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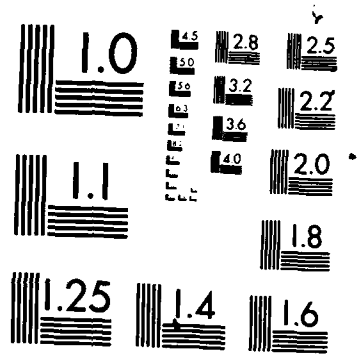

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REPORT NO. T13/86

AN AIR TUNNEL TO ENHANCE RELIABILITY OF THERMOHYGROMETER INSTRUMENT READINGS

US ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE
Natick, Massachusetts

MAY 1986

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1. REPORT NUMBER T13/86	2. GOVT ACCESSION NO. AD-A172	3. RECIPIENT'S CATALOG NUMBER 654
4. TITLE (and Subtitle) An Air Tunnel to Enhance Reliability of Thermohygrometer Instrument Readings		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James A. Devine and Jose A. Miletti		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Research Institute of Environmental Medicine, Natick, MA 01760		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 3M161102BS10 64682101002
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Research Institute of Environmental Medicine, Natick, MA 01760		12. REPORT DATE May 1986
		13. NUMBER OF PAGES 28
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

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An air tunnel has been designed that will control air velocity passing thermohygrometer temperature/humidity air probes thereby improving accuracy and reliability of readings. The air tunnel produces a constant air velocity passing a sensing probe to create stable, accurate measurements in areas where air movement is classified as "low to stagnant" (0-50 m/sec, 0-100 ft/min). Measurements of temperature and relative humidity using a thermohygrometer may vary significantly depending on how data are being collected (static, swinging or air-tunnel probe). Static probe is unreliable because the measuring circuit

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) has an electrical current that heats the sensor causing readings to be above ambient in relative humidity. Erratic readings produced by swinging the probe in order to cancel the heating effects are attributable to user techniques and variable air velocities. Responsiveness, accuracy, and reproducibility of measurements are consistently improved by using the air tunnel.

AN AIR TUNNEL TO ENHANCE RELIABILITY OF THERMOHYGROMETER INSTRUMENT READINGS

JAMES A. DEVINE

JOSE A. MILETTI

FOREWARD

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ABSTRACT

An air tunnel has been designed that will control air velocity passing thermohygrometer temperature/humidity air probes thereby improving accuracy and reliability of readings. The air tunnel produces a constant air velocity passing a sensing probe to create stable, accurate measurements in areas where air movement is classified as "low to stagnant" (0-50 m/sec, 0-100 ft/min). Measurements of temperature and relative humidity using a thermohygrometer may vary significantly depending on how data are being collected (static, swinging or air-tunnel probe). Static probe is unreliable because the measuring circuit has an electrical current that heats the sensor causing readings to be above ambient in temperature and below ambient in relative humidity. Erratic readings produced by swinging the probe in order to cancel the heating effects are attributable to user techniques and variable air velocities. Responsiveness, accuracy, and reproducibility of measurements are consistently improved by using the air tunnel.

INTRODUCTION

An air tunnel has been designed that will control air velocity passing temperature/humidity air probes of thermohygrometer instruments thereby improving accuracy and reliability of readings. The prototype air tunnel was designed and constructed using cast acrylic resin (Fig. 1).

The air tunnel is an upright cylinder (Fig. 2) containing an installed boxer fan (Pamoter 4600X) located in the lower section and mounted in the inverted position to direct a downward flow of air. A supporting collar, designed to contain an instrument's temperature/humidity probe (Fig. 3), is mounted in the upper cylinder section. Supporting collars may be interchangeable to accommodate different size probes. For this evaluation, a thermohygrometer instrument (Wallac EP-400) was used although the applicability extends to all temperature/humidity measuring instruments requiring constant air movement for optimal performance. Probe support is located above the fan so as not to be subjected to temperature increases produced by the fan operation.

Four holes (3.8 cm) bored into the cylinder base allows for exhaust air. Perpendicular supports are fastened to the cylinder sides and base for stability. Power is supplied to the boxer fan from a variable autotransformer (Staco 2PF1210) for control of fan speed and hence air movement through the tunnel. Air velocity is necessary to achieve optimum instrument performance. An anometer (Davis MD-62-B-80) was used to measure air velocity as prescribed by the Wallac operating manual for its optimum performance.

PRINCIPLE OF OPERATION

The air tunnel is designed to produce a constant air velocity passing a sensing probe to create stable, accurate measurements. Rapid and accurate response of sensing probes lies in the control of air velocity. In still air, insufficient heat transfer results in either failure of the probe to achieve equilibrium with the ambient environment (temperature/humidity) or, at best, protracted equilibrium. Self-heating of the probe's electronic element appears to be the cause of this performance deficiency by radiating an envelop of heat away from the sensor.

The air tunnel provides the essential element of constant air velocity to enhance reliability of the temperature/humidity measurements in areas where air movement is classified as "low to stagnant." Such areas as environmentally controlled rooms, air-conditioned testing laboratories and computer facilities, large open bays or storage rooms, and office building spaces, have been classified as "low-stagnant air places" (1). Low air velocity could generally be described as the movement of air which results in human comfort with a "comfort index" being 0.13-0.25 m/sec (25-50 ft/min. fpm). Air velocities less than 0.50 m/sec (100 fpm) do not cancel the effect of self-heating in the temperature probe. The air tunnel then, was designed for use with thermohygrometer/sensors where general air velocities are below 0.50 m/sec.

PROBLEM IDENTIFICATION

In principle, thermohygrometer's response times to accurate readings of temperature and relative humidity are directly proportional to air velocities up to 2 m/sec, above which readings will become unreliable without a shield over the probe (2). The temperature measuring circuits have an electrical current through the sensor causing a self-heating reading of 1-2°C above ambient. According to instructions that accompany such instruments, the probe must be swung back and forth creating an airstream of at least 0.50 m/sec to cancel this effect. In still air, relative humidity (RH) readings are also rendered questionable since they are an integral part of the same temperature-compensated electrical bridge. A suitable air velocity range for measuring relative humidity is 0-2 m/sec. Reaction time constants for accurate readings depend on the magnitude of humidity change. The 90% values can be achieved within 1-3 min for small humidity changes, 3-6 min for greater humidity changes, and 6-20 min for great humidity changes in still air. To speed up reaching the balance, the air probe is moved evenly back and forth until the meter reading reaches a stable balance. Uneven or fragmentary moving hinders the reaching of a balance.

In order to achieve efficiency, accuracy, and rapid response, the probe must be subjected to a constant air velocity. But is swinging the probe going to provide a steady, constant air flow for reliable readings? How rapidly and in what manner must the probe by swung to achieve an air velocity of 0.5 m/sec? What exactly is "uneven or fragmentary" movements and how much of an adverse effect do they have on reliable readings? These are specific questions that impact on the reliability of data when using a thermohygrometer air probe to measure temperature and relative humidity while in a static or swinging mode.

EXPERIMENTAL DESIGN AND METHODS

This study was undertaken because it seemed likely that replacing the variabilities caused by user techniques with a controlled air flow would significantly improve both the response time and accuracy of thermohygrometer readings.

The investigative plan was to evaluate the response, control and accuracy of thermohygrometer temperature and relative humidity measuring circuits using static probe, swinging probe, and probe inside the air tunnel. The environmental test conditions were as follows:

Condition 1 - Comparison of temperature data from thermohygrometer instrument against reference psychrometer in an ambient temperature;

Condition 2 - Same as Condition 1 except for initial exposure of probe to $5^{\circ}C$ prior to rapid transfer (< 3 sec) and evaluation at ambient temperature;

Condition 3 - Same as Condition 1 except response to ambient humidity, rather than temperature, was evaluated;

Condition 4 - Same as Condition 3 except for rapid transfer of probe from 100% relative humidity to ambient humidity.

All tests were conducted in an environmentally-controlled chamber. The study objectives were to evaluate which method of measurement (static probe, swinging probe, air-tunnel probe) produces the most rapid response, demonstrates optimal control (less erratic performance, or null point oscillations), and yields the greatest accuracy in terms of sensitivity to reference temperatures and humidities. The apparatus used for test measurements can be seen schematically in Figure 4. Measurements using the test thermohygromter and reference control motorized psychrometer were recorded at 1-min intervals while the duration of data collected ranged form 10-20 min. During test Condition 4 (100% RH to ambient humidity), four test subjects were used to examine individual variabilities in swinging the probe. Prior to testing, each individual was given the following instructions: "You have purchased an instrument to measure temperature and relative humidity in your laboratory experiments; read the instructions presented in the instruction manual very carefully, and then proceed to collect data using the air probe." Air velocities in the air tunnel were controlled at 1 m/sec for temperature and relative humidity experiments.

Reference temperatures and humidities were measured with a dry/wet bulb motorized psychrometer. Fluctuations seen in the psychrometer readings are the inherent control loops observed in the test chamber's environmental control system. These oscillations were viewed as having a positive impact on the data collection, since it allows for a comparison of the air probe sensitivity in tracking temperature and humidity to those of the motorized psychrometer. In some of the graphs there is a slight difference in the readings between the thermohygrometer and motorized psychrometer that could be attributed to minor calibration drifts. This has no effect in terms of the study design of evaluating the thermohygrometer's response, stability and sensitivity. Relative humidity values were obtained from psychrometric tables and charts (3), using dry bulb psychrometer readings at standard atmospheric pressure (760 Torr). Jennings (1) states that errors are introduced in computing psychrometric readings under varying barometric pressures. The error is not serious for small variations less than an inch of mercury (1 in Hg = 25 Torr). Since all data were recorded within those confines, it was not necessary to calculate the effect of ambient barometric pressure on psychrometer readings, but only to annotate the barometric pressure during each of the four experimental conditions in which the three testing procedures were employed (static probe, swinging probe, and air-tunnel probe).

EXPERIMENTAL RESULTS

CONDITION 1: Data for this condition were collected for only a 10-min period since probe measurements at ambient temperature do not require lengthy reaction times. In Figure 5A, the effect on the static probe of the 1-2°C self-heating circuit can be seen. Note that the thermohygrometer readings were constant throughout the 10-min period but are consonant with the reference psychrometer readings. Although swinging the probe (Figure 5B) does show a closer correlation to the reference temperature due to air movement, its erratic performance can be traced to user technique and resultant variable air velocities. When the probe is inserted into the air tunnel (Figure 5C) there is a more rapid response, and a greater correlation to the reference line than seen in Fig 5B.

CONDITION 2: Data were collected for 15 min to allow for stabilization of readings following transfer of the probe from a initial temperature of 5°C. Figure 6A illustrates an inordinately long (> 15 min) equilibrium period in the static mode. Figure 6B indicates that a much shorter but more erratic response is obtained with the swinging probe. Figure 6C demonstrates the same rapid response as in Figure 6B, but temperature differences are less using the air-tunnel probe position.

CONDITION 3: Data were collected for 10 min since reference control was already at ambient humidity. Figure 7A shows a large discrepancy (approximately 5% RH) between the reference psychrometer and thermohygrometer readings in the static probe position. This can be attributed to the effects of thermal expansion by the 1-2°C heating of the air immediately surrounding the probe which would cause readouts of relative humidity to be lower than ambient when the air is stagnant. In Figure 7B, the relative humidity gradient between the thermohygrometer and psychrometer is seen to alternately widen and narrow as a result of the erratic nature of the swinging probe. With use of the air tunnel, the thermohygrometer readings approximate very closely to those of the psychrometer (Figure 7C) through the 10-min period of measurement, demonstrating that optimum performance can be aligned when the air probe is subjected to a controlled air velocity.

CONDITION 4: Figure 8A shows a rapid response (less than 2 min) of the static probe to the ambient conditions. However, the 5% lower RH readings are caused by thermal expansion of the air as noted in Figure 7A. The data noted in Figures 8B, C, D, E were collected from four different individuals swinging the air probe. In each case, the response time was approximately twice as rapid as the static probe position.

Although humidity measurements were invariably lower with the swinging probe, large inter-individual variability is apparent and reflected in the erratic response. In Figure 8F the air tunnel provided a constant air velocity to produce a rapid response and correlation with the reference psychrometer readings.

SUMMARY AND CONCLUSIONS

Measurements of temperature and relative humidity using a thermohygrometer may vary significantly, depending on how data are being collected (static, swinging or air-tunnel probe). This results from an inability to achieve accuracy in measuring temperatures (1-2°C above ambient) and relative humidity (equivalent to 5% below ambient) in the static probe mode, as well as difficulties of reproducing readings while swinging the probe. The air tunnel was designed and fabricated to test the hypothesis that measuring probe accuracy and reliability can be achieved by maintaining an optimal air velocity. The data reinforce the concept that without a controlled air velocity, thermohygrometer readings are likely to be in error. The probe readings of temperature and relative humidity in the static probe are subject to errors introduced by internal heating. The erratic readings produced by swinging the probe are attributable to user techniques and variable air velocities. Experimental results confirm the hypothesis that responsiveness, accuracy, and reproducibility of a thermohygrometer measurements are consistently improved by use of the air tunnel. The applicability of the air tunnel extends beyond the Wallac Thermohygrometer tested, to all temperature/humidity measuring instruments requiring air movement for proper performance.

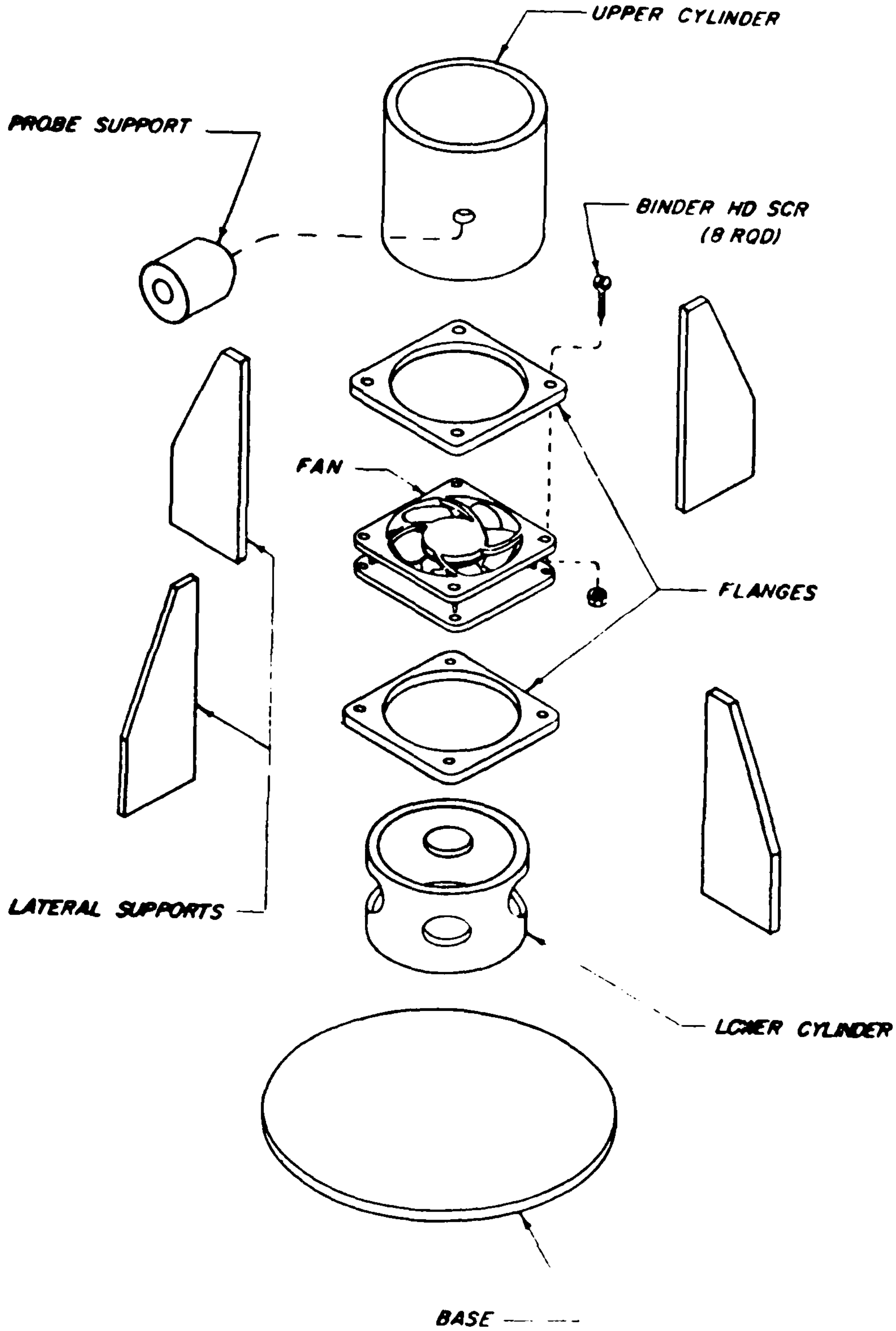

Fig. 1. Exploded view of the air tunnel showing the individual parts and their proper relationship to the unit when assembled.

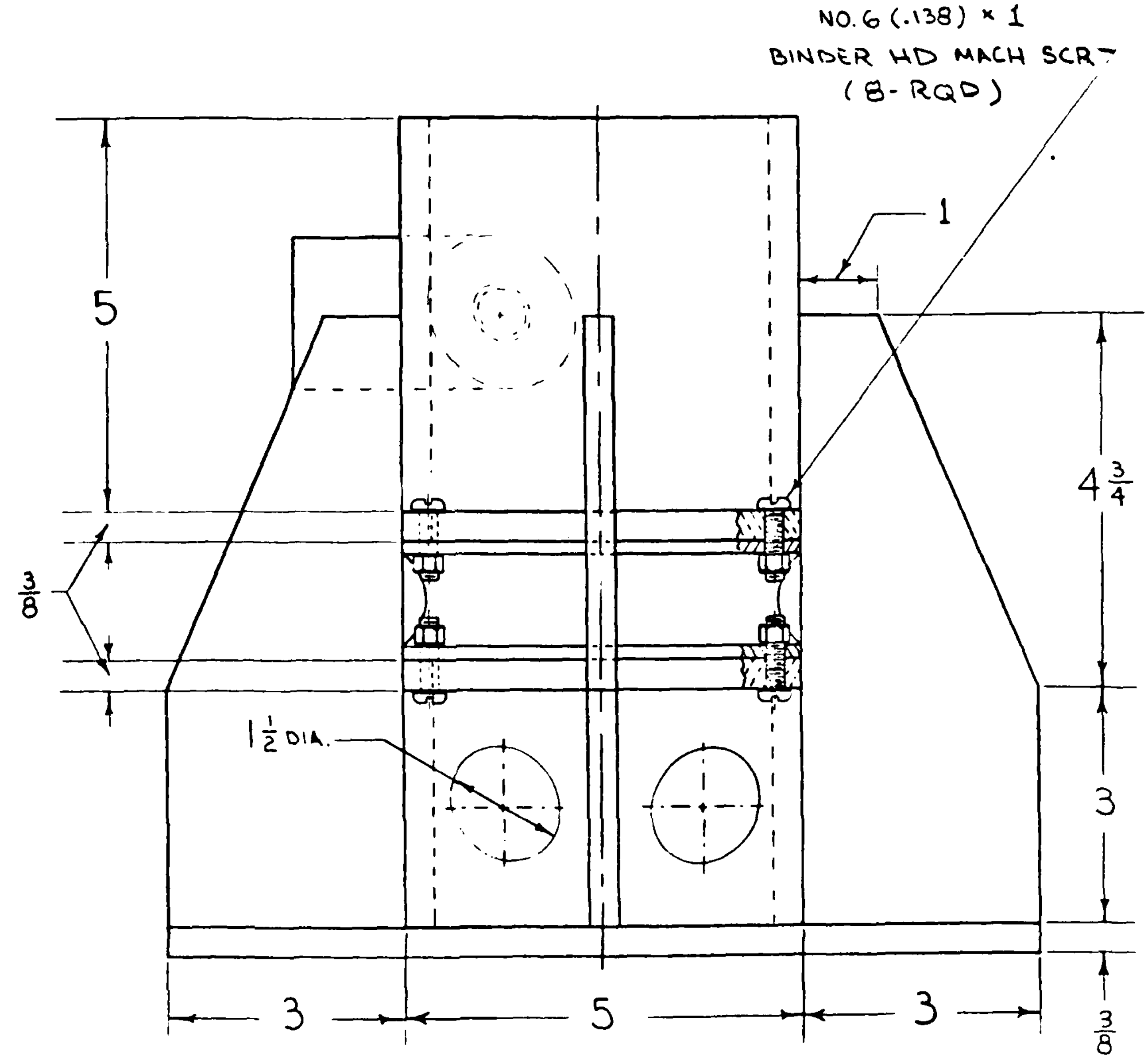

Fig. 2. Elevation plan of the air tunnel with dimensional data.

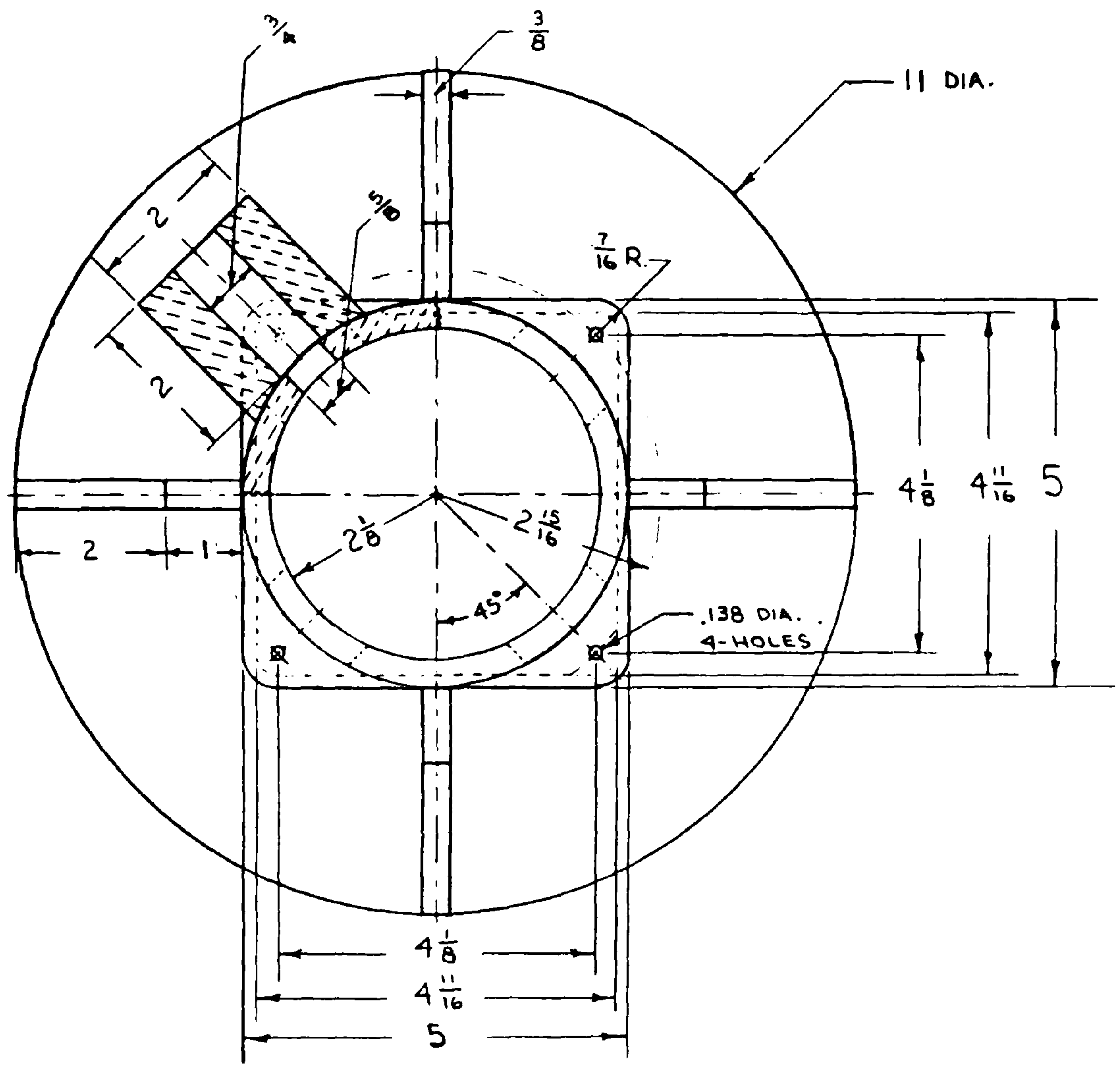

Fig. 3. Top view of the air tunnel showing thermohygrometer probe support (upper left) with dimensional data.

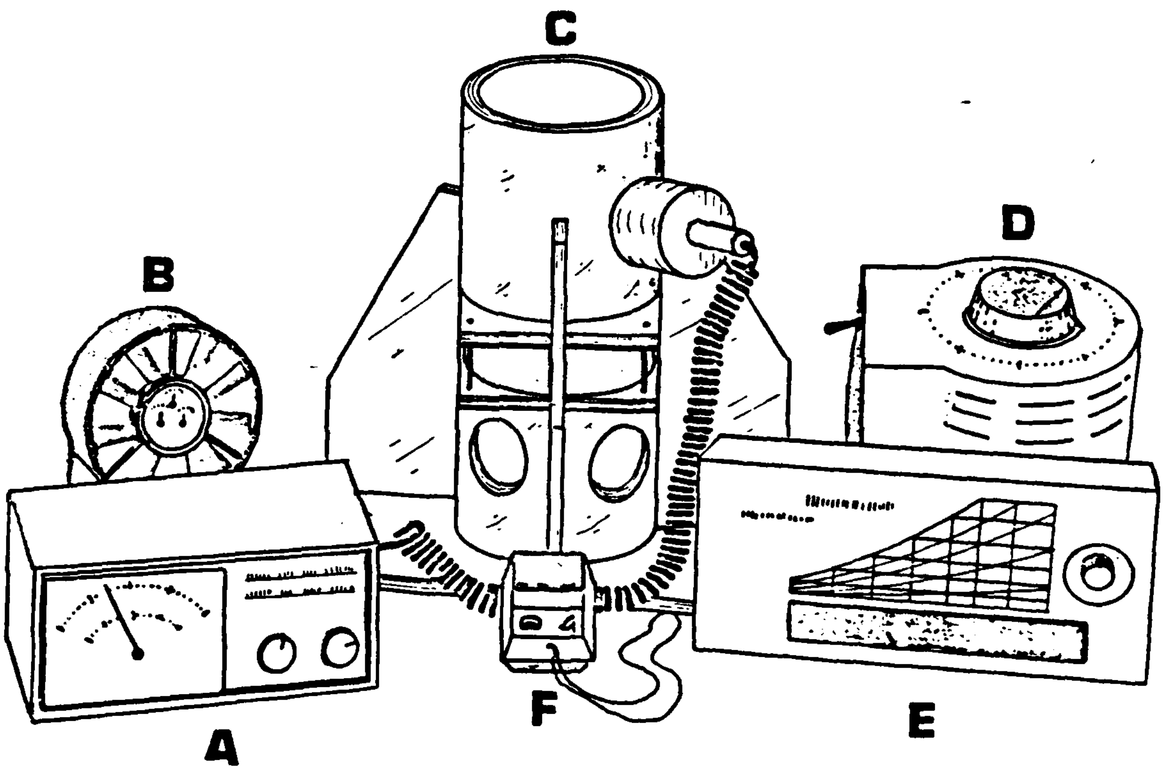

Fig. 4. Experimental set-up with item description listed; A) Thermohygrometer, B) Anemometer, C) Air Tunnel, D) Autotransformer, E) Motorized Psychrometer, and F) Digital Stopwatch.

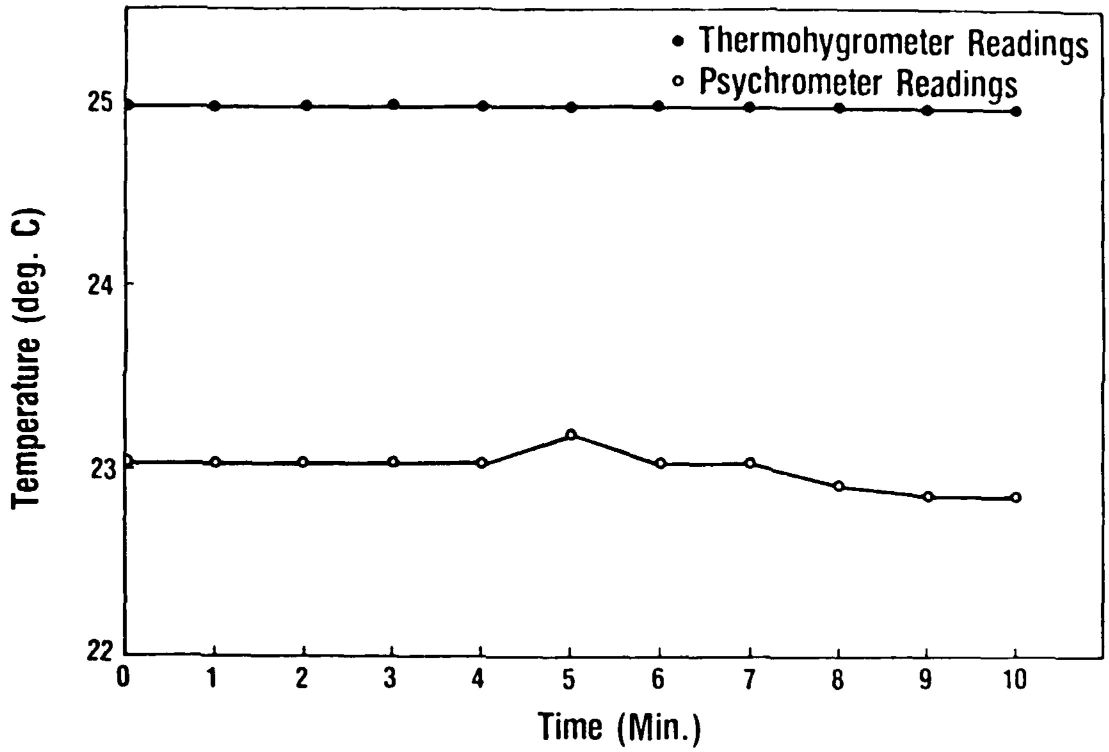

Fig. 5A. Comparison between temperature readings of psychrometer and thermohygrometer instruments for static probe at an initial ambient temperature.

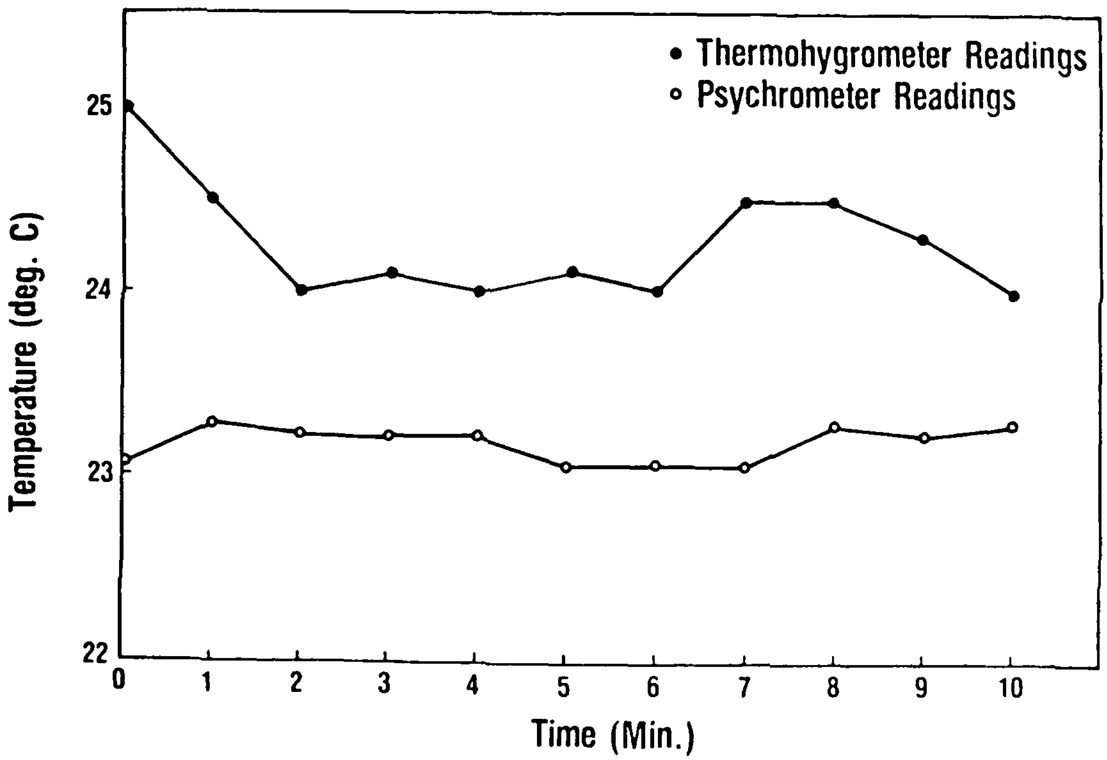

Fig. 5B. Comparison between temperature readings of psychrometer and thermohygrometer instruments for swinging probe at an initial ambient temperature.

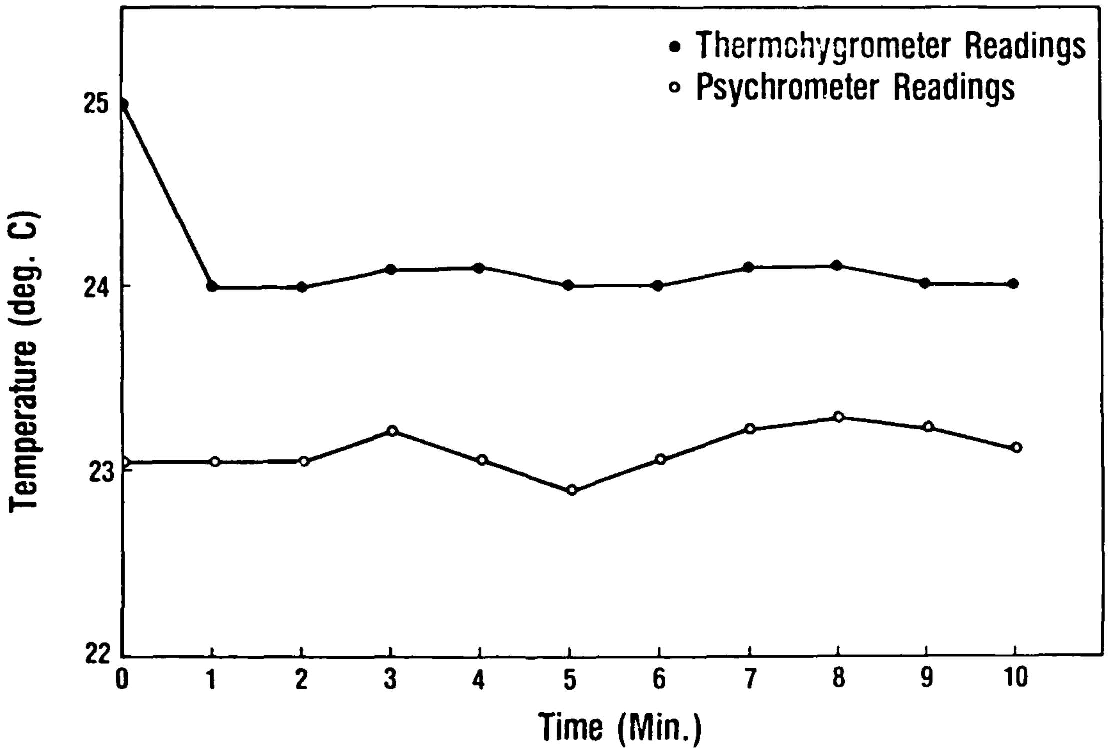

Fig. 5C. Comparison between temperature readings of psychrometer and thermoygrometer instruments for air tunnel at an initial ambient temperature.

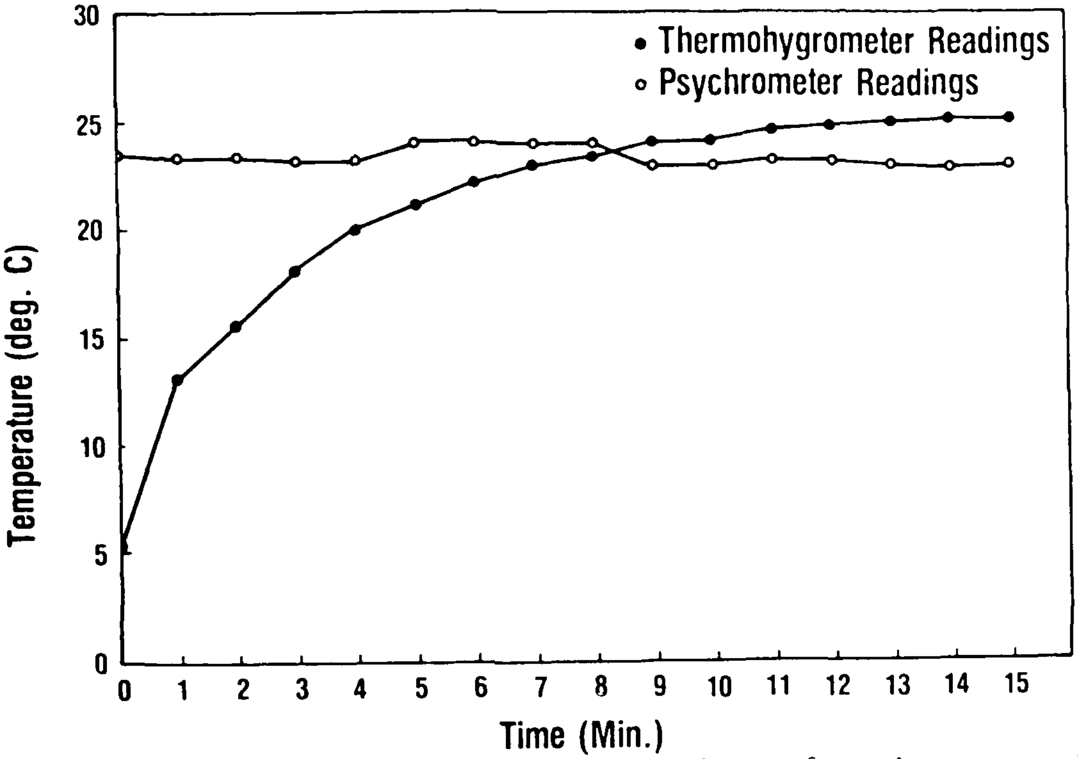

Fig. 6A. Comparison between temperature readings of psychrometer and thermohygrometer instruments for static probe at an initial temperature of +5°C.

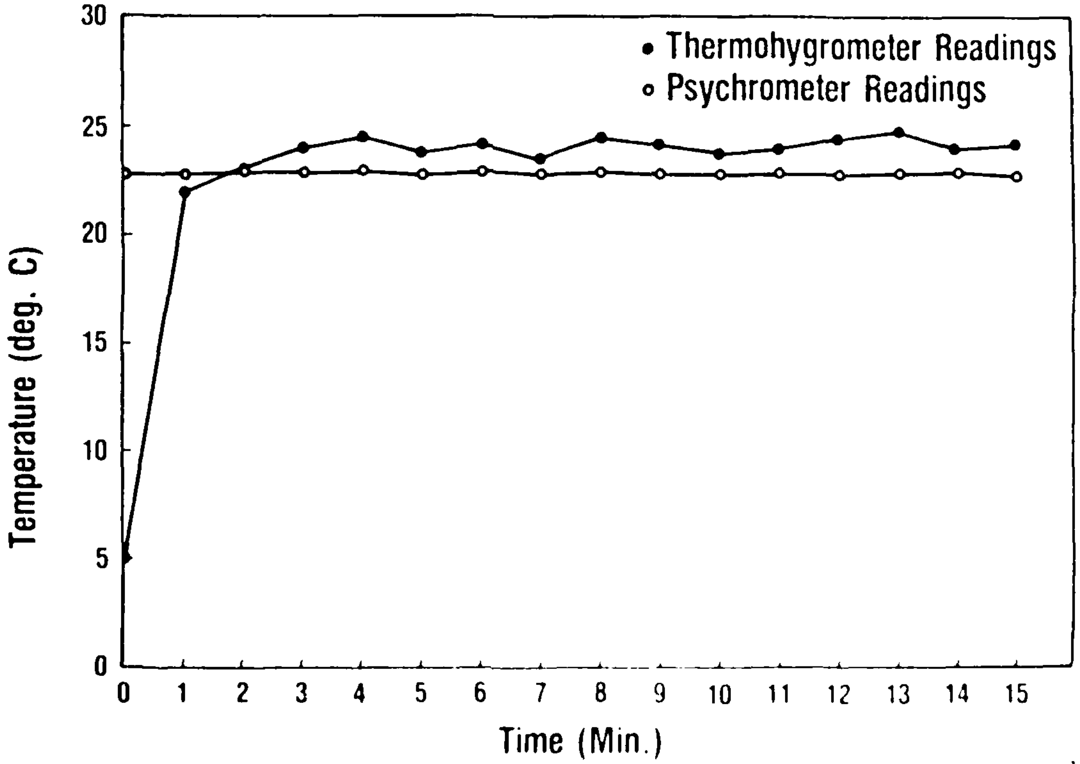

Fig. 6B. Comparison between temperature readings of psychrometer and thermohygrometer instruments for swinging probe at an initial temperature of +5°C.

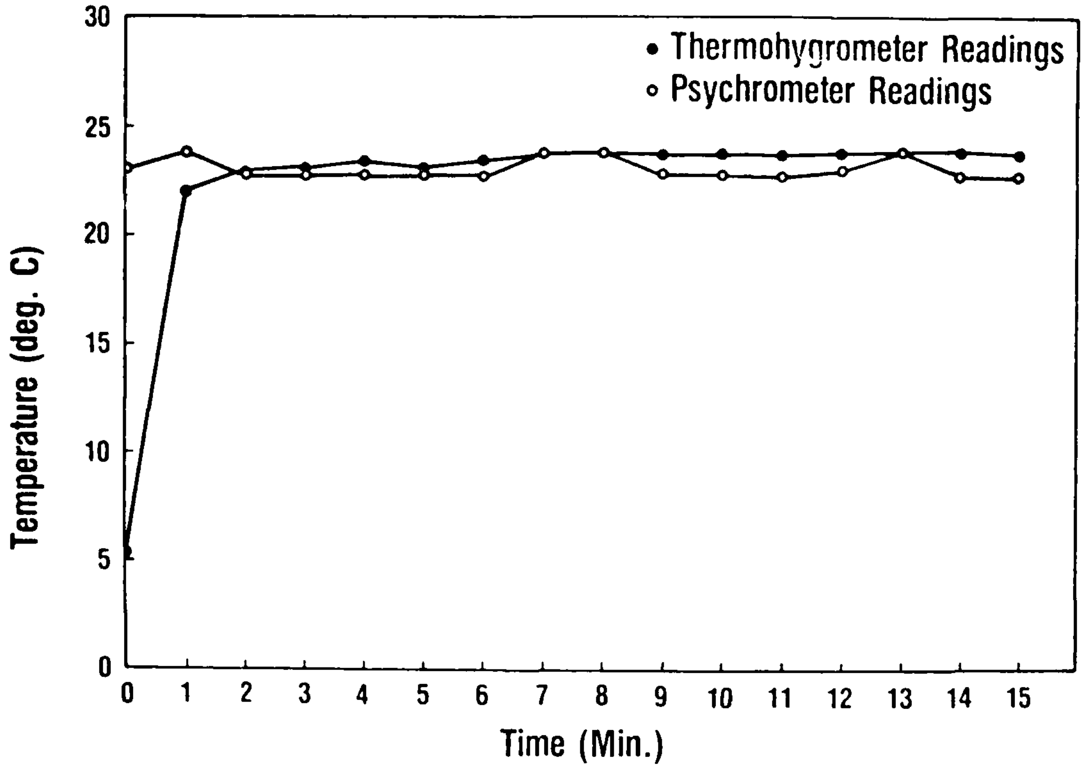

Fig. 6C. Comparison between temperature readings of psychrometer and thermohygrometer instruments for air-tunnel probe at an initial temperature of +5°C.

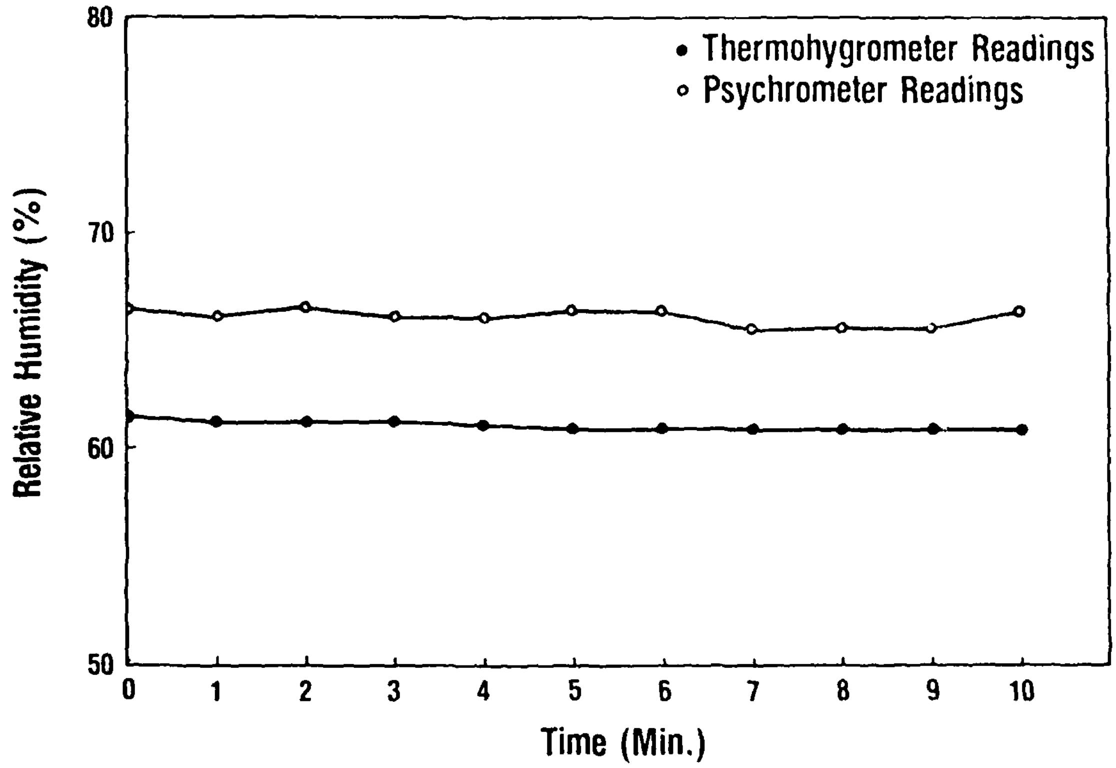

Fig. 7A. Comparison between relative humidity readings of psychrometer and thermohygrometer instruments for static probe at an initial ambient relative humidity pressure 767 Torr.

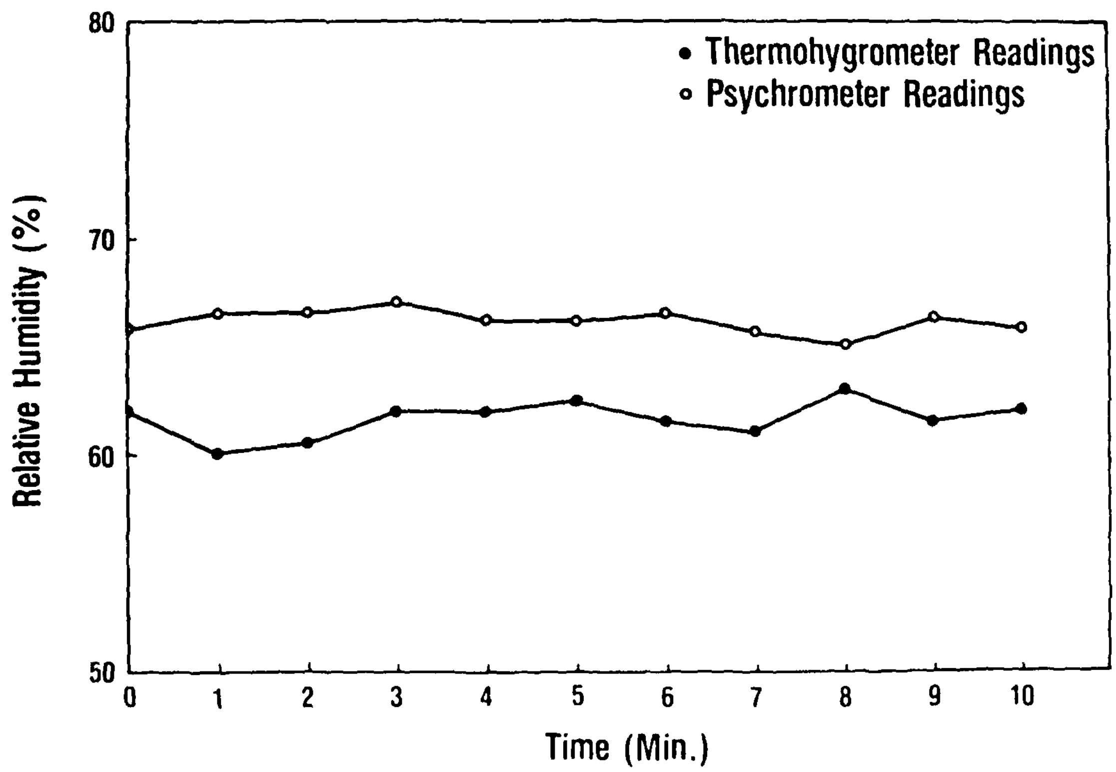

Fig. 7B. Comparison between relative humidity readings of psychrometer and thermohygrometer instruments for swinging probe at an initial ambient relative humidity, pressure 767 Torr.

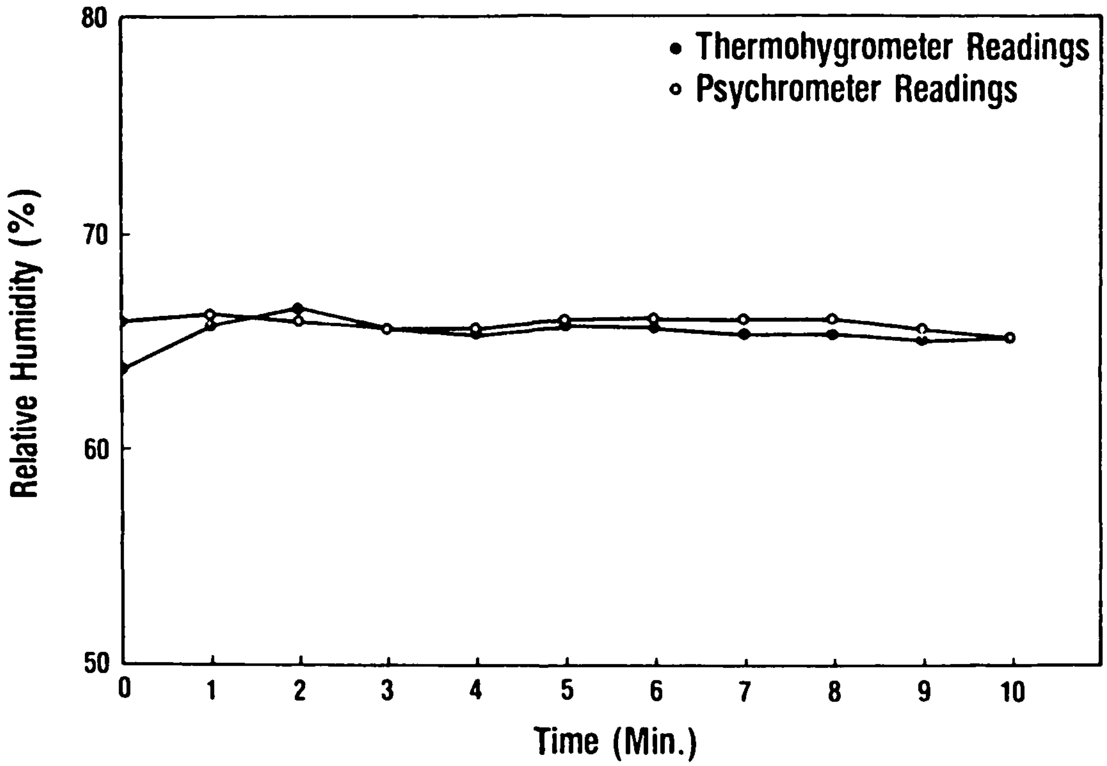

Fig. 7C. Comparison between relative humidity readings of psychrometer and thermohygrometer for instruments for air-tunnel probe at an initial ambient relative humidity, pressure 767 Torr.

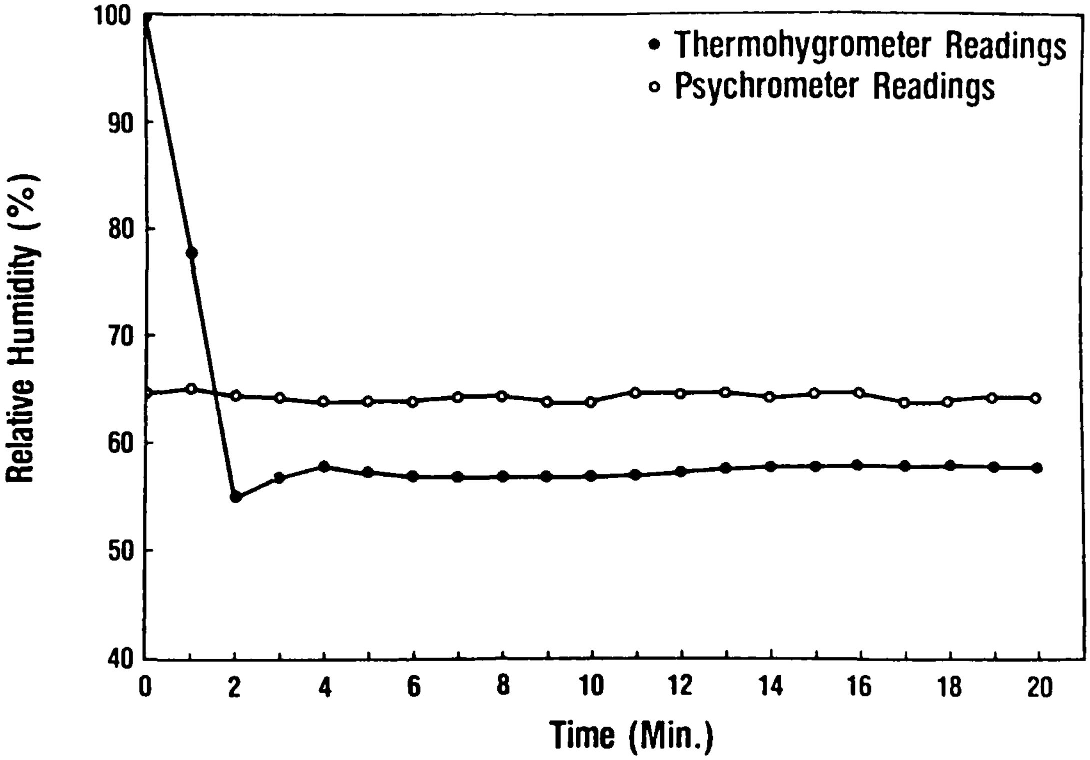

Fig. 8A. Comparison between relative humidity readings of psychrometer and thermohygrometer instruments for static probe at an initial relative humidity of 100%, pressure 766 Torr.

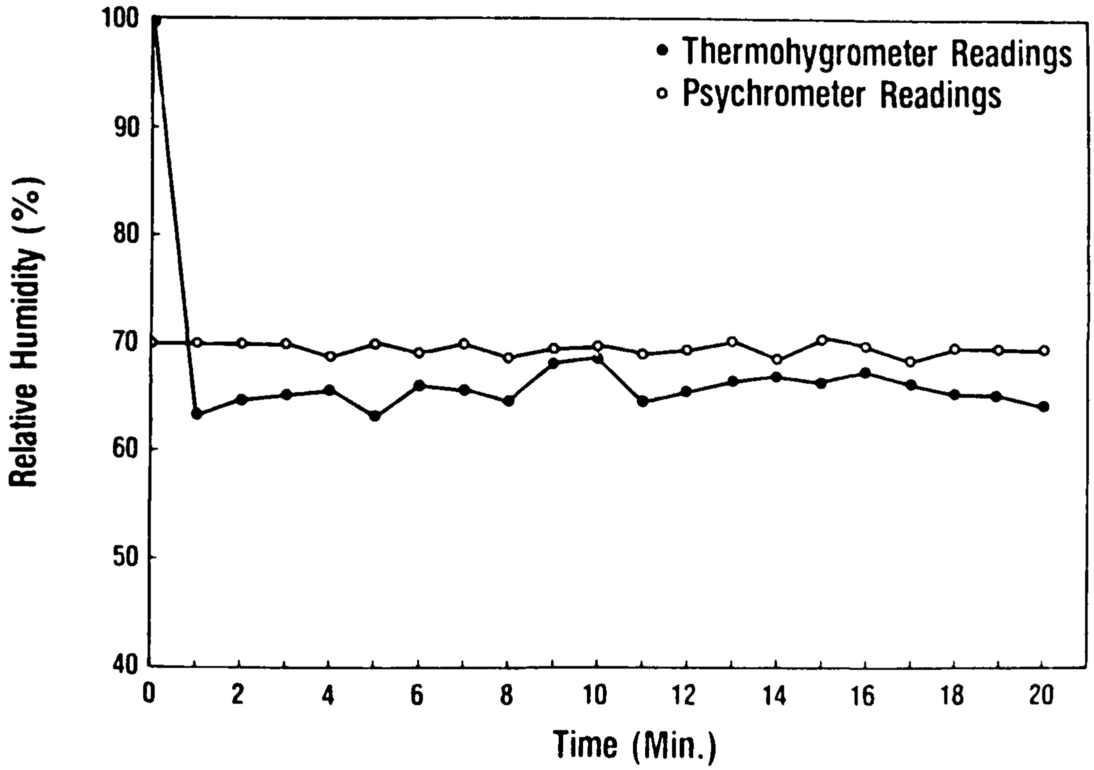

Fig. 8B. Comparison between relative humidity readings of psychrometer and thermohygrometer instruments for swinging probe at an initial relative humidity of 100% by Subject #1, pressure 758 Torr.

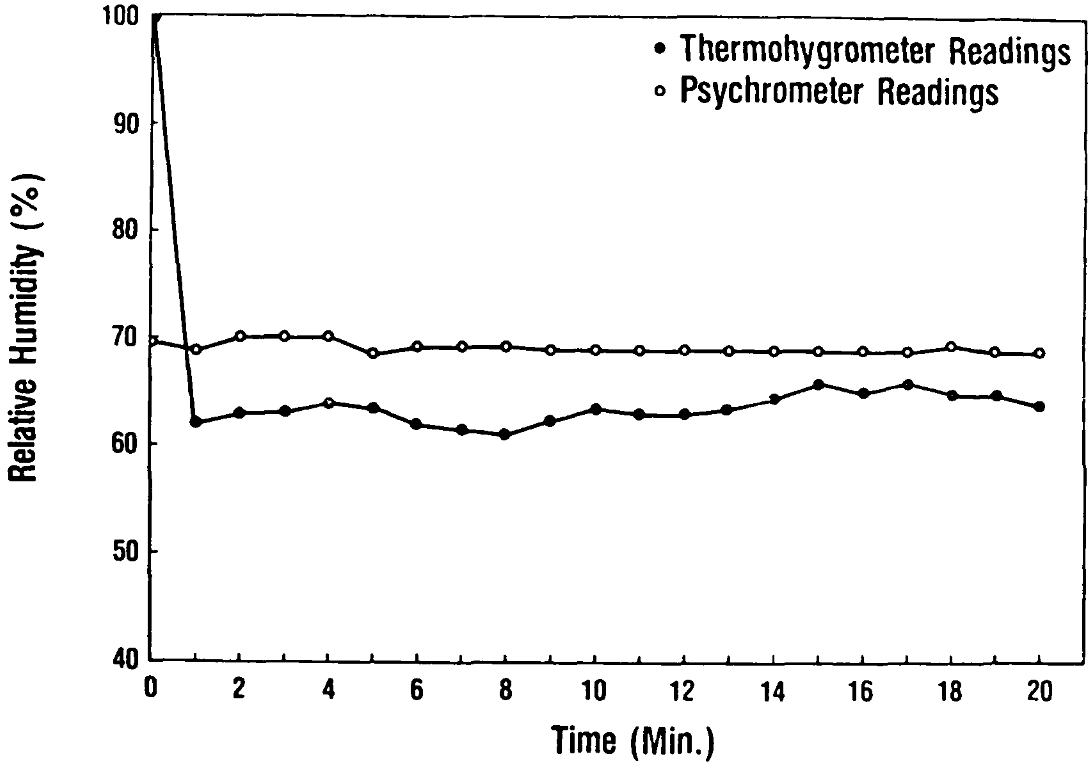

Fig. 8C. Comparison between relative humidity readings of psychrometer and thermohygrometer instruments for swinging probe at an initial relative humidity of 100% by Subject #2, pressure 758 Torr.

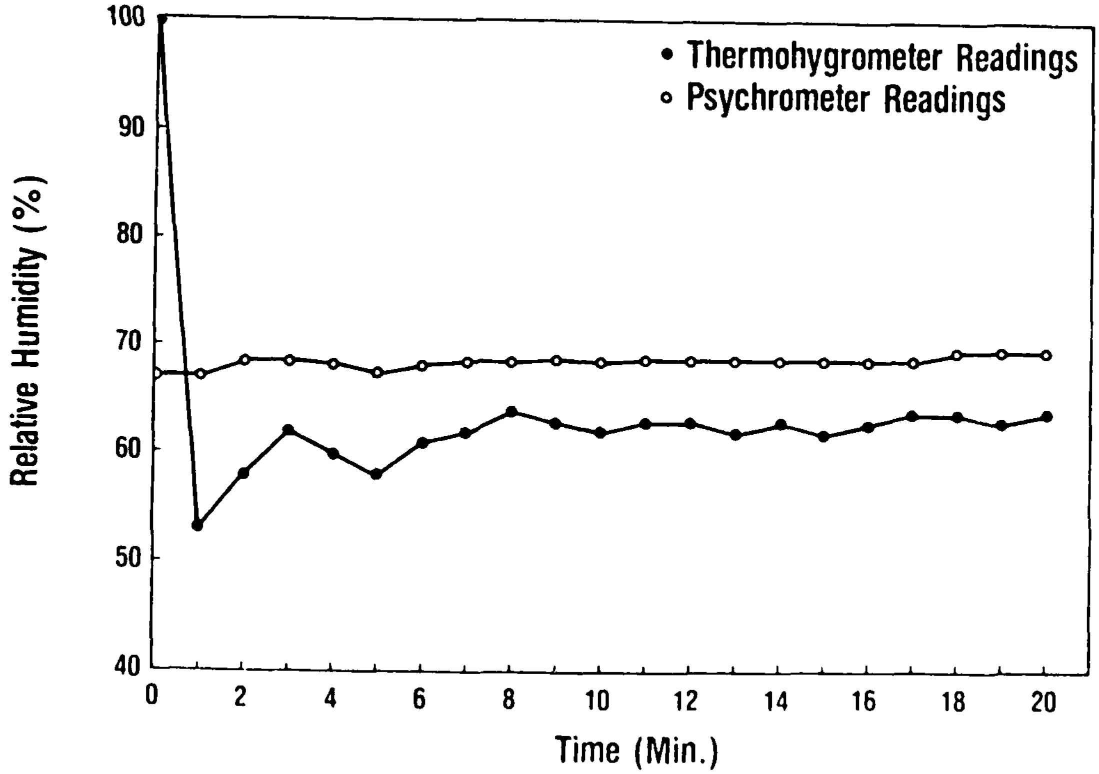

Fig. 8D. Comparison between relative humidity readings of psychrometer and thermohygrometer instruments for swinging probe at an initial relative humidity of 100% by Subject #3, pressure 758 Torr.

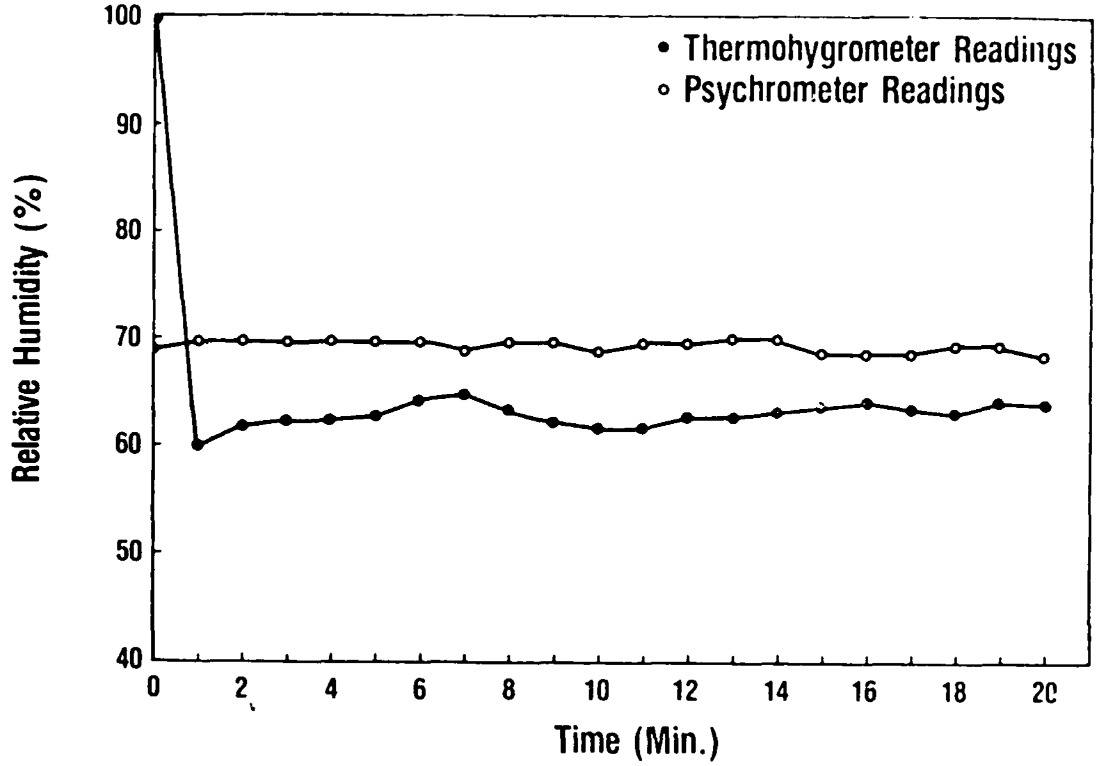

Fig. 8E. Comparison between relative humidity readings of psychrometer and thermohygrometer instruments for swinging probe at an initial relative humidity of 100% by Subject #4, pressure 754 Torr.

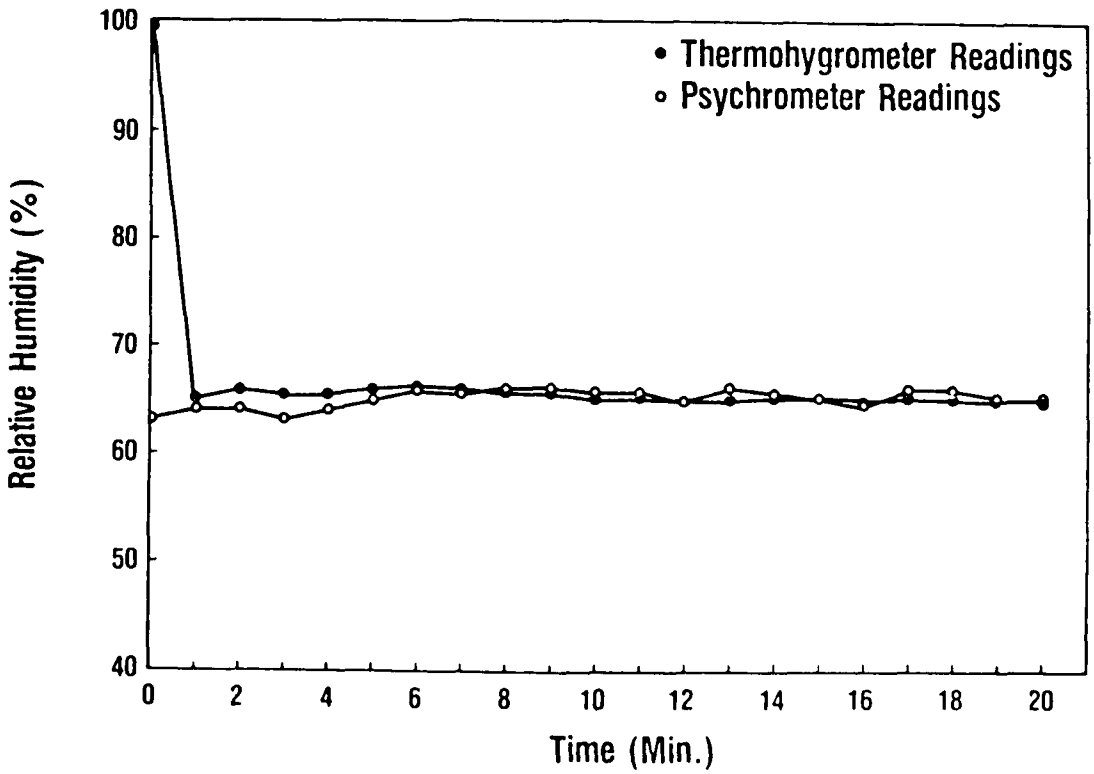

Fig. 8F. Comparison between relative humidity readings of psychrometer and thermohygrometer instruments for air-tunnel at an initial relative humidity of 100%, pressure 766 Torr.

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