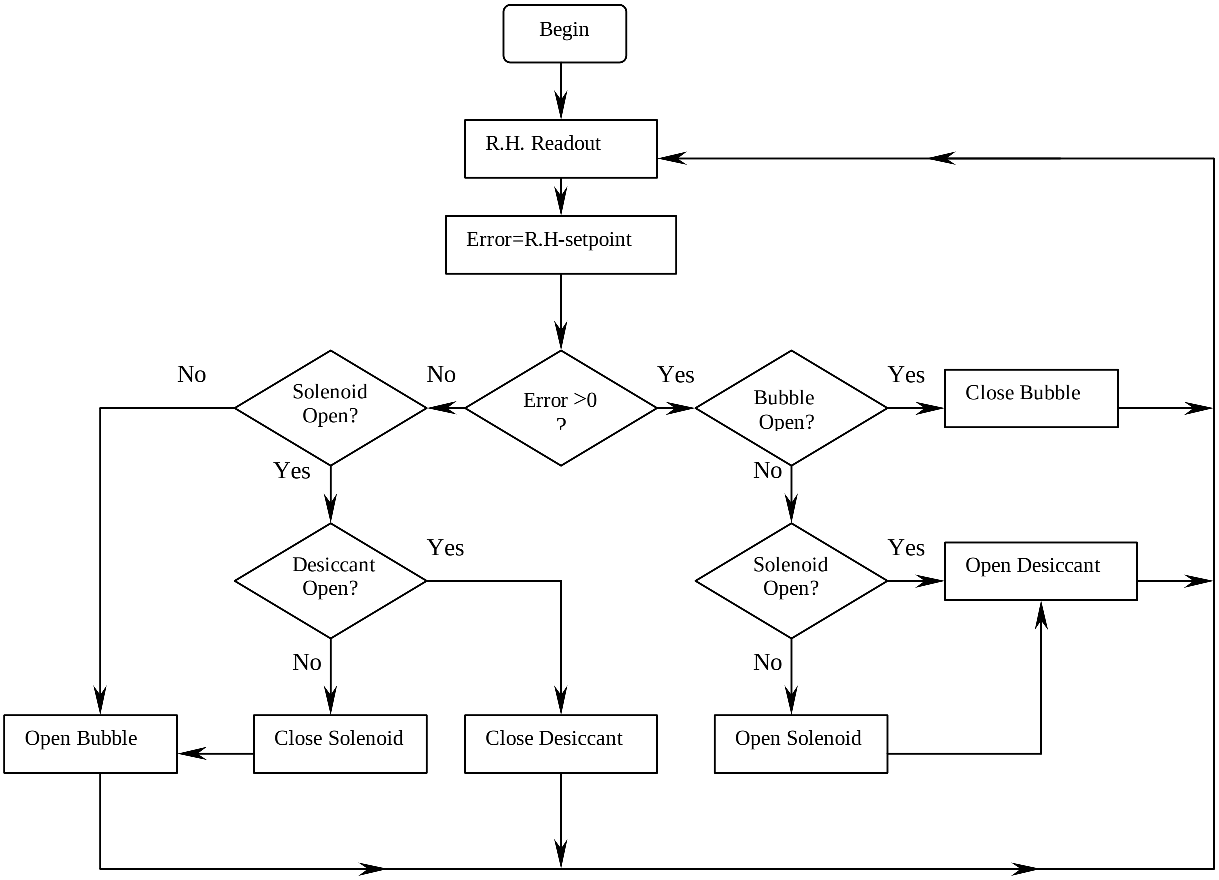

Figure 2.7 Automated relative humidity control logic diagram.

2.3.3 Pressure Control

It is important to maintain both sides of the specimen at the same static pressure. Otherwise, a static pressure difference across the specimen would induce an additional mechanism for moisture transfer. In order to minimize this source of error, a rubber bladder was connected to each chamber to minimize the static pressure difference between the chambers. This task was accomplished by the capacity of the rubber bladders to expand or contract, hence maintaining constant pressure. The bladders are intended to ensure that diffusion is the only moisture transfer mechanism present. The pressure difference between the chambers was measured initially by a Magnehelic™ pressure gauge, and later by a micro-manometer. The micro manometer used is a Datametrics type 590 vacuum/pressure transducer, which operates in conjunction with a Newport 2003B digital panel voltmeter. The nominal sensitivity of the latter transducer is 0.0001 inches of water gage (iwg).

A mercury manometer, attached to the top chamber, is used to ensure that the chambers pressure is essentially that of the surrounding atmosphere.

2.4 INITIAL TESTING AND CALIBRATION

As indicated earlier, the procedure for calculating the moisture transfer through the specimen depends on the measurement of the water mass change between the chambers. In order to obtain a reliable set of measurements, the chambers as well as the rest of the apparatus must not have any direct contact (leaks) with the surroundings. Otherwise, moisture could be added or removed from the system due to its interaction with the outside environment. This situation would cause an error on the mass change measured and the calculated moisture transfer rate.

A good portion of preparation time is spent on the detection, elimination, and prevention of leaks. Leak tests are conducted before every experimental series, and immediately after replacing any connections or parts on the system.

The first step in the leak testing procedure is to pressurize the entire system to approximately one psig and observe for possible leaks. A pressure drop indicated by the gage implies a possible leak. In this case, the system would be again pressurized to one psig and soap bubbles would be used on every fitting of the apparatus in an attempt to locate the source of the leak.

If the leakage problem cannot be solved with soap bubbles, a second step is taken. The second step involves injecting Freon-22 into the system and using an electronic leak detector. Although both of these methods are long and tedious, it is essential to maintain the system leak-free in order to obtain acceptable results. The apparatus is deemed acceptable for operation once a maximum pressure drop of 0.05 psig per day is reached. For a chamber at 22°C and 90 per cent relative humidity, a change in mass of vapor of approximately 0.023 g/wk, is attributed to a pressure drop of 0.05 psig per day.

2.5 MEASUREMENTS

All the measurements needed for determining the moisture transfer are taken at steady state. At steady state, the amount of moisture loss from one chamber, should equal the amount of moisture gained by the other one. The system is considered to be at steady state when the change of mass in the conditioning tubes for both chambers is within 15 per cent difference. The measurement method consists of weighing all four conditioning tubes periodically over a specific period of time.

The weight of the conditioning tubes is accurately measured using a Mettler™ scale; the typical time lapse between readings is 24 hours. The conditioning tubes can be disconnected promptly from the system with self-sealing quick-release fittings which minimize any leakage during the weighing process. The time required to weigh the tubes is kept under 20 seconds per tube, and therefore, does not perturb the system significantly.

2.6 DATA VALIDATION

The data collected during each measurement consists of the mass change of the conditioning tubes, the date, time, relative humidity, temperature, and pressure differences. This information is essential in the calculation of the corresponding moisture transfer rate. The moisture transfer rate in units of kg/m^{2}s is given by

$$\dot{n}'' = \frac{\Delta m}{A_s \Delta t} \tag{2.2}$$

Where Δm is the change of mass in the conditioning tubes in a chamber, A_s is the specimen surface area (0.146 m^2) and Δt is the time interval in seconds. Under ideal conditions at steady state, the moisture transfer rate would be the same for both chambers but in opposite directions.

2.7 DISCUSSION

Overall, the moisture transfer rate of the specimen can be measured with a minimum of effort, once the system is leak-free. Both the temperature and the relative humidity can be maintained with only a small deviation from the set points for weeks. The new ASHRAE FDC method yields results more rapidly than the ASTM method cup, although an adequate set of data for the OSB specimen may require between 2 to 3 weeks to obtain even with the former.