

Relative Humidity Measurements at VLBA, VLA, and AOC Sites

C. Janes and B. R. Martin
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Introduction

Tribological studies show that lower relative humidity (RH) extends magnetic tape head life. Although an optimum RH for operation is still under discussion, the goal of this study was to achieve an RH of 30% + or -10% RH, with the idea that above 40% RH the head wear is excessive and below 20% RH static problems can be introduced. RH was measured for two months at each of the VLBA sites, the VLA site, and at the correlator playback drives to determine if the VLBA tape drives are being operated within the prescribed range.

RH Control at sites and AOC

At the VLBA site, RH for the computer room where the VLBA tape recorder is located is controlled by a Contempo HVAC (heating, ventilation, and air conditioning) unit which includes both a humidifier and a dehumidifier. The system is closed; that is, no outside air is intentionally included in the air handling cycle for the computer room.

In Socorro, air is drawn from the AOC Computer Room to control temperature and RH for the Correlator Operations area, the environment to which the playback drive heads are exposed. Five Model 2100 Compu-Air HVAC units in the Computer Room operate independently to control the Computer Room environment. The air drawn into the Operations area is heated 6 degrees F because the air temperature in the Computer Room is too cool for comfort.

RH Measurement

The RH hygrometer used for the VLBA sites is a Vaisala HMW50U humidity transmitter, which uses an active thin film polymer sensor called the Intercap (Figure 1). The Intercap sensor can be replaced to recalibrate the device; hygrometers typically need to be calibrated periodically, but the calibration equipment is expensive and the procedure can be cumbersome. With a drift of 1% per year, and an initial error of + or - 3%, the Vaisala sensor will have a worst case error of 6% in 3 years, at which point the Intercap should be replaced.

A 0 to 10 VDC output from the Vaisala is automatically read by the station computer periodically via address #4200 in the Utility Module. The data are saved in the monitor program and are accessible via MONDISP (see Appendix A).

Readings with a sling psychrometer are a little higher than the Vaisala unit, but it is difficult to get accurate readings from an inexpensive psychrometer when the RH is low. Many of the

other gauges at the sites do not agree favorably with either sling psychrometer or Vaisala, presumably because they are inaccurate gauges to begin with, and have not been calibrated recently. As a result, the Vaisala readings were taken on faith for this report.

A Weathertronics model 5020 Hygrothermograph in the AOC Computer Room and another in the AOC Correlator Operations area provide charts for the environment in those areas.

Both the Contempo and the Compu-Air HVAC units contain their own humidity sensing devices.

Results at the VLBA sites

Relative humidity was monitored continuously at each VLBA site from June 7 until August 8. Average readings are shown in Table 1.

Figures 2 through 4 are example plots of relative humidity from selected VLBA sites. In Figure 2, the 12% RH peak-to-peak swings in RH over a 2.5 to 3 hour period are common when the Contempo humidifier is used. The RH curve is relatively flat when the dehumidifier is used. At Mauna Kea where these data were taken, there is typically a big jump in ambient dew point every afternoon as shown in the figure. For substantiation, the phenomena is seen by the weather station and the tipping radiometer as well. The increase in absolute humidity outside couples quickly to the computer room in the station building, causing the humidifier to turn off, thus the flat intervals in RH between the cycling.

That the relative humidity in the VLBA computer room increases with ambient dewpoint is also clearly evident in the data from other sites; for example, the arrival of the summer rainy season at Pie Town is shown in Figure 3.

Some VLBA sites show greater excursions of relative humidity during the hours when personnel are present. For example, Figure 4 shows fluctuations in RH during daylight hours on Tuesday through Friday, but the curve is relatively flat on nights, weekends, and the Monday holiday. It may be those sites are leaving the door to the computer room open during working hours.

Three VLBA sites are in areas with high humidity: Hancock, North Liberty, and Saint Croix. Table 1 shows that Hancock was able to control RH at 30%, but both North Liberty and Saint Croix are high. Dropping the Contempo set point from 30% to 26% at Saint Croix dropped the RH from 38% to 35.5%.

Results at the AOC

Figures 5 through 8 are charts showing RH in the AOC Computer Room and Correlator Operations Room during June and July. To compare with the VLBA sites, simultaneous measurements with a Vaisala HMW50U RH transmitter are shown on two of the charts.

Because the Operations Room is warmer, the RH there is 5% to 10% drier than in the Computer Room, according to the charts.

Therefore, a setpoint of 40% RH in the Computer Room would probably maintain the Operations Room at about the desired 30%. The list of Computer Room equipment in Appendix B shows that all the equipment in that room is specified to operate at least down to 30% RH so that a setpoint of 40% would be satisfactory.

The control panels for the Compu-Air HVAC units in the Computer Room permit a set point of 40%, but the data show that the equipment is currently not servoing correctly. NRAO has contracted with Trane to investigate the control problem and propose a correction.

Results at the VLA

A VLBA tape recorder is located in the equipment room of the Control Building for use in tying the VLA into the VLBA VLBI network. Neither remote sensing nor chart recording of relative humidity in the equipment room is currently available; a Weathertronics 5020 Hydrothermograph like the ones in use at the AOC has been placed on order. Spot checking of an inexpensive gauge at the recorder showed an RH of 50% on one occasion.

Conclusions

A log of elapsed time for the tape recorders in the Monitor system will allow correlation of head wear and perhaps other performance problems with humidity. The software "elapsed time meter" should increment whenever tape is moving across the head. There is a manually readable elapsed time meter in the drives, but some of the meters have not been activated, and keeping track of meter readings manually promises to be cumbersome, inaccurate and incomplete.

A recent VLBA Data Acquisition Memo, #363, reports that signal recovery drops off at 30% RH. A practical compromise needs to be reached between the requirement to run substantially under 45% RH, and an evolving requirement to operate substantially over 30%. Comparing head wear from elapsed time data with average RH at the site computer room will help identify an optimum operating point.

All the VLBA sites had RH within the 20% to 40% limit during the test period; however, both Saint Croix and North Liberty have an average operating point above the 30% RH goal. Once an optimum operating point for RH is defined, it may be necessary to add supplemental dehumidification at Saint Croix and/or North Liberty. In the interim, it would be helpful if those two sites would experiment with lower set points.

Making the MONDISP monitor data display program available to the sites will permit the site tech to better monitor the RH and other parameters at his site. Currently, the display package requires a Tektronix 4010 display format, which is not available on a PC at the sites. As well, MONDISP frequently overruns disk allocations and is not available at all.

Sites are reminded to keep the door to the computer room closed and to monitor RH periodically once MONDISP becomes available to the sites.

If not done so already, a low of 20% RH and a high of 40% RH should be installed as alarm trip points in Checkall until a better range is defined.

The humidity control in the AOC Computer Room needs to be repaired, but once it is and the setpoint put at 40%, it appears that the VLBA playback tape drives in the Correlator Operations area will be held at 30% RH.

A recording hygrometer once installed at the VLA equipment room may show the need for a change in RH set point once the optimum RH operating range is better defined.

List of figures:

1. Data Sheet for Vaisala HMW50U Humidity Transmitter
2. Plot of RH at Mauna Kea June 28 to July 4.
3. Plot of RH at Pie Town July 26 to August 1.
4. Plot of RH at Fort Davis July 5 to July 11.
5. Chart of RH and temperature for AOC Correlator Operations, June.
6. Chart of RH and temperature for AOC Computer Room, June.
7. Chart of RH and temperature for AOC Correlator Operations, June.
8. Chart of RH and temperature for AOC Computer Room, June.

References:

Measurement of Magnetic Tape Abrasivity by Interchanging Tape Thickness, A. E. E. Rogers and H. F. Hinteregger, Tribology Transactions, Volume 36(1993), 1, 139-143, 1993.

VLBA Data Acquisition Memo #363, Maintenance and Head Wear, H. F. Hinteregger, August 4, 1993.

Table 1.

Station	Average RH from plots June - August, 1993
vlbabr	27% + or - 3% RH
vlbafd	30% + or - 3% RH
vlbahn	30% + 8%, -3% RH, varying with ambient conditions.
vlbakp	30% + or - 2% until rainy season, then 33%
vlbala	30% + or - 10%, variation apparently depending on whether dehumidifier or humidifier in use.
vlbank	29% + or - 10%, variation apparently depending on whether dehumidifier or humidifier in use.
vlbanl	37% + or - 3%
vlbaov	28% + or - 5% until July 16 when it appears that the humidity control was disabled.
vlbapt	25% + or - 5% until August 3 with the rainy season started, then 29%.
vlbasc	38% + or - 2%; dropped to 36.5% when setpoint dropped from 30% to 26%.

APPENDIX A

Subject: Plotting relative humidity data from VLBA sites.

This appendix contains a procedure for plotting relative humidity data from each VLBA site computer room, room 103.

The program used to obtain and plot the data is called `mondisp`. This program is located at `/vlbacc/home/vlbsoft/CodeSunNew/sun3/`. To run this from your home directory, you must either copy the program to your home directory or add the path to your `.cshrc` file.

Start the program by typing the name of the program; something similar to Figure 1 will appear on your screen. This program operates like the screen program; to move between data fields on the screen use the cursor keys, tab key, or control key combinations. The top line of the screen explains the purpose of the field that the cursor is in. Help can be obtained for most fields by typing a question mark while the cursor is in that field. Nothing is changed in any field until the enter or return key is pressed while the cursor is in that field.

The next step is to set up the data fields to obtain the desired plots. This is done by moving the cursor to the various fields and entering the appropriate information. The `OUT_FILE_NAME` field determines where the raw data for your plots will be stored. The `DATA_DIRECTORY` field tells the program where to find the data it needs; this field defaults to `/vlbacc/mdata` which is where the data are normally stored. (Ron Weimer told me that the data might be found in `/pingora2/vlbaops/mdata` if it can't be found in the normal place.) The `FROM` and `TO` fields determine the date range of the plotted data, these are set by moving the cursor to these fields and using control-p (previous) or control-n (next). The `AT` fields after the `TO` and `FROM` fields set the time of day that the plots start and end. These are set by typing in the desired time. All times and dates are in Universal (Greenwich) Time.

The next block of fields sets up the actual data to be plotted. The `STATION` field selects which VLBA site the data will be obtained from, use control-p and control-n to select the site or enter the two letter identifier for the site. The `DEV` and `MPT` fields select the specific data to be plotted; these are selected with control-n or control-p. The items selected in these fields are listed beside the `mondisp` screen after they are chosen. For computer room relative humidity and temperature, set `DEV` to "CR Utility Data" and set `MPT` to "Rm 103 relative humidity" and "Rm 103 temperature", respectively. For ambient temperature and dew point, set `DEV` to Weather Data and set the appropriate selections for `MPT`. The `DEV_UNIT_#` field should be left at none. Multiple plots can be displayed on a single graph by using the `COL` field. After setting up the first plot, change the `COL` field to 2 and enter the information for the next plot. For more plots, set `COL`

to 3, 4, etc. The program automatically picks a different plot symbol for each plot.

The last block of fields determine the plot format and control the plot functions. The TITLE field determines the title printed over the final plots. The X_LABEL and Y_LABEL set the horizontal and vertical axis labels, respectively. The PLOT DEVICE field should be set to /PS for a landscape oriented plot. The AXIS field determines how the plot frame will look. The SKIP field determines how much of the data gets plotted: a 1 here causes every data point to be plotted, a 2 causes every other point to be plotted, etc. The X_AXIS and Y_AXIS fields can be used to set the limits on the plot axis set to AUTO for auto ranging.

The screen setup that you create can be saved to a file for later recall by moving the cursor to the SAVNAME field, typing a name for the file you want to save the screen to, and pressing the enter or return key. The SAVE field has 3 options selectable by using control-n or control-p and then pressing enter or return. The AUTO option saves the screen whenever the GO command is executed. The NOW option saves the screen only when the enter or return key is pressed while the cursor is in this field and the NOW option is selected. The NO option prevents the screen from being saved at all. To retrieve a saved screen, enter the name of the file in the SAVNAME field, move the cursor to the [READ] field and press enter or return.

Figure 2 shows the setup screen I used to plot the data from the Brewster site, as an example. I created a screen setup for each of the 10 VLBA sites and saved them in my directory so that all I had to do was recall each one and change the date range of the data to plot out the latest seven days of data. Clint Janes has the plots in his office.

BRM

<CR> to Recall Screen Parameters Saved in File SAVNAME
[K]*MONITOR DATA DISPLAY/PLOT SCREEN** You have entered the mondisp program

```
[READ] SAVNAME .mondisp      SAVE AUTO  
OUT_FILE_NAME mondisp.dat  
DATA_DIRECTORY /vlbacc/mdata  
FROM_ yyyymmdd AT 00H00M  
TO   yyyymmdd AT 24H00M  
-----  
COL 1 STATION xx [PLOT ]  
DEV none  
MPT none  
DEV_UNIT_# none  
-----  
[GO] [RESET] # OF COLUMNS 1  
[DISPLAY] [DO_PLOT] PLOT AGAINST TIME  
TITLE No Title Given  
X_LABEL xaxis  
Y_LABEL yaxis  
PLOT_DEVICE /null  
AXIS AXES SKIP 1  
X_AXIS [AUTO] TO  
Y_AXIS [AUTO] 0.0000 TO 0.0000  
*****
```

FIGURE 1 - APPENDIX

<CR> to Recall Screen Parameters Saved in File SAVNAME
[K]*MONITOR DATA DISPLAY/PLOT SCREEN** Recalled screen parameters.

```
[READ] SAVNAME br-setup      SAVE AUTO  
OUT_FILE_NAME mondisp.dat  
DATA_DIRECTORY /vlbacc/mdata  
FROM_ 1993JUL26 AT 00H00M  
TO   1993AUG01 AT 24H00M  
-----  
COL 1 STATION BR [PLOT ]  
DEV CR Utility Data  
MPT Room 103 Relative humidity  
DEV_UNIT_# none  
-----  
[GO] [RESET] # OF COLUMNS 4  
[DISPLAY] [DO_PLOT] PLOT AGAINST TIME  
TITLE Brewster Plots  
X_LABEL 26 Jul - 01 Aug  
Y_LABEL Rm 103 RH, Temp; Amb DP, Temp  
PLOT_DEVICE /PS  
AXIS GRID SKIP 1  
X_AXIS [AUTO] TO  
Y_AXIS [ ] -20.0000 TO 40.0000  
*****
```

FIGURE 2 - APPENDIX

Appendix B Computer Room Equipment

Listed below are the environmental requirements for our equipment presently located in the Computer Room:

1. Hewlett-Packard 88780B 1/2" tape drive.

Temperature:

Operating	15 to 32 degrees C
Non-operating	0 to 55 degrees C
Storage	-40 to 70 degrees C
Rate of Change	20 degrees C per hour

Relative Humidity:

Operating	tape medium limited to 20%-80% at <20 degrees C maximum wet bulb temperature.
Storage/shipment	90% at 40 degrees C maximum wet bulb temperature.

2. Hewlett-Packard 35470A SCSI DAT Drive.

Temperature:

Operating	5 to 40 degrees C ($\Delta T < 10 \text{ deg C/h}$)
Operating (mech)	0 to 55 degrees C ($\Delta T < 20 \text{ deg C/h}$)
Non-operating	-40 to 70 degs. C ($\Delta T < 20 \text{ deg C/h}$)

Relative Humidity:

Operating	20 to 80% RH (non-condensing. Maximum wet bulb temperature = 26 degrees C 15 to 95% RH ($\Delta RH < 30\%/h$)
Operating (mech)	5 to 95% RH ($\Delta RH < 30\%/h$)
Non-operating	same as above

3. Micropolis 1924 2.0 GB disk drives

Temperature:

Operating	10 to 50 degrees C
Non-operating	-40 to 65 degrees C

Relative humidity:

Operating & non-oper.	10% to 90% RH (80 degrees F max wet bulb non-condensing)
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4. Sun IPX, IPC, and SPARC2 Workstations

Temperature:

Operating	32 to 104 degrees F
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Relative Humidity:

Operating	5% to 80% RH, non-condensing
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5. Deltec UPS
 - Temperature:
 - Operating 0 to 40 degrees C
 - Relative Humidity 0 to 95% RH non-condensing

6. QMS 800 Laser printer
 - Temperature:
 - Operating 10 to 30 degrees C
 - Relative humidity:
 - Operating 10% to 80% RH non-condensing

7. QMS 1500 Laser printer (includes 1500PS)
 - Temperature:
 - Operating 10 to 32 degrees C
 - Relative humidity:
 - Operating 20% to 80% RH non-condensing

8. QMS 1700 Laser printer
 - Temperature:
 - Operating 10 to 30 degrees C
 - Relative humidity:
 - Operating 10% to 80% RH non-condensing

9. Exabyte 8200 and 8500 Tape drives.
 - Temperature:
 - Operating 16 to 32 degrees C
 - Relative humidity:
 - Operating 20% to 80% RH non-condensing

10. Telex 9270 1/2" Tape drives.
 - Temperature:
 - Operating 5 to 43 degrees C
 - Storage -45 to 70 degrees C
 - Relative Humidity:
 - Operating 30% to 80% RH non-condensing

Preferred temperature/relative humidity per ANSI Standard X3.40:

Temperature between 65 and 75 degrees F
 Relative humidity 40 to 60%

11. Convex C1 Computer
 - Temperature:
 - Operating 50 to 140 degrees F
 - Non-operating -40 to 140 degrees F

Relative Humidity:
Operating 20% to 80% RH non-condensing
Non-operating 0.5 to 95% " " "

12. IBM 1000S, Micropolis 2112, and Conner 3.5" disk drives

Temperature:
Operating 10 to 50 degrees C
Non-operating -40 to 66 degrees C

Relative humidity:
Operating 8% to 90% RH non-condensing
Non-operating 10% to 90% RH non-condensing

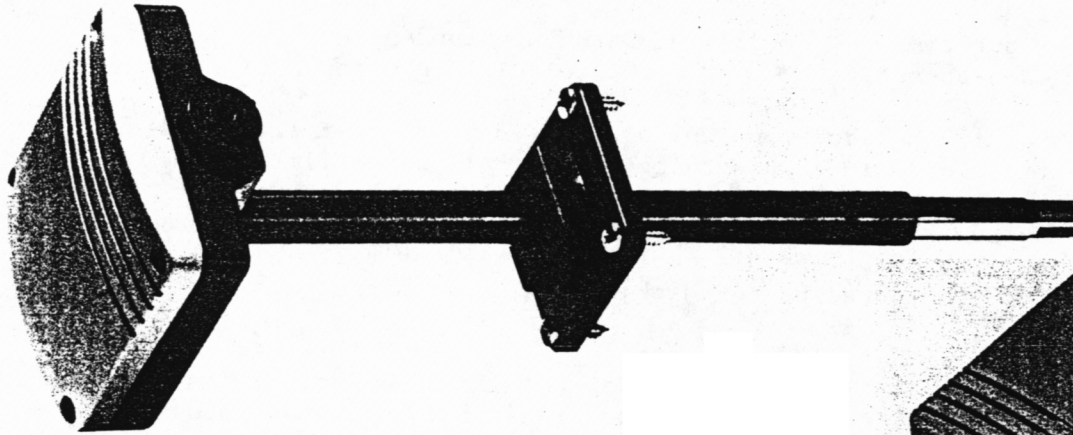
This is all the equipment which provided me with environmental specifications. I found nothing on the Solitaire film imaging machine nor the Tektronix color laser printer. I assume that the Tektronix printer matches the QMS printers and also assume that the IBM 1000s and Micropolis 2112 disk drives are a close match to the Conner/Maxtor disk drives, for which specs were provided.

I forgot VLBACC, ZIA, and ARANA on the list, however, I assume that their environmental specifications meet or exceed those for the Convex C1. As a matter of fact, I just looked at Zia's specs and they do exceed Yucca's.

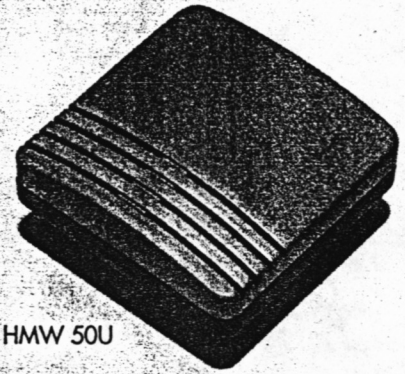
Fred Dunn



CALIBRATION-FREE WALL/DUCT MOUNTED HUMIDITY TRANSMITTERS



HMD 50U



HMW 50U

FEATURES/BENEFITS

- 3-wire selectable output
- Never need calibration
- Easy-to-replace, fully interchangeable INTERCAP® sensor
- 0 - 100% RH measurement

INTERCHANGEABLE FILTERED SENSOR

Vaisala's HMD 50U and HMW 50U never need calibration. Both models incorporate the fully-interchangeable INTERCAP® sensor which has been designed and manufactured so precisely that the operator can easily replace the sensor with another INTERCAP® sensor without calibrating the instrument. And, the sensor's membrane filter/mechanical housing protects it from dust and dirt.

SELECTABLE FUNCTIONS

The HMD 50U and HMW 50U transmitters feature selectable output signals of 0 to 4V and 0 to 10V. Powered by either AC or DC voltage, these transmitters can be duct or wall mounted.

HIGH PERFORMANCE AT LOW PRICES

Specifically designed for HVAC/EMCS applications, the HMD 50U and HMW 50U typically measure humidity levels with $\pm 3\%$ RH accuracy and $\pm 1\%$ stability per year. Easily installed directly into air ducts or within the controlled area, these transmitters feature three-wire connections, making retrofitting, upgrading or new installations easy. Competitively priced and requiring no routine maintenance, the HMD 50U and HMW 50U are a smart choice for your applications.

TECHNICAL DATA

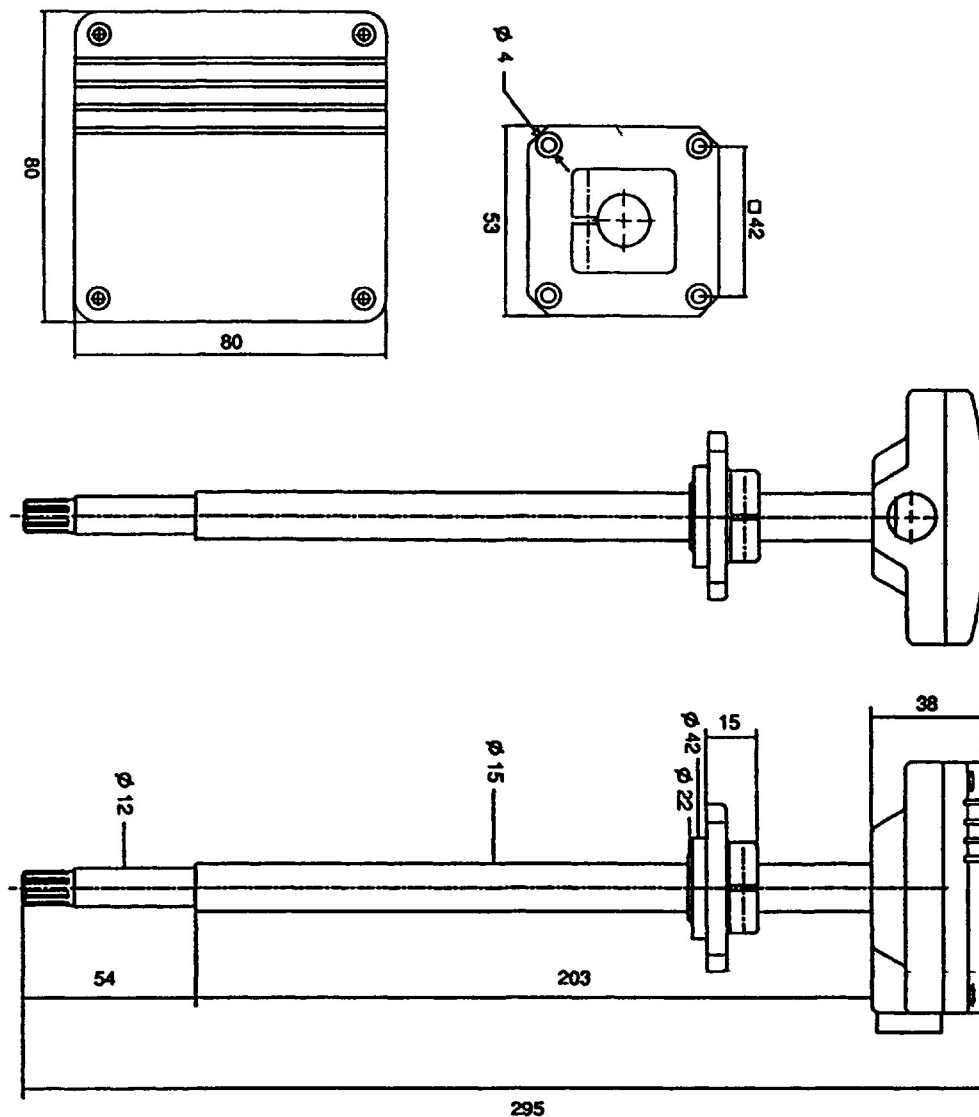
CALIBRATION-FREE HMD 50U/HMW 50U HUMIDITY TRANSMITTERS

General

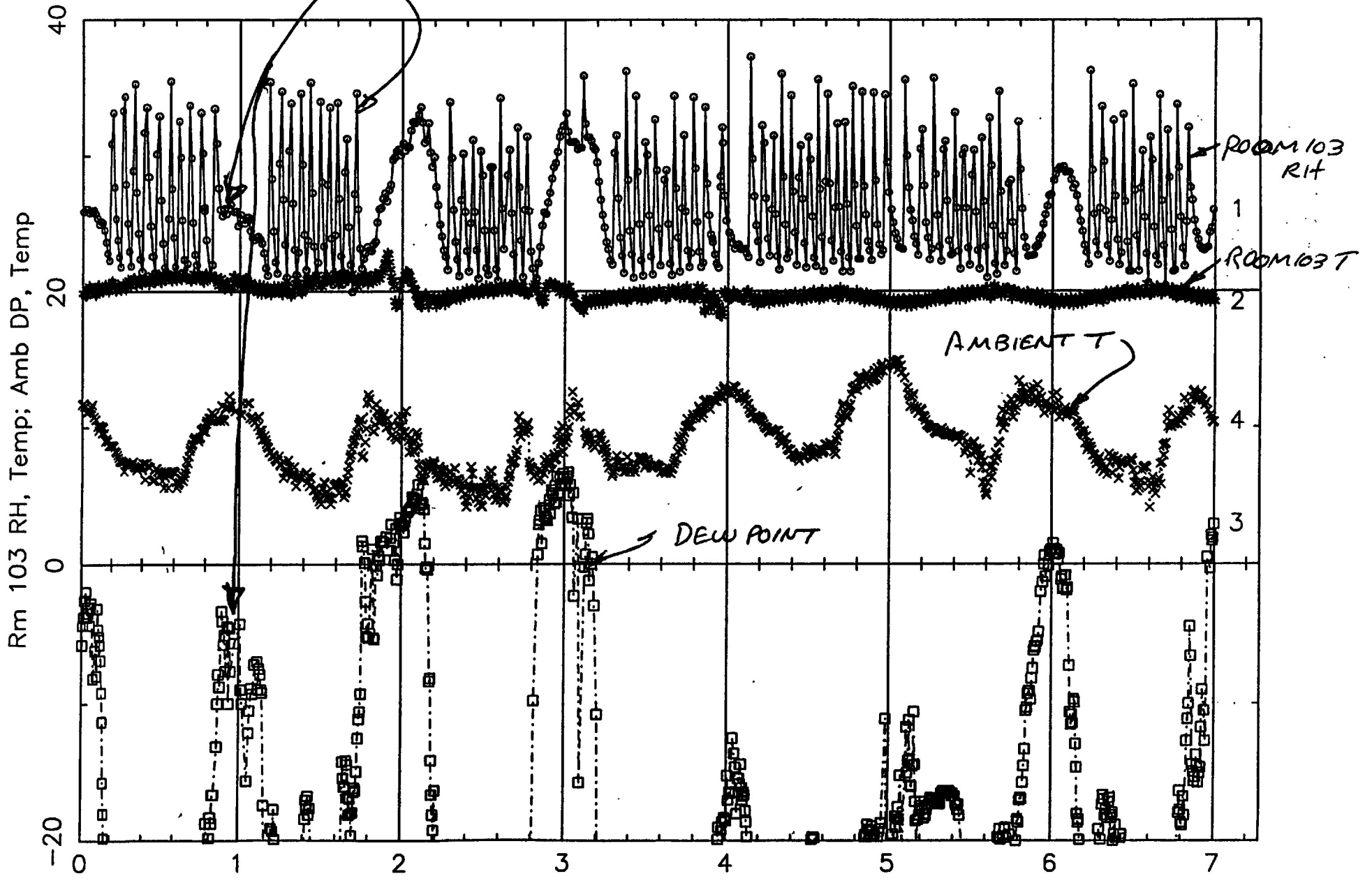
Power supply: 15...35 VDC
12...24 VAC
Current consumption: 6.0 mA typical
Operating temperature range: +14...+140°F (-10...+60°C)
Operating humidity range: 0 ... 100% RH
Sensor protection: Plastic grid with 0.5 micron membrane filter
Housing material and classification: ABS plastic, IP 65
Dimensions: See figure

Relative Humidity

Measuring range (for which accuracy is specified): 10 ... 90% RH
Accuracy at +20°C: better than $\pm 3\%$ RH
Stability: $\pm 2\%$ RH over 2 years
Temperature dependence: $< \pm 2\%$ from -10°C to +60°C
Output signal: 0...1V and 0...10V, $R_i > 10\text{ k}\Omega$
Sensor: INTERCAP® interchangeable capacitive humidity sensor



CYCLING DURING HUMIDIFYING CYCLE
CYCLING STOPS WHEN AMBIENT DEW POINT RISES
Mauna Kea Plots



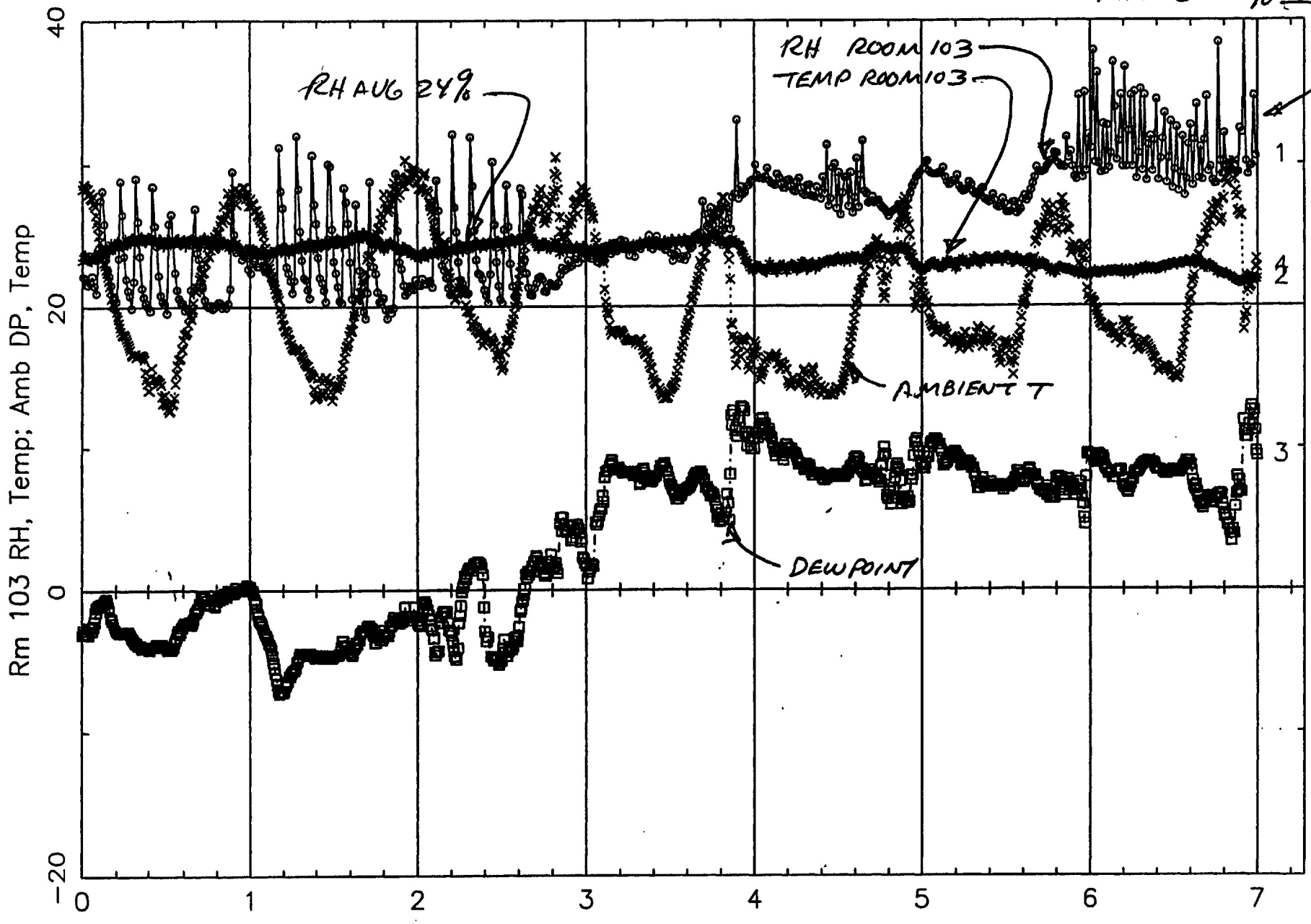
28 Jun - 04 Jul

FIGURE 2

Pie Town Plots

AVERAGE RH IN ROOM 103 INCREASES AS AMBIENT DEW POINT INCREASES

RH AUG 30%



26 Jul - 01 Aug

FIGURE 3

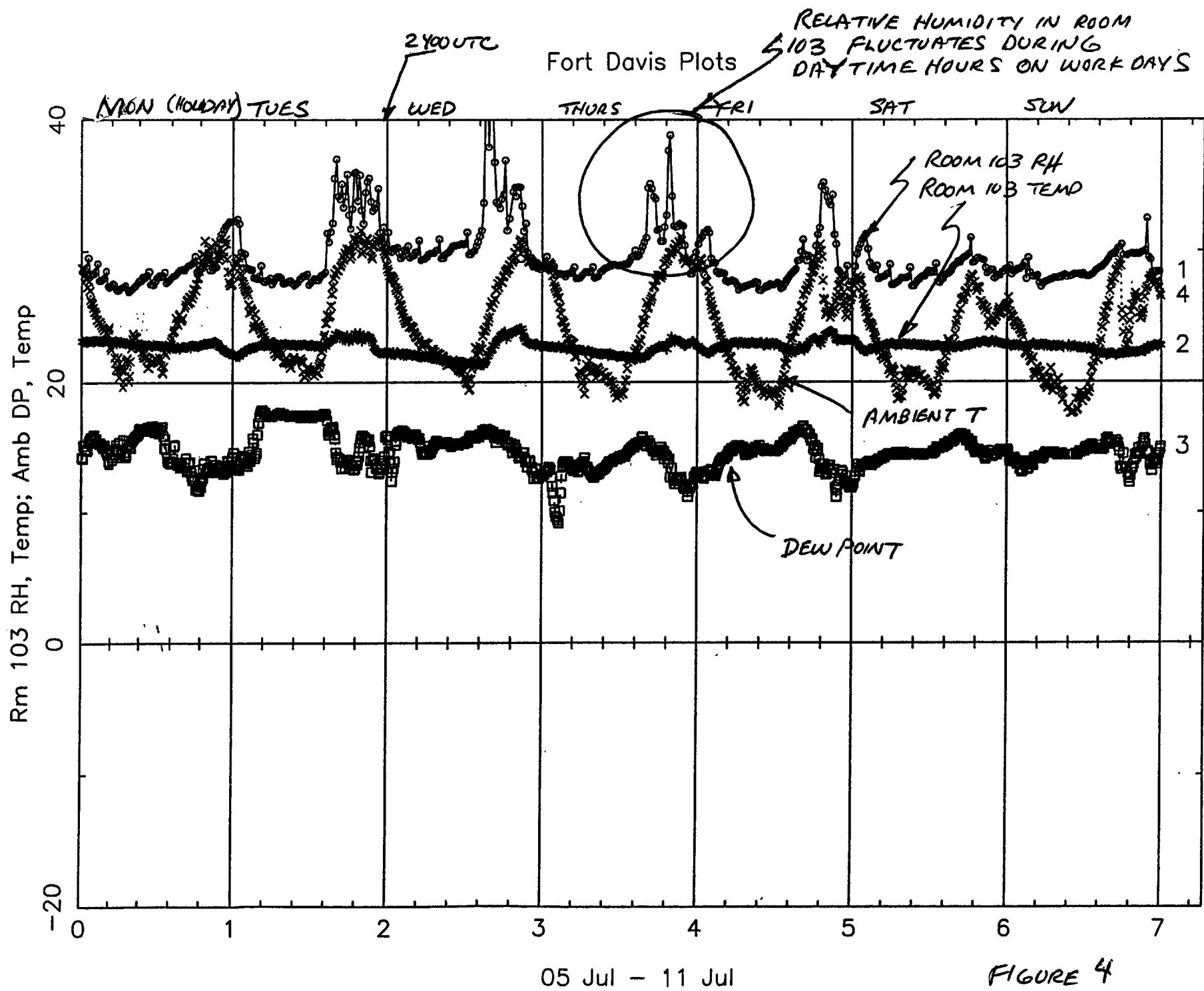


FIGURE 4

AOC OPIN
 1 JUNE - 30 JUNE 93
 □ - HYGROMETER IN PBD5
 ○ - VAISALA HYGROMETER
 SET POINT 50%

FIG 5

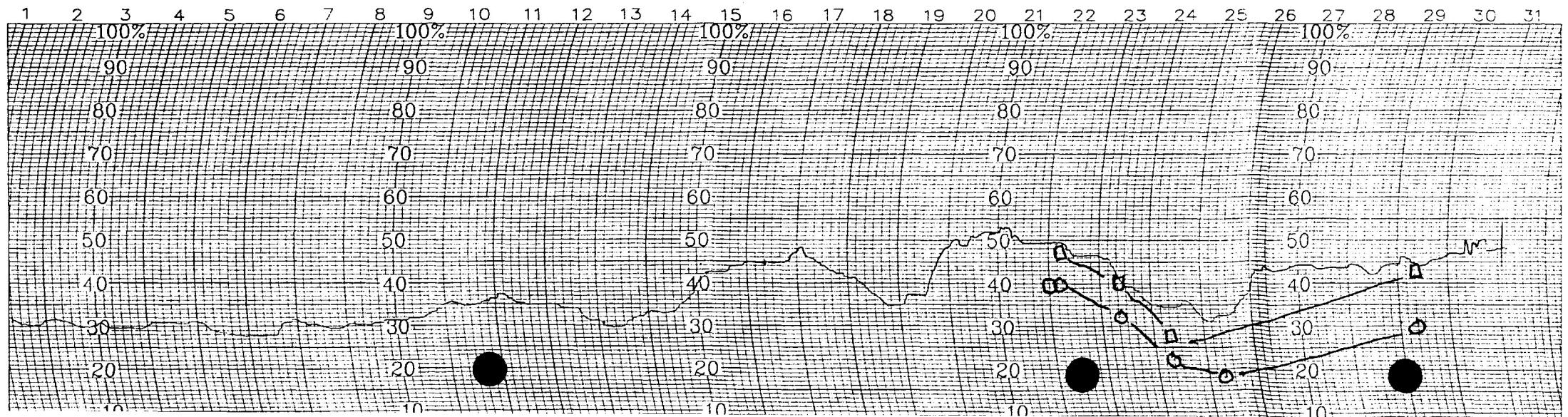
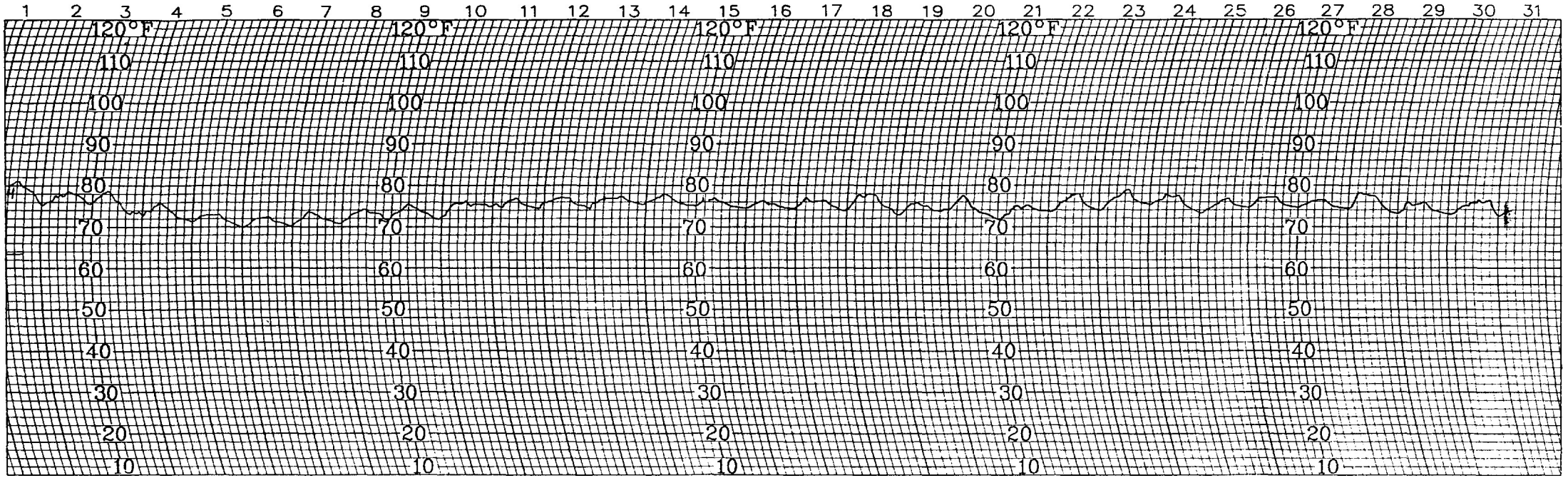
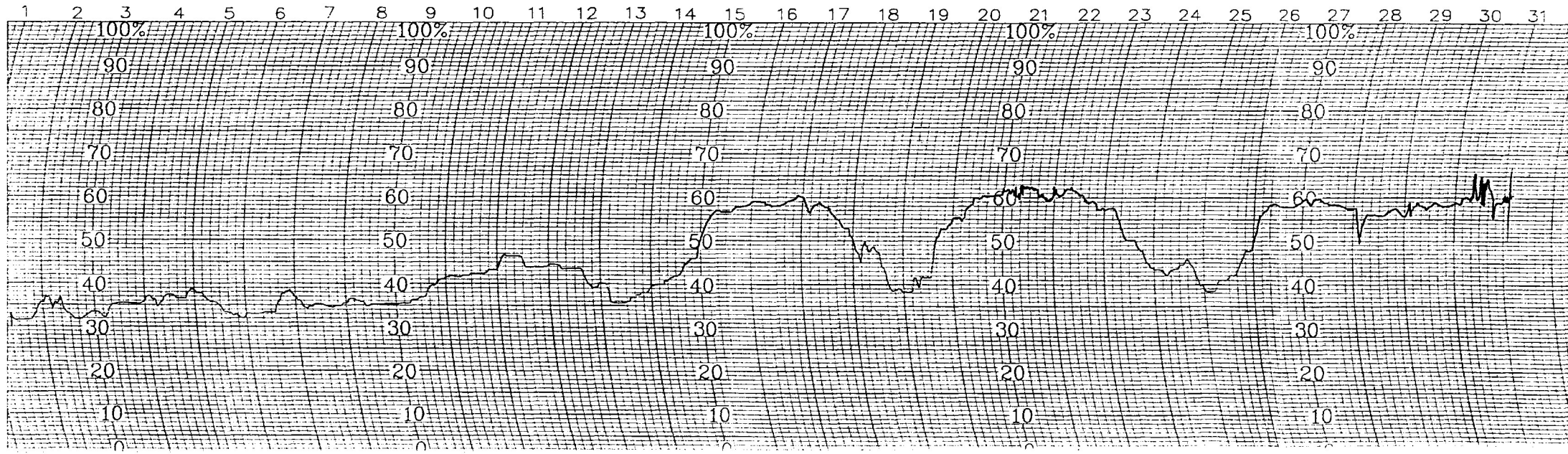
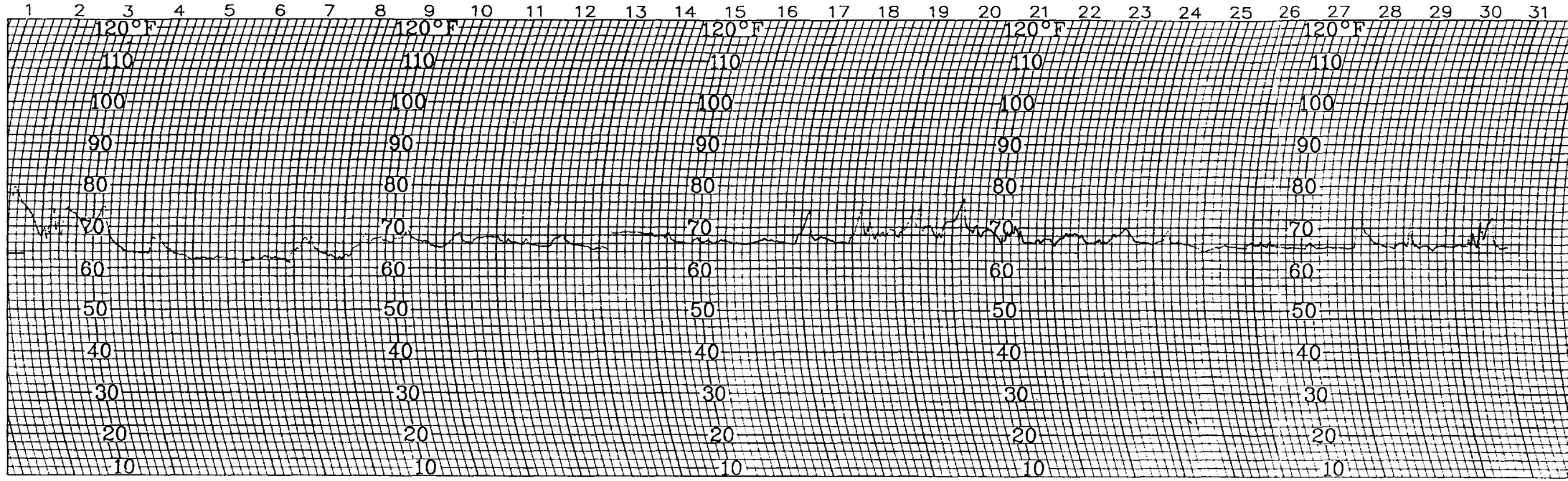


CHART NO. 50208
 ECN 2717
 3-15-88

HYGROTHERMOGRAPH
 31 DAY

P.O. BOX 41039
 SACRAMENTO, CA. 95841
 PHONE: (916) 923-0055

WeatherMeasure
 WEATHERtronics



Weather Measure
WEATHERMETRICS
DIVISION OF QUALIMETRICS, INC.
P.O. BOX 41039
SACRAMENTO, CA. 95841
PHONE: (916) 923-0055

HYGROTHERMOGRAPH
31 DAY

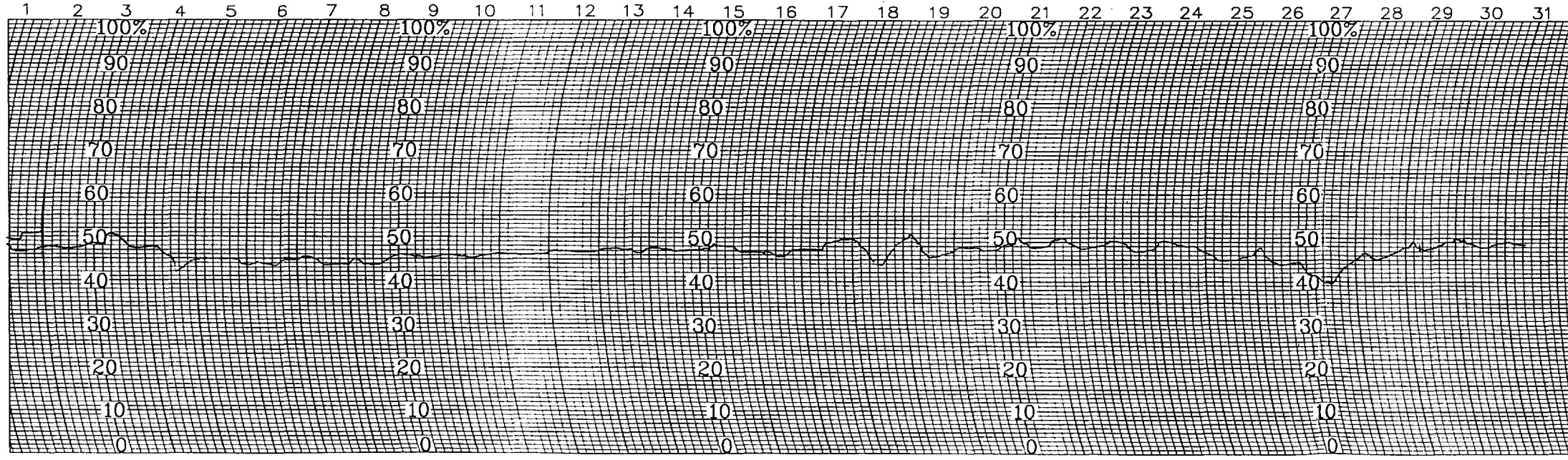
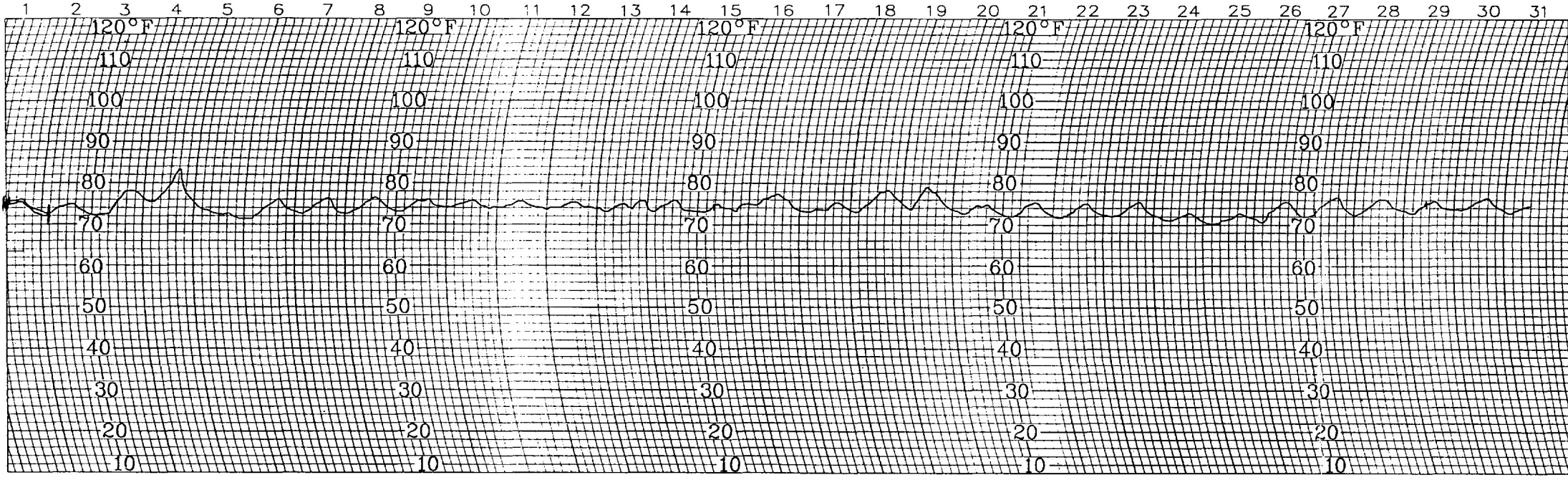
CHART NO. 50208
ECN 2717
3-15-88

COMPUTER ROOM

JUNE, 1993

FIG 6

JULY 93



WeatherMeasure
WEATHERtronics
Division of QUALMETRICS, Inc.

P.O. BOX 41039
SACRAMENTO, CA. 95841
PHONE: (916) 923-0055

HYGROTHERMOGRAPH
31 DAY

CHART NO. 50208
ECN 2717
3-15-88

STATION ADC Ops VISA DATE ON 1 July 93 DATE OFF 2 Aug 93

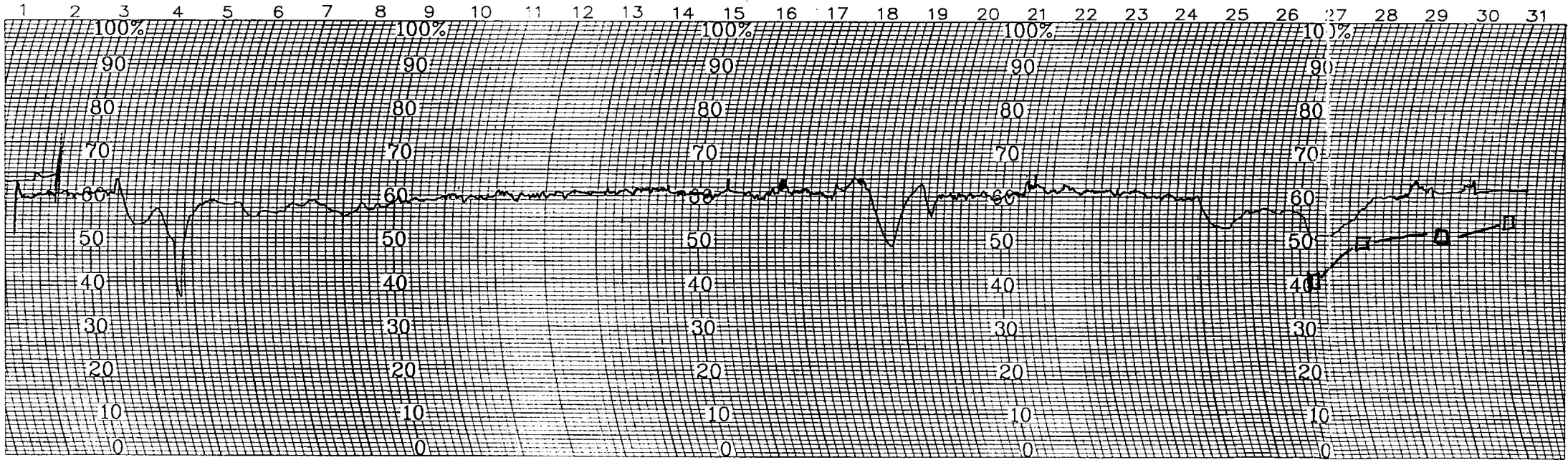
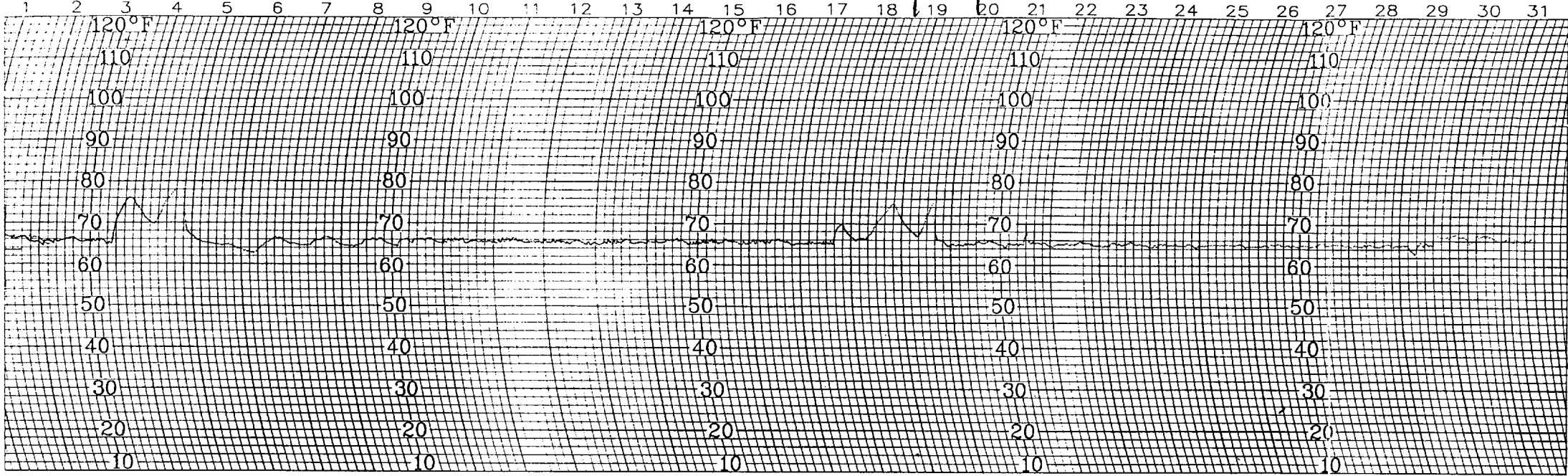
FIG 7

SET POINT 50%

SET POINT 40%

SET POINT 45%

D - VAISA HYGROMETER
S



Weather Measure
WEATHERtronics
Division of QUALMETRICS, Inc.

P.O. BOX 41039
SACRAMENTO, CA. 95841
PHONE: (916) 923-0055

HYGROTHERMOGRAPH CHART NO. 50208
ECN 2717
3-15-88

31 DAY

STATION AOC Computer RM DATE ON 1 July 93 DATE OFF 2 Aug 93 FIG# 1168

Relative Humidity Measurements at VLBA, VLA, and AOC Sites
Addendum to VLBA Test Memo No. 45

C. Janes
September 7, 1993

Introduction

After reading VLBA Test Memo No. 45, Terry Cotter noted that relative humidity (RH) measurements have been made in the VLA Control Building Equipment Room for the past 3 years. There is concern that high RH may be effecting maser ion pump performance as well as the tape recorder.

Measurements

Members of the LO/IF Group have recorded readings from a wall-mount hygrometer in the VLA Control Building Equipment Room since September 1990; the results of those measurements are shown in Figure 1. The graph shows that the RH in the equipment room increases to over 50% during the summer rainy season, or about 25% of the time. The figure also shows a slow increase in RH from year to year outside the rainy season. This increase in the "continuum" may be real or a drift in the hygrometer. That question may be resolved by a hygrothermograph recently installed in the equipment room to record RH continuously.

Concern over RH

The exponential relationship between head wear and RH is the problem addressed in Memo No. 45. In addition, measurements show that the current to the ion pump used to evacuate the maser cavity doubles during periods of high RH. The reason why the current increases or even what effect that doubling has on the maser power supply or the ion pump is not known, but the concern is that the higher current may mean accelerated wear on the pump. In any case, it is very unlikely that any good is resulting from the increased current.

Recommendations

Steve Troy points out that the dehumidification of the air to the equipment room could be improved by dropping the temperature of the air intake to the HVAC. The lower temperature would cause more water vapor to be condensed from the air. Heat exchangers in the HVAC would use the removed heat to warm the air output of the HVAC so that energy costs would not increase dramatically. Troy estimates that the addition of 110 gallons of glycol to the 500 gallon chilling system would permit

dewpoint necessary for 30% RH in the air output. The cost of two 55 gallon drums of glycol would be about \$400.

An alternate scheme would heat the head of the tape recorder, but such a solution does nothing for the maser ion pump, and requires a special modification to the tape recorder so that it would be different from the others in the VLBA configuration.

