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Technical Report

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ASSESSMENT OF
TEST CELL
HUMIDITY MEASUREMENT
AND
CONTROL

by

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ABSTRACT

The accuracy of measurement and degree of control of humidity during light duty emissions and fuel economy tests have become matters of increasing concern. Specific humidity values are used in the calculation of NOx test results. It is also possible that in some vehicles humidity may have an effect on the fuel economy test.

Comparison tests were made with the dew point method and the presently used wet bulb psychrometer. It was found that the wet bulb method can produce significant errors primarily due to factors in the wet bulb temperature measurement. The dew point hygrometer proved to be accurate, reliable, and easy to calibrate. It is the preferred method to measure humidity in the vehicle test cells.

A series of humidity measurement location comparison tests were made at three locations in Room 515. With proper seals maintained around the overhead doors, the center of the room proved to be a suitable location to measure humidity.

Tests were made on the room's air handling system. A few improvements are suggested on the humidity control.

I. INTRODUCTION

This paper is part of a continuum to earlier investigations on this subject. It relates to and answers questions that were raised on the earlier work. It not only supplements some of the earlier data but also provides some additional information in a more accurate manner under actual test conditions.

II. BACKGROUND

In late 1979, automotive manufacturers claimed that the EPA laboratory's procedural, equipment, and environmental changes since 1975 had a detrimental effect on fuel economy measurements. One of these changes involved humidity levels. In 1975, specific humidity levels in our test cells averaged about 50 grains of water per pound of air. In 1977 these levels were raised to 75 grains to control the NOx correction factor closer to 1.0. Although the manufacturer claims were not conclusively proved, the Administrator ruled that we would lower our humidity levels back to the 1975 conditions, (50 grains). These claims also indicated there were areas in our measurement procedures and equipment that needed further investigation. Therefore, we designed a test plan that would provide us more information on humidity measurement and control.

This investigation was completed and a report written on April 17, 1980. The report included the comparisons of readings of humidity measured with three wet bulb-dry bulb units, one in front of each dynamometer and one in the center of the room. These tests showed the following characteristics and observations:

A. A definite trend of lower humidity was seen at Dyno 1 at the 75 grain level in the range of a 19 grain average. At the 50 grain level the average was 9 grains lower.

B. Humidity levels always increased during highway fuel economy tests.

C. Stability of room temperature and humidity improved at the 50 grain level.

D. Wick contamination and angle of air flow across the wick can cause a 2-3 degree F error on wet bulb units. An additional error of 1 degree or more can be realized from thermocouple error (J thermocouple).

E. Humidity control for the air handler became a source of suspicion when: a) outdoor conditions change, controls would have to be re-adjusted; b) humidity would increase during high heat load, such as the HWFET tests.

F. A 1.0°F change in wet bulb measurement can result in approximately a 2% change in the NOx correction factor.

G. A number of other laboratories are using the more accurate dew point meter to measure humidity.

III. TEST PLAN

After the first report was completed, it was determined that we needed to investigate humidity further in our test cells. Surveys were made with instrument manufacturer and automotive manufacturers to gather information on available instruments. The General Eastern Model 1200 APS Dew Point Meter was selected because of the experienced usage available, its claimed reliability, accuracy and delivery schedule. Three instruments were purchased and set up on the bench. A test plan was designed to include check out and evaluation of the instruments, tests to identify and characterize any differences in measurement between the wet bulb psychrometer and the dew point meters, tests to find best cell location for humidity measurement, further characterization of the room air handling control and the development of an interactive LCS computer programs that will calculate humidity from inputs of barometer, dry bulb, wet bulb and/or dew point temperatures.

Evaluation, calibration procedure, and check out of the General Eastern dew point meters was done in a series of steps. Information on calibration, maintenance and reliability was collected from General Motors and General Eastern Corp. Bench checking was done by using ambient and ice bottle temperatures to check calibration as described in the instruction manual. An operational check was devised by blending various levels of humidity in air in a sample bag and passing it through the instrument. Comparisons were made to other instruments in the lab and to a certified thermometer accurate to ± 0.2°F.

Tests were made to determine the difference in measurements between the wet bulb and the dew point method. Sixteen point to point comparisons were run. Since the dew point meter showed a definite trend in the negative direction a set of controlled parameters tests was designed and run. This was an experimental test set-up, devised and installed in a small room with a closely controlled (humidity and temperature) environment. The set-up used three GE dew point units measuring in series, one Sargent-Welch wet bulb-dry bulb aspirated psychrometer, a calibrated mercury thermometer, clean wicks, temperature controlled distilled water, a heated wire anemometer, a variable speed blower, and a Honeywell temperature recorder. Comparisons were made with the wet bulb to the calibrated thermometer with and without the wet sock, with the same velocity of air and with the higher recommended velocity, with ambient temperature for wick moisture and with water cooled to 60°F or just above the wet bulb reading. (Results are shown in Appendix D and D1).

Tests were made to find the best measurement location and to characterize the room control system by installing three General Eastern Model 1200 APS dew point meters in Room 515, one sensor in front of the cooling fan for Dyno 1, one in front of Dyno 2, and one in the center of the room. Also a Sargent-Welch (wet bulb) unit measured humidity in the center of the room. Eleven certification FTP's were measured along with six Highway Fuel Economy Tests (HWFET).

Additional room control characterization was done by making a series of various humidity settings in Room 515 on a day when no vehicle tests were scheduled. This was done to determine response of change and stability. A probe connected to the dew point sensor was traversed across the vertical inlet duct and across all room air inlets to determine humidity mix in the air. Also, heated air from a heat gun was blown on the room's humidity sensor to determine if any effect on room humidity.

An interactive humidity calculation was developed and implemented on LCS that will provide specific and relative humidity, partial vapor pressure and NOx correction factor by inputting, wet bulb, dry bulb and/or dew point temperatures. This makes information immediately available for experimental tests.

IV. SUMMARY OF RESULTS

The results of the major objectives of the test plan can be summarized as follows:

A. The initial bench checks and calibration procedures of all three dew point meters show that they measure temperature at ice point and ambient to an accuracy of $\pm$ 0.5°F and that they correlate to each other to less than 0.5°F difference.

B. Four methods were found to be acceptable to check calibration of the General Eastern unit. They are the ambient temperature check, the ice point method, the blended sample bag method and by maintaining an NBS traceable unit in the calibration department.

C. Differences in the wet bulb psychrometer and the dew point meter ranged as high as 15 grains but averaged 5.6 grains with the dew point meter normally lower (See Appendix C and D). The dew point meter method is considerably more accurate. Error in measurement of wet bulb-dry bulb can be attributed to thermocouple error, contamination of wick, angle and velocity of air flow across wick, and temperature of water.

D. As long as there are no outside leaks to the room, humidity levels at the vehicle cooling fans and at the center of room locations prove to be within 1°F dew point (See Appendix B). Specific humidity levels continued to rise during HWFET's.

E. The facility humidity control system appeared to have a deadband that is extremely wide. This results in no response to routine external humidity changes. It was found that for any given humidity setting, the system sensor controls on a relative humidity rather a specific humidity. This causes specific humidity to rise during the high heat load condition of the Highway Fuel Economy Tests (HWFET).

F. There is no evidence of humidity stratification in the inlet ducts.

V. DISCUSSION

The EOD study on humidity in the Light Duty test cells on which a report was written in April 1980 led to the determination to purchase three General Eastern Model 1200 APS dew point meters for in-house evaluation.

These units use the basic principle of dew condensation at a temperature relative to the specific amount of humidity per pound of air. They use a platinum RTD thermometer accurate to ±0.2°C (See Appendix A) to measure surface temperature of a mirror on which the dew collects. The mirror is thermoelectrically cooled. Cooling is controlled by a photodetector which senses amount of light reflectance from the mirror. A light emitting diode provides the source of light that is directed on the mirror. The units also have a self cleaning mirror feature which works automatically or manually.

These units were extensively bench checked upon receipt by connecting the sensors in series, removing the cooler fuses, and comparing ambient temperature readings to a certified mercury thermometer. Units were also checked at the ice point by flowing air through a coil in a bottle of ice and through the sensors. Response to humidity changes and stability was also checked. Units were run at three operational levels of 90, 75, and 50 grains of water as measured from a blended sample bag. This method was developed in-house by calculating volume and weight of different blends, injecting measured amounts of water into a blended time measured bag of air. After a blending time period, sample was drawn through the DP meter sensors and dew point temperature measured. This value was then used to calculate specific humidity (grains of H_2) per pound of air). Even though this procedure needs further refinements, all tests were within acceptable tolerances of advertised specifications.

After initial check out of the units comparison tests were made with the presently used wet bulb psychrometers. Differences in measurement were seen as much as 15 grains with the dew point measuring the lower. Under closely controlled point to point readings, the psychrometer read 4-5 grains higher than the dewpoint. After extensive comparisons confirmed this fact an investigation was initiated to determine the cause of these differences. This was done by a controlled parameters test as described in the test plan and results tabulated in Appendix D.

The difference is mostly attributed to wick water temperature (should be just slightly above wet bulb temperautre ref. NBS Circ. #512) and air velocity across the wick (should be a minimum of 900 feet per minute, ref. NBS Cinr. #512 and Humidity Measurements, Instrument Technology). Wick contamination and angle of air flow contribute in lesser degrees.

Once differences between our standard measurement devices (Sargent-Welch) and the new dew point meters had been resolved, a series of eleven FTP's and six HWFET comparison tests on Dynos 1 and 2 were run to determine a suitable location to measure humidity and to observe room humidity control capabilities. The tests were performed during actual certification tests. Humidity levels in the cell were reasonably stable during the FTP comparisons. However, after a portion of the tests had been run, the humidity traces for Dyno 1 became erratic and showed lower readings than Dyno 2 and the center of the room. Finally it became unacceptable and the problem was investigated. It was finally traced to a damaged overhead door and a torn rubber seal. The seal was repaired.

However, air current leaks then became apparent at the Dyno 2 door but of a less magnitude. Even though both doors appeared to have been damaged and are not 100% sealed the leakages are now only causing transients of less than 1°F dew point at the front of the fan and was not considered to be a problem. (The test results during the door leaking problems were not tabulated nor included in this report since that was an abnormal condition). During this investigation, a profile of humidity mixture of inlet air was sampled traversing a probe across the inlet ducts to check for possible stratification. None was found. The leaking door problem could possibly explain the differences that were seen on Dyno 1 as documented in the April 1980 report. Results of all tests (FTP + HWFET) showed close correlation (less than 1°F dew point difference) from each dyno to the center of the room (See Appendix B). Due to the fact that on the HWFET comparisons, humidity traces from the three locations tracked on top of each other and that on some tests (high heat load) overall specific humidity increased as much as 10-15 grains. Hence, a table of estimated average values for these tests would be meaningless and was not included.

To further investigate this occurrence, a stream of heated air from a heat gun was directed at the room humidity sensor. Within a few seconds steam was being injected into the room at a very high rate indicating humidity control relative to room temperature. Further investigation into building engineerng drawings confirmed this to be true. Room humidity controls sense <u>relative</u> humidity explaining why specific humidity rises during high heat load tests. Further review of past work done on room air handling systems revealed a memo written in October 1975 by Doug Berg based on a study by Bene Engineering attesting to this fact. It also agrees with this writer's recommendation that we should study our system to determine if we could modify our humidity sensing and control system to control on specific humidity levels rather relative. NOx factor is calculated from a specific humidity value. Furthermore if a vehicle's carburetion system is calibrated such that it would be sensitive to humidity levels, then it is specific humidity values with which we are concerned, not relative (See Conclusions/Recommendations).

VI. CONCLUSIONS/RECOMMENDATIONS

A. The General Eastern Model 1200 APS dew point meter is a more accurate and reliable instrument for measuring humidity than our presently used wet bulb psychrometers. It is recommended that the three units be installed, one in each Light Duty test cell mounted on the equipment rack with outputs connected an analog (0-10 VDC) recorder and the LCS Computer. It would be necessary to modify the computer program to accept dew point input. Dew point temperature could then be monitored and integrated over the period of the test and then calculated directly to specific humidity and NOx factor. The L&N thermocouple should also be input to the recorder and the LCS for measurement of ambient temperature.

B. Differences in measurement of the dew point meter and the wet bulb units are the result of errors in the wet bulb units. These differences are caused by lower air velocity than recommended across the wick, using ambient temperature water for wick moisture (should be just above wet bulb temp), and wick contamination. The high degree of maintenance attention required causes a potential error situation. It is recommended the wet bulb units be phased out of service completely. If the method of measuring and setting humidity is changed to dew point it could be expected the actual test cell humidity would average 4-5 grains higher than is currently seen from the wet bulb control and measurement.

C. Air leakage from the soak area through the the overhead door seal can cause humidity stratification at the front of the vehicle. It is recommended that an additional sensor and sampling kit be purchased for a routine measurement with the sensor mounted on the cooling fan as part of the Repca diagnostics. This will minimize the possibility of any long term problem existing undetected.

D. Relative humidity is the value reported on emissions test results. Test cell humidity is controlled as relative to ambient temperature. Given specific humidity (grains of water per pound of air) is an engineering unit value used to calculate NOx factor. It should be the value reported. Also, since some test vehicles carburetion may be more sensitive to specific humidity, it is recommended a study be initiated to determine the feasibility of changing the air handling systems in the test cell to control on specific humidity levels. This would prevent the system from adding moisture where the internal heat load is high, such as the fuel economy tests. This recommendation agrees with the Bene Engineering study report and Doug Berg memo of October 1975. Also it should be investigated to determine if after changing the control to specific humidity that the deadband width settings could be adjusted to be more realistic and applicable.

E. The use of the General Eastern dew point meter method for measuring humidity can provide reliable and accurate data if certain procedures of calibration checks and preventive maintenance are followed. It is recommended the following procedures be used.

1. Mirrors in the sensors should be cleaned as prescribed in the instruction manual once a month.

2. The thermometer should be checked every 90 days by removing the cooler fuse to allow ambient air temperature to be compared to a certified mercury thermometer accurate to ±0.2°F.

3. Condensation and operation checks should be made at different levels (90, 75 and 50 grains, . . .) by using the blended bag method developed in-house. This procedure needs to be documented.

4. Two more units should be purchased for accuracy traceability and maintenance back up. One unit should be sent to NBS for certification and maintained in the Electronics Shop as a standard. The other unit would be used as a spare or for additional studies.

VII. APPENDICES

A. General Eastern Model 1200 APS Dew Point Hygrometer Information

B. Humidity Measurement Location Comparisons

C. Wet Bulb-Dry Bulb vs. Dew Point Meter Humidity Measurement Comparisons

D. Controlled Parameters Test WB-DB vs. Dew Point Method

D1 Wick H_2O Temp and Air Velocity Effect on WB vs DP Method

E. Room 515 Humidity Sensor and Control

F. Dew Point/Wet Bulb Temp vs. Specific Humidity

VIII. REFERENCES

1. Reports and Critique on In-house Air Handling Systems. April - Ocotber 1975, Bene Engineering and Doug Berg.

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13. EPA Paper, A Procedure for Calculating Humidity, Eric Zellin, July 1975.

14. Discussion of Paragraph 85.1320-1 of Proposed Rule Making, Eric Zellin, June 1975.

15. EPA Paper, Test Cell Humidity Investigation Report, Sherman D. Funk, April 17, 1980.

16. Technical Literature on Humidity Measurements, General Eastern Corp., John Harding and P.R. Widerhold, June 1978 and June 1979.

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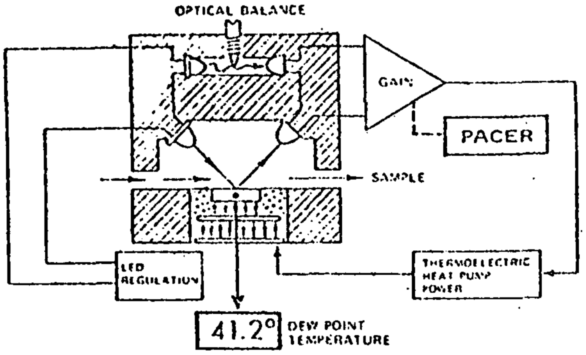
SECTION II
PRINCIPLE OF OPERATION

2.0 PRINCIPLE OF OPERATION

The Series 1200 Dew Point Hygrometers are thermoelectrically-cooled, optically-detected, automatically-controlled, condensation (or "dew point") hygrometers. The principle of operation may be seen from the accompanying figure.



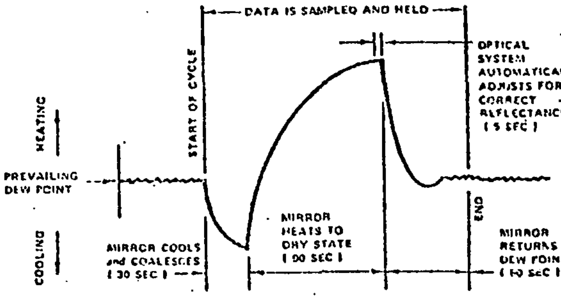
The condensate detection mirror is illuminated with a high intensity, solid state, light-emitting-diode (LED). A photodetector is configured so as to monitor the specular (direct) component of the light from the mirror. A separate LED and photodetector combination are used to compensate for any thermally-induced changes in the optical components. The photodetectors are arranged in an electrical bridge circuit such that the specular detector is fully illuminated when the mirror is clear of dew, and sees reduced light as dew forms on the mirror, due to scattering losses.

An optical offset is designed into the bridge, such that a large bridge output current is developed whenever the mirror is in the "dry" condition. The bridge output is amplified and used to control the direct current to the thermoelectric cooler, causing the mirror to cool toward the dew point. As dew begins to form on the mirror, the optical bridge is driven toward its balance point, causing a reduction in the specular light, causing the bridge output to decrease, and the cooling current to reduce. A rate feedback loop within the amplifier is employed to insure critical response, and the system quickly stabilizes at a condition wherein a thin dew or frost layer is maintained on the mirror surface, i.e., the dew, or frost, point. A precision thermometer element is embedded within the mirror which monitors this dew point temperature directly.

The condensation hygrometer is a fundamental method for measuring water vapor, affording a degree of accuracy not available in other methods. Additionally, the repeatabilty of the instrument can be checked at any time by opening the control loop and allowing the mirror to heat and the dew to evaporate, and then reclosing the control loop. Long term accuracies in the order of ±0.1°C are common with the condensation hygrometer, making it suitable as a laboratory reference instrument.

AUTO-REFLECTANCE/PACER™ FEATURE*

The 1200 "S" Series instruments are equipped with General Eastern's Programmable Automatic Contaminant Error Reduction circuitry (PACER™) which permits the instrument to check its own performance and make any necessary optical adjustments on a periodic basis (once per 2, 6, 12, or 24 hours, or on command). This circuit automatically places the instrument into the "optical adjust" mode, then cools the mirror for 30 seconds causing soluble contaminants to dissolve into the excess water. This circuit then automatically causes the mirror to heat to a dry condition and, as the dew layer evaporates, any remaining soluble contaminants collect at isolated sites, leaving a mirror surface with substantial surface area available for undisturbed growth of condensate. When the mirror is heated to the dry condition the PACER™ circuit then automatically adjusts the offset current to its correct value, regardless of mirror contaminants. While this function is being performed, the output signal is held at a constant value, equal to the last dew/frost point value, allowing full compatibility with process control loop equipment. The autoreflectance circuit then returns the instrument to normal operation. Logic signals are provided at the rear of the instrument to identify "normal" and "autoreflectance adjust" conditions.



TYPICAL PACER™ CYCLE
(Times can be programmed by user)

NBS TRACEABILITY

The 1200 Series of General Eastern Corporation Instruments utilize a fundamental measuring technique. When provided with platinum resistance thermometer mirror temperature sensors with NBS traceable coefficients, 1200 Series instruments are suitable for metrological standards. *Certificates of traceability are provided with all 1200 series sensors incorporating platinum RTD mirror thermometers.*

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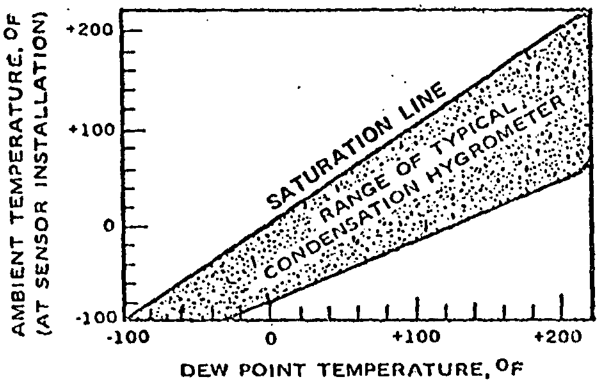
*Patents applied for.

2.1 SUMMARY OF SPECIFICATIONS

2.1.1 RANGE

The basic dew point range of the sensor is dictated by the heat pumping capacity of the thermoelectrically-cooled mirror, and is typically from +80F to -40F. That is, with the sensor installed in a typical environment of +80F, dew points can be measured from the saturation temperature (+80F), down to -40F. Below +32F, of course, the sensor actually measures the frost point temperature, since dew cannot exist below +32F on a continuous basis. If the ambient temperature of the sensor is lower than 80F, then the lowest measurable dew point is lowered. Conversely, if the sensor is installed at a higher-than-ambient temperature, the high end of the range is increased, and the lowest measurable dew point is raised. (See Range Graph)



Each sensor is equipped with an optional water cooling jacket which, when supplied with water at approximately 0.5 gpm, will permit a 0.67°F improvement in the lowest frost point attainable, for each 1°F reduction in temperature of the sensor provided by the coolant. For example, if 55°F cooling water is available, the sensor can measure frost points from +55F down to -56F.

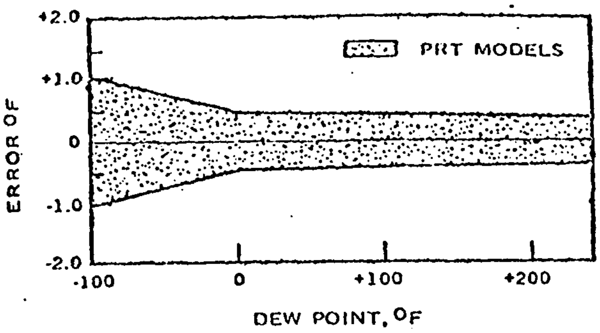
2.1.2 HIGH DEW POINTS

The sensor may be operated at dew points up to +212°F, as long as the sensor body is kept above the highest dew point anticipated to prevent condensation on the walls of the sensor. Usually, the gas (or oven, kiln, dryer, etc.) has sufficient heat capacity to raise the temperature of the sensor body, if properly located or if equipped with a simple insulative jacket.

2.1.3 ACCURACY

The accuracy of the Series 1200 dew point sensor is determined almost entirely by the accuracy of the condensation mirror temperature sensor.

The mirror is provided with a precision platinum resistance thermometer with NBS-traceable coefficients. The accuracy is typically, ±0.40°F, as shown in the graph.



2.1.4 DEW POINT SENSITIVITY

The fundamental sensitivity of all Series 1200 dew point sensors is ±0.05°F.

2.1.5 DEW POINT RESPONSE

The response of all Series 1200 dew point sensors is a function of the cooling and heating rate of the mirror (typically, 3°F/sec), the sample flow rate, and the absolute value of the actual dew or frost point being measured. At dew points above 32F, the response is almost entirely a function of the mirror cooling rate and gas flow rate. Below 32F, the response is slowed by the increasingly reduced availability of water vapor in the sample as the dew point is lowered, and by the outgassing characteristics of sampling lines. At −40F frost point, the response is several seconds. At −60F, several minutes are required for a 63% response to a change, and the lag is a function of the outgassing characteristics of the sampling lines, sample flow, or availability of water molecules and crystal growth rate.

2.1.6 AMBIENT TEMPERATURE LIMITS

The Series 1200 sensor will operate over the ambient temperature extremes of +212F to -75F. The electronic control module is suitable for operation between +120F to +32F.

2.1.7 CIRCUIT DESCRIPTION

The 1200 "S-Series" instruments all have essentially identical circuitry. The only fundamental difference between systems is the omission of the digital readout meter in those systems packaged in NEMA enclosures.

The System consists of several separate subsystems: (see Functional Block Diagram)

1. The mirror temperature dew point control loop is located on the 1201CAS printed circuit card. This circuit amplifies the signals from the phototransistor detectors in the sensor to a level suitable to drive the thermoelectric cooler power amplifier transistor. The final power transistor is mounted directly to the instrument chassis for heat sink purposes.

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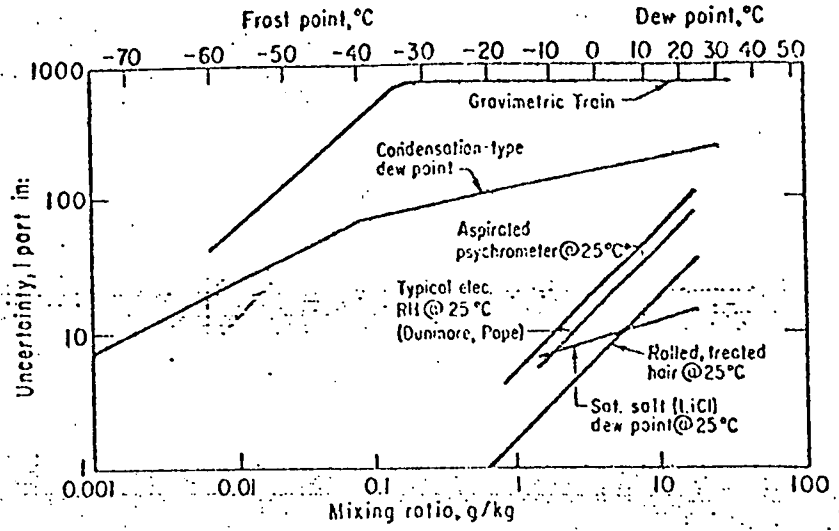


Figure 3. Uncertainties in typical humidity sensors, under laboratory conditions, are illustrated here. The gravimetric train, an extremely accurate sensor which weighs actual moisture content in known air volumes, is used by NBS to calibrate other sensors. In industrial installations, few devices attain the accuracies indicated.

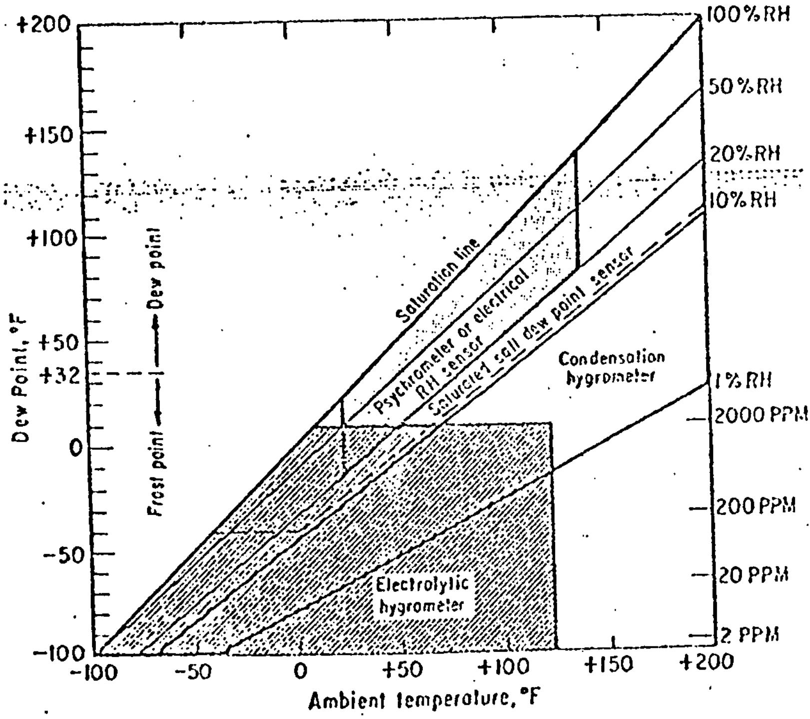


Figure 2. Useful operating ranges of various humidity sensors. Psychrometers, percent RH, and saturated salt dew point sensors operate in the mid-ranges of temperature and humidity. Condensation hygrometers are useful over a large temperature span and to humidities as low as one percent. Electrolytic hygrometers operate at low dew points over the entire range of humidity.

APPENDIX B
Humidity Measurement
Location Comparisons & WB

Date	FTP Test Pair Numbers	Barometer	Dew Point Temp.	Dew Point Spec. Hum	Wet Bulb Temp.	Dry Bulb Temp.	WB Spec. Hum	Hum Diff
10-9-80	80-6369		44°					
	6370	28.86	44°	44.0GR	59.5F	75.0F	54.4GR	-10.4
	CENTER		44°					
10-10-80	6863		44°					
	6864	28.86	44°	44.0	59.8	75.5	54.1	-10.1
	CENTER		44°					
10-15-80	6388		51°					
	6375	29.20	51°	56.8	59.0	72.0	54.6	2.2
	CENTER		51°					
10-16-80	6371		47°					
	6391	29.05	47°	49.1	59.2	76.0	49.2	-.1
	CENTER		47°					
10-17-80	6353		48°					
	6429	28.70	48°	51.6	59.3	75.5	51.4	.2
	CENTER		48°					
10-30-80	6586		44°					
	6621	29.25	44°	43.4	57.5	75.0	43.0	.1
	CENTER		44°					
10-31-80	6652		48°					
	6576	29.98	48°	49.4	59.5	76.0	48.1	1.3
	CENTER		48°					
11-20-80	6820		46°					
	6822	29.23	46°	46.9	59.5	76.5	49.3	-2.4
	CENTER		46°					
11-20-80	6816		47°					
	6823	29.13	47°	48.9	60.3	77.3	52.0	-3.1
	CENTER		47°					
11-21-80	6869		43°					
	6865	29.14	43°	41.9	58.5	77.0	44.3	-2.4
	CENTER		43°					
11-21-80	6825		45°					
	6833	29.18	45°	45.2	58.5	76.5	45.0	.2
	CENTER		45°					
							AVG.	-2.2

NOTE 1: WB-DB readings are results of operator eye averaging resulting in a less accurate comparison of WB-DB vs dew point meter than by point to point as referred to in the text report. Dew Point was most always lower.

2: 1st Number of Pair is D001 2nd Number of Pair is D002. CENTER is center of room.

APPENDIX C

Wet Bulb-Dry Bulb vs. Dew Point Meter Humidity Measurement Comparisons

TEST #	BAROMETER IN HG	WET BULB TEMP. °F	DRY BULB TEMP. °F	WET BULB SPEC. HUM.	DEW POINT TEMP. °F	DEW POINT SPEC. HUM.	DIFF. DP HUM -WB HUM.	DIFF NOx FACTOR
01	28.81	60.5	76.0	55.7	45.8	47.3	- 8.5 GR	-.0323
02	29.00	58.0	73.0	49.1	45.3	46.1	- 3.0	-.0113
03	29.00	58.0	72.5	49.9	44.9	45.4	- 4.5	-.0169
04	29.00	58.0	72.0	50.8	45.6	46.6	- 4.2	-.0155
05	29.06	58.5	76.0	46.1	44.5	44.6	- 1.5	-.0058
06	28.21	61.2	76.0	60.8	45.8	48.3	-12.5	-.0490
07	29.00	58.2	72.2	51.3	45.0	45.5	- 5.8	-.0215
08	29.00	58.0	74.5	46.6	43.9	43.6	- 3.0	-.0108
09	28.81	60.0	75.0	55.1	45.3	46.3	- 8.8	-.0332
10	29.18	57.4	74.0	44.4	42.6	41.2	- 3.2	-.0115
11	28.88	59.0	75.0	50.5	45.3	46.3	- 4.2	-.0157
12	29.15	61.0	76.0	57.1	45.3	45.8	-11.3	-.0439
13	29.10	58.9	76.0	47.8	43.6	43.0	- 4.8	-.0175
14	28.94	58.3	74.8	47.6	44.3	44.4	- 3.2	-.0115
15	29.05	63.0	76.0	66.8	48.0	51.0	-15.8	-.0643
16	29.20	60.5	76.7	53.5	46.9	48.6	- 4.9	-.0132
						Ave.	-6.1	Ave. -.0233

NOTE: [1] This table lists a portion of over 50 comparisons. Maximum and minimum differences are included. Most differences were 3-4 grains, dew point being lower.

[2] Comparisons were point to point with no vehicles being tested.

APPENDIX D
Controlled Parameters Test
WB-DB vs Dew Point Meter

Test #	Wet Bulb Thermometer	WB Wick Water Temp.	Air Vel. Across Wick	Bar In. HG	Dry Bulb Temp.° F	Wet Bulb Temp.° F	Wet Bulb Spec. Hum.	Dew point Temp.° F	Dew point Spec.Hum.	Diff Dp Hum. -WB Hum.
01	J THERMOCOUPLE	75.0	650.FPM	29.00	76.0	60.5	55.2 GR	46.9	49.2 GR	-8.3 GR
02	CERT MERC ±0.2F	75.0	650.FPM	29.00	72.2	58.4	52.2	44.9	45.4	-6.8
03	CERT MERC ±0.2F	75.0	850.FPM	29.00	75.0	58.4	47.5	44.9	45.4	-2.1
04	CERT MERC ±0.2F	75.0	950.FPM	29.00	75.0	58.2	46.7	45.0	45.6	-1.1
05	CERT MERC ±0.2F	65.0	950. FPM	29.00	75.3	58.0	45.3	44.7	45.0	-0.3
06	CERT MERC ±0.2F	60.0	950.FPM	29.00	75.6	58.0	44.8	44.6	44.8	0.0
07	J THERMOCOUPLE	60.0	950.FPM	29.00	74.8	58.0	46.1	44.3	44.3	-1.8
08	CERT MERC ±0.2F	75.0	750.FPM	29.00	75.5	58.2	45.8	43.9	43.6	-2.2
09	CERT MERC ±0.2F	60.0	750.FPM	29.00	74.5	58.0	46.6	43.9	43.6	-3.0
10	CERT MERC ±0.2F	65.0	700.FPM	29.00	73.00	58.0	49.1	44.3	44.3	-4.8

APPENDIX D1

WICK H_2O TEMP & AIR VELOCITY EFFECT
ON WB VS. DP METHOD

1-15-81

AIR VELOCITY
feet per min

WB ≃ 58°F		650	700	750	850	950
	60		-3.0(M)			0.0(M) -1.8(J)
WET BULB H_2O TEMP°F	65		-4.8(M)			-0.3(M)
	75	-6.8(M) -8.3(J)		-2.2(M)	-2.1(M)	1.1(M)

Decreasing Diff. ↑

Decreasing Diff. →

(M) = Certified mercury thermometer ±0.2°F

(J) = J thermocouple non-certified

DIFFERENCE IN GRAINS/# AIR

APPENDIX E

1-15-81

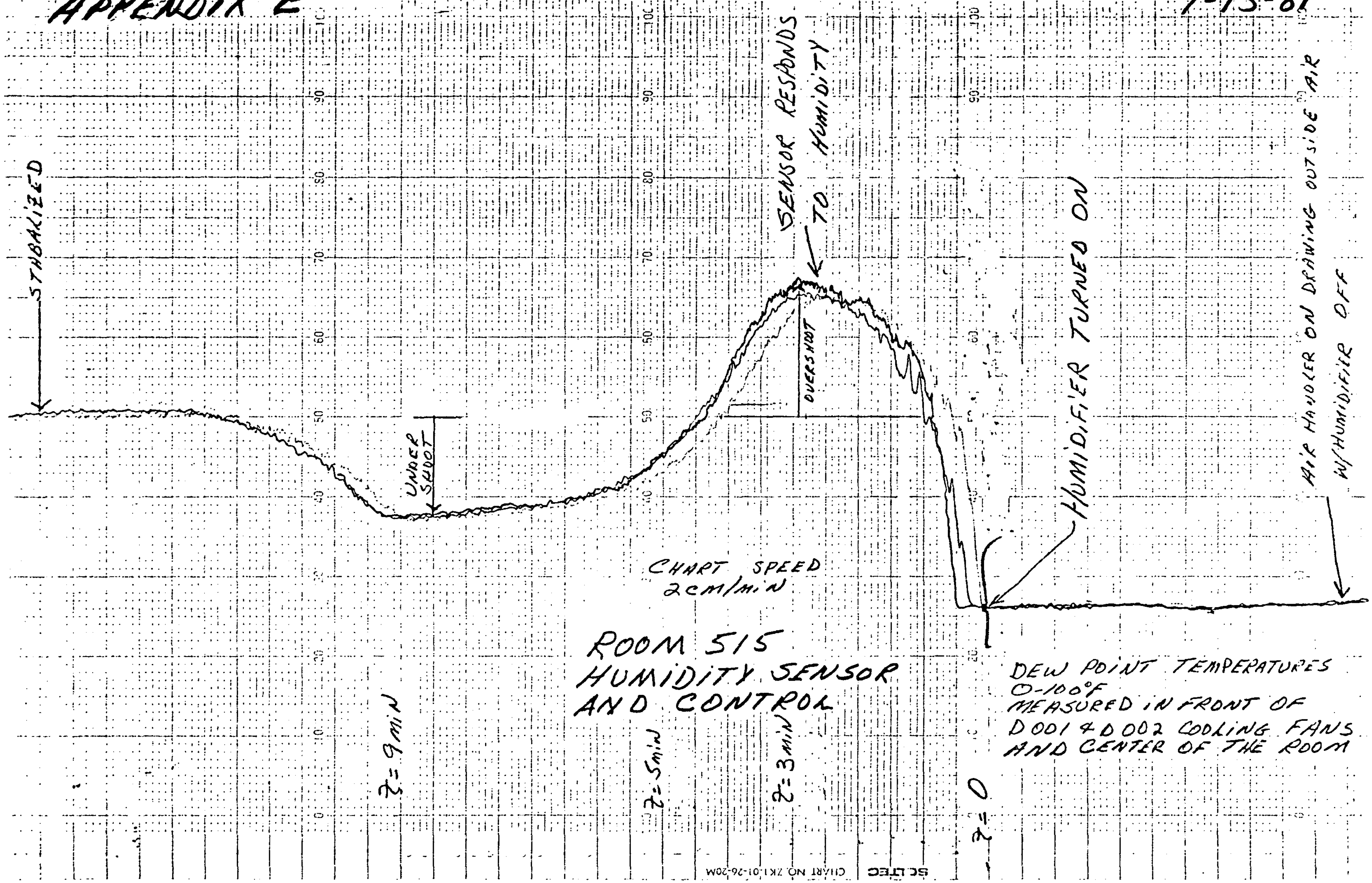
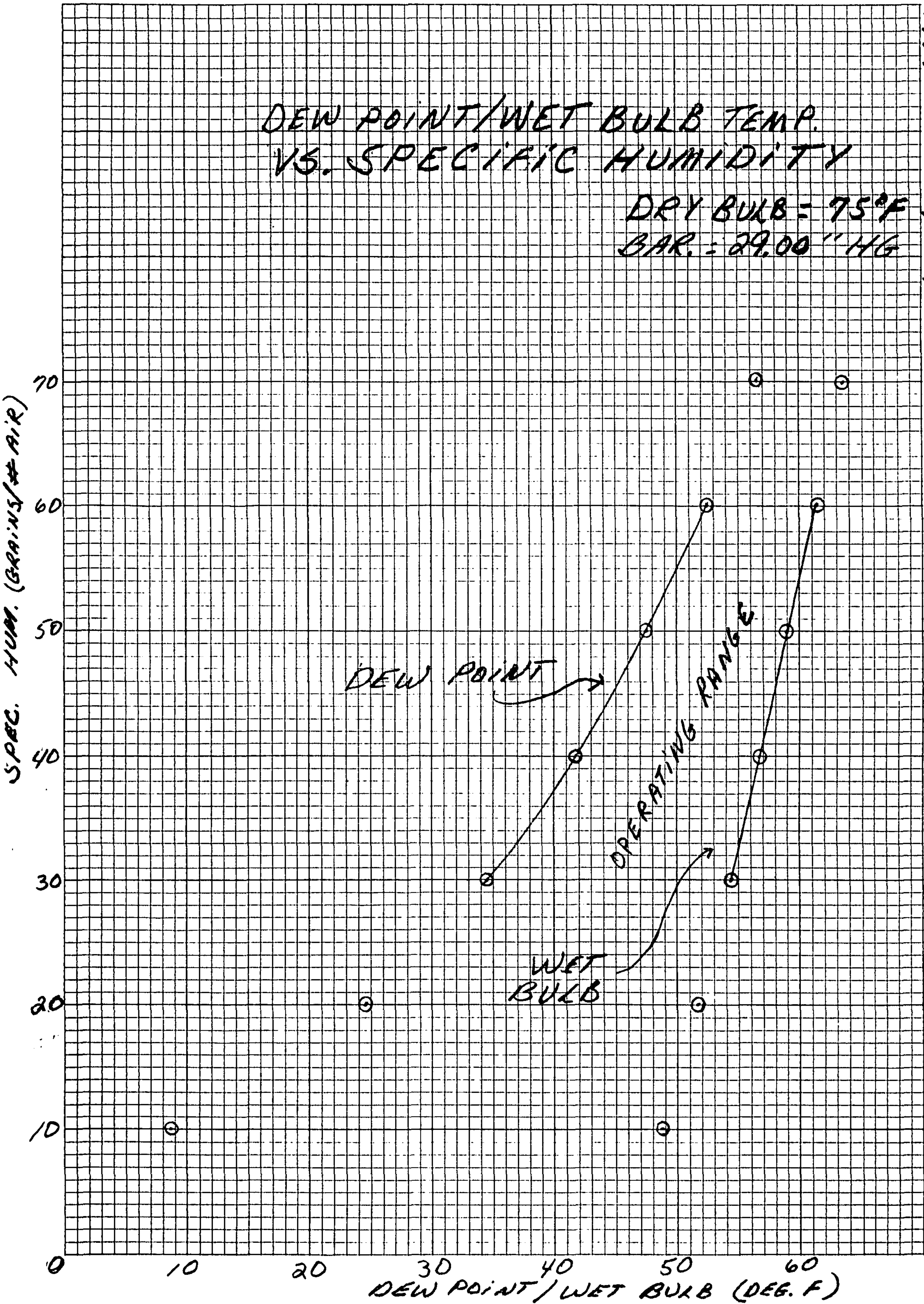


CHART SPEED
2cm/min

ROOM 515
HUMIDITY SENSOR
AND CONTROL

DEW POINT TEMPERATURES
0-100°F
MEASURED IN FRONT OF
D001 & D002 COOLING FANS
AND CENTER OF THE ROOM

APPENDIX F



DEW POINT/WET BULB TEMP. VS. SPECIFIC HUMIDITY

DRY BULB = 75°F
BAR. = 29.00 " HG

1-15-81