

RELATIVE HUMIDITY MEASUREMENT ASSURANCE PROGRAM RESULTS

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ABSTRACT

During the summer of 1992, the National Conference of Standards Laboratories sponsored a relative humidity measurement assurance program (RHMAP) whose purpose was to enable each participating center to assess the quality of relative humidity calibrations being performed by their respective standards laboratories. A total of seven laboratories, which were all located in the Southern California area, participated in the inter-comparison. This paper presents the data which was submitted by the participants during the first round of the program and shows the multi-laboratory comparisons of the 20%, 50%, and 80% relative humidity measurements performed. Additionally, the data has been analyzed utilizing Youden diagrams in order to quantitatively assess the bias and precision errors associated with each participants' calibration system and procedures.

INTRODUCTION

This paper provides the final results of a relative humidity measurement assurance program (RHMAP) which was conducted during the summer of 1992 under the sponsorship of the National Conference of Standards Laboratories. The program was cooperative effort between various metrology laboratories located in the Southern California area, the NIST, and manufacturers of standards quality relative humidity instrumentation. The following is a list of companies and organizations which participated in the RHMAP:

Jet Propulsion Laboratory, Pasadena, CA
Loral Aeronutronic, Newport Death, CA
McDonnell Douglas Space Systems Company, Huntington Beach, CA
Navy Primary Standards Department, San Diego, CA
Rockwell International Corporation, Anaheim, CA
Southern California Edison, Westminster, CA

TRW Electronic Systems Group, Redondo Beach, CA

The primary purpose of this inter-comparison was to provide a dependable and cost effective method for participants to assess the quality of relative humidity calibrations being performed by their respective standards laboratories. Some of the benefits which resulted from participation in the program are listed below:

- 1) Assurance that participants' current relative humidity calibration systems are truly satisfying their accuracy requirements.
- 2) Allows for the assessment of the bias and precision errors associated with the participants' calibration systems.
- 3) Enables the metrology community to gain an understanding of the quality of relative humidity calibrations being performed on a large scale basis.
- 4) Provides evidence of measurement assurance for use in laboratory audits, certification, and ISO9000 registration.
- 5) Provides NIST traceability.

Thus, participation in measurement assurance programs can provide many metrological and cost advantages.

RELATIVE HUMIDITY MAP DESCRIPTION

The RHMAP was implemented in the form of a "round robin". In this way, the transfer standards were first calibrated at the National Institute of Standards and Technology in Gaithersburg, MD and were then subsequently hand carried to each of the various participants for use in measuring the relative humidity of the environments produced in their calibration chambers. Once all of the participants had completed their measurements, the transfer standards were returned to the NIST for an additional calibration. This method provided several benefits such as the ability to monitor the stability of the transfer standards, the reduction of the total time in which it took to complete the round, the minimization of bias errors associated with transfer standard sensor drift, and the reduction of the possibility that the transfer standards would be damaged while in transport.

The first round of the RHMAP concentrated on the following data points: 20% RH, 50% RH, and 80% RH. All measurements were performed at a calibration chamber temperature of 70 °F (21.1 °C) and a flow rate of 100 SLPM. In order to minimize the measurement uncertainty associated with operator error a detailed procedure was developed and distributed to each of the RHMAP participants which described the proper setup and operation of the transfer standards. Also, a RHMAP data sheet was provided in order to standardize and facilitate data reduction. A more detailed description of the RHMAP procedure and data sheet is given in a previous paper [1].

Six of the seven RHMAP participants utilize two pressure humidity generators as working standards for relative humidity calibrations. An environmental chamber with a chilled mirror hygrometer and sampling system is used as a working standard at one of the participating facilities. All RHMAP participants indicated that the measurement uncertainty of their calibration systems was on the order of $\pm 1\%$ RH or better.

As is typical in this type of program, the anonymity of the participating facilities was held in the strictest of confidence. This was done in order to insure that the participants would not be subject to reproach for any possible shortcomings in the data which they submitted to the program. For the purposes of this report, each participant was issued a letter code for identification. It is important to note that the objective of the RHMAP is not to show deficiencies in any participants calibration system but rather to make them aware of the quality of their calibration techniques and procedures. If participating facilities are satisfied with the level of uncertainty which they are achieving, then the purpose of the RHMAP will have been accomplished.

DESCRIPTION OF RHMAP TRANSFER STANDARDS¹

Two transfer standards were selected for use in this experiment. These are an electronic psychrometer from Thunder Scientific Corporation (Model 5A-IMP) and a chilled mirror hygrometer from General Eastern Instruments (Model M2/D2). These instruments were chosen for use in the RHMAP because they are widely used as transfer standards in secondary calibration laboratories and because, when carefully used, the measurements performed with these instruments are directly traceable to the SI units of temperature and pressure [2]. Furthermore, the use of two transfer standards was selected in order to facilitate the formulation of Youden diagrams which were used for the analysis of the bias and precision errors associated with the participants' humidity calibration systems.

The electronic psychrometer is a microprocessor based laboratory standard designed for precise measurement of air temperature and relative humidity. It employs a 2-bulb measurement system consisting of a Wet and a Dry calibrated platinum resistance thermometer (PRT) operating under a controlled air velocity. The Dry Bulb is used for sensing air temperature while the Wet Bulb utilizes a specially weaved wick, which is saturated with distilled water, to measure a depression temperature. The signals from the PRTs are converted to digital format, read by the microprocessor, and mathematically corrected to temperature data. The data is then used to calculate percent relative humidity and dewpoint temperature. The specified accuracy of the instrument is $\pm 1.0\%$ RH.

¹In order to adequately describe the experimental procedure, certain commercial products are identified in this paper. Such identification does not imply recommendation or endorsement by the National Aeronautics and Space Administration, the National Institute of Standards and Technology, or any of the RHMAP participants, nor does it imply that the instruments are necessarily the best available for the purpose.

The chilled mirror hygrometer utilizes a metallic mirror whose surface is thermoelectrically cooled until it reaches a temperature at which condensation begins to form on it. The dew layer is optically detected and the mirror is held at that temperature, which is by definition the dewpoint temperature. The temperature of the mirror surface is measured through the use of an embedded platinum resistance thermometer. In-bus, an accurate measurement of the dew/frost point temperature is achieved. Another PRT is used to measure the ambient temperature of the test environment. The data is then used to calculate percent relative humidity. The RH accuracy of this instrument is a function of the dewpoint and temperature accuracy, which is usually ± 0.2 °C worst case over the range, with NIST traceability.

INTER-COMPARISON DATA

The calibration results which have been submitted by the seven participating centers during the first round of the RHMAP are presented in figures 1 through 6. These plots show the difference (in percent RH) between the participants value of the relative humidity of the environment which was produced in their calibration chambers and the value which was measured with the specified transfer standard at each of the nominal setpoints. Note that figures 1, 3, and 5 correspond to measurements which were performed with the psychrometer and figures 2, 4, and 6 correspond to measurements which were performed with the chilled mirror hygrometer. Each laboratory has been given a letter designation (A-G) and since participants were encouraged to repeat their measurements, a number is used to designate the various datapoints which were submitted by a particular participant.

Also included in figures 1 through 6 is the NIST calibration datapoints. These points are shown as asterisks on the plots and can be used as baselines for comparing the participant's measurements against those performed at the NIST. The error bars on the NIST datapoints are set to ± 1 % RH and are to be used as indicators of the difference between a participant's datapoint and the NIST data. The actual estimated uncertainty of the NIST calibrations is ± 0.2 % RH.

Analysis of the inter-comparison data shows a high degree of repeatability an-long the measurements performed by individual participants for both the hygrometer and psychrometer readings. An exception to this can be seen in the Lab F data. This can be attributed to the fact that Lab F utilized two different procedures in the setup and operation of their calibration system which resulted in a systematic difference between the readings obtained by the two different procedures (points F1 and F2 compared to points F3 and F4). Thus, through participation in the RHMAP, Lab F was able to determine which of the two procedures provides the best results.

Also of interest is the difference between the participant's data and the data provided by the NIST. These values were obtained by subtracting the first NIST datapoint from each participant's datapoint and are shown in Table 1. In this case, the columns are labeled with an abbreviation of the corresponding

transfer standards and the nominal setpoint value. Thus, the column labeled "20% CM" shows the difference between the participant's calibrations and the NIST1 calibrations for the chilled mirror hygrometer 20%RH measurements.

In summary, 80 of the 102 measurements submitted by the seven participants were within 10/0 RH of the NIST1 data. The average difference between the participants data and the NIST data ranged from -0.01% RH for the 80% RH chilled mirror readings to -0.72% RH for the 20% RH psychrometer readings. The standard deviation of the difference between participants data and the NIST 1 data varied from 0.45 %RH to 0.78% RH.

SITE	20% CM (%RH)	20% PSY (%RH)	50% CM (%RH)	500' PSY (%RH)	80% CM (%RH)	80% PSY (%RH)
NISI 1	0.0	0.0	0.0	0.0	0.0	0.0
LAB A	-0.02	-0.67	-0.13	-0.52	-0.82	-0.49
LAB B1	-0.03	0.3	-0.48	-0.33	-1.37	-1.27
LAB B2	-0.25	0.26	0.11	0.01	-0.91	-1.34
LAB C1	0.67	-0.66	0.76	-0.34	0.04	-0.21
LAB C2	0.55	-0.89	0.64	-0.38	0.42	-0.23
LAB D1	0.38	-1.36	1.05	-0.16	0.62	-0.68
LAB D2	0.28	-1.17	0.95	-0.03	0.62	-0.06
LAB E1	2.1	0.35	1.33	-0.19	0.12	-0.25
LAB E2	2.14	0.4	0.89	-0.05	0.1	-0.2
LAB F1	0.18	0.03	0.45	1.06	0.82	1.52
LAB F2	0.48	-0.24	0.75	0.19	1.22	1.58
LAB F3	0.08	-1.42	0.05	0.00	0.22	0.23
LAE3 F4	0.28	0.07	0.15	-0.86	0.32	0.09
LAF3 G1	0.38	-2.2	0.25	-1.11	-0.28	-0.72
LAB G2	0.38	-2.02	0.25	-1.19	-0.38	-0.86
LAB G3	0.38	-2.05	0.25	-1.11	-0.38	-0.9
LAB G4	0.38	-2.13	0.25	-1.42	-0.48	-0.94
NISI 2	0.27	-0.31	0.36	-0.11	0.02	-0.02
Average	0.45	-0.72	0.41	-0.34	-0.01	-0.25
Range	2.39	2.60	1.81	2.48	2.59	2.92
Std Dev	0.63	0.92	0.45	0.59	0.63	0.78

Table 1. Difference Between RHMAP Participants Data and NIST Data

Table 1 also gives an indication of the stability of the transfer standards during the inter-comparison process. As can be seen in the table, the difference between the first NIST calibration and the second NIST calibration varies from approximately 30.02/40 RH at 80 % RH to approximately $\pm 0.3\%$ RH at 20% RH for each of the two transfer standards.

YOU DEN DIAGRAMS

A Youden diagram is a statistical tool which is widely used to graphically represent and analyze interlaboratory comparison data [3]. Essentially, Youden diagrams are formed by setting up a scale on the X axis of a Cartesian plot which will cover the range of measured values for one transfer standard and repeating the process for another transfer standard on the Y axis. The results reported by each participating center, for both transfer standards, are used to plot a point on the graph. In order to finalize the Youden Diagrams for the RHMAP, the participants who submitted more than one calibration must decide which data point will be used to represent their laboratory. This is because the group mean and standard deviation will be more influenced by participants who submitted several calibrations than by those who submitted only one. In order to properly perform a Youden analysis of the laboratory inter-comparison data, there must be one point per participant on the Youden diagrams. The guideline for excluding data points was as follows. Participants who experimented with different procedures or setups for their calibrations were instructed to only include the data which was obtained with the standard calibration procedure used at their facility. Those participants which used the same procedure or setup for all of their calibrations used the average of the values obtained,

Analysis of the interlaboratory comparison data was achieved by adding four key elements to the Youden diagram [4]. First, the median of the measured values submitted by each participant, for both transfer standards, was calculated and a line was drawn through the median value perpendicular to the corresponding axis. The next element is a 45 degree tangent line which is drawn through the intersection of the median lines. An uncertainty circle, of radius three times the standard deviation for precision of the measured values used in calculating the median, was also added to the Youden diagram. For comparison purposes and to assess the accuracy of the measurements submitted by each of the participating centers, NIST data is included on the graph. The NIST point is shown as an asterisk and the error bars associated with the point are set to $\pm 1\%$ RH for the reasons previously described.

Based on the information given by the Youden diagrams developed from the data submitted for evaluation as part of the RHMAP (Figures 7-9), it is possible to quantitatively assess the errors associated with the relative humidity calibration systems and procedures utilized at each of the participating facilities. The two components which make up a calibration laboratory's total measurement error are known as precision errors and bias errors (also known as random and systematic errors). Precision errors result from the inability of a given laboratory to make precise, repeatable measurements and are caused by factors such as calibration drift in the equipment used to perform the measurements, stability of the environment, faulty cables and standards, and nonrepeating operator errors. In reviewing the Youden diagrams, laboratories whose measurements are primarily influenced by precision errors will have data points which fall into the upper left and lower right quadrants and will be far from the 45 degree tangent line. On the other hand, laboratories whose data point does fall along the 45 degree tangent line have performed repeatable measurements which are primarily influenced by bias errors caused by inherent

biases in the standards and procedures employed. In either case, the magnitude of the total measurement error can be ascertained from the distance between a laboratory's data point and the NIST data.

In general, an analysis of the Youden diagrams yields the conclusion that most of the measurements performed by the seven RHMAP participants were in good agreement with NIST. Table 2 shows the number of participants which performed measurements which were within 1% RH of NIST for each of the two transfer standards at the nominal 20% RH, 50% RH, and 80% RH setpoints.

	20% CM	20% PSY	50% CM	50% PSY	80% CM	80% PSY
Number of participants within $\pm 1\%$ RH of NIST	6	5	6	6	6	6

Table 2. Youden Analysis Summary - Seven Total Participants

Although the participants seem to be in good agreement with NIST when compared against the measurements obtained with each transfer standard individually, there is an indication of precision errors in the intercomparison process which may be attributable to operator error in the setup and use of the transfer standards.

This is most evident in the psychrometer data where most of the participant values are lower than those obtained by NIST. This can be attributed to the flow dependency of the psychrometric measurements and deviations from the specified procedure. The RHMAP participants were instructed to seal off their calibration chambers in order to insure that all of the calibration gas flowed through the psychrometer and did not escape through the chamber vent and ports. If the chamber was not properly sealed, then the flow rate through the psychrometer would be substantially lower than the specified 100 SLPM. Since the maximum wet-bulb depression is a function of the rate of ventilation, a flow rate which is exceedingly low would result in a high relative humidity reading from the psychrometer [5]. Other factors which may have caused a bias in the psychrometer readings for some participants include incorrect inputting of the barometric pressure and differences in the purity of the distilled water used to wet the wick. The most extreme examples of this type of bias error is exhibited in the Lab G data.

Although not as pronounced, a similar situation was also noticed in the chilled mirror data. Again, it is evident that a bias exists between the participant readings and the NIST readings which resulted in most of the participant's datapoints being above the NIST data on the Youden diagrams. In this case however, it is less apparent that a systematic flaw in the inter-comparison process resulted in the bias. This is due to the fact that the accuracy of the chilled mirror hygrometer readings are virtually independent of barometric effects [6] and flow considerations. Instead, the large deviations with respect to

NIST which were exhibited by Lab E and Lab D can be attributed to operator error in the use of the chilled mirror hygrometer.

CONCLUSIONS

The first round of the NCSL sponsored relative humidity measurement assurance program shows good agreement among the participating facilities and the NIST. Eighty of the 102 measurements performed with the two transfer standards at the three nominal setpoints were within $\pm 1\%$ RH of the NIST data and no participant's data point deviated from the NIST datapoint by more than $\pm 2.2\%$ RH.

Youden diagrams were used to graphically display the first round RHMAP data. Based on the information contained in these plots, it was possible to assess the measurement errors in each of the seven participating centers' relative humidity calibration systems and procedures. An indication of the participant's total measurement error may be ascertained from the distance between a participant's data point and the NIST datapoint. The significance of these measurement uncertainties is left to each center to evaluate. Any center whose calibrations did not fall within $\pm 1\%$ RH of the NIST datapoint and the 3σ uncertainty circle should review this data and determine if their calibration capabilities satisfy their center's requirements. An exception to this can be made for participants who obtained good results with one transfer standard, but not with the other. In these cases, it is possible that the RHMAP procedure was not properly adhered to and systematic biases resulted during the calibration process.

In the future, efforts will be made to minimize the effects of bias errors in the intercomparison process. These will include assurance that the RHMAP participants are thoroughly familiar with the use of the transfer standards, better control of the distilled water that is utilized in the electronic psychrometer, and a more detailed datasheet in order to better monitor the transfer standards.

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RHMAP PSYCHROMETER COMPARISONS AT 20 % RELATIVE HUMIDITY

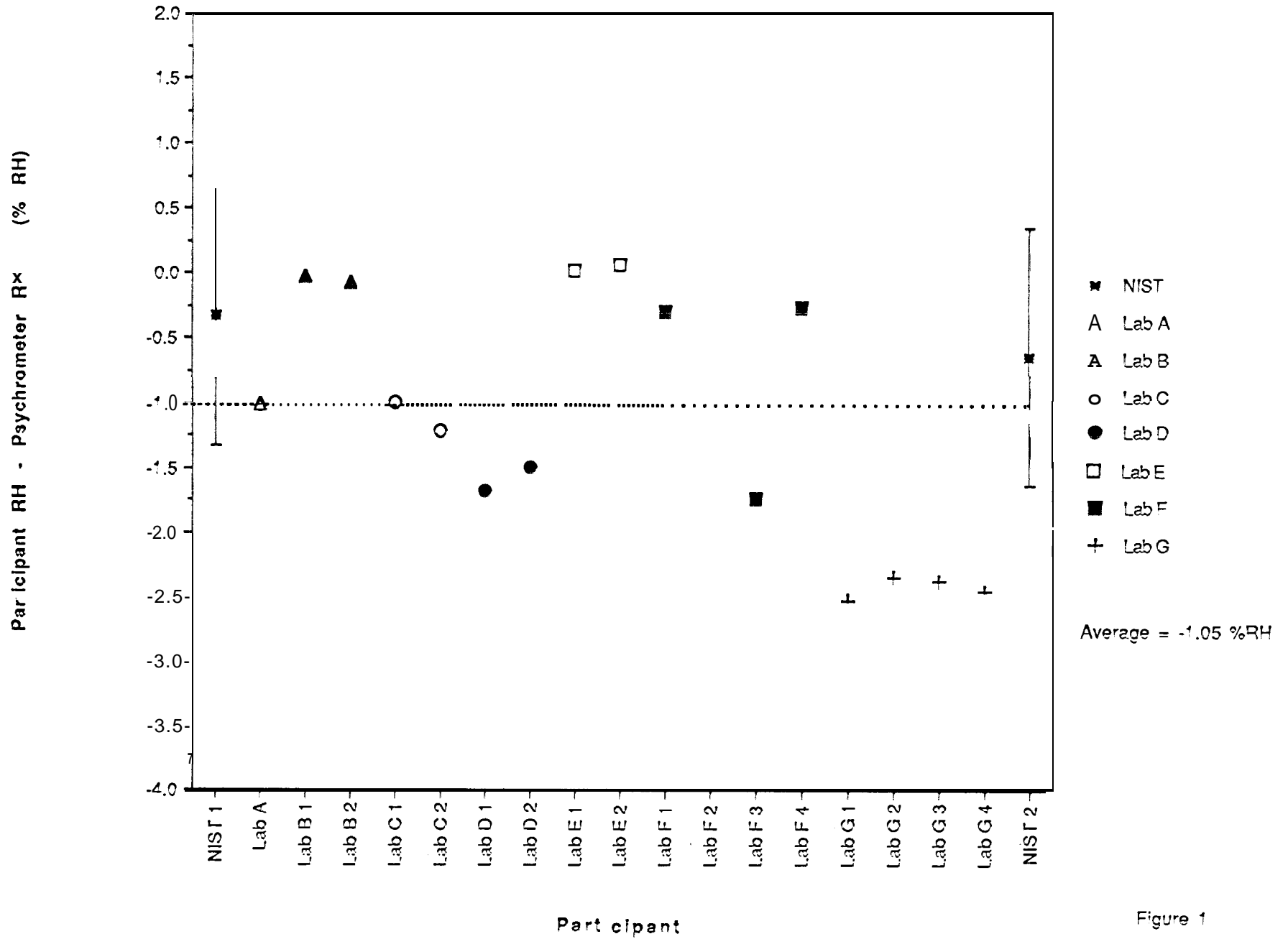


Figure 1

RHMAP CHILLED MIRROR COMPARISONS AT 20 % RELATIVE HUMIDITY

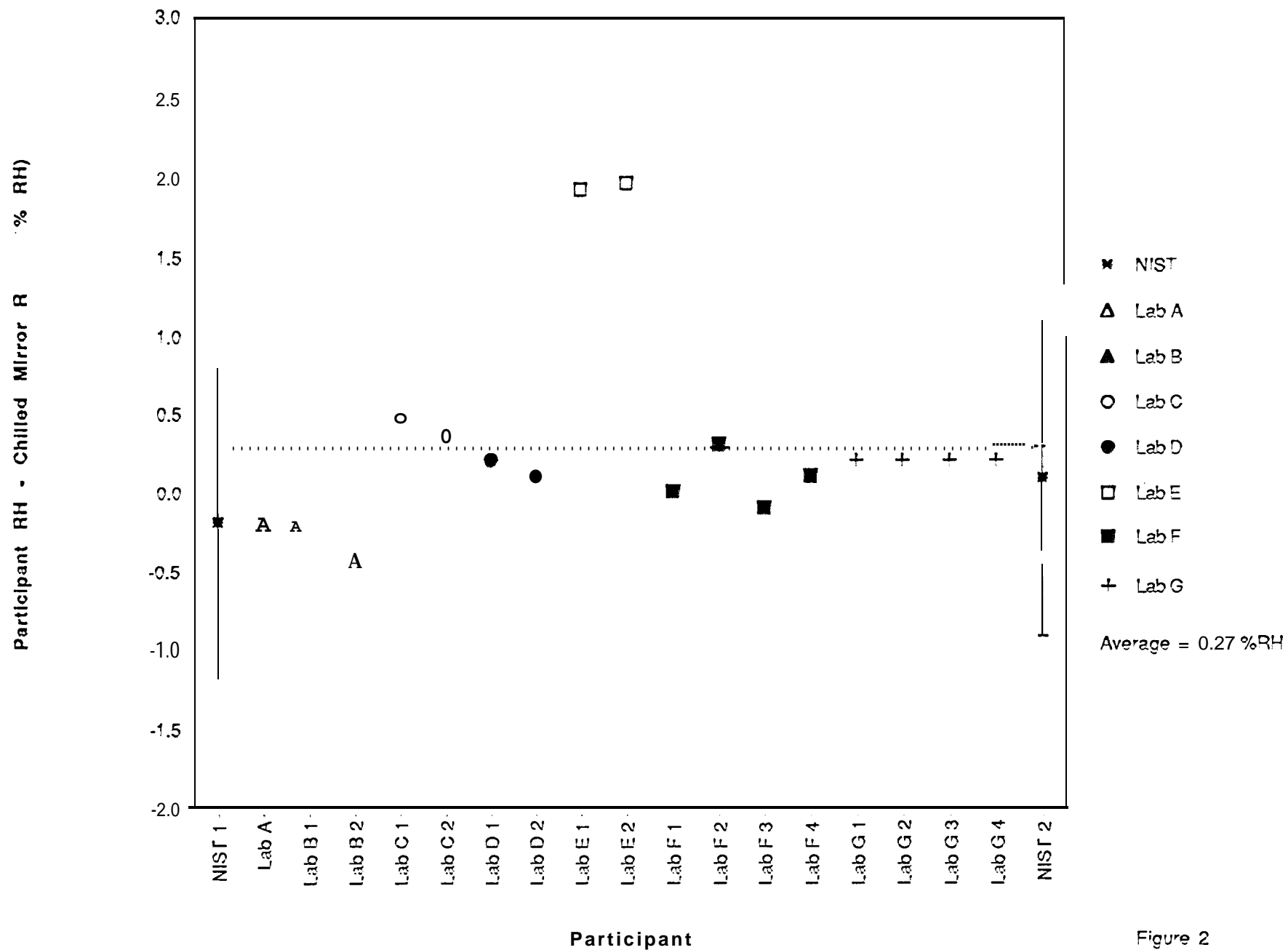
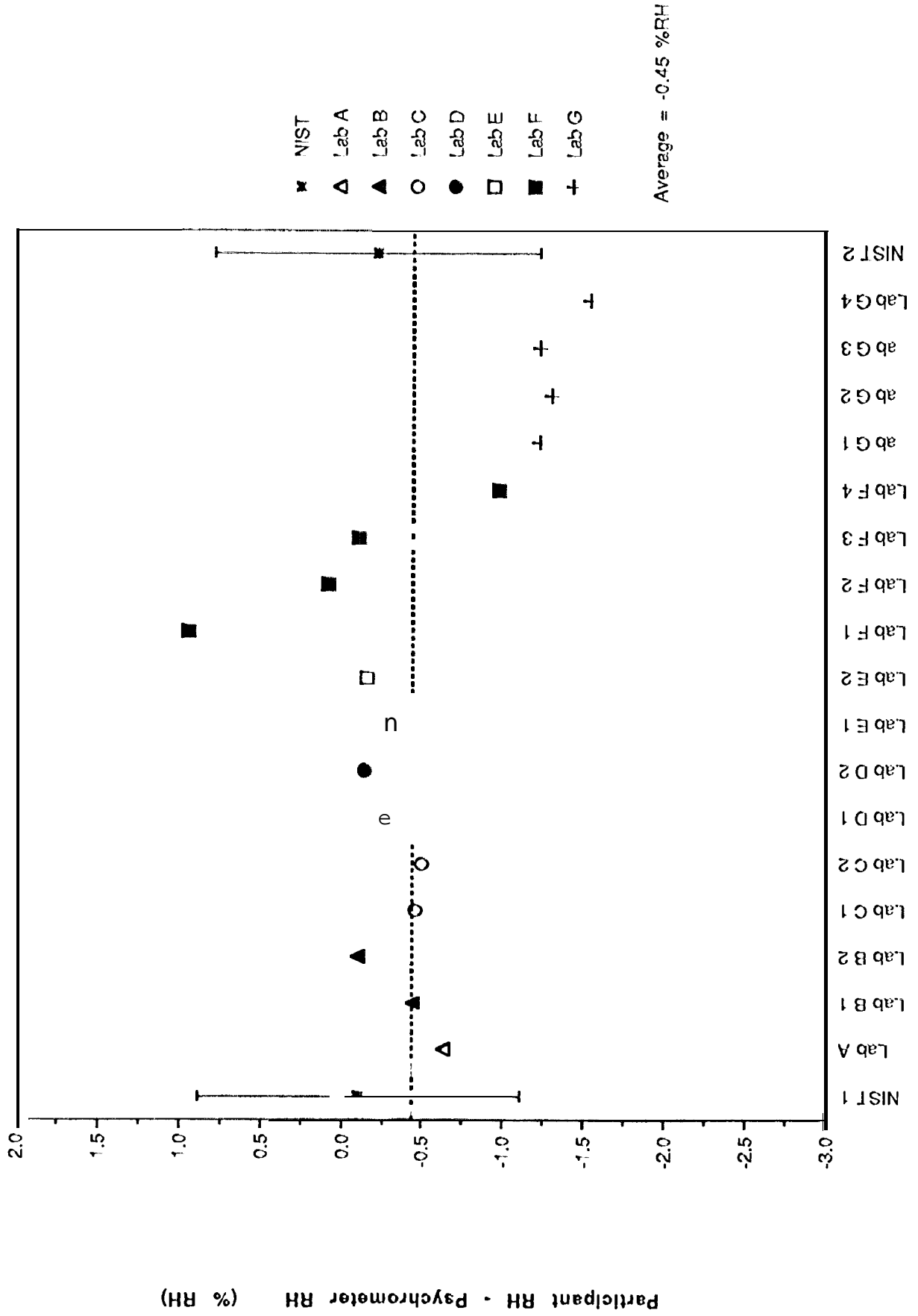


Figure 2

RHMAP PSYCHROMETER COMPARISONS at 50 % RELATIVE HUMIDITY



RHMAP CHILLED MIRROR COMPARISONS AT 50 % RELATIVE HUMIDITY

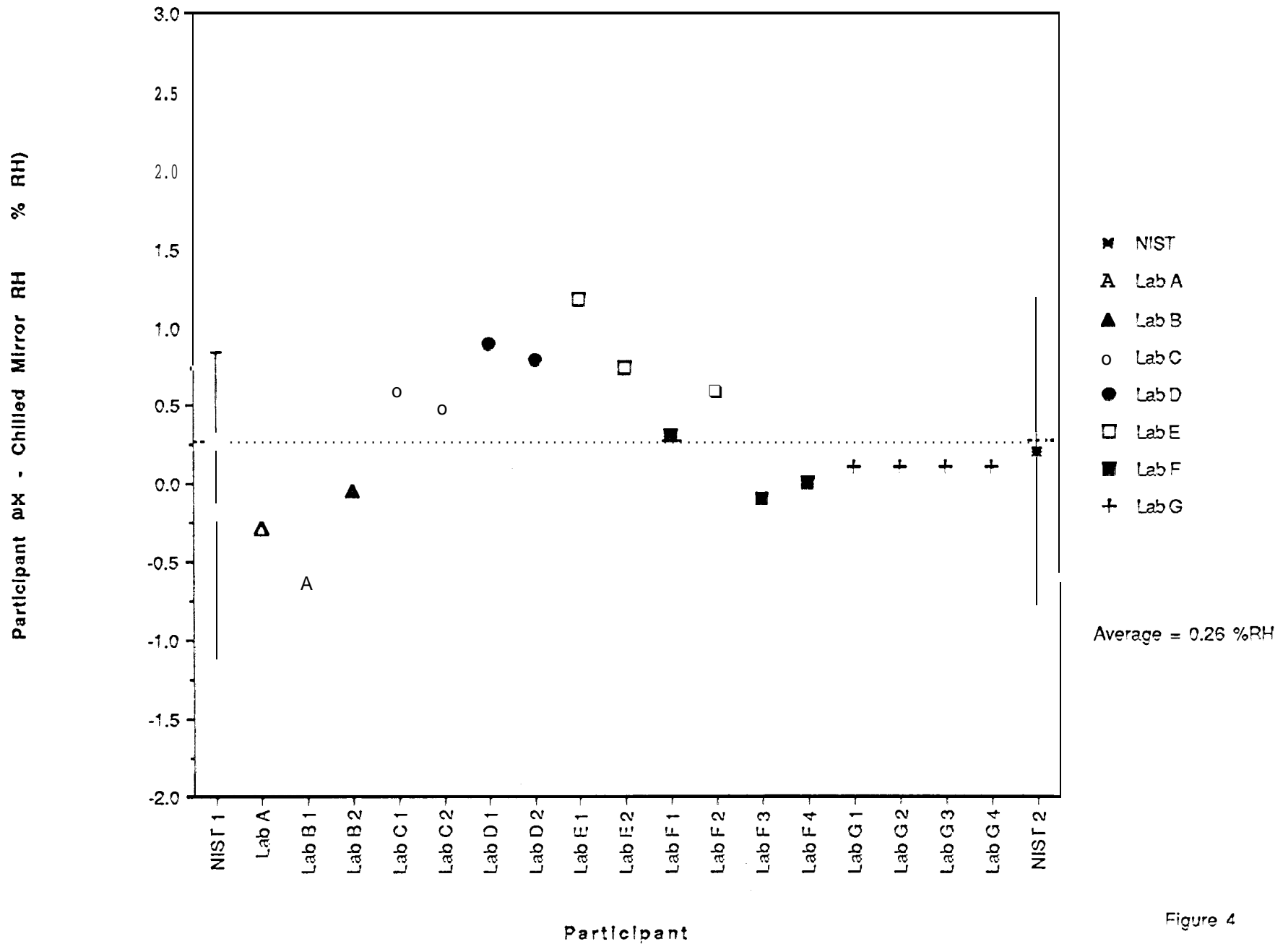
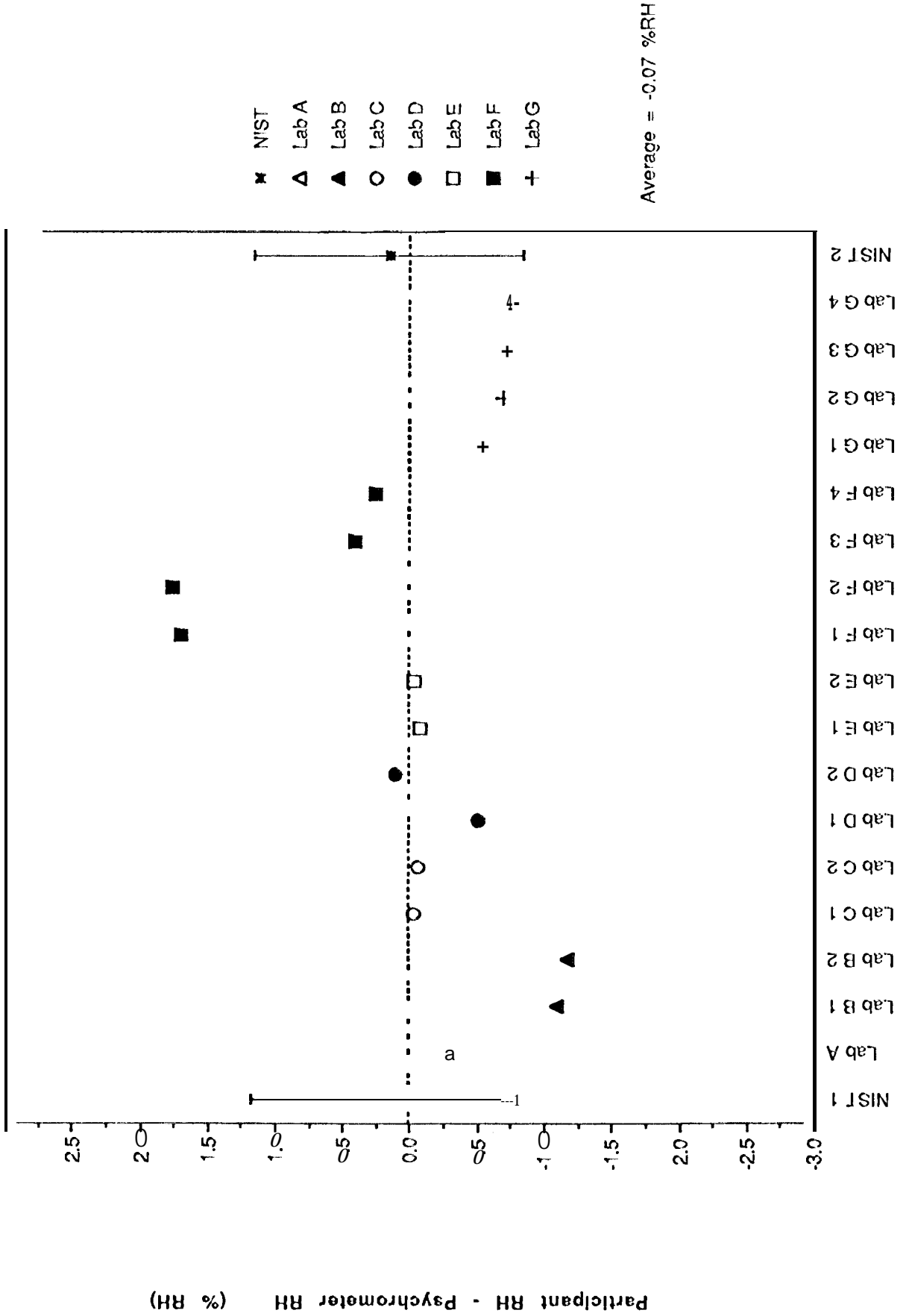


Figure 4

RHMAP PSYCHROMETER COMPARISONS AT 80 % RELATIVE HUMIDITY



RHMAP CHILLED MIRROR COMPARISONS AT 80 % RELATIVE HUMIDITY

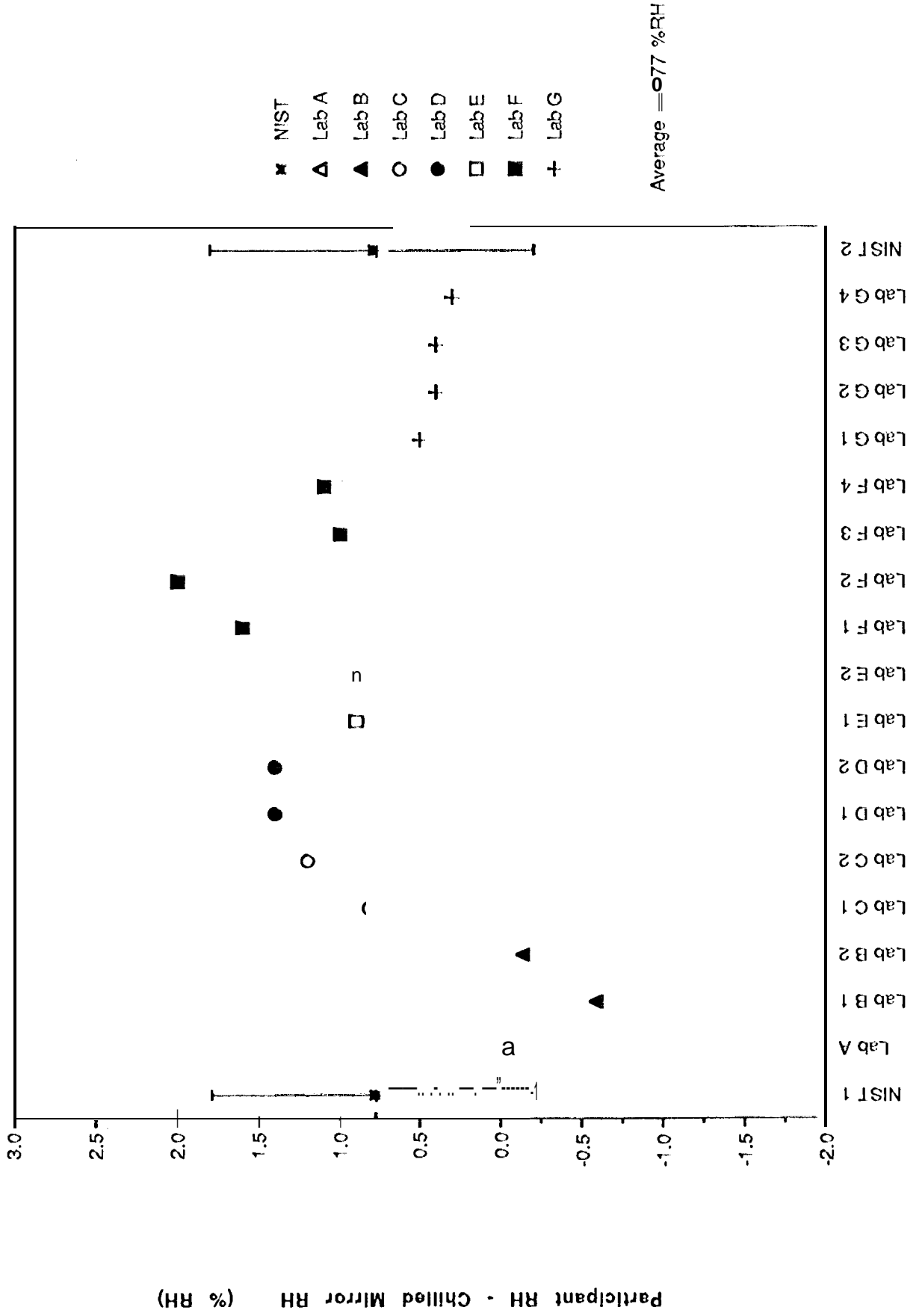


Figure 6

Part cipant

RHMAP YOUTDEN DIAGRAM AT
20% RELATIVE HUMIDITY

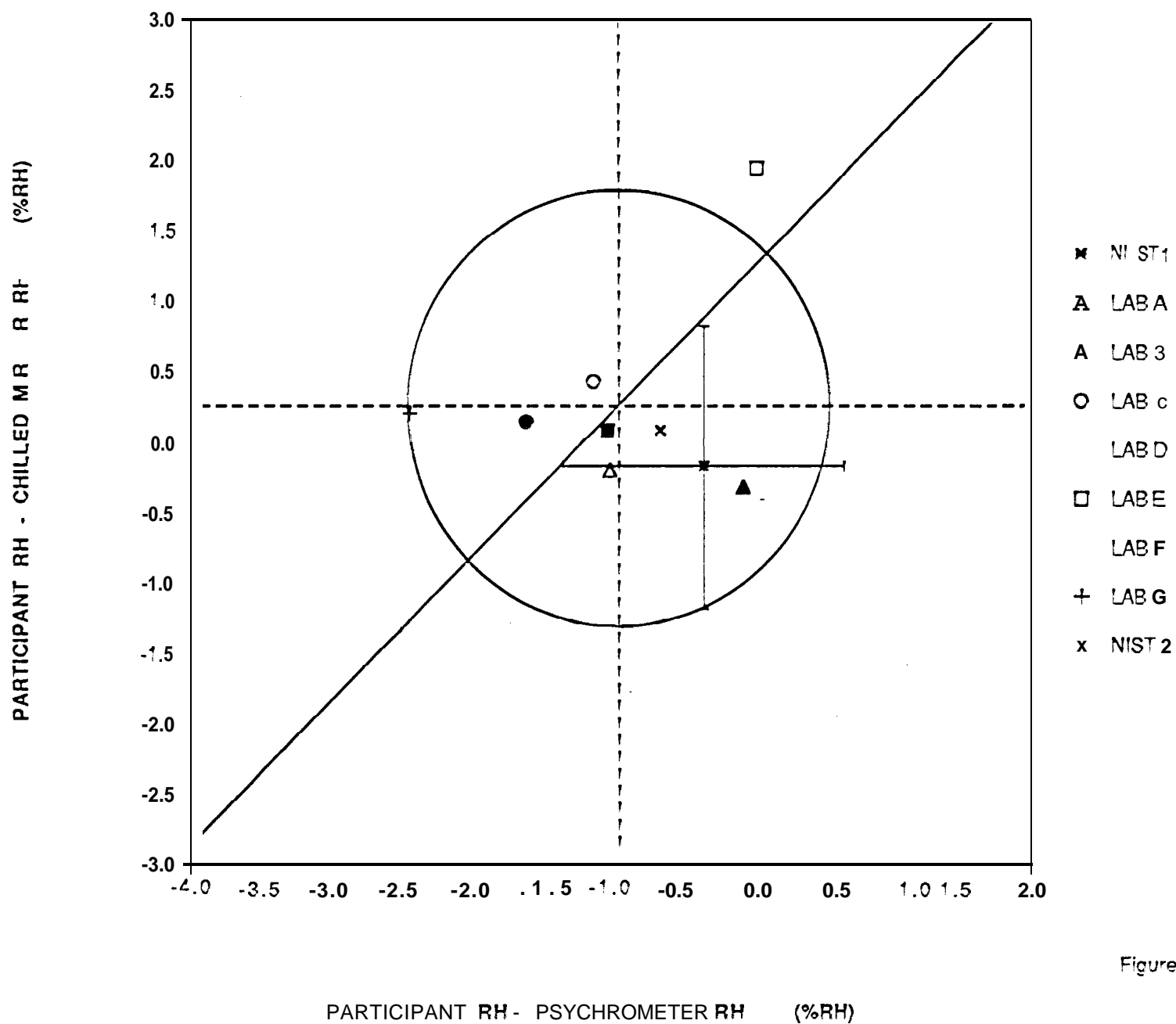


Figure 7

RHMAP YOUTDEN DIAGRAM AT
50% RELATIVE HUMIDITY

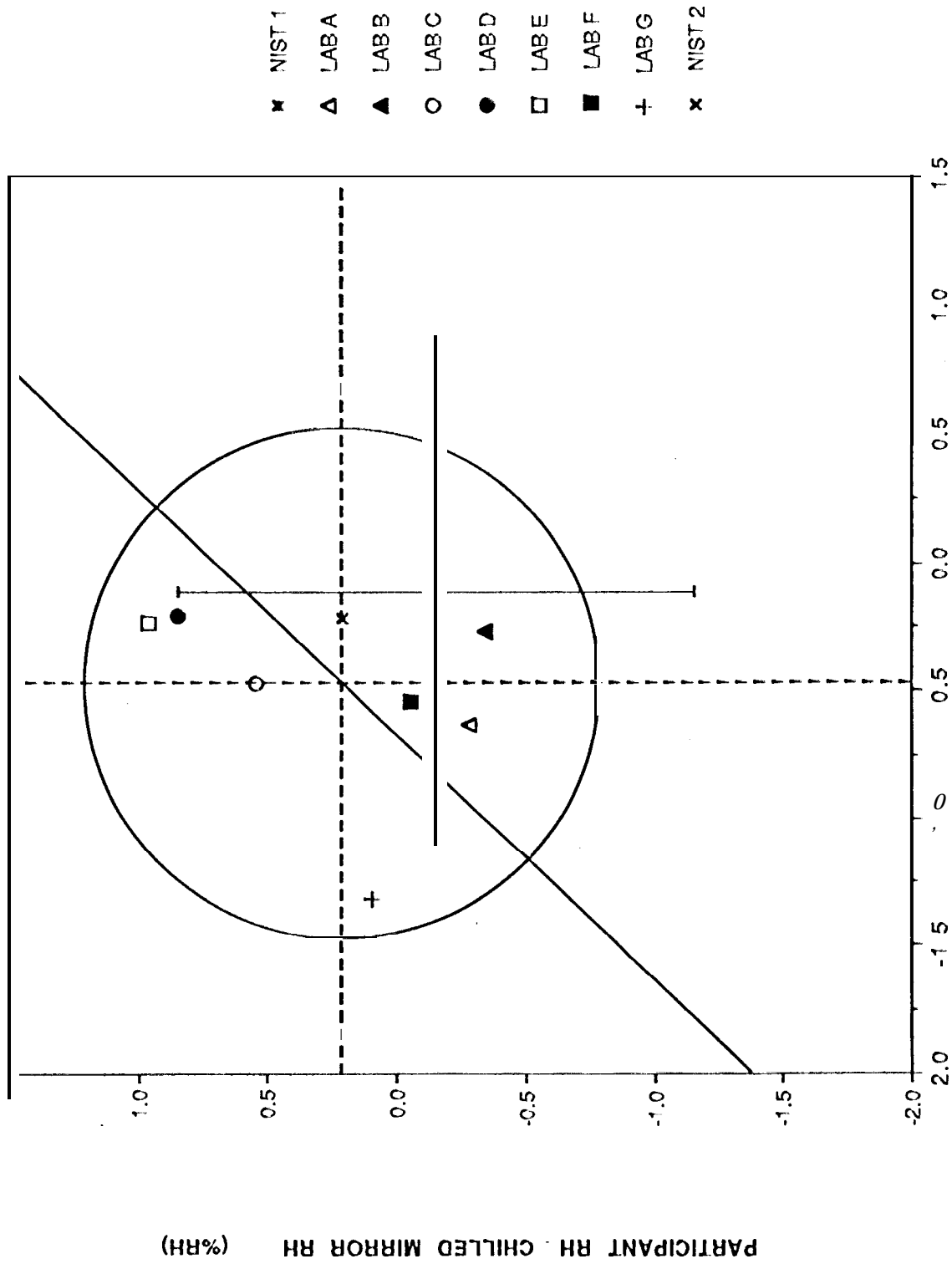
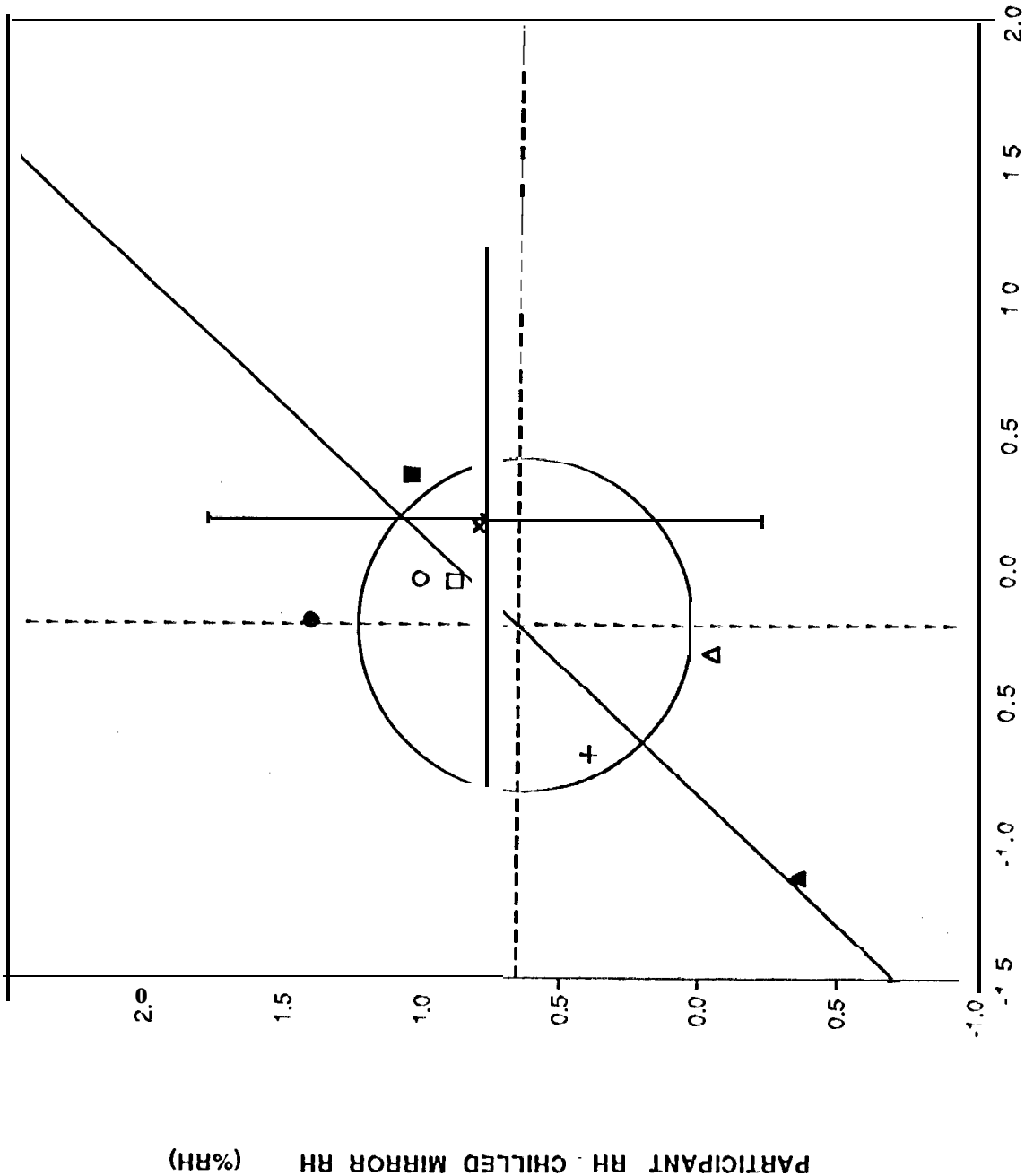


Figure 8

PARTICIPANT RH - PSYCHROMETER R (%RH)

RHMAP YOUDEN DIAGRAM AT 80% RELATIVE HUMIDITY



- x NIST1
- △ LAB A
- ▲ LAB B
- LAB C
- LAB D
- LAB E
- LAB F
- + LAB G
- x NIST2