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Design Description of the Large Scale Climate Simulator

W. R. Huntley

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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Energy Division

DESIGN DESCRIPTION OF THE LARGE SCALE CLIMATE SIMULATOR

W. R. Huntley

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The on going revolution in the number and types of materials for use in low-slope roof construction has created a need for a facility such as the Large Scale Climate Simulator (LSCS), where dynamic testing of whole roof systems can be accomplished. Hundreds of roofing products have been introduced to the marketplace in the past few years, and there is a serious need to evaluate the thermal, hygric, and mechanical performance of typical whole roof systems (e.g., the deck, insulation, fasteners, membrane and ballast in combination) and not just the individual products themselves under dynamic conditions. The LSCS provides such capability.

Evaluations of U.S. roofing problems began at ORNL in the early 1980s. This led to the construction and operation of an outdoor test facility in 1984 where small (4 ft × 8 ft) roof sections were tested dynamically against Tennessee weather conditions while typical indoor conditions were maintained below the roof tests. Experience with the outdoor facility demonstrated the need for a more complex system, where wide ranges of weather conditions could be created as needed for either steady-state or dynamic tests.

This report covers the LSCS design and construction activities at ORNL during a 2.5-year period in which criteria were assembled, specifications were prepared, a new building to house the chamber was built, and construction and acceptance tests of the LSCS were completed. The use of design/build contractors for both the new building and the LSCS was successful; both construction projects were within budget and on schedule. Another significant factor in successful completion of the project was the use of a nine-member industrial advisory board throughout the entire project. The Roof Industry Research Advisory Panel consisted of leaders from all facets of the roofing industry and their advice was invaluable. The advisory panel will continue to function in the future in setting experimental priorities and goals.

The LSCS has been built to test square roof test sections up to 3.9 m × 3.9 m (12 ft 9 in. by 12 ft 9 in.) over a range of membrane temperatures from -40 to 93°C (-40 to 200°F). Typical indoor temperatures and humidity are maintained below the roof. Programmable infrared lamps simulate diurnal solar cycling and rain making can be provided. The LSCS

can be operated as an environmental chamber or as a guarded hot-box test facility. This report describes the capabilities and operating parameters of the LSCS. Design requirements, safety requirements, system limitations, and brief operating procedures are included. The report also describes the various subsystems and support facilities such as the HVAC systems, data acquisition systems, diagnostic platforms, rain systems, infrared lamp system, and humidity control systems. Performance data from the acceptance tests are provided to demonstrate the actual capability of the completed chamber.

The LSCS was primarily designed for the testing of low-slope roofs but can be used for other configurations. For example, a residential attic test (5 in 12 sloped roof with shingles) is now under construction to evaluate attic heat loss effects and heat retarding barriers within the attic. The chamber is designed for short-term testing and is not envisioned as an aging or long-term test facility. Special reusable test support frames called diagnostic platforms are available to allow assembly of each roof test section exterior to the chamber. Also, special instruments quick-connects are used to allow complete instrument calibrations and check-out on the computerized data acquisition system prior to installation within the chamber. These features allow relatively rapid change-out of experiments and maximum experimental throughput in the LSCS.

The ORNL Roof Research Center has been designed and built to respond to industry problems for whole roof systems testing and, ultimately, to develop the capability to predict whole roof performance with the aid of mathematical modeling. The LSCS is the centerpiece of the Roof Research Center and it provides a unique capability for testing whole roof systems. The Roof Research Center is designated a National User Facility; as such, it is available to industry, academia, and governmental agencies for their test programs. A brief Users Manual is available upon request from ORNL for anyone interested in use of the Center. Telephone Sherry Samples at (615) 574-4345 if you wish to receive a copy of the Users Manual.

The LSCS has been completed and is now ready for use by the roofing industry to aid in the development of energy-efficient, practical whole roof systems. It is expected that this report will be of interest to present and future operators and researchers using the LSCS and, perhaps, to other builders of environmental chambers for the building industry.

DESIGN DESCRIPTION OF THE LARGE SCALE CLIMATE SIMULATOR*

W. R. Huntley

ABSTRACT

Construction of the Large Scale Climate Simulator has been completed at Oak Ridge National Laboratory under the sponsorship of the U.S. Department of Energy. This new facility provides the roofing industry with a unique capability for testing whole roof systems under dynamic conditions. The facility has been designated a National User Facility and, as such, is available to roofing researchers from industry, academia, and government agencies for their test programs. This report is primarily a design description of the Large Scale Climate Simulator and outlines the test capabilities of the various subsystems which make up the chamber. The chamber can provide roof test temperatures from -40 to 93°C (-40 to 200°F) and can operate either as an environmental chamber or as a guarded hot box. Typical performance data obtained during the acceptance testing of the chamber are included in this report.

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1. INTRODUCTION

Low-sloped roofs are the main type of roof installed on commercial buildings. Until the late 1970s, the multi-ply, built-up roof with little or no insulation served as a reliable design choice. There was little incentive to seek alternatives either to lower the cost of materials for the roof or to lower the operating cost for the building the roof covered.

Cost of heating and cooling energy, especially electricity, increased dramatically in the late 1970s. Also, materials derived from petroleum, such as asphalts for built-up roofs, became more expensive to use in multi-ply construction. A revolution followed in the low-slope roofing industry as new materials and construction techniques were substituted for the traditional, multi-ply, built-up roof. The result has been a mix of construction techniques and materials used on low-slope roofs.

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Roof research began at Oak Ridge National Laboratory (ORNL) in the early 1980s in the interest of the U.S. Department of Energy toward energy-efficient, yet practical, roofing systems. The ORNL Roof Research Center (RRC) was formed to provide facilities and expertise to test whole roof systems for roofing researchers from industry, academia, and governmental agencies. Some of the documented research that formed the basis for construction of the facilities at ORNL are included in refs. 1-7.

Initial reviews by ORNL of U.S. roofing problems led to the construction and operation of the Roof Thermal Research Apparatus (RTRA) in 1984. The RTRA is an outdoor test facility where small (4 ft × 8 ft), whole roof systems can be dynamically tested against the weather at the ORNL site.[8] Experience with this facility demonstrated the need for a Large Scale Climate Simulator (LSCS) where wide ranges of weather conditions could be created as needed for steady-state or dynamic tests. Also, experience with the RTRA provided valuable insights into the criteria required for construction and operation of the LSCS.

Construction of the LSCS was essentially completed by August 31, 1987. The LSCS was built under a competitively bid design/build contract to take advantage of expertise outside ORNL in environmental chamber design and manufacture. Several firms in the United States have provided guarded hot-box systems for testing use to customers in the international market. After visiting several such vendors, ORNL staff prepared the detailed procurement specification for the LSCS. Vista Scientific Corporation of Ivyland, Pennsylvania, was the successful bidder. LSCS construction was completed on schedule and shakedown operations were completed in early 1988. The first roof test specimen for the LSCS was subsequently built at ORNL and has undergone preliminary testing.

The LSCS is the centerpiece of the ORNL Roof Research Center. It provides the roofing industry with a unique capability for testing whole roof systems under steady-state or dynamic conditions. The Roof Research Center is designated a National User Facility: it is available to industry, academia, and governmental agencies for their test programs. The overall objectives of the facility are

- to respond to industry problems for whole roof systems testing;

- to provide careful measurements under controlled steady-state and dynamic conditions;
- to combine thermal, hygric, and mechanical performance tests of whole roof systems; and
- to develop the capability to predict whole roof performance.

This report is primarily a design description of the LSCS and a record of design decisions and design criteria that were developed for the project. Some operational procedures and initial performance data are also discussed. As steady-state and dynamic operational experience are gained, other reports will be issued.

1.1 FUNCTIONS AND DESIGN REQUIREMENTS

The LSCS at ORNL of the U.S. Department of Energy (DOE) can provide experimental results that can lead to improved thermal efficiency and durability of commercial and residential roofs. The LSCS is a unique facility that is capable of testing whole roof systems under either steady-state or dynamic conditions. The design temperature range at the membrane surface is from -40 to 93°C (-40 to 200°F). The Climate Chamber can stimulate typical U.S. weather extremes with a lower ambient temperature limit of -40°C (-40°F) and an upper limit of 66°C (150°F). Membrane temperatures above 66°C (150°F) are created by heating from an infrared heating lamp system which can be controlled to simulate a wide range of thermal effects from diurnal solar cycling. A sprinkler and drainage system can be provided to simulate a wide range of rainfall rates and rain water temperatures. There are no plans for the manfacture of snow within the Climate Chamber, although freeze-thaw cycles with ponded water are possible.

The LCSC can be operated as an environmental chamber or as a guarded horizontal hot-box test facility with outdoor conditions simulated above the roof test specimen and indoor conditions below. One requirement is to conduct a steady-state tests in accordance with ASTM Designation C-236: "Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box." The chamber is designed to test thermal performance, water tightness, and structural integrity of 3.9 × 3.9 m (12-ft 9-in. × 12 ft 9 in.) square roof sections, having R-values ranging from

0.7 to 7.0 m^2K/W (4 to $h \cdot ft^2 \cdot {}^\circ F/Btu$). The facility will also be used to develop procedures for dynamic hot-box operation.

The LSCS chamber is designed for periods of continous operation for as long as several days to weeks. All controls and data collection are automatic and programmable. Thus, operators are not needed routinely at night or on weekends, leading to significant operational cost savings.

The LSCS is designed to operate at pressures slightly above or below atmospheric pressure. The Roofing Industry Research Advisory Panel recommended that the Climate Chamber be capable of operating at a negative pressure difference of at least 1.44 kPa (-5.8 in. of water gage), which provides an uplift force of more than 1.44 kN/m^2 (30 lbs force per ft^2) to duplicate a common wind-uplift simulation test used in the U.S. roofing industry and to do exfiltration studies. The Climate Chamber can be pressurized to 1.24 kPa above atmospheric pressure (+5.0 in. of water gage) so that air infiltration tests can be conducted. The positive pressurization can also be used to simulate uniform loading on the upper surface of the test roof.

The LSCS is primarily for relatively short-term dynamic tests of whole roof systems, not for long-term aging tests. Maximum periods of only a few months are anticipated. Therefore, neither ultraviolet lighting (to simulate long-term solar aging effects) nor other environmental aging effect simulators are planned within the Climate Chamber. If such aging tests become needed, they will be carried out in preconditioning tests. Such tests would be external to the chamber with intermittent testing within the LSCS to observe the effects of aging on roof performance. Similarily, the rain system is not intended to evaluate long-term effects from acidrain. Therefore, ordinary tap water will be used in the rain making system.

1.2 OPERATING REQUIREMENTS

A major LSCS operating requirement is that whole roof systems be tested under either steady-state or dynamic operating conditions. Computerized parameter control and automatic data acquisition are built-in to allow unattended operation on nights and weekends. The data system must handle over 300 data channels during some tests.

The high fixed cost of experimental equipment such as the LSCS dictates that it be kept in useful production of data as much as possible. Test specimens can be installed rapidly in the LSCS by means of an overhead 89-kN (10-ton) crane. Quick installation is needed because most tests will be of relatively short duration. In addition, different test specimens are put in uniform Diagnostic Platforms, which are reusable mounting frames containing prewired connections to the data acquisition system. Multi-pin quick-disconnectors will be used on the numerous data channels to aid rapid installation of a new test specimen and its Diagnostic Platform within the Climate Chamber. Extensive precalibration, wire continuity, and polarity tests can be performed on the instrumentation of a new specimen while it is in a Diagnostic Platform prior to its introduction into the chamber. This preliminary work expedites installation and subsequent operation.

1.3 SYSTEM CONFIGURATION AND MAJOR FEATURES

Figure 1 is a schematic drawing showing the design concept of the LSCS. The four major elements of the system are the Climate Chamber, Metering Chamber, Guard Chamber, and a Diagnostic Platform containing a low-slope roof test specimen.

The Guard and Metering Chambers are located below grade in a pit, primarily to reduce the overall height of the ORNL building (Bldg. 3144) in which the LSCS is located. The entire chamber is mounted on a series of I-beams along the pit floor to provide load distribution. The I-beams also allow room for access to modify the base of the chamber if test program developments so indicate.

The Metering Chamber may be raised or lowered on a hydraulically operated lifting mechanism. When the Metering Chamber is in the raised position and the system is operated at steady-state conditions, the LSCS meets all the requirements of ASTM C-236 for guarded hot boxes. In this case the metering area will be 2.4 × 2.4 m (8 × 8 ft) and the guard area extends to 3.7 × 3.7 m (12 × 12 ft). It is expected that the LSCS will be operated more frequently with the Metering Chamber lowered and under dynamic temperature conditions using the full 3.7 × 3.7 m (12 × 12 ft) underside × specimen area.

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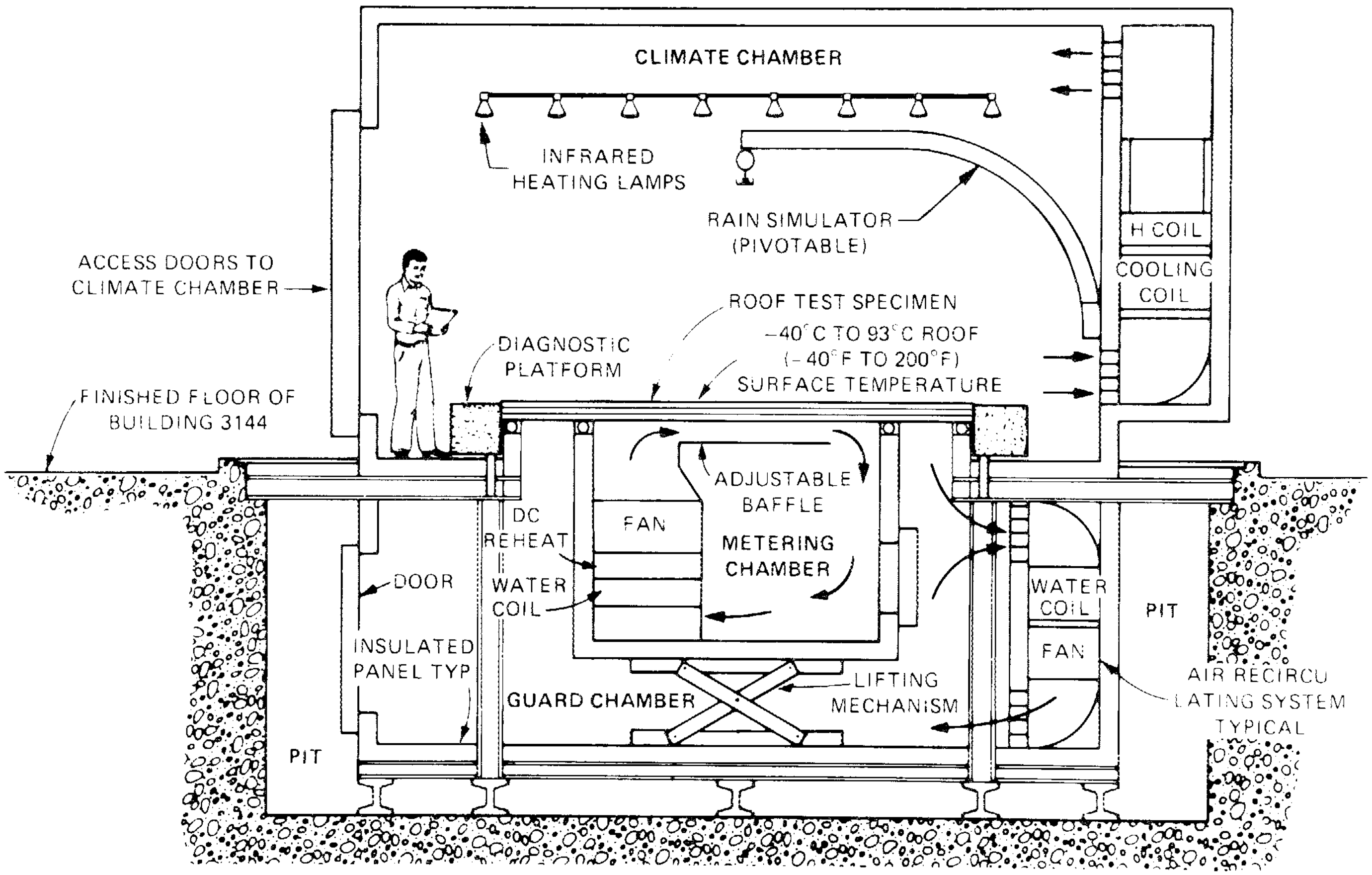

Fig. 1. Large Scale Climate Simulator design concept.

The LSCS is designed to accommodate a wide range of roof test specimen weights ranging from lightweight metal roof decking to more massive concrete roof support structures. Therefore, the chamber is built with eight integral support columns to withstand the anticipated heavy vertical loading. These columns are located directly under the Diagnostic Platform and are designed to transfer the load directly to the heavily reinforced concrete pit floor. Total combined weights of the Diagnostic Platform and roof test specimen up to 80 kN (18,000 lb) can be accommodated.

The Guard and Metering Chambers are designed to simulate a wide range of indoor temperatures from 7 to 66°C (45 to 150°F). In these two chambers, the ambient air temperature is conditioned by finned heat exchanger coils. Tap water is used as the heat transfer fluid to supply the coils.

The Climate Chamber can be operated over an ambient temperature range of -40 to 66°C (-40 to 150°F). An array of infrared heating lamps are mounted on the ceiling of the Climate Chamber, with temperatures automatically controlled up to 93°C (200°F) at the upper surface of the test specimen, usually the roof membrane.

A nozzle can be located just below the level of the infrared lamps on a pivotable arm for use in selected tests to simulate rain in the Climate Chamber. Cooling of the Climate Chamber is done with a two-stage halocarbon-based refrigeration system, which is located on a concrete pad external to the building. Heating of the Climate Chamber air is provided by a 42-kW electric heating coil within the chamber. Heating and cooling are controlled separately in the Climate, Guard, and Metering Chambers.

Wood is the basic structural material of the LSCS. The walls, floor, and ceiling of both the Climate and Guard Chambers are built of kiln dried fir and are covered with coated plywood of various thicknesses, depending on location. Cavities in the wall interior are filled with fiberglass insulation. The lower portion of the Climate Chamber is waterproofed by a field-applied coating of fiberglass-reinforced polyester to provide protection from simulated rainfall.

The Metering Chamber is fabricated of 4-in.-thick polyisocyanurate foam insulation covered by figerglass-reinforced polyester. The chamber consists of a floor and four walls, fabricated in a single piece to reduce opportunitites for air infiltration during operation. The Metering Chamber has a small, crawl-through access door on its west wall. The upper perimeter of the chamber has a double gasket of soft rubber that compresses against the underside of the test specimen when the Metering Chamber is in the raised position.

1.4 SAFETY REQUIREMENTS

The LSCS is located in a building that is protected by an overhead fire sprinkler system. Moreover, added sprinkler protection is provided within both the Climate and Guard Chambers. The minimum operating temperature of -40°C (-40°F) in the Climate Chamber requires that dry-type pendant sprinkler nozzles be used to preclude freezing problems. Four such nozzles are mounted through the ceiling of the Climate Chamber to provide coverage for the floor area. The Guard Chamber is protected by four side-wall sprinklers of conventional wet-type design that are located near the ceiling. All sprinkler heads in both chambers are regulated to activate at 131°C (268°F).

Provisions have been made to monitor possible off-gassing of the roofing membranes that will be enclosed within the Climate Chamber during operation. The most obvious time for concern would be during operation at maximum membrane temperatures up to 93°C (200°F), but safe operation with the anticipated wide range of roofing products dictates that continuous monitoring be done. A hydrocarbon detector is provided to monitor any build-up of an explosive vapor concentration. A chamber ventilation system is also provided so that fresh air can be circulated through the chamber and exhausted outside prior to entry of personnel. This ventilation provision should allay any concern about operator safety due to off-gas build-up.

An exhaust hood is at the northeast corner within Bldg. 3144 so that fumes from roof materials can be removed without disrupting other operations in the building during assembly of roof test specimens. Materials of concern requiring venting are hot coal tar, hot asphalt, and as yet unspecified adhesive materials related to single-ply roofing membranes.

Inside the Climate and Guard Chambers are telephones for use in the unlikely event that someone becomes trapped inside. Both the high and low temperature limits of the chambers could be life-threatening over protracted periods. The fire department at ORNL is on continuous duty and can provide immediate response to an emergency call.

Safety training programs will be provided for all operators of the large equipment used in assembling, installing, and testing the roof test specimens, some of which weigh up to 8165 kg (18,000 lb).

2. DETAILED FACILITY DESCRIPTION

The LSCS is located within Bldg. 3144 at ORNL. The building is a new, pre-engineered metal building with overhead crane facilities that was built specifically to house the LSCS and its related roof research work. The LSCS is the centerpiece of the RRC, but related roof research is also carried out in the RTRA. Some support personnel and data acquisition and analysis apparatus are housed in the adjacent Bldg. 3114. Figure 2 is a photograph of these buildings.

2.1 DESIGN FEATURES OF BUILDING 3144

A new building houses the LSCS because no suitable facilities were available in the Oak Ridge area. Pre-engineered metal building construction was selected because of both cost and schedule considerations. The building was erected by Lee Wan and Associates, Inc., of Decatur, Georgia, under a design/build contract. The design/build concept eliminates one of the two rather lengthy bid and award processes inherent to separate design and build procedures. Moreover, change orders due to drawing interpretations are usually fewer in number when the designer is also the builder. The concept worked well and the new building was completed within funding and on schedule. Figure 3 is a photograph of the building interior that was taken when its construction was completed but before installation of the LSCS. The room on the right side houses the control room and the instrument shop for the LSCS.

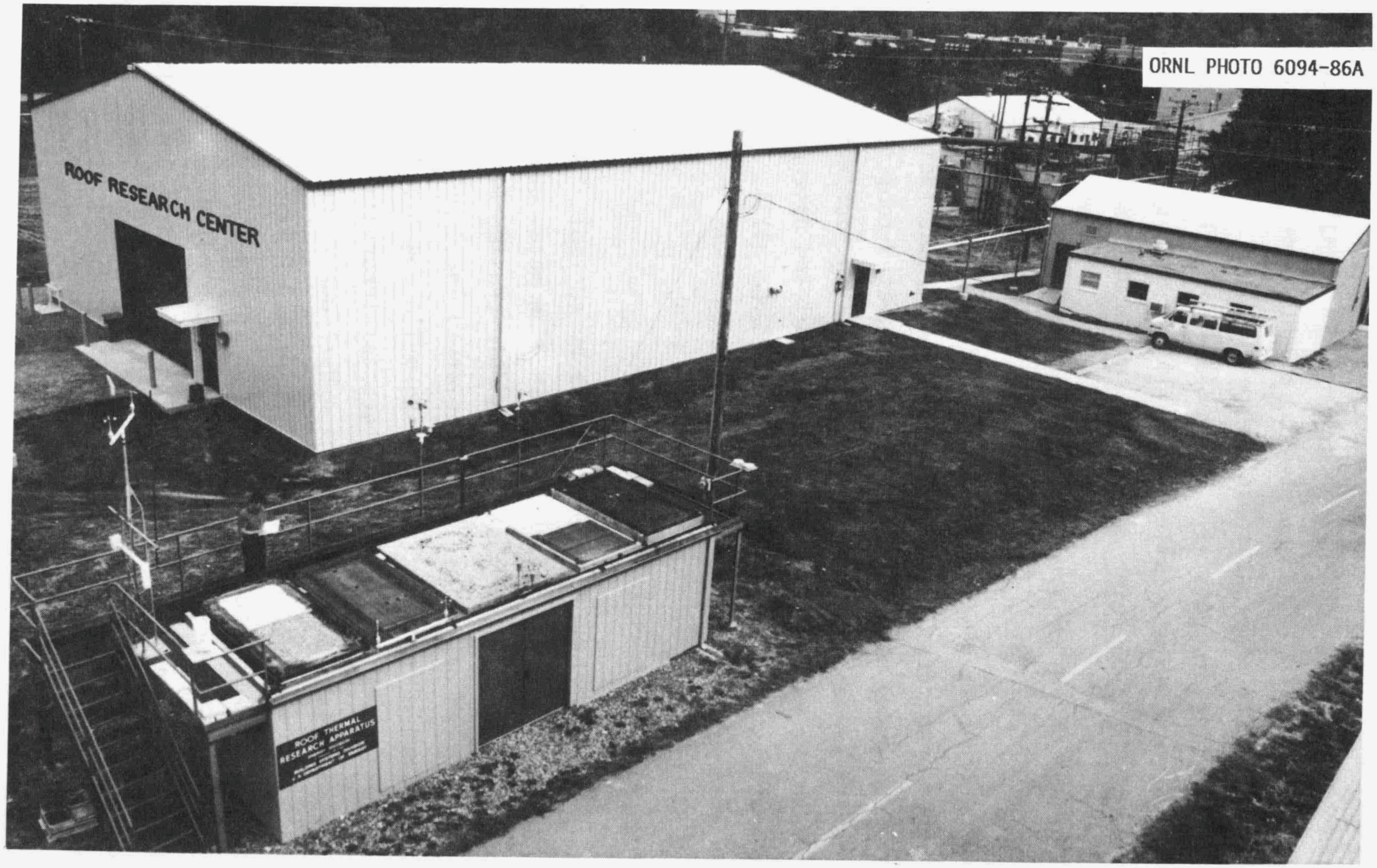

Fig. 2. Photograph of the three buildings which house the Roof Research Center at ORNL.

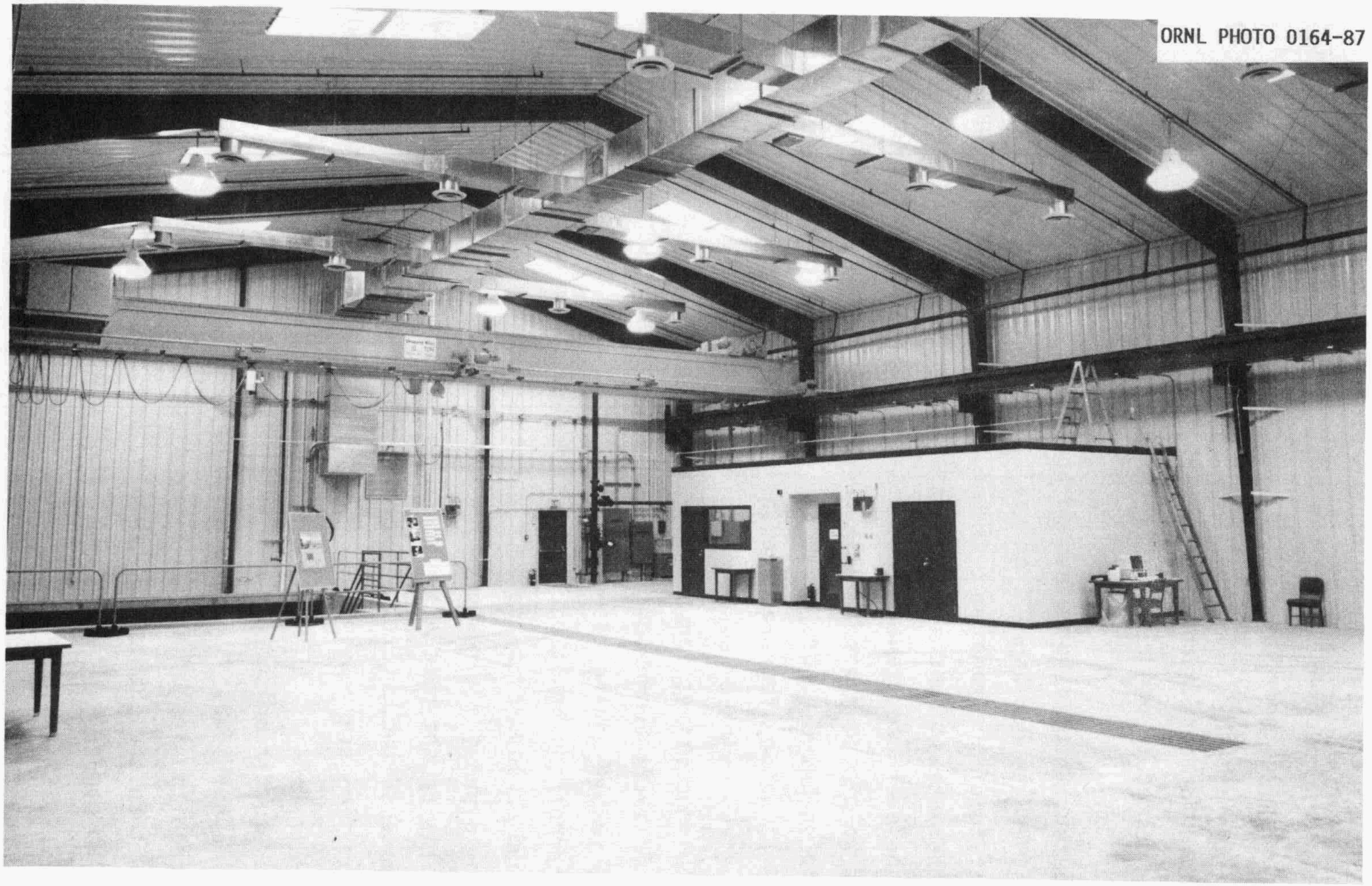

Fig. 3. Interior view of Building 3144 prior to installation of the Large Scale Climate Simulator.

The facility layout of Bldg. 3144 is shown in Fig. 4. The LSCS is located in the southeast corner of the 650 m² (7000 ft²) building. Large floor areas are required within the building because of the size of the test specimens in their Diagnostic Platforms, namely, about 4.5 × 4.5 m (14 ft 8 in. × 14 ft 8 in.) square in the plan view. Two assembly areas will be used for construction of new roof test specimens. This construction is expected to occur concurrently with test operations within the LSCS.

An exhaust hood is provided so that roof assembly operations with materials such as hot asphalt or coal tar may be conducted without vapor contamination of the remainder of the building. A manually operated roof door on the exhaust hood allows access for roof specimens into the hood area by the overhead crane. The west side of the exhaust hood has a fire-resistant welding curtain that is drawn closed during assembly operations to contain unwanted vapors.

Several safety features are included in the design of the exhaust hood. A fire sprinkler system is provided in case hot asphalt materials or flammable adhesives ignite. All electric wiring and lighting within the hood is explosion-proof in the unlikely event that explosive air moistures result during assembly operations. The exhaust fan blades are of spark-proof construction. An escape door is provided in the south wall of the hood enclosure to preclude personnel entrapment. The exhaust fans are sized to provide air approach velocities of 46 m/min (150 ft/min) when the curtains on the hood are drawn. In accordance with Martin Marietta Energy Systems, Inc., (Energy Systems) Health and Safety Procedure 70-26, such velocities are required at ORNL when handling carcinogenic vapors such as coal tar.

A "preconditioning" area is shown adjacent to the LSCS in the facility layout (Fig. 4). This area is for roof test specimens that require conditioning or aging either prior to or during intermittent testing within the LSCS. For example, long-term aging effects such a ultraviolet damage to roofing membranes could be demonstrated here. Similarly, long-term aging of foamed insulation materials or long-term moisture migration might be evaluated here. This general approach will

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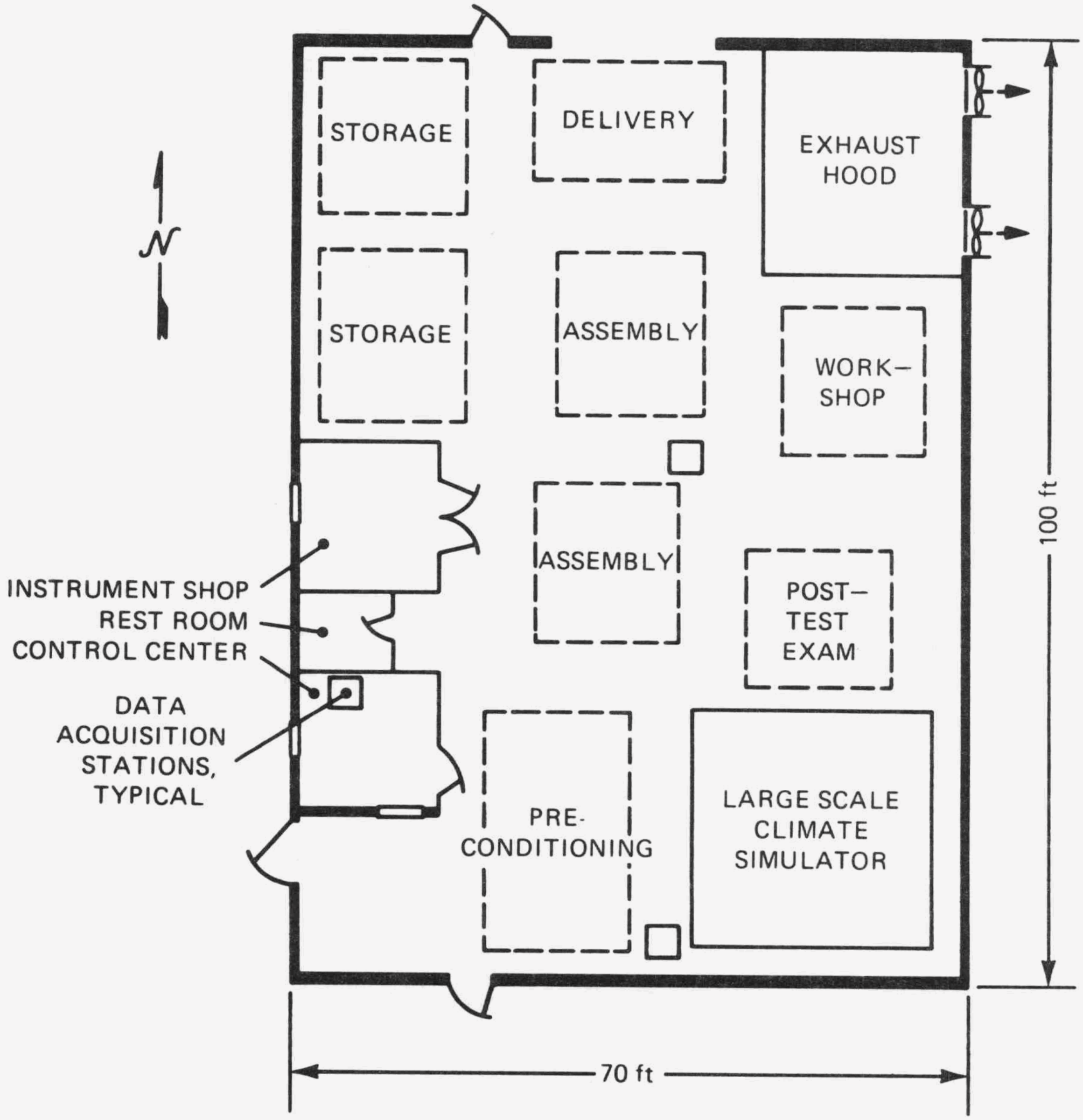

Fig. 4. Equipment layout for Building 3144 at the Roof Research Center.

allow the LSCS to be used to maximum benefit by increasing the number and types of tests being studied within a given time period.

Storage of several roof test specimens is anticipated. Racks in the storage areas of the building are reserved for this purpose, and their design is described later.

The insulated pre-engineered metal building has interior prefinished metal liner panels that cover the thermal insulation on both the walls and roof. The wall and roof insulation is fiberglass (R-11 walls, R-19 roof). The normal eave height is 7.3 m (24 ft), and the entire building area is served by a 89-kN (10-ton) overhead bridge crane. The floor is 15-cm-thick (6-in.) reinforced concrete with a grate-covered utility trench near the center of the building floor. A 3-m-deep (10-ft) pit which houses the lower half of the LSCS is located in the southeast corner. The entire building is air conditioned by a 88-kW (25 tons of refrigeration) pad-mounted packaged unit, which is located outside the building. Building heating is provided by steam coils that are fed from the ORNL steam plant. The control room and instrument shops also have individual ceiling-mounted 5.3-kW (1.5-ton) water source air conditioners and 3-kW electric heaters so that these areas may be temperature controlled separately from the main building. The entire building is protected by a wet pipe sprinkler system with 74°C (160°F) sprinkler heads.

2.2 DETAILED DESCRIPTION OF THE LSCS

The capabilities of the LSCS are summarized in the tabulation of design parameters shown in Table 1. The ability to vary operating conditions within these ranges shows the flexibility of the apparatus. Diagnostic Platforms add to the range of possible experiments.

All access doors to the Climate Chamber of the LSCS must be open for the Diagnostic Platform to be moved into the chamber as shown in Fig. 5. The roof door allows access by the overhead crane so that roof test specimens may be moved horizontally into the Climate Chamber and then lowered into final position. The box-like structure of the LSCS is strengthened by externally mounted steel members, some of which are visible in Fig. 5. The Guard Chamber walls are not visible in Fig. 5 because this chamber is

Table 1. Design parameters for the Large Scale Climate Simulator

Test operation	24/h day; operators not present on nights or weekends
Size of roof specimen	3.9 × 3.9 m (12 ft 9 in. × 12 ft 9 in.) with variable thickness insulation
Size of diagnostic pattern	4.5 × 4.5 m (14 ft 8 in. × 14 ft 8 in.) outside dimensions
Size of metering chamber	2.4 × 2.4 m (8 × 8 ft) inside dimension × 1.7 m (5 ft 6 in.) high
Size of guard chamber just below roof specimen	3.7 × 3.7 m (12 × 12 ft) inside dimension × 2.54 m (8 ft 4 in.) high
Size of climate chamber	6.1 × 6.1 m (20 × 20 ft) inside dimension × approx. 3.1 m (10 ft) high
Temperature and dew point ranges	
Climate Chamber	Air temperature −40 to 66°C (−40 to 150°F); infrared heating to 93°C (200°F) at the membrane surface controlled dew point range 3 to 50°C (37 to 122°F)
Guard Chamber	Air temperature 7 to 66°C (45 to 150°F); controlled dew point range 3 to 50°C (37 to 122°F)
Metering Chamber	Air temperature 7 to 66°C (45 to 150°F); dew point not controlled
Wind velocities	0.9 m/s (2 mph) from HVAC fans 0.9 to 9 m/s (2 to 20 mph) from Diagnostic Platform fans (conceptual)
Rainfall (planned)	0.5 to 13 cm/h (0.2 to 5 in. h) (tap water)
Infrared heating	0 to 1000 W/m² (0 to 340 Btu/h-ft² at the membrane surface)
Maximum test piece weight including Diagnostic Platform	80 kN (18,000 lb)
Diagnostic Platform weight	12 kN (2700 lb)
Z-frame weight	0.67 kN (1500 lb)
Typical roof specimen weight	27 kN (6000 lb)
Vacuum uplift in Climate Chamber to simulate infiltration or insulation compression	−1.4 kPa ΔP (0 to −5.8 in. w.g.) (30 lb/ft² loading)
Pressurization of Climate Chamber t- imulate infiltration or insulation compression	1.2 kPa ΔP (0 to +5.0 in. w.g.) (26 lb/ft² loading)
Heating rate of temperature change in Climate Chamber	−40 to 66°C (−40 to 150°F) in 2 h
Cooling rate of temperature change in Climate Chamber	66 to 2°C (150 to 35°F) in 1 h; 2 to −40°C (35 to −40°F) in 2 h

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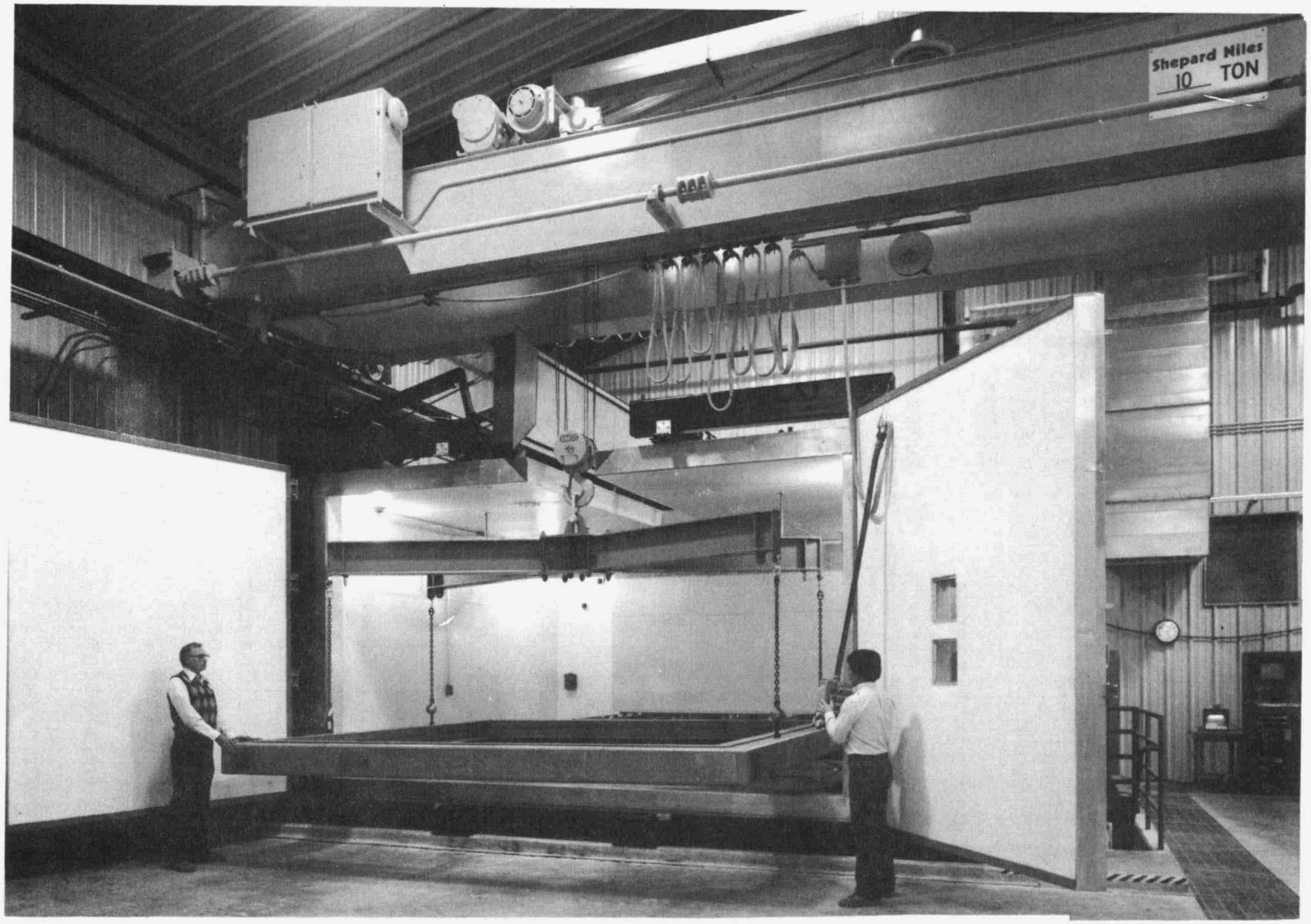

Fig. 5. Moving a Diagnostic Platform into the Large Scale Climate Simulator.

located in the pit (below the main floor level) that is accessed by a stairway visible at the right side of the Climate Chamber. The infrared heating lamp system and rain-making system had not yet been installed within the Climate Chamber when this photograph was taken.

2.2.1 Wall Construction Details

The Climate and Guard Chambers are of similar construction with wooden framework, plywood sheathing, and fiberglass thermal insulation in the walls, floors, and ceilings. The wooden framework studding is 3.8 × 20-cm (1.5 × 8-in.) kiln dried fir located on about 61-cm (24-in.) centers. The interior plywood sheathing is 1.2-cm (0.5-in.) thick with a white, plastic coating (Kemply) which provides waterproofing. The exterior plywood sheathing is 8-mm (5/16-in.) thick with a painted aluminum cladding. Detailed drawings were prepared by the vendor for each prefabricated wooden panel of the chamber. One set of these drawings is available at the RRC for record purposes (listed in item 3 of Appendix A).

The wall and floor construction of the Metering Chamber is quite different from that of the other two chambers. It is formed from polyisocyanurate cellular plastic board foam insulation that is coated with resin and fiberglass. The coating is about 25% chopped fiberglass with fire-retardant polyester. The entire Metering Chamber was built by a subcontractor, Warminster Fiberglass of South Hampton, Pennsylvania, as a single unit so that it would be airtight and have minimum areas for thermal bridging. The thermal insulation is formed from two layers of insulation, each 5-cm (2-in.) thick with overlapping joints. The fiber-reinforced plastic was hand-sprayed onto the foam and is about 3-mm (1/8-in.) thick. Physical properties of the laminate, which contains about 25% glass fiber, are shown in Table 2.

The polyisocyanurate insulation for the Metering Chamber was manufactured by the Dow Chemical Company as "Trymer 190" rigid foam insulation. The foam insulation has a nominal density of 30.4 kg/m^3 (1.9 lb/ft^3) at 23°C (74°F) with a quoted "aged" R-value per unit thickness of 37.4 m·k/W (5.4 h·ft^2·°F/Btu·in.). The insulaton has a rated service temperature from -40 to 107°C (-40 to 225°F), which greatly exceeds the operating temperature range of the Metering Chamber.

Table 2. Physical properties of fiber-reinforced plastic resin

		ASTM test method
Tensile strength	14,000 psi	D638
Flexural strength	25,000 psi	D790
Flexural modulus	1.0×10^6	D790
Impact, Notched, Izod, foot pounds per inch	15	D256
Barcol hardness	40 min. avg.	D2583
Water absorption, %, 24 h	0.1%	D570
Average coefficient of thermal expansion, per °F	10.5×10^{-6}	D696

Aging of foam insulation is a topic of great current interest in the building industry. Therefore, 16 extra foam insulation boards were procured during the Metering Chamber fabrication for continued evaluation at ORNL. Thermal conductivity tests were conducted on these extra boards at the ORNL Screen Tester by D. L. McElroy and R. S. Graves in May 1987, when the board age was 163 days. At 24°C (75°F), the boards had a thermal conductivity of 0.023 W/m·K (0.158 Btu·in./h·ft^2·°F) or a unit thickness R-value of 6.3 h·ft^2·°F/Btu·in. Future tests are planned to follow the potential loss of insulation value in both the extra uncoated insulation boards and the insulation within the Metering Chamber walls.

2.2.2 Climate Chamber Design

The floor plan layout and selected dimensions of the Climate Chamber are shown in the upper half of Fig. 6. The two main access doors at the north end of the Climate Chamber provide a wide opening [5.2 m (17 ft)] for introduction of experiments into the chamber via the slotted roof access door and the overhead crane. The height of the Climate Chamber main access door is 2.82 m (9 ft. 3 in.). However, the clear height for introduction of experiments is reduced because the infrared lamps and fire

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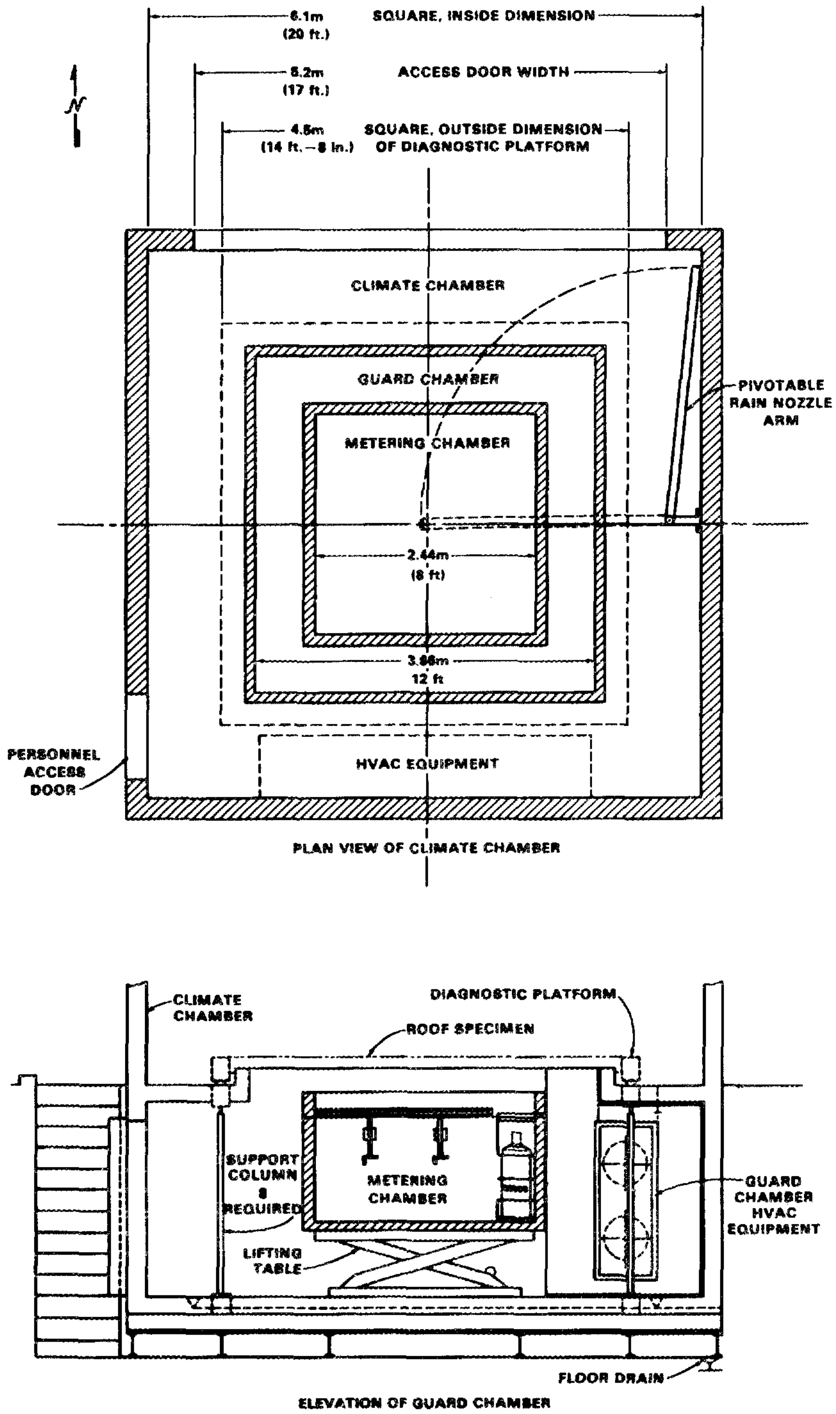

Fig. 6. Floor plan view of the Climate Chamber. Elevation view through Guard Chamber showing the Metering Chamber shown in a partially lowered position.

sprinklers project downward from the ceiling. The four fire sprinkler nozzles project 0.53 m (21 in.) below the ceiling. Therefore, the clear height for introduction of experiments is nominally about 2.29 m (7 ft 6 in.). The infrared heating lamps are located above the plane of the sprinkler nozzles.

Other miscellaneous features of the Climate Chamber are described below. The Diagnostic Platform is outlined by dotted lines in Fig. 6 to show clearances available within the Climate Chamber when a roof experiment is in position for testing. A 1-m wide × 2.1-m high (3-ft wide × 7-ft high) personnel access door is located at the southwest corner of the Climate Chamber. The future location of the nozzle arm is on the east wall of the chamber. The rain nozzle arm will be designed to pivot out of the way when it is not in use. Elevation views of the Metering Chamber and the Guard Chamber, which are located immediately below the Climate Chamber, are also shown in Fig. 6 and will be discussed in Sects. 2.2.3 and 2.2.4. A complete list of all engineering drawings related to the LSCS is attached as Appendix B. These drawings are on file at the RRC.

2.2.2.1 HVAC design

The Climate Chamber refrigeration system is shown in Fig. 7. This two-stage system uses refrigerant 502 (an R-22/R-115 azeotrope) to obtain temperatures as low as -40°C (-40°F) in the chamber. For operating temperatures down to -18°C (0°F), only one stage (75 hp) of refrigeration is needed. The combined compressor motor power for both stages is relatively high due to the design requirement of maintaining -40°C (-40°F) with the heating lamp system in operation. The high refrigeration capacity also permits down-ramping of temperatures while removing the stored energy associated with the relatively massive steel Diagnostic Platforms and related roof test specimens within the chamber. The system was designed for the following live loads:

	kW	Btu/h
Infrared lamps	56.1	191,500
Internal lighting	1.6	5,460
Wall losses	1.6	5,400
Losses across roof specimen	2.4	8,030
Air blower energy input	3.0	10,180
Subtotal	64.7	220,570
10% safety factor	6.5	22,000
Totals	71.2	242,570

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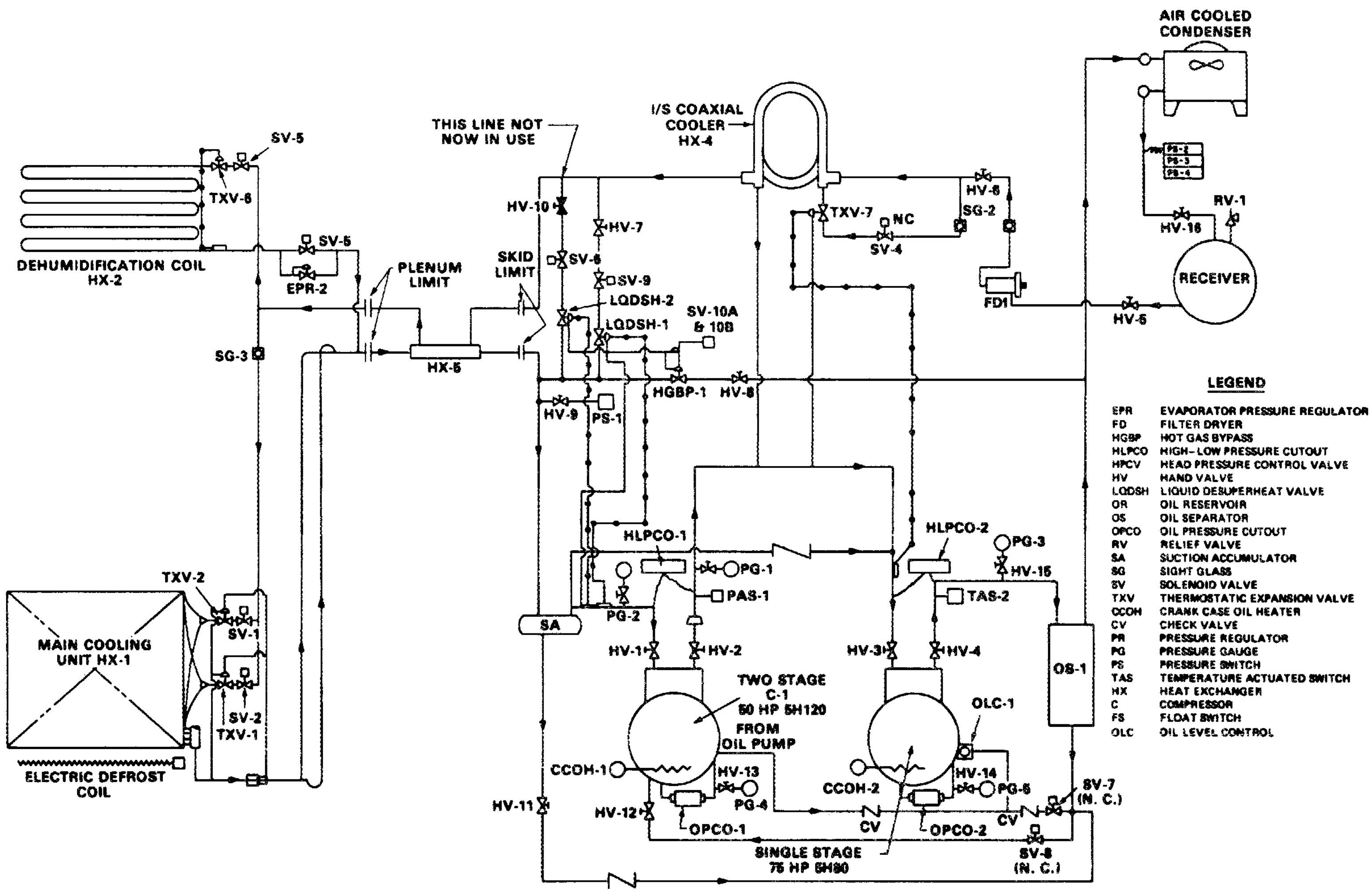

Fig. 7. Schematic drawing of the refrigeration system for the Climate Chamber.

The above live loads exceed the dynamic loads for downward temperature ramps and, thus, are the governing loads in the design. Figure 8 shows the calculated performance of the two-stage refrigeration system assuming 46°C (115°F) cooling air for the outdoor condenser.

An electric heater is provided in the Climate Chamber to meet the design requirement of ramping the chamber temperature from -40 to 66°C (-40 to 150°F) in 2 h; a 480-V, 42-kW heater provides this capability. The heater is designed with two stages to provide both the maximum capability for upward temperatures ramps as well as the fine control at low loads. One stage of the heater is 18 kW with off-on control and no modulation. The remaining 24 kW is controlled by a zero-fired silicon controlled rectifier to provide adjustable power control as needed. The electric heater is a bare-wire Nichrome heating element that provides low mass and quick response. The heater is located physically just above the main expansion coil within the Climate Chamber; however, it is downstream of the expansion coil in relation to the direction of air flow.

The Climate Chamber humidification system provides humidity control over the dew point range from 3 to 50°C (37 to 122°F). The lower dew point limit was set primarily by economics because this was the lowest pratical value for a condensing dehumidification system using refrigerant cooling coils. If future experimental programs require lower dew point limits, it will be necessary to add some type of desiccant dryer to the LSCS.

The capacity of the humidification system was based on the specified maximum leakeage rate of the Climate Chamber, 1.1 m^3/kW (40 cfm), plus an arbitrarily assumed leak rate of 0.42 m^3/min (15 cfm) through a roof test assembly (e.g., a permeable roof penetration). Therefore, an 18-kW Sussman Model ES-18 electric boiler was selected that supplies steam to both the Climate Chamber and Guard Chamber, as required. The boiler can supply up to 27 kg/h (60 lb/h) of steam, if needed. The boiler is mounted on an equipment skid that is located along the south wall of the pit in Bldg. 3144. Vapor from the boiler is injected into the Climate Chamber through a series of orifices that are located just above the 42-kW heater. To prevent any water droplets on the bare-wire electric heater, the nozzle

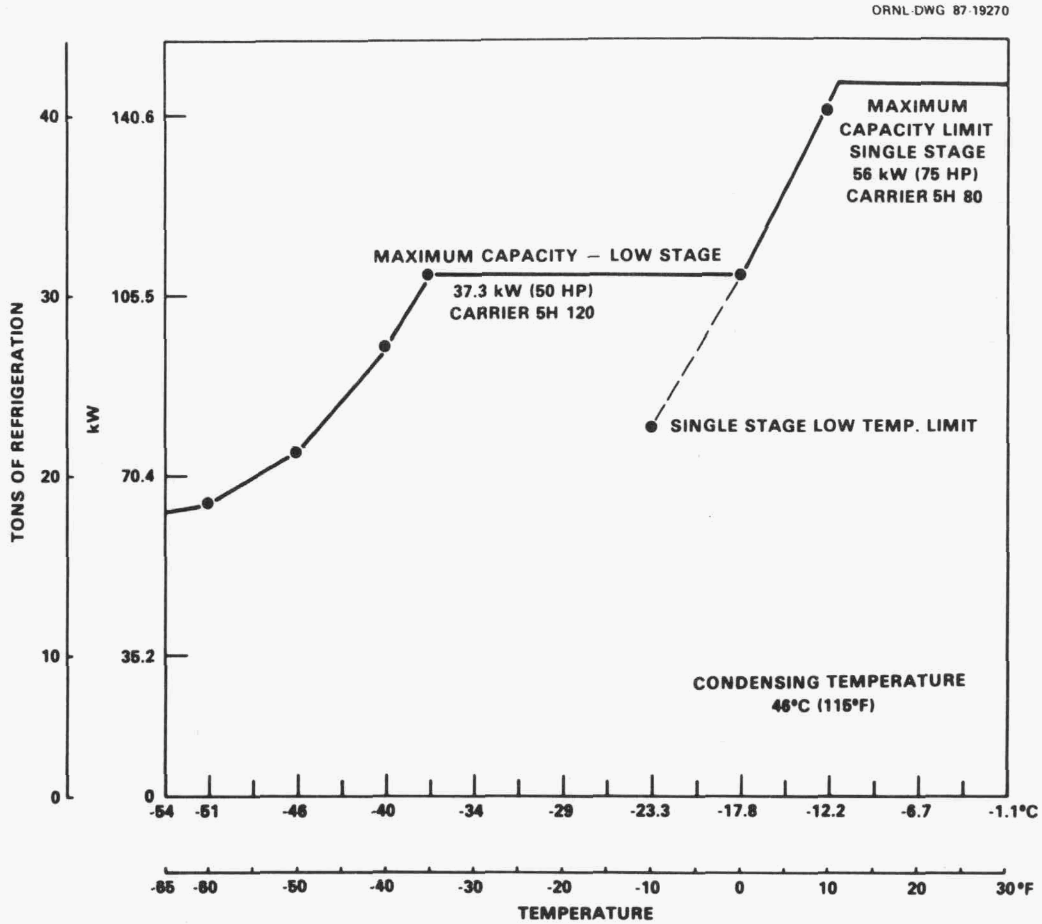

Fig. 8. Calculated performance of the two-stage refrigeration system for the Climate Chamber. *Source*: Vista Scientific Corporation.

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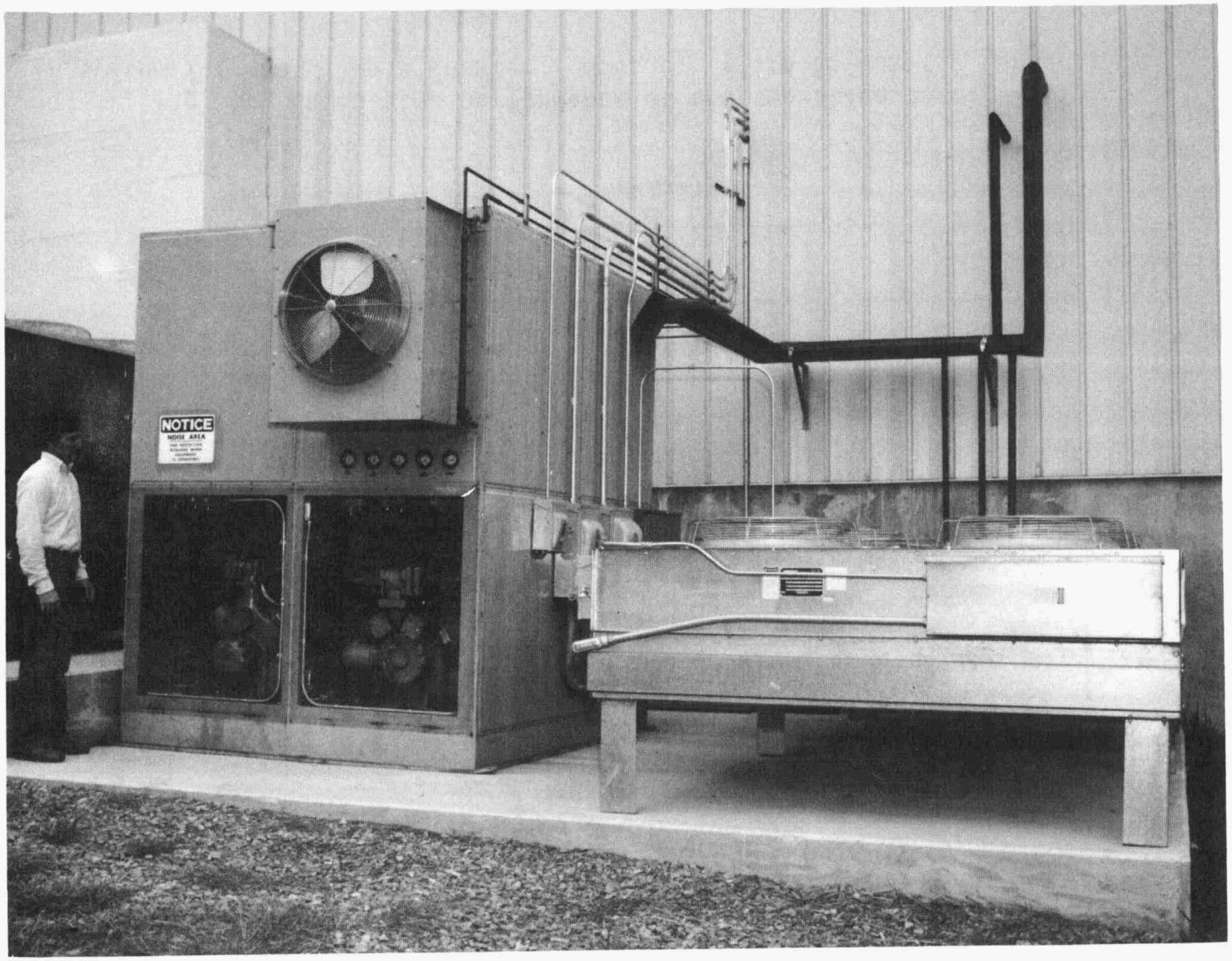

Fig. 9. The compressors and air-cooled condenser for the Climate Chamber are located outside Building 3144.

header is specially designed so that incoming steam preheats the outlet orifices and drains away resulting condensate through a steam trap, as required. The steam injection systems are shown schematically in a later section of this report.

The two-stage compressors are mounted on an enclosed skid that is installed on an outdoor pad at the south end of the building as shown in Fig. 9. Noise level measurements of 90 dBA have been observed inside the metal enclosure with both compressors in operation. Therefore, ORNL safety requirements dictate that protective earmuffs be worn during maintenance or operational exposure inside the enclosure. Required warning signs about ear protection have been mounted on the exterior of the compressor enclosure. Figure 10 is a closeup of the compressors after extended operation and shows the frost pattern to be expected during normal operation.

The air-cooled condenser for the Climate Chamber refrigeration system is also mounted on the outdoor pad beside the compressor skid as shown in Fig. 9. The condenser is forced-air cooled by eight fans that discharge air upwards. The fans are automatically energized in pairs from pressure switches on the condenser discharge line.

A summary of the design features for the Climate Chamber refrigeration system follows:

- Two-stage compound R-502 system with capability to run one stage only at temperatures above -18°C (0°F)
- Oil separator with oil level control system
- Air-cooled condenser
- Interstage heat exchanger for liquid subcooling
- 100% unloading with hot-gas by-passing
- Automatic defrost on main cooling coil using electric heaters and electric timer control
- Liquid desuperheat on each stage of compression
- High and low refrigerant pressure safety switches
- Oil pump pressure safety switches
- Suction-line accumulator

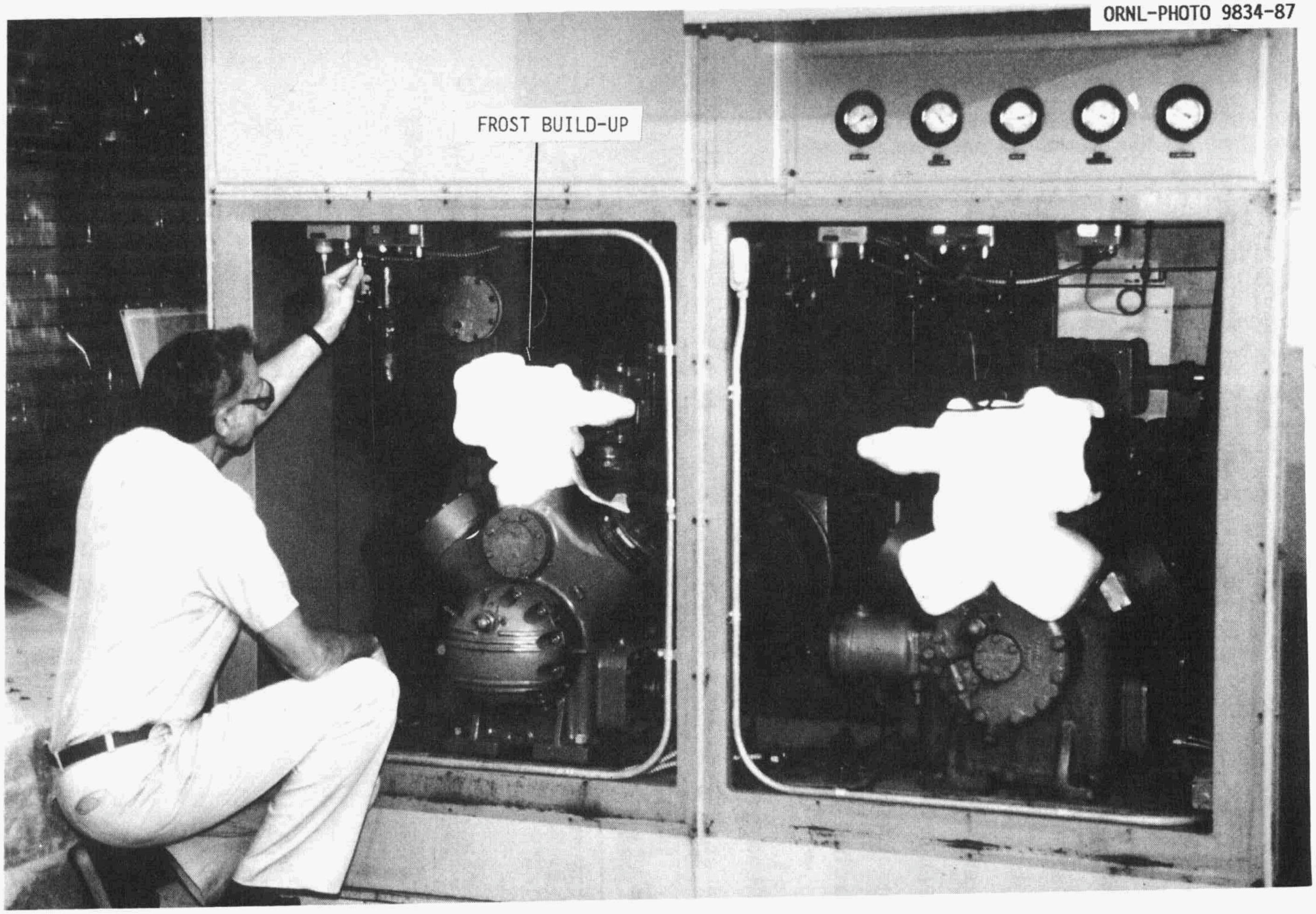

Fig. 10. Manual frost patterns on the compressors after extended operation.

- Multiple circuit evaporator for varying capacity
- Dehumidification coils with an expansion pressure regulator set at 0°C (32°F) for humidity control
- Expansion regulator by-pass on the dehumidification coils for rapid moisture removal
- Two air flow rates are available over the expansion coil depending on test requirements or the refrigeration load

2.2.2.2 Rain system design

The rain system was deferred during initial construction due to funding limitations. The rain system was chosen for deferral because tests requiring simulated rainfall did not appear to be of highest priority during initial operation of the LSCS. Therefore, this section deals only with the proposed installation of the rain simulation system and not the actual hardware. However, the drainage system for water removal was installed because of the difficulty of retrofitting this piping system into the fiberglass-coated floor of the Climate Chamber. The drainage system piping carries the simulated rainwater to the storm drain system via a floor drain in the pit and is ready to use. The remainder of the rain simulation system will be installed as the LSCS test program develops a funded need for it.

The rain system, as now envisioned, is planned to simulate primarily short-term thermal effects on roofing systems; for example, a cold rain falling on a relatively warm roof surface or the reverse. These conditions would be of interest in evaluating thermal stresses in the membranes of typical roof systems. The rain system is not planned to simulate long-term aging effects in accordance with the overall objectives of the LSCS. Therefore, only tap water is used to supply the system. No attempts are planned to simulate conditions such as acid rain within the Climate chamber.

The rain system is shown schematicaly in Fig. 11 and is to be a "batch" system in which 1.1 m^3 (300 gal) of tap water will be conditioned to the desired rain temperature and then introduced into the chamber with a centrifugal pump. The pump is to be located at the bottom of the pit to

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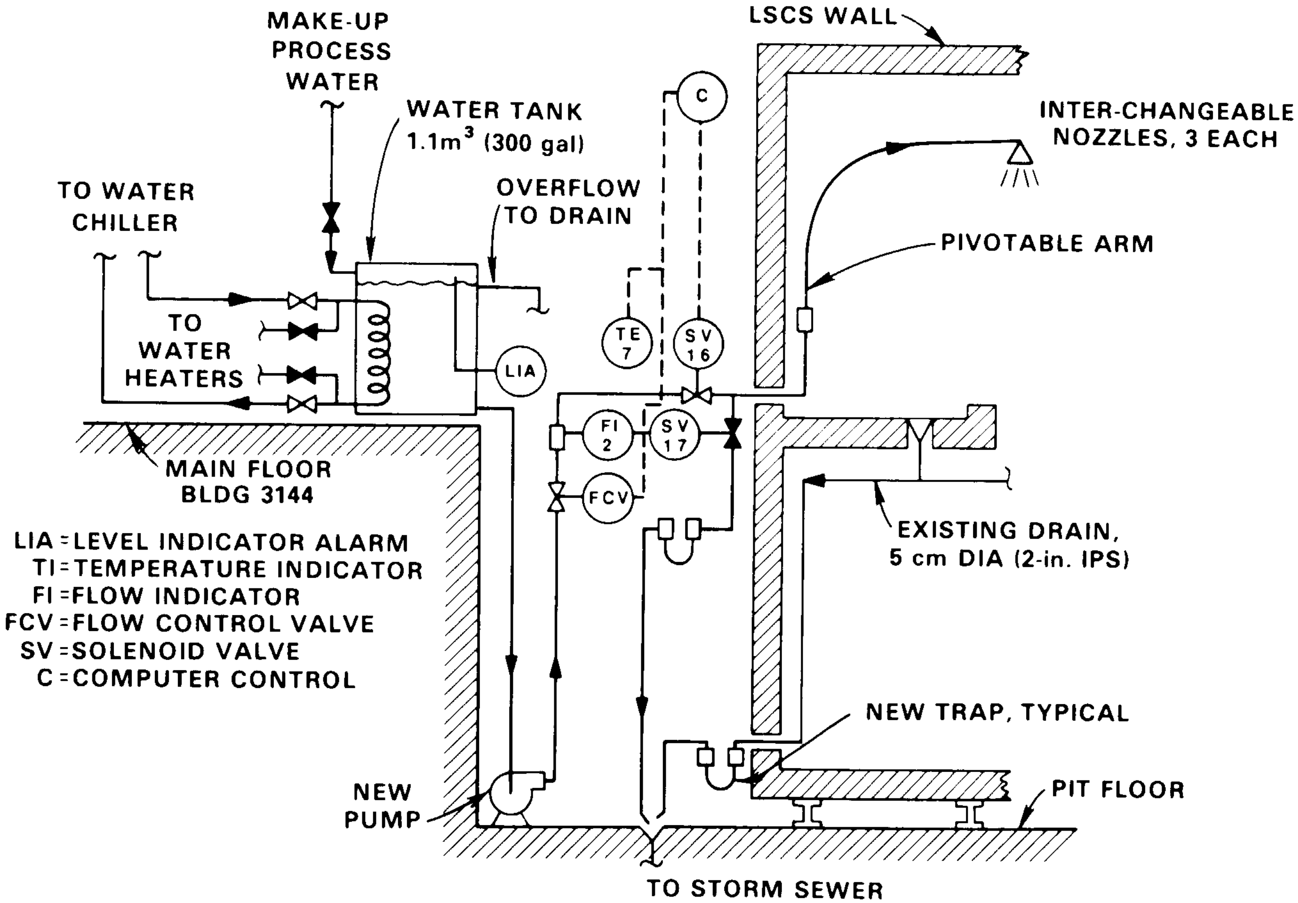

Fig. 11. Schematic drawing of the rain system for the Climate Chamber.

provide adequate net positive suction head. Rain water temperatures will range from 4 to 38°C (40 to 100°F), and rates will range from 0.5 to 13 cm/h (0.2 to 5 in./h) on the roof test surface. This is equivalent to a flow rate of 1.3 to 32 L/min (0.34 to 8.4 gpm). The supply tank will provide 35 min of rain at the maximum rate. At the lowest rainfall rate, the supply tank water would be adequate for 14 h of operation.

The roof test surface can be covered with spray from a single nozzle, which is pivoted out from the chamber wall over the center of the roof test specimen. The present design calls for selection and manual installation of one of three nozzles to get uniform spray coverage, depending on the rainfall rate desired. Alternatively, if it is mandatory to have the full range of rainfall available without entering the chamber, all three nozzles and their individual rubber supply line hoses could be installed initially within the pivotable arm. Then rain water could be introduced remotely and/or automatically to any of the three nozzles by switching external solenoid valves such as SV-16 in Fig. 11.

The spray nozzles specified are supplied by Spraying Systems Company and are designed as "Fulljet" wide-angle stainless steel spray nozzles. The nozzles sizes required are 1/8 GG, 4.3 W; 1/4 GG, 14 W; and 1/2 GG, 35 W to cover the design flow rate range. A tabulation of spray coverage data is shown in Table 3.

Table 3. Spray nozzle data

Nozzle No.	Flow capacity range		Operating pressure range		Spray coverage diameter	
	L/min	gpm	MPa	psig	m	ft
1/8 GG 4.3 W	1.6–4.2	0.43–1.1	0.17–0.65	10–80	3.07–3.7	10–12
1/4 GG 14 W	3.8–13.3	1.0–3.5	0.14–0.65	5–80	2.9–4.1	9.5–13.5
1/2 GG 35 W	9.9–21.7	2.6–5.7	0.14–0.65	5–80	3.2–4.4	10.5–14.5

The pivotable arm and its related piping within the Climate Chamber must be protected from being frozen when full of water. That is the purpose of SV-17 (Fig. 11) which will be used to drain the water whenever the Climate Chamber temperature approaches the freezing point of water. This function may be automated, if desired, via the computerized control system.

Water traps are shown in the two rain system drain lines that exit the Climate Chamber in Fig. 11. The Climate Chamber may be operated at any design pressure level from 1.44 kPa (5.8 in. water gage) below atmospheric pressure to 1.24 kPa (5.0 in. water gage) above atmospheric pressure and still provide drainage automatically because of these traps. The traps must be of siphon-breaking design so that they will always retain some water for sealing of potential differential operating pressures within the Climate Chamber.

Some second-hand equipment for the rain system is stored within Bldg. 3144 for future use. Both a water chilling system and an electric water heating system were obtained (surplus equipment from another ORNL program) to provide the rain water temperature control for the LSCS. The water chiller is a portable 35-kW (10-ton) unit with R-22 refrigerant and also includes a 1.1-kW (1.5-hp) centrifugal water pump to circulate brine to the heat exchanger coil located within the batch tank of the rain system. The electric heater is rated at 10-kW, 460-V, 3-phase, and also has an integral brine circulation pump. Both the chiller and heater were manufactured by Moyer Refrigerating Engineers, Inc., Paramus, New Jersey. Vendor catalog data and equipment descriptions are on file in the LSCS equipment catalog files for future use.

All piping, pumps, tanks, and valves for the rain system will be rust proofed to reduce fouling of the nozzles or discoloring of the test roof surfaces. All equipment will be thermally insulated because the lower operating temperature limit of 4°C (40°F) could cause moisture condensation problems from the air within the building.

2.2.2.3 Infrared heating lamp system design

The infrared heating lamp system is designed to provide typical solar thermal effects on the test roof surface and can be automatically controlled to simulate diurnal cycling. The energy source is a bank of 169 infrared lamps mounted on 30-cm (12-in.) centers on the ceiling of the Climate Chamber as shown in Fig. 12. One removable lamp section provides access for the overhead crane through the roof door.

A computerized calculation was performed to establish a distribution of available lamp wattage sizes so that a uniform energy flux heats the membrane surface. (This calculation is on file at Bldg. 3114 as indicated by item 5 of Appendix A.) Manufacturer's data on energy

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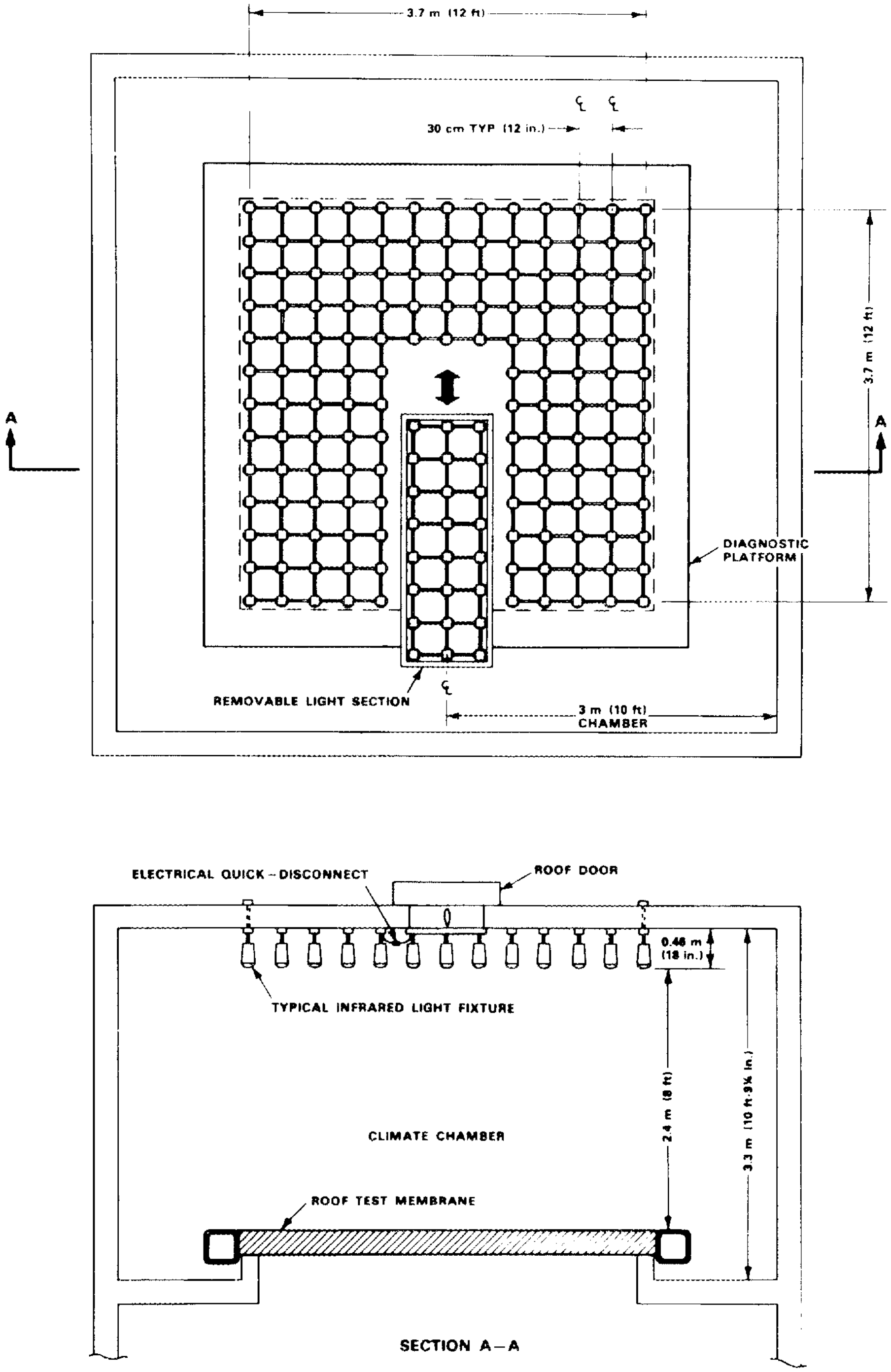

Fig. 12. Layout of the infrared lights within the Climate Chamber.

distribution for the 12.7-cm-diam (5-in.) 120-V heating lamps were used in this procedure. The end result is a lamp placement pattern in which nine 125-W lamps are in the center of the grid with forty 250-W lamps surrounding the central nine. The remaining 120 lamps are each 375-W and are in the three rows at the outer perimeter. This arrangement is expected to produce a uniform heat flux over the entire Metering Chamber area but the heat flux will, of course, be somewhat lower at the outer perimeter of the Guard Chamber area. The voltage of all lamps will be varied simultaneously by the control system to provide heat fluxes from 0 to 1000 W/m^2 (0 to 340 $Btu/h \cdot ft^2$) at the membrane surface. The lamp fixtures have pivotable bases so heat flux variations at the membrane surface, if required, can be obtained by tilting the lamps. Also, reflectors could be used at the perimeter of the roof test specimen to further improve flux patterns.

The electric schematic one-line diagram of the power supply system for the infrared heating lamp is shown in Fig. 13. The silicone controlled rectifier (SCR) controller is 480-V, 3-phase, 90-A capacity, and is phase-angle fired. Zero firing was originally preferred due to less potential for electronic noise generation in the data acquisition system. However, during the design of the system it was discovered that the lamp filaments have reduced lifetimes under zero firing. Therefore, phase firing was selected.

The infrared heating lamp system is described by three Energy Systems engineering drawings listed here for reference purposes: E3E 21188 - D007, E3D 21188 - D008, and E3C 21188 - D009. The design requires 30 individual 120-V circuits to carry the 169 lamps. The lamps are distributed among the circuits so that uniform loading of the 3-phase power supply is obtained.

When installation of the lighting system is complete, field tests will be made to demonstrate the heat flux distribution at the membrane surface. An instrumented field test must be made to assure that the sprinkler nozzles within the Climate Chamber will not be overheated during high temperature operation of the Climate Chamber and the infrared heating system.

2.2.2.4 Pressurization/evacuation system design

The Climate Chamber is designed to be operated from pressures slightly above to slightly below atmospheric pressure, as required. The

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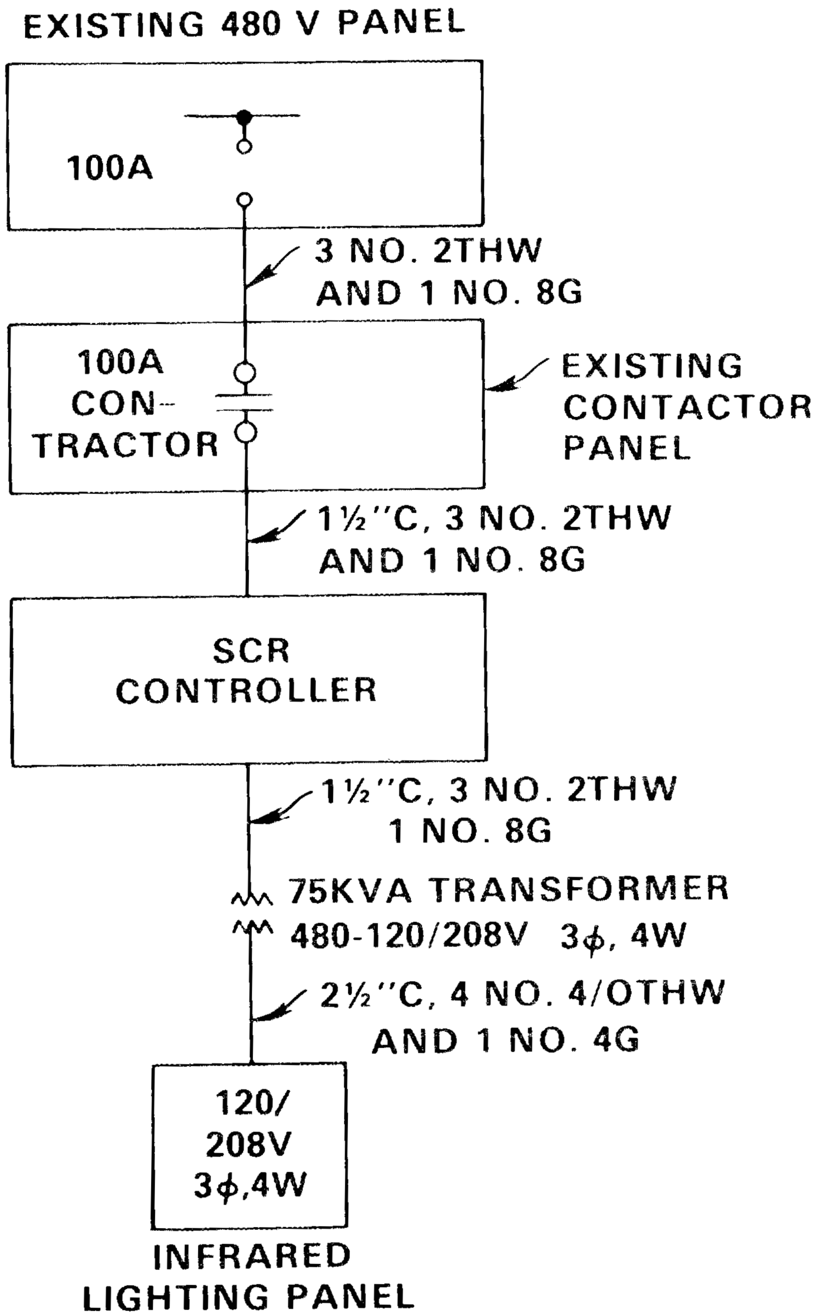

Fig. 13. Electrical schematic of the infrared lighting system.

purpose of operating below atmospheric pressure is to provide vacuum uplift loading to simulate dynamic wind uplift forces. A standard roof test used in the industry provides as much as 1.44 kPa (30 lb/ft^2) of vacuum uplift. Therefore, the chamber was designed to provide this same test condition over the entire roof test specimen surface within the Climate Chamber. In addition, it is anticipated that the ability to operate at any desired pressure level below the maximum may have value in conducting future exfiltration tests on some specimens. Likewise, the Climate Chamber can be operated at positive pressures up to 1.24 kPa (26 lb/ft^2) loading for use in infiltration studies or, for example, to simulate loading on compressible roof insulation materials.

The pressurization or evacuation of the chamber is produced by a single centrifugal air blower with three automatically controlled valves that can connect the pump suction or pump discharge to the Climate Chamber to provide positive or negative pressures as needed. The pressure control system is designed to maintain the desired pressure level within ±5 Pa (±0.02 in. water gage).

The blower was manufactured by Cincinnati Fan and Ventilator Company, Cincinnati, Ohio, model PB-9, 26-cm (10.25-in.) wheel diameter operating at 3450 rpm and driven by a 0.56-kW (3/4-hp) electric motor. Some typical performance data for the blower are shown in Table 4.

Table 4. Performance data for the pressurization/evacuation blower on the Climate Chamber

Static differential pressure		Flow rate		Power	
kPa	inches of water gage	m^3/m	cfm	kW	hp
0.75	3	11.4	403	0.34	0.46
1.0	4	9.8	347	0.31	0.42
1.24	5	8.0	284	0.29	0.39
1.5	6	5.9	210	0.25	0.33

The piping material for the pressurization/evacuation system is 10-cm (4-in. pipe-size) polyvinyl chloride. The control valves are DeZurich "Figure 660" butterfly valves with resilient seats and pneumatic actuators. A photograph of the blower and control valves is shown in Fig. 14.

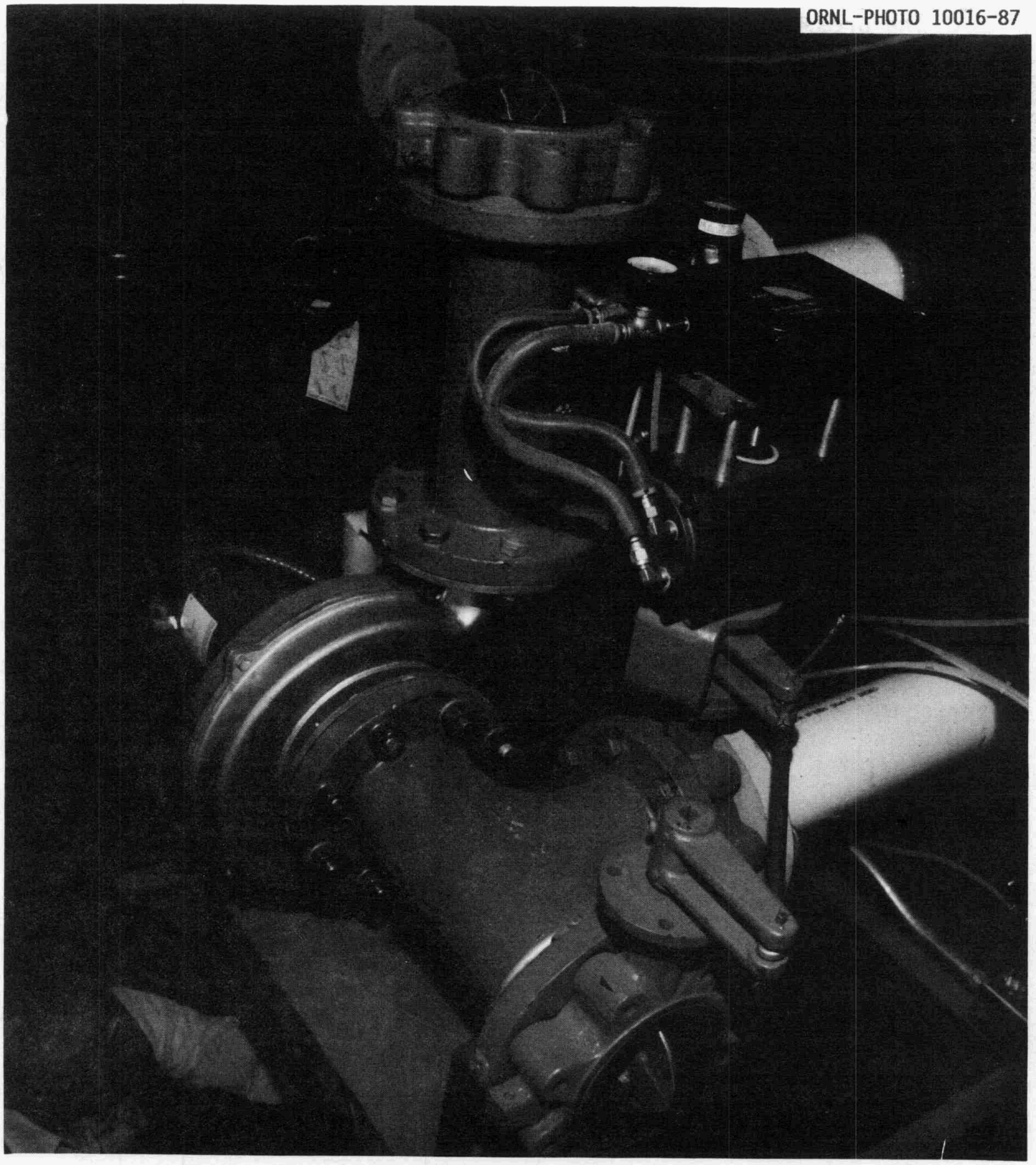

Fig. 14. The blower and control valves of the pressurization/ evacuation system for the Climate Chamber.

The pressurization blower has an auxiliary function for use in purging the Climate Chamber with fresh air in any future situation where outgassing of a membrane may have occurred during operation, particularly at the higher operating temperatures up to 93°C (200°F). To remove possible air contaminants, the valves on the blower would be positioned to force fresh air into the southeast corner of the Climate Chamber while the air is vented from an exhaust valve located at the southwest corner of the chamber roof and discharged outside of Bldg. 3144. This feature was provided to ensure healthful conditions within the chamber prior to occupancy by the operators. Operation of the blower during acceptance tests of the chamber demonstrated that the purge system can provide up to 0.2 m^3/s (394 cfm) of purging air through the chamber. Therefore, the Climate Chamber air volume could be exchanged about once every 10 min.

Outgassing of membranes, bitumens, adhesives, etc., within the sealed Climate Chamber is monitored by a hydrocarbon detector. An alarm will sound if significant levels of hydrocarbons are detected. The alarms and the detector are mounted on the exterior of the Climate Chamber near the personnel access door at the southwest corner of the chamber.

2.2.2.5 Support system for the roof test specimens

The combined weight of the Diagnostic Platform and roof test specimen is supported by eight steel columns that are located below the Climate Chamber and within the Guard Chamber. The weight of the Diagnostic Platform and roof test specimen is transmitted through the floors of both the Climate and Guard Chambers by solid wood inserts within the floors. Below the Guard Chamber floor, the load is transmitted through the steel I-beams and a steel support grid directly to the heavily reinforced concrete floor of the pit.

The load on the support columns will usually be a compression load whenever the specimens, weighing up to 80 kN (18,000 lb), are installed. However, the support columns are also designed to take some tensile loading for a nontypical situation in which a relatively lightweight roof specimen might be subjected to a vacuum uplift test at 1.44 kPa (30 lb/ft^2). In such a test, the uplift force acting on the test specimen can reach about 21 kN (4800 lb) of force, which could levitate a lightweight test piece if not restrained. In fact, this situation was anticipated and occurred during acceptance testing of the chamber with the dummy roof test specimen installed.

Each of the eight support columns has a tapered pin located at the top of the column. This pin will aid in guiding the rather massive Diagnostic Platform into the proper location as it is lowered into position in the Climate Chamber by the overhead crane. These tapered pins and an integral shoulder, which bears the load, are vertically adjustable from within the Climate Chamber by means of a threaded shaft. Figure 15 shows two of the eight support points prior to their installation on the floor of the Climate Chamber. The vertical adjustment is needed to account for manufacturing tolerances in both the chamber and the Diagnostic Platform. Figure 15 also shows one of the support pins with the tapered thread protector cap removed. This cap would be removed only after the Diagnostic Platform has been lowered into position within the Climate Chamber for the special cases where positive hold-down of the Diagnostic Platform is required due to large pressure differentials across the test roof membrane. In this case the protective caps would be replaced by a flat washer and hex nuts to provide the hold-down capability.

2.2.3 Metering Chamber Design

The Metering Chamber is a one-piece molded shell with interior air conditioning devices and a vertically adjustable positioning system that raises or lowers the chamber (Fig. 6). The chamber is designed in accordance with the requirements of ASTM Designation C236: "Standard Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box." The wall construction of the Metering Chamber was described in Sect. 2.2.1.

During guarded hot-box operation, the Metering Chamber is held in position against the lower side of the roof test specimen by a commercially manufactured hydraulic operated X-frame lifting table (Fig. 16). A pendant control is located within the Guard Chamber so that the operators can view the lifting operation directly as the Metering Chamber's rubber seals make contact with the underside of the roof specimen.

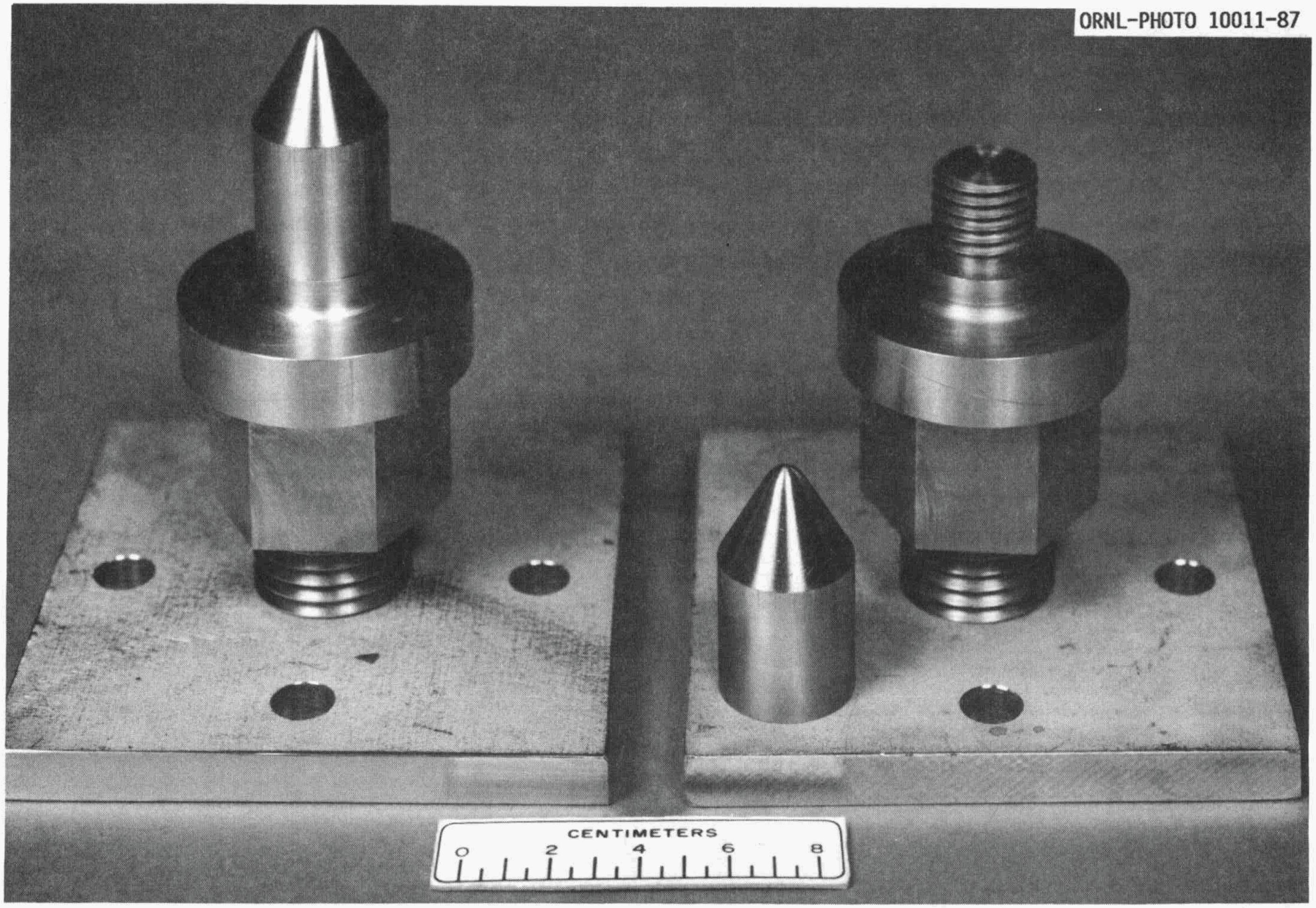

Fig. 15. Adjustable height support points for the Diagnositic Platforms. Eight are required.

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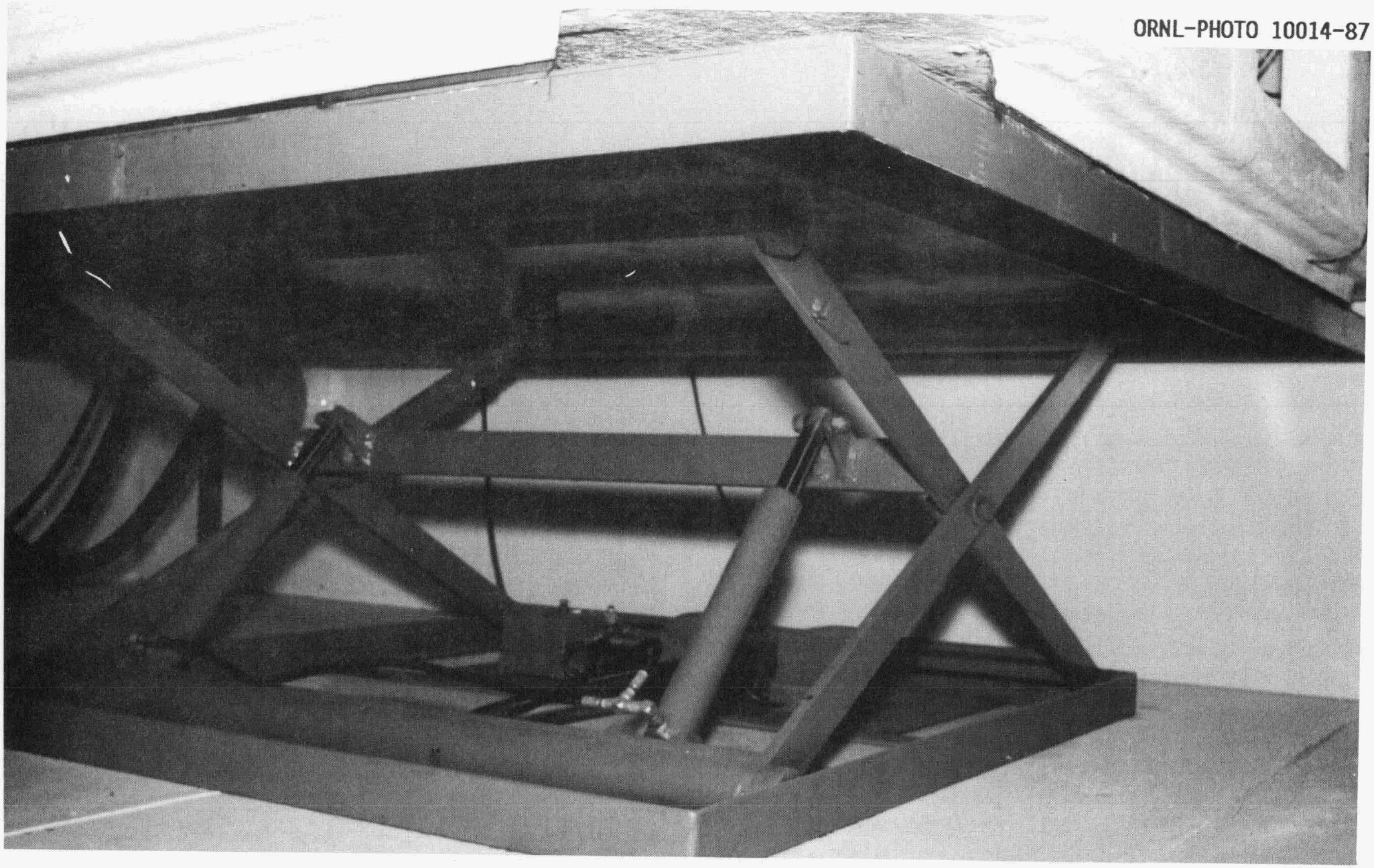

Fig. 16. Hydraulic lifting table for the Metering Chamber.

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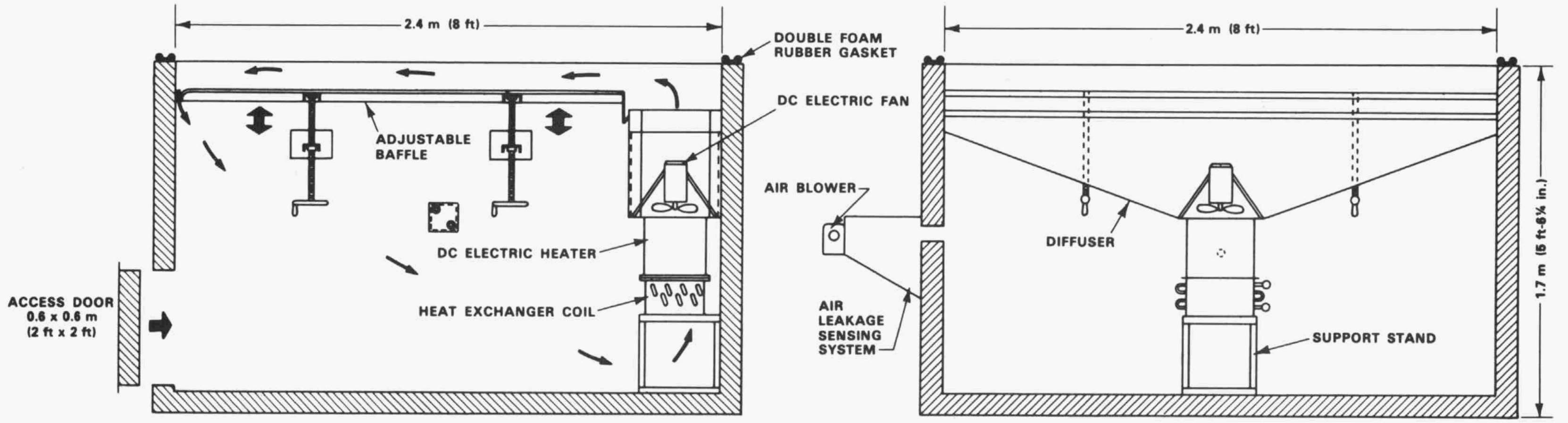

Fig. 17. Cross-section views of the Metering Chamber.

Special mechanical locks are installed manually to lock the table in the raised position to preclude any downward drift of the hydraulic table during prolonged test periods.

When the Metering Chamber is not in use, it may be lowered below the Guard Chamber curb by the hydraulic lifting table to make room for air circulation below an unguarded roof test specimen or to provide space for other experimental apparatus. When the table is in the fully lowered position, the vertical distance from Guard Chamber curb to the top of the double-P seal on the Metering Chamber is 0.58 m (23 in.). The hydraulic lift table has the capability to raise the Metering Chamber considerably more than 0.58 m to effect double-P gasket sealing as required on the lower surface in future tests.

A direct current (dc) variable speed fan motor provides variable air flow rates along the underside of the roof test specimen as shown in Fig. 17. Air velocity in this same region may be further adjusted by vertical movement of the horizontal air baffle by means of manually operated handwheels to adjust four separate screwjacks. The dc fan may be remotely controlled at speeds up to 3000 rpm to provide measured air flow rates up to about 0.29 m^3/s (605 cfm). Direct current electric power for the air circulation fan was chosen to provide precise power measurement as the fan speed is varied. The servocontroller for the dc motor was manufactured by Infranor, Inc., model 90/10/20, and is rated at 90-V output and 10-A continuous load. The fan motor was also manufactured by Infranor, Inc., and is a Mavilor Motor model MO 300 T with integral tachometer. The motor input is rated 54-V and 9-A which provides a power output of 400 W with an efficiency of about 82%.

Air from the fan is discharged upward into the diffuser and flows horizontally under the roof test specimen to two discharge slots at the other end. The air then returns to the floor of the Metering Chamber, flows upward through a chilled water coil, and then flows through a dc powered electric heater to return to the suction side of the fan. Figure 18 is a photograph of the interior of the Metering Chamber.

The chilled water coil has a face area of 25.4 × 30.5 cm (10 × 12 in.) and is built of 1.3-cm (0.5-in.) OD copper tubing with aluminum

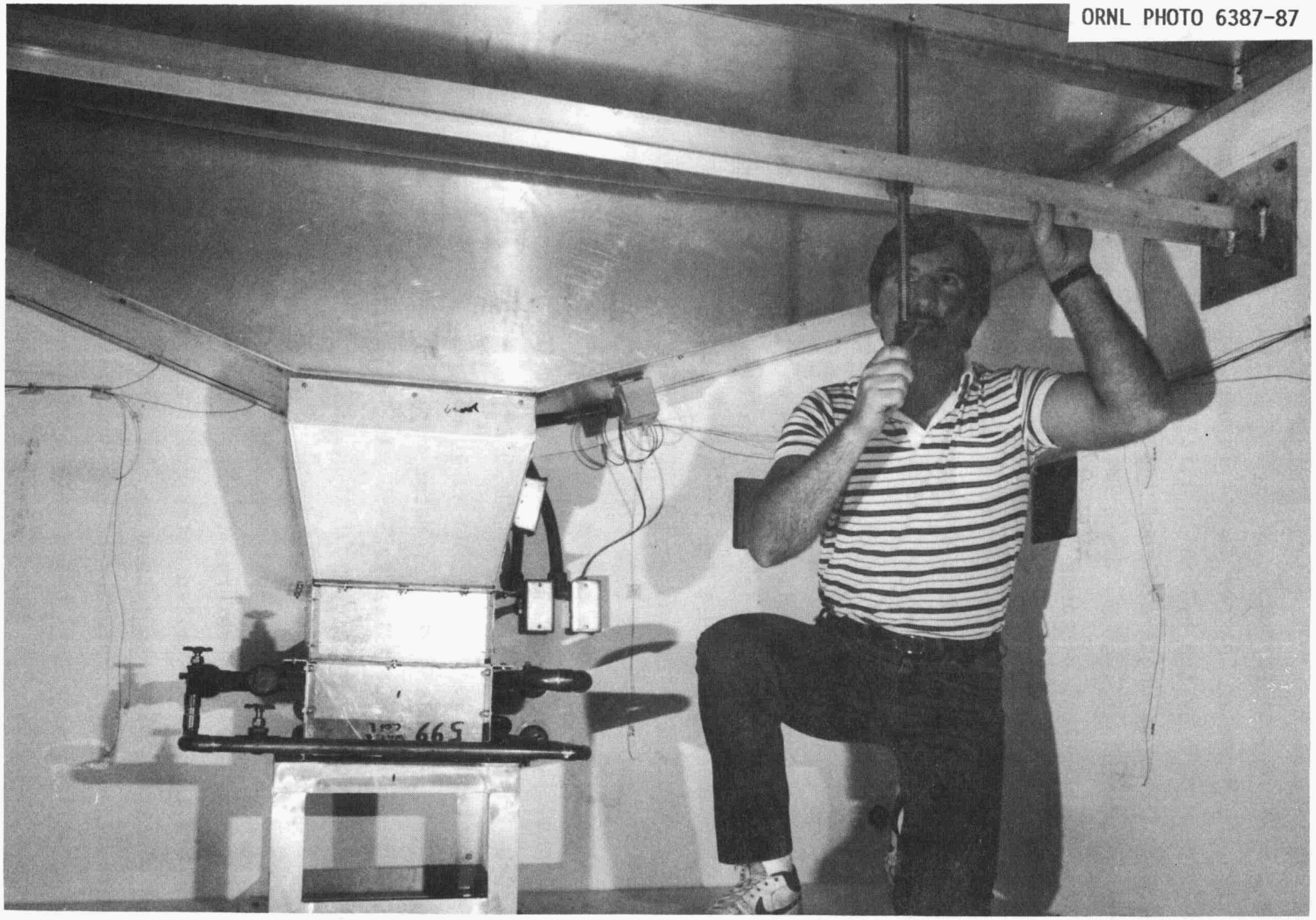

Fig. 18. Interior view of the Metering Chamber.

fins. There are eight tubes in the face area and the tubes make six passes through the heat exchanger. To provide flexibility for a wide range of heat exchanger duty, valves are provided on the heat exchanger headers within the Metering Chamber so that water flow may be directed through either one pass or all six passes of the heat exchanger.

The electric heater is of bare wire design so that it has a low mass for quick response. Direct current power was selected to permit precise power measurements under varying power inputs. Two dc power supplies manufactured by Electronic Measurements, Inc., model TCR 500 T10-4-D, provide power for two 3-kW heating elements to give as much as 6-kW of power. The power to one of the heating elements is continuously variable to provide 0 to 3 kW as needed. The other is on-off controlled for cases where power inputs above 3 kW may be required. Alternatively, both 3-kW power supplies can easily be connected to provide 0 to 6 kW of modulated power. To provide very fine control for experiments requiring low dc power inputs, the heater sizes could be reduced.

2.2.3.1 Chilled water system design

The chilled water system for the Metering Chamber is shown in Fig. 19. Water was chosen as the heat transfer medium because of its well-known physical properties. The minimum design dry bulb temperature of both the Metering and Guard Chambers is 7°C (45°F). Therefore, brine solution is not required to obtain desired temperatures. A common chilled water circuit supplies both the Metering and Guard Chambers because both operate normally at the same dry bulb temperature. As shown in Fig. 19, the water is chilled in a tube and shell heat exchanger with refrigerant 502 supplied from a small 2.2-kW (3-hp) refrigeration system. The heat exchanger and refrigerant compressor are both located on an equipment skid in the pit within Bldg. 3144.

Chilled water flow to the Metering Chamber is automatically adjusted by control value FCV-1 and then enters auxiliary pump PMP-2. After leaving PMP-2, the flow can be either manually or automatically by-passed at RGV-2 to obtain the desired flow rate through heat exchanger WC-1 within the Metering Chamber. Field tests showed that the maximum water flow rate obtainable through heat exchanger WC-1 was 35 L/min (9.2 gpm). A 5-μm full flow filter is placed directly upstream of the turbine flow meter to

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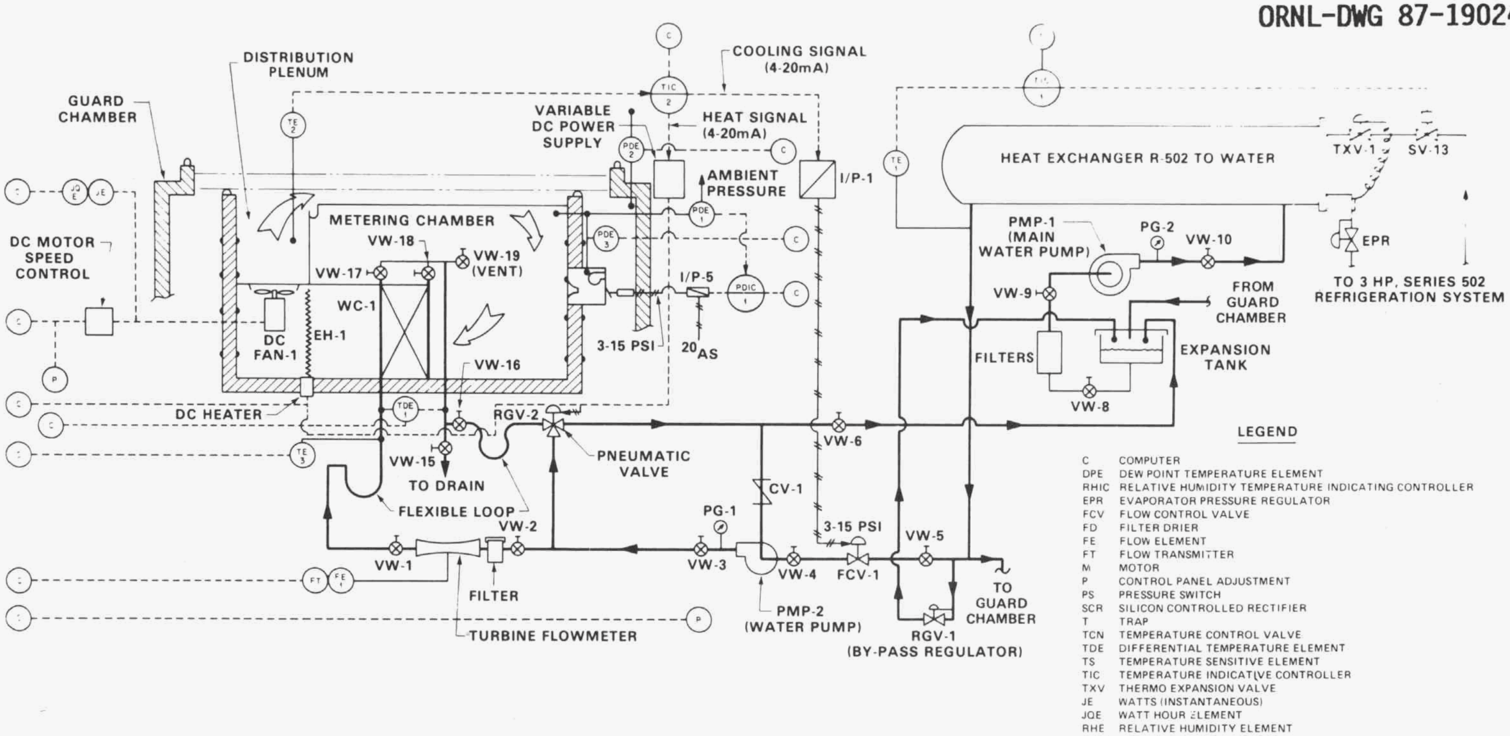

Fig. 19. Flow schematic for the Metering Chamber.

protect its bearings from particulate matter. As a further precaution, water was circulated through the piping system filters for several days prior to the installation of the meter in the system. The calibrated turbine meter, Flow Technology, Inc., model FT8-8 NEYW-LAD-1, serial No. 804091, was selected and installed because of its high precision. The flow meter was calibrated at flow rates from 0.6 to 31.2 L/min (0.159 to 8.26 gpm). Also, a spare calibrated flow meter is on hand in case rapid replacement is required.

The water flows through heater exchanger WC-1 in one of two paths. Manual valves can select either one or six heat exchanger passes, depending on the expected heat load of a particular test series. The temperature change across coil WC-1 is measured with a differential resistance temperature device (RTD) which has an accuracy of 0.1% of calibrated span. The RTD instrument was manufactured by Weed Instrument Company, model 4001 DT 221 BS 00S, and was calibrated at differential temperatures from 0 to 5.56°C (0 to 10°F). The chilled water exits from the Metering Chamber and returns through the expansion tank, two parallel 20-μm filters, the main water circulation pump PMP-1, and the heat exchanger to complete the water circuit.

The Metering Chamber does not have humidity control because the chilled water coil surface will operate dry when the Metering Chamber is in use. Furthermore, the Metering Chamber will be unused and in the lowered position for many tests. Then, the Guard Chamber humidity control system will suffice for both areas. Dew points are controlled over the range from 3 to 50°C (37 to 122°F) for both the Guard and Climate Chambers in the initial design of the LSCS. Dessicant air dryers may be added, if needed in the future, to extend the humidity control range.

A small drain valve, VW-15, is provided on the Metering Chamber heat exchanger WC-1. One function of this drain valve is to drain the coil after isolation valves VW-1 and VW-16 are closed. This drainage would be useful in tests when the chilled water coil is not required and only input from the dc electric heater is needed. For this type of test, water drainage would remove this unwanted mass from within the Metering Chamber.

2.2.3.2. Metering Chamber thermocouples and thermopiles

The Metering Chamber is heavily instrumented with type-T thermocouples and heat flux transducers so as to exceed considerably the requirements of ASTM C236. Thirty-three thermopiles are arranged as shown in Fig. 20, which is an exploded view of the inside walls and floor of the Metering Chamber. The thermopiles consist of thermocouples located on both the inner and outer surface of the Metering Chamber walls and are connected so that they "buck" each other. Therefore, whenever the interior and exterior surfaces are at identical temperatures, the output of the thermopile should be zero. Ten thermocouple rakes are also installed in the Metering Chamber walls and are designated by the symbol "IR" in Fig. 20. These rakes consist of three individual thermocouples with one located in the center of the wall insulation and the other two located directly opposite on the inner and outer surfaces.

2.2.3.3 Metering Chamber heat flux transducers

Another measure of heat transfer through the Metering Chamber walls is available from 10 heat flux transducers, which are identified as "HFT" on Fig. 20. The heat flux transducers were manufactured by HY-CAL Engineering, El Monte, California, model BI-7-420-X6, and have overall dimensions of 5 × 5 × 3 mm thick (2 × 2 × 0.12 in. thick). The transducers were installed by ORNL personnel after the LSCS was assembled by removing 15 × 15 × 29 cm deep (6 × 6 × 1.25 in. deep) plugs with an electric router from the interior walls and floor of the Metering Chamber. Precisely machined plugs of fiberglass laminate and foam insulation were then reinstalled in the routed holes so as to locate the inner surface of the transducer about 2.9-cm (1-1/8-in.) from the inner surface of the fiberglass laminate surface as shown in Fig. 21. Calculations indicated that this depth location might be advantageous during future dynamic testing instead of a location in the middle of the 10-cm-thick (4-in.) foam insulation of the walls and floor.

Each transducer was calibrated in the ORNL Screen Tester prior to installation in the LSCS while mounted in the same type of foam insulation used in the Metering Chamber walls. This technique accounts for thermal shunting effects of the transducers within the foam insulation. Thermal shunting effects must be considered because the particular heat flux

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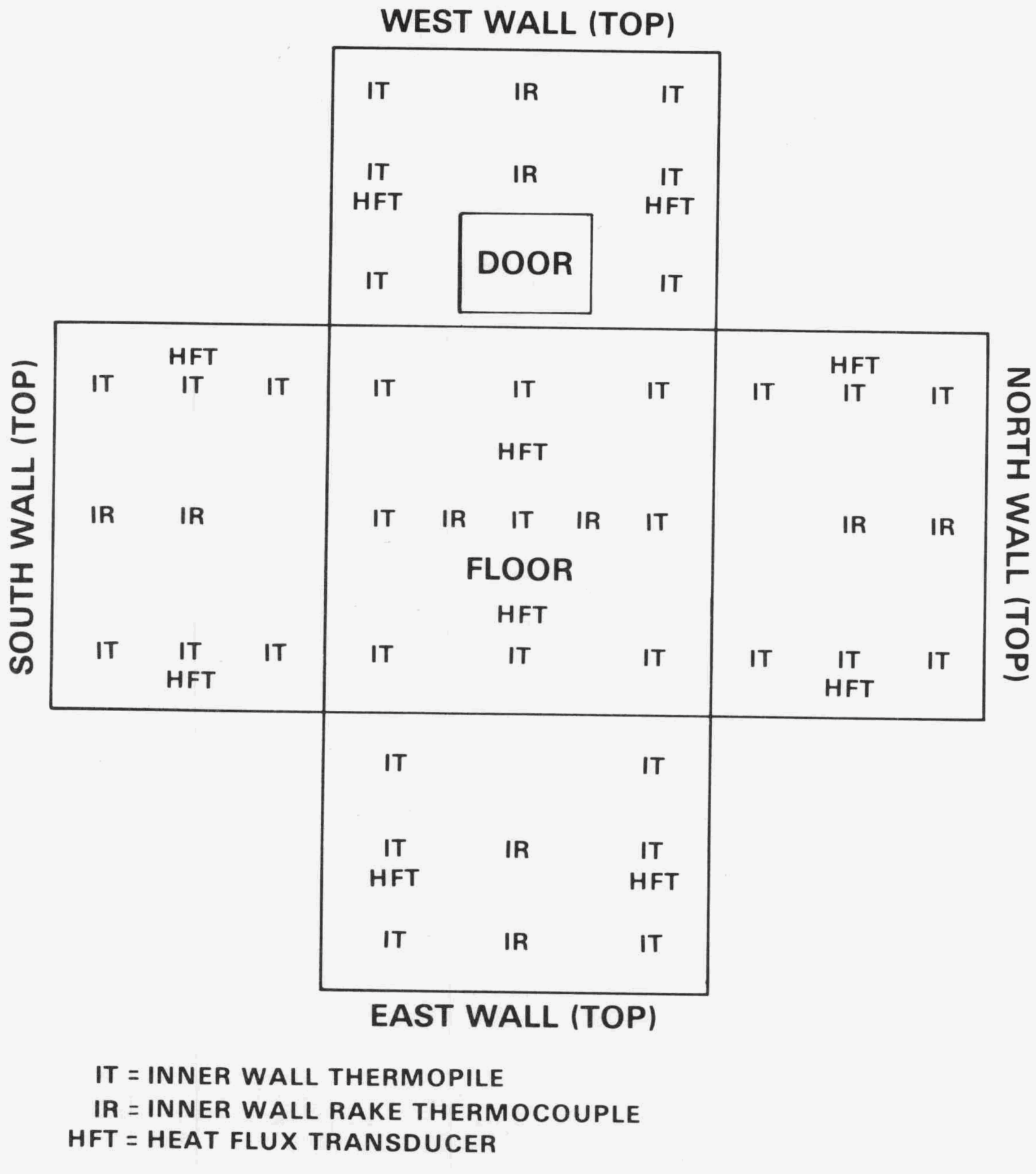

Fig. 20. Exploded view of the Metering Chamber showing locations of instrumentation within walls.

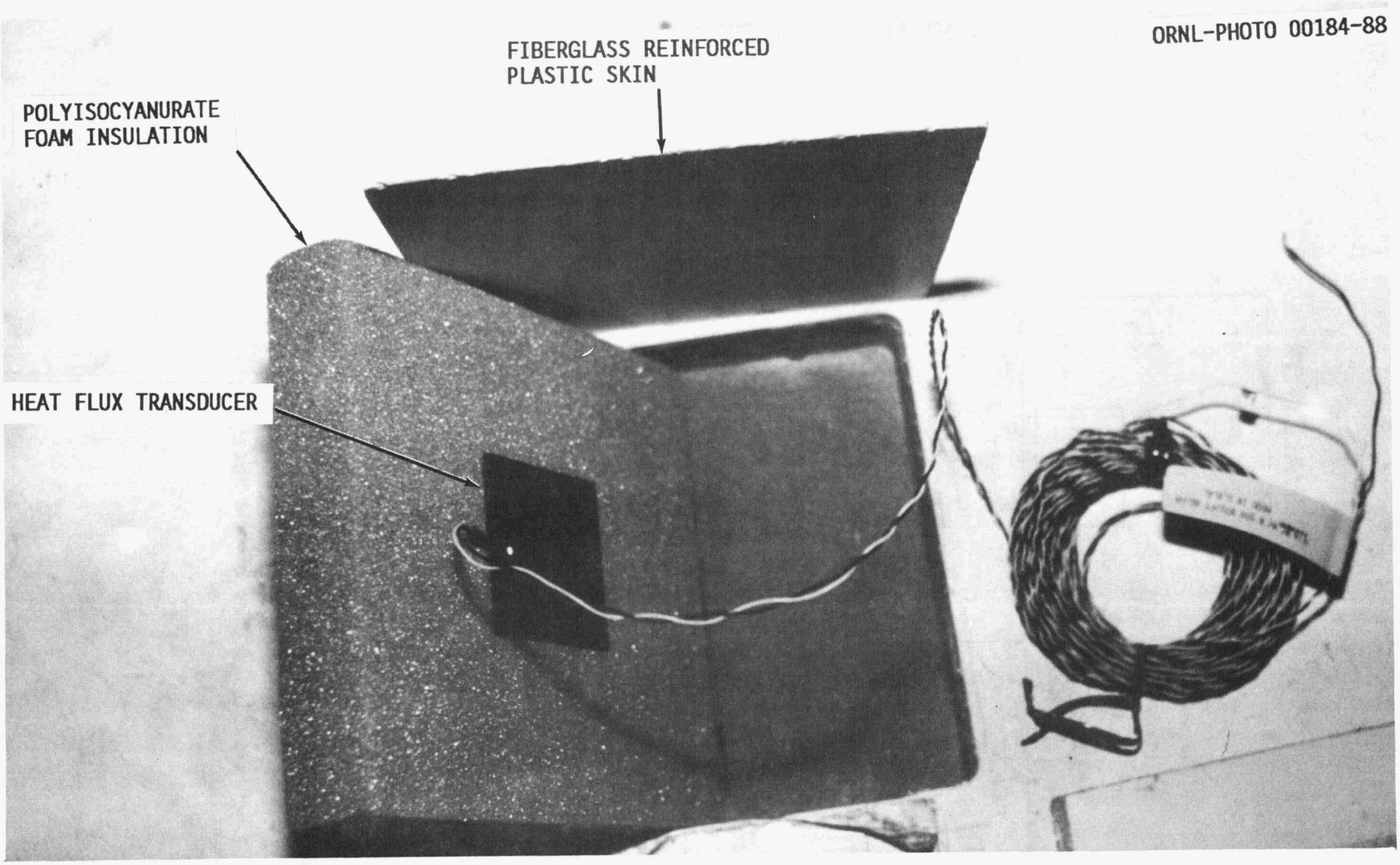

Fig. 21. Method of heat flux transducer installation within the walls and floors of the Metering Chamber.

transducer used has a thermal conductivity different from that of the foam insulation. This specific transducer does <u>not</u> feature a guard region of like thermal conductivity surrounding the sensor region of the transducer. Extra foam insulation samples from the same batch of insulation used in the Metering Chamber construction were purchased expressly for calibration purposes. (Refer to Sect. 2.2.1.)

No heat transfer grease was used in the installation of the transducers within the foam insulation of the Metering Chamber. This decision was based on tests completed in the ORNL Screen Tester about May 27, 1987, in which evaluation tests were conducted both with and without Thermalcote joint compound. These calibration results showed less than 1% difference. It was decided to install the Metering Chamber heat flux transducers without heat transfer grease to avoid potential problems with the grease in the wide range of test conditions to be encountered.

The precise locations of the thermopiles, thermocouple rakes, and heat flux transducers are recorded on Vista drawing No. 599-3-75, sheet 1, on file at the RRC (listed in Appendix B).

2.2.3.4 <u>Air leakage measurement system</u>

An air leakage measuring system is attached to the north side of the Metering Chamber as shown in Fig. 22. This system is provided for a class of experiments in which measurable air flows through the Metering Chamber would be expected during tests of features such as relatively "leaky" roof penetration flashings on buildings where differential pressures are present to create air flows. For example, most commercial buildings operate at slight negative pressure due to the numerous exhaust fans that are typically used. The air handling and measuring system is designed for air flow rates up to 0.42 m^3/min (15 cfm). The system automatically maintains the required exhaust flow from the Metering Chamber to prevent a pressure build-up due to the air inleakage from the Climate Chamber. The pneumatically operated damper valve by-passes flow through the air blower to control air flows from the Metering Chamber into the Guard Chamber. The air flow from the Metering Chamber is measured by elliptical nozzles in accordance with ASHRAE Standard 16-83. Two interchangable 1.2-cm -diam. (0.5-in.) diam nozzles are used to keep nozzle velocities within standard

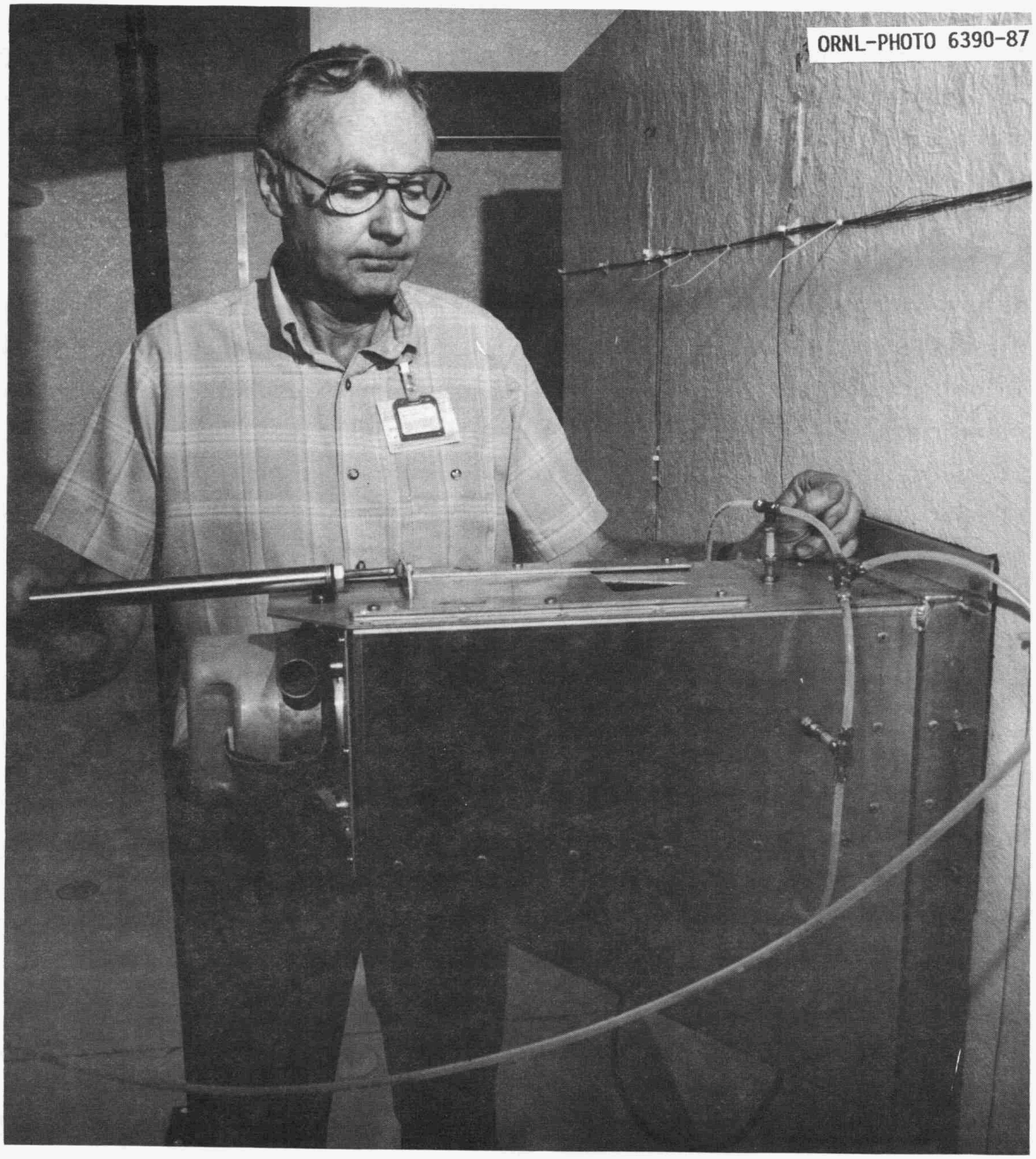

Fig. 22. Air leakage measurement system installed on the north wall of the Metering Chamber.

ranges to provide air flow measurement accuracies within ±0.5%. When the air inleakage measuring system is in use, it is necessary to equalize pressure between ambient air in the pit and the Guard Chamber by venting of the air flow. Pressure equalization takes place through a relief damper that is located in the personnel access door to the Guard Chamber. When the air leakage system is not in use, the pressure equalization panel in the access door is sealed by a removable panel. Also, the entire air leakage measurement system may easily be removed from the side of the Metering Chamber when not in use and stored elsewhere. The 10-cm-diam (4-in.) PVC pipe penetration through the metering chamber wall should be sealed and filled with foam insulation to reduce heat losses whenever the air inleakage system is not in use.

For cases in which air flow is reversed due to a lower pressure above the membrane surface than below it, the air leakage measurement system will be mounted inside the Metering Chamber. In this mode of operation it will be necessary to measure the fan motor power input with the air leakage measurement system to account for all energy inputs within the Metering Chamber.

The high-speed fan on the air leakage measurement system is an Ametek, model #116634-00, which operates at speeds from 3,000 to 12,500 rpm and can create suction pressures up to 4 kPa (16 in. of water) at shut-off. Therefore, care should be exercised when using the air leakage blower because the differential pressure loading both on the Metering Chamber walls and on floor surfaces and the test roof specimen can be significant. For example, at the shut-off head for 12,500 rpm, the differential pressure is equivalent to a load of about 3830 N/m^2 (80 lb/ft^2).

2.2.4 Guard Chamber Design

A Guard Chamber is provided to meet the requirements of ASTM C236. However, for most tests, it is expected that the LSCS will be operated only as an environmental chamber. Thus, the primary function of the Guard Chamber is to simulate the required indoor temperatures below the entire test specimen surface. Whenever the LSCS is used as a guarded hot box, then the Guard Chamber is to provide, as nearly as practical, a temperature identical to that within the Metering Chamber so that there will be minimum heat transfer through the four walls and floor of the Metering Chamber. The wall construction of this Guard Chamber has been described earlier in Sect. 2.2.1.

Temperature control in the Guard Chamber is obtained via a circulating water system. A common chilled water circuit supplies both the Guard and Metering Chambers as noted above in Sect. 2.2.3.1. The Guard Chamber's control systems are shown schematically in Fig. 23. Chilled water enters the Guard Chamber circuit through control value FCV-2 under the direction of Micristar controller TIC-3. Heater HE-1 provides ac electric power input to the water stream from an SCR control circuit as needed to provide temperatures up to 66°C (150°F) in the Guard Chamber.

After passing through heat exchanger coil WC-2 the water returns to the common chilled water loop. Check valve CV-2 allows the continuously operating pump PMP-3 to circulate water through the Guard Chamber regardless of the amount of water introduced into this circuit via control value FCV-2. As noted in a later section of this report, operating experience has shown that this system can control the temperature at the platinum resistance temperature sensor TE-4 to within ±0.06°C (±0.1°F), which exceeds the specified control accuracy.

Air humidity is controlled in the Guard Chamber over a dew point range from 3 to 50°C (37 to 122°F). Dehumidification is accomplished by three copper coils, shown in Fig. 24, which are located near the air inlet to the heat exchanger coil WC-2. Each of the three coils has an outer surface area of about 0.65 m^2 (7 ft^2). The copper coils are chilled by refrigerant 502 that is fed from the chilled water refrigeration compressor. The coils are supplied refrigerant through thermostatic expansion value TXV-2. Evaporator pressure regulator EPR-2 is located in the exit line from the coils to maintain the coil surfaces at a minimum temperature level of 2°C (35°F), and prevent ice formation during dehumidification. Water removed at the dehumidification coils or the main chilled water coil is drained through a trap to a drainage system located in the floor of the pit.

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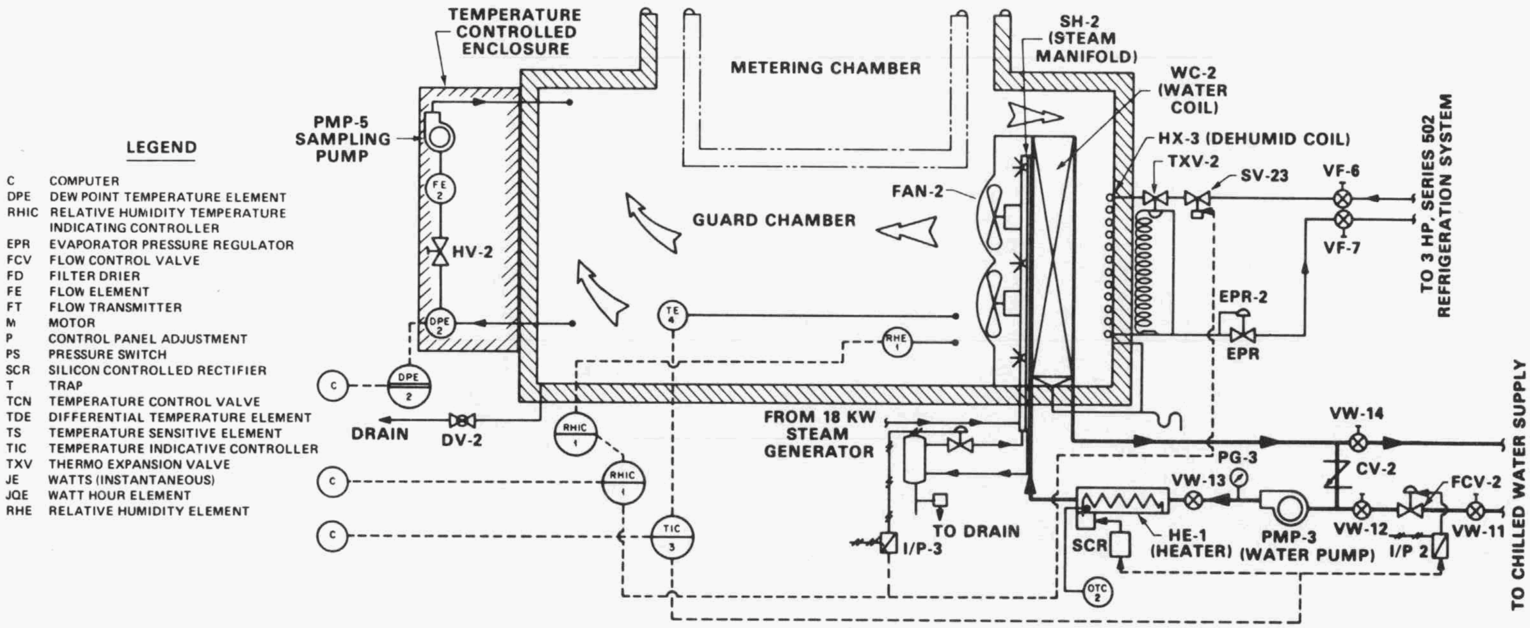

Fig. 23. Schematic drawing of the Guard Chamber control systems.

Fig. 24. Dehumidification coils within the Guard Chamber.

A steam injection system is provided to increase the humidity of the Guard Chamber when required. The steam is supplied from the same 18-kW steam generator that supplies the Climate Chamber's humidity control system. The steam injection nozzle is built as a concentric heat exchanger such that entering steam first preheats the shell and nozzle exterior surfaces and then exits to a steam trap. Condensate is removed and dry steam leaves the trap and enters the preheated nozzles from which it flows into the air of the Guard Chamber.

The moisture sensor for the Guard Chamber control system is a relative humidity sensor manufactured by Vaisala, of Helsinki, Finland, model HMT 14-T0075-1.2. This instrument has an accuracy of ±3% relative humidity at 20°C over the full range of 0 to 100% relative humidity. The meter has rapid response time for transient control purposes. To provide more accurate air moisture readings, a General Eastern dew point hygrometer sensor, DPE-2, model 1200 APS with 1211D sensor, is also provided for the Guard Chamber as shown at the left side of Fig. 23. Air is drawn by a sampling pump from the Guard Chamber through the dew point hygrometer and returned to the chamber. The inlet sampling line and the moisture sensing equipment can be heated electrically to prevent moisture condensation whenever the Guard Chamber is operated at dew points above ambient temperature.

2.2.5 Data Acquisition and Control System Design

The RRC Data Acquisition and Control System is a microprocessor-based network for acquiring, displaying, and storing data obtained during roofing material assembly and testing activities. The system uses two International Business Machines Advanced Technology Personal Computers (IBM PC/AT) located in the experimental area and a third AT clone computer located in the Control Room.

The system consists of all hardware and software components necessary to perform the following operations:

- Interface directly with sensors and process equipment.
- Sample both high level (0-5 V dc) and low level (0-10 mV dc) analog signals.

- Convert sampled measurements to engineering values.
- Display values in real-time in both tabular and graphic formats.
- Store data on removable disk storage media.
- Print hardcopy records.
- Display data trends in graphic plot format.
- Transmit data to other computers in the network.
- Exchange control information with the dedicated Micristar process controllers in the Control Room.

Start-up or shutdown of the LSCS and its support equipment is done from the control panels in the Control Room. When the data acquisition and control system are not being used to alter the setpoints of the Micristar controllers, they can be changed on the control panels. The values of the controlled variables, the current setpoints and the operational status of the LSCS components and support equipment are continuously displayed on the control panels.

The primary computer of the data acquisition and control system is located near the southwest corner of the Climate Chamber. This location was chosen to allow easy verbal communication during check-out operations within the Climate Chamber and to keep the length of the hundreds of experimental sensor wires to a practical minimum. The Climate Chamber computer is an IBM PC/AT industrial rack-mounted computer. An identical rack-mounted IBM PC/AT serves the experimental assembly area to provide complete check-out of system hardware and software during assembly of a roof test specimen prior to its movement into the Climate Chamber. The system in the assembly area is configured to look exactly like the Climate Chamber system for the instrumentation on a roof test specimen and its Diagnostic Platform. A third computer system is provided in the Control Room for use in data analysis, data printout, and for communication with the ongoing experiments as desired. It is a Synergistic Business Systems computer manufactured by NCR, configured similarly to the IBMs.

Block diagrams of the data acquisition and control system are shown Figs. 25a through 25d. The Climate Chamber and Control Room computer systems are discussed in more detail in the following sections.

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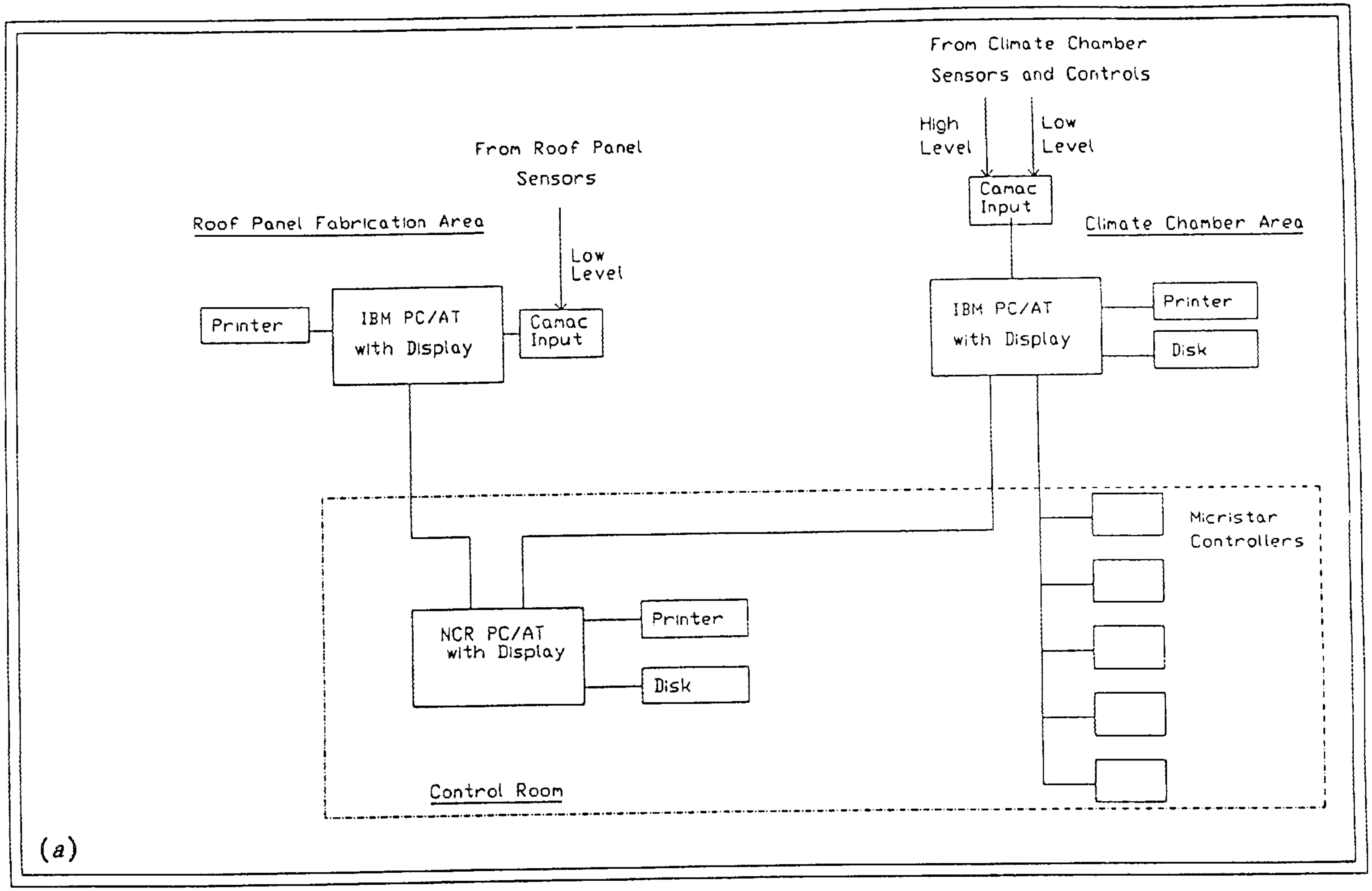

Fig. 25. (*a*) A Roof Research Center data acquisition system network block diagram. (*b*) LSCS data acquisition system block diagram. (*c*) Control Room data acquisition system. (*d*) Experimental assembly area data acquisition system.

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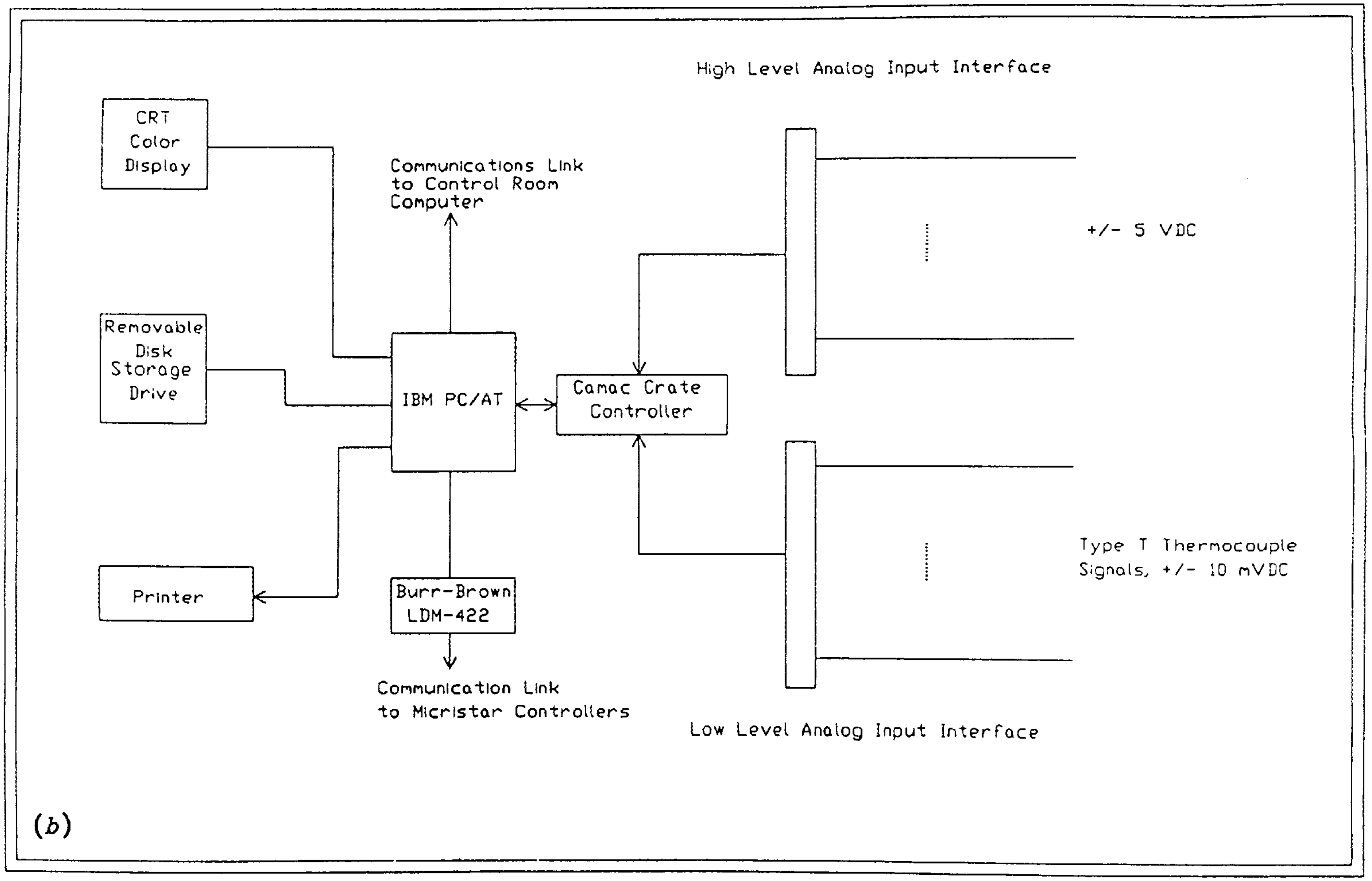

Fig. 25 continued

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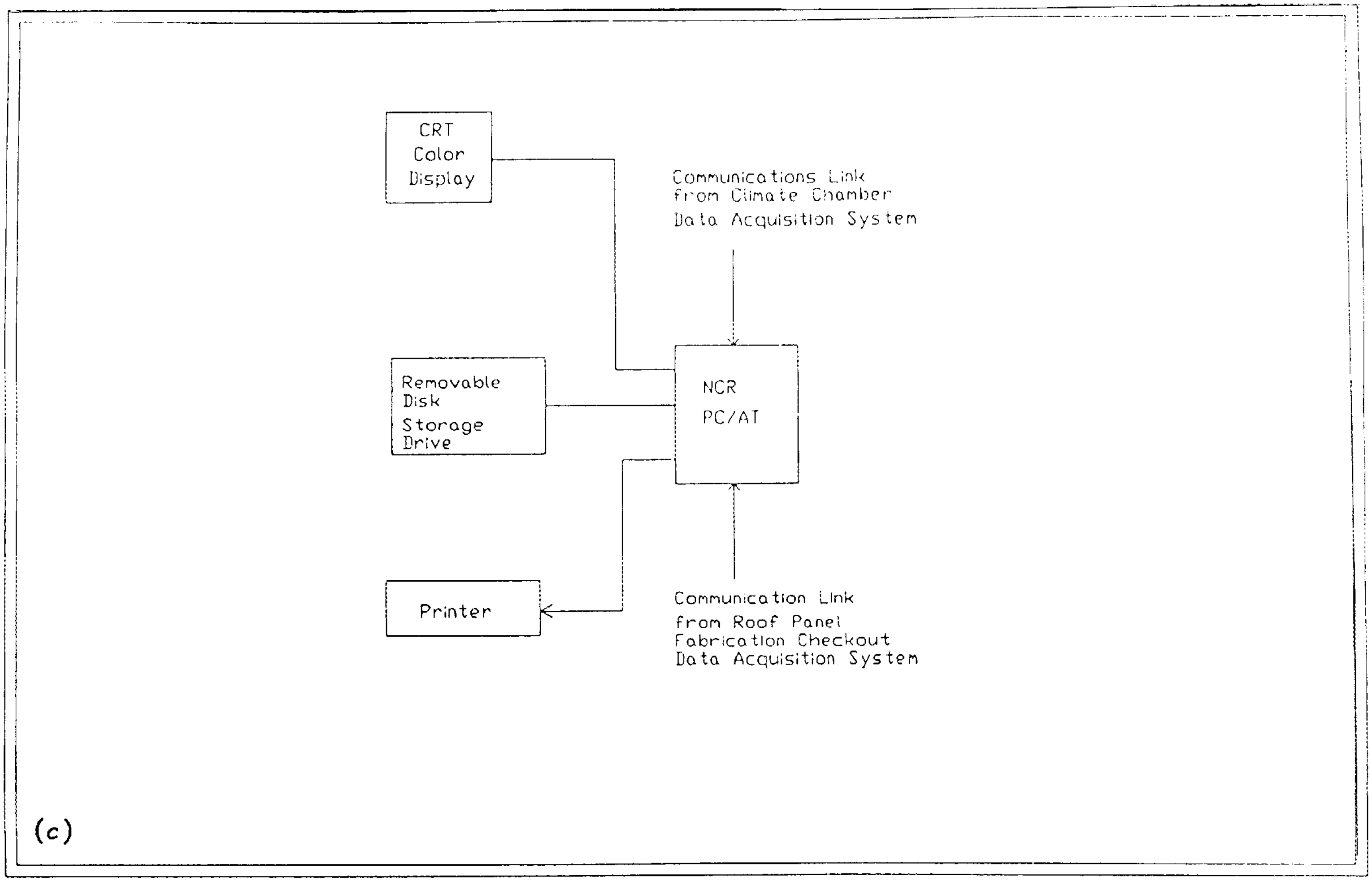

Fig. 25 continued

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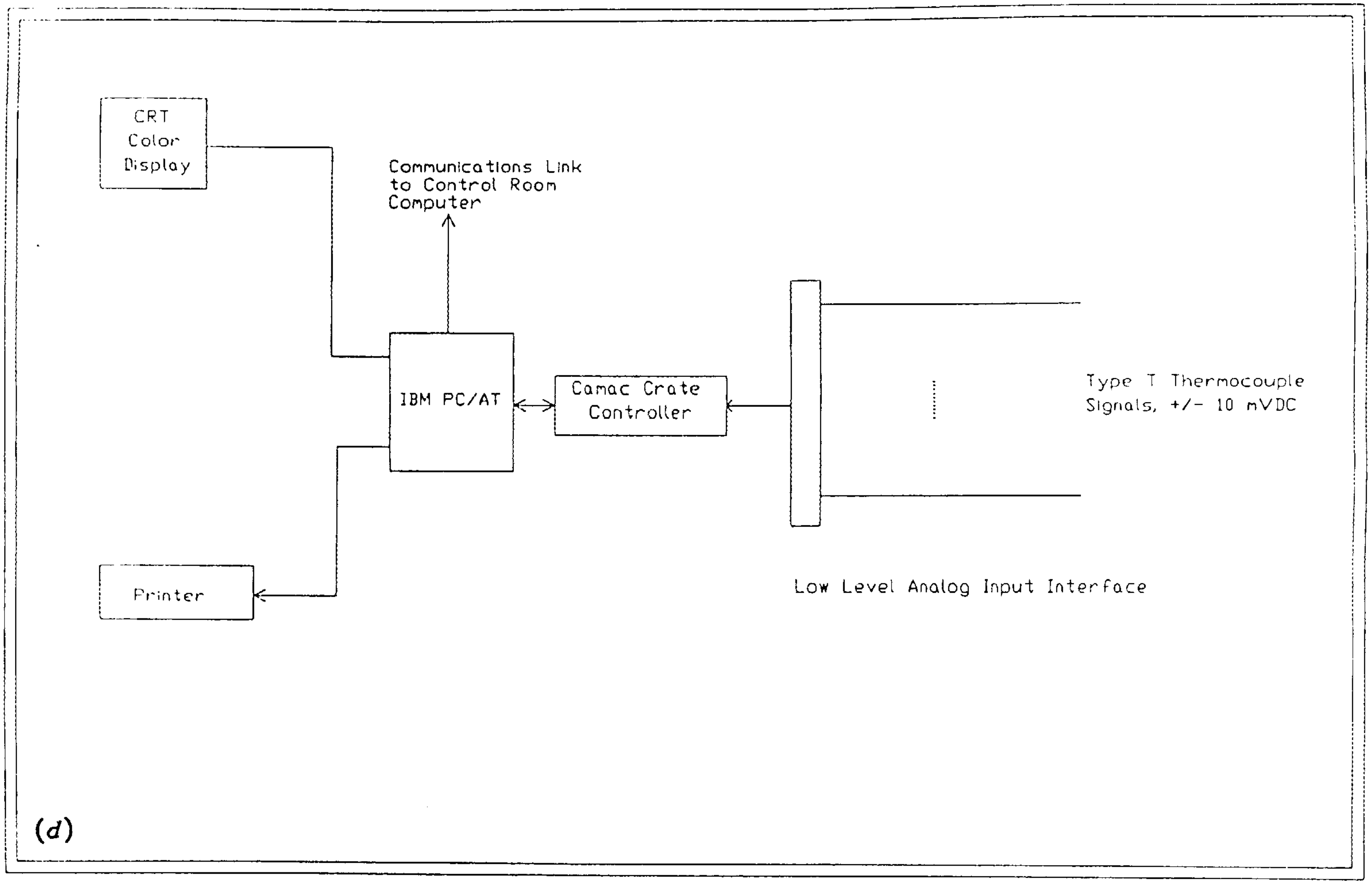

Fig. 25 continued

2.2.5.1 Hardware configuration

The central processing unit for the LSCS computer system is an IBM model 7532 industrial rack-mounted computer. At the time of installation, the unit was equipped with 640-Kbytes of random access memory, a real-time system clock, a 40-Mbyte fixed disk drive, a 1.2-Kbyte floppy diskette drive, and a 360-Kbyte diskette drive with suitable disk drive controllers. The processor operates at a system clock frequency of 8 MHz.

The user interface to the system is by means of the keyboard and an IBM model 7534-964 industrial rack-mounted, color graphics CRT display. The display is mounted directly above the processor in a 19-in. industrial cabinet and provides both tabular text and color graphic data display as shown in Fig. 26. It is driven from the processor through VEGA Deluxe graphics adapter card manufactured by Video-7 Inc. The interface provides a graphics resolution of 640 x 350 dots per inch and is operated in SCREEN mode 9 by the software.

Hardcopy data presentation and program listing capability are provided by a Mannesmann Tally 85 dot matrix printer. The printer is interfaced to the processor by means of a parallel printer interface. If desired, hard copies of screen contents can also be produced. See Sect. 2.2.5.2 for details about this capability.

Program and data storage capability is provided by the following disk peripherals:

- 1 - 1.2-Mbyte floppy diskette drive
- 1 - 360-Kbyte floppy diskette drive
- 1 - 40-Mbyte nonremovable hard disk drive
- 1 - Dual drive, 20-Mbyte/drive Bernoulli removable cartridge disk drive.

The 1.2-Mbyte and 360-Kbyte floppy diskette drives are intended primarily for small volumes of program and data transfer. Both data densities are supported for maximum compatibility with other computers. The single 40-Mbyte, nonremovable disk drive is intended for the operational storage of programs, utilities, user-defined files, and program support files. This disk is backed up periodically onto one or more removable cartridge disks to ensure minimum downtime and recovery in the event of damage to

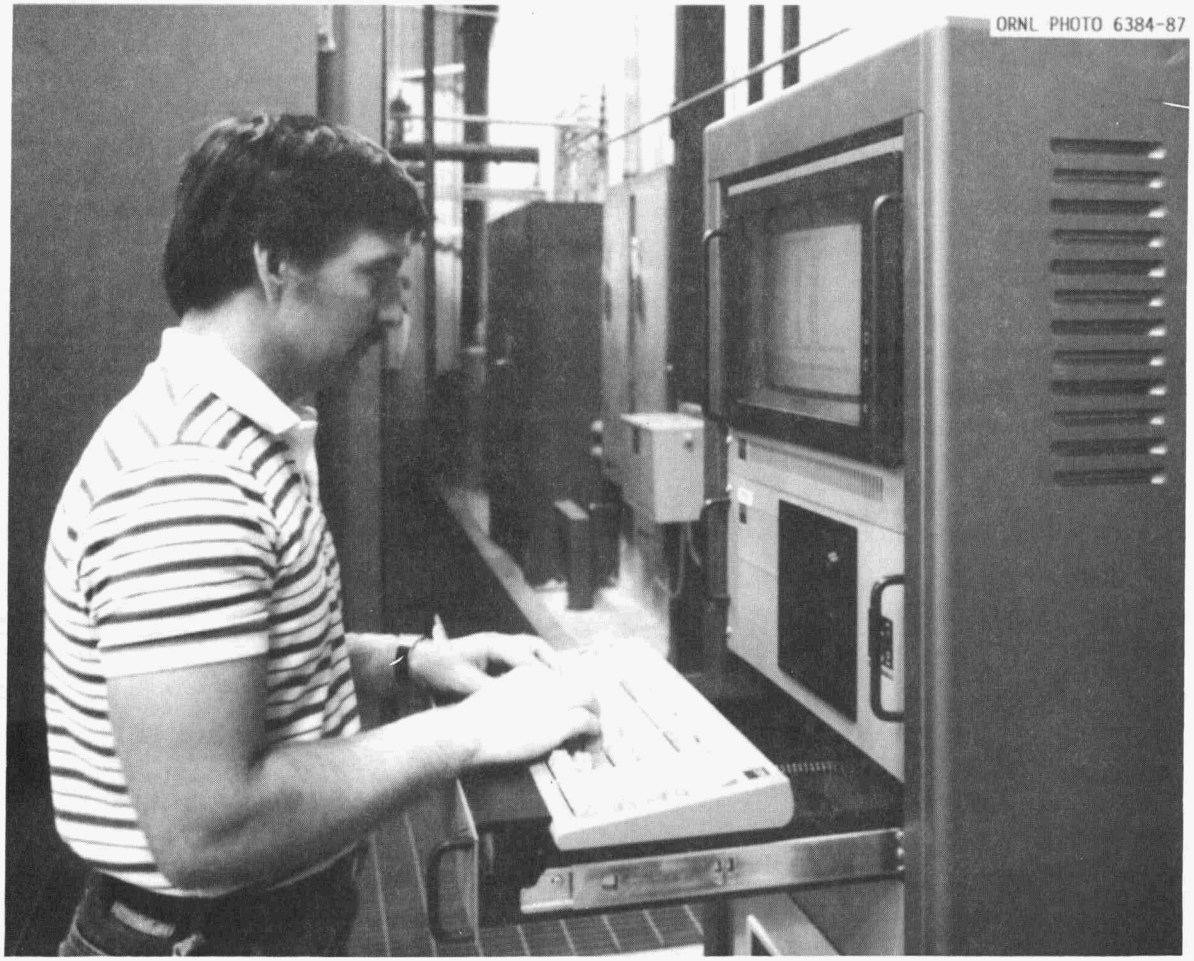

Fig. 26. Rack-mounted computer and CRT located near the Large Scale Climate Simulator.

the hard drive. The dual-drive 20-Mbyte/drive removable cartridge disk drive is provided primarily to permit real-time storage of large volumes of research data for subsequent analysis and interpretation. The organization and conventions for disk data storage are defined and discussed below.

All data obtained from sensors are acquired through Kinetics Systems, Inc., CAMAC analog interface units. The analog to digital converters and multiplexers are mounted in a Kinetics Systems model 1502 powered CAMAC crate, located in the bottom of the system cabinet. The units provide the capability to measure both high level (0-5 V dc) and low level (0-10 mV dc) analog signals. The CAMAC interface was selected based on the need for standardization of CAMAC hardware and software interfacing and support for a wide range of card types (e.g., RTD, strain gage, and thermocouple). Only thermocouples and heat flux transducers are used currently, but support is available when needed for RTDs and strain gages.

High-level signals such as those that originate from the Metering Chamber control equipment (e.g., fan motor speed, fan motor current, and fan motor voltage) are acquired through the high-level analog interface. Amplified signals from heat flux transducers are also connected to the high-level analog input interface. This interface is a Kinetics Systems analog interface module combined with Kinetics Systems FET multiplexing modules. Low-level analog signals such as those originating from thermocouples are acquired through the low-level analog interface. This interface consists of a Kinetics Systems, Inc., Low-Level Analog-to-Digital Converter and several Kinetics Systems, Inc., mercury-wetted reed relay multiplexer modules. All analog input signals are conditioned (scaled) to a level that is compatible with the analog input ranges available. Table 5 shows sensor/signal types, signal magnitude (and sign, if applicable), type of conditioning, and input channel type (level).

The central processing unit for the LSCS computer is equipped with two serial communications ports, COM-1 and COM-2. COM-1 is used for communication with the Micristar controllers, while COM-2 is used for communication with the Control Room system. The exact configuration of each of these interfaces is discussed in the following paragraphs.

Table 5. Sensor and signal descriptions for the LSCS

Sensor/signal type	Magnitude and sign	Type of conditioning	Analog input level
Thermocouple	-1.5/3.0 V dc	none	low
Heat flux	±60 mV dc	amplifier	high
Fan speed	0–15 V dc	voltage divider	high
Fan voltage	0–5 V dc	isolation amplifier	high
Fan current	0–50 mV dc	isolation ampliifer	high

The data acquisition and control system for the LSCS exchanges information with the Micristar controllers over a multi-drop communications cable configuration. Since COM-1 is an RS-232 serial link that does not support multi-drop or partyline serial communications, a Burr-Brown model LDM-422 communications module is used to interface the processor to the Micristar controllers. This interface allows up to 31 devices to share a single communications link. In this configuration, there are a total of six, dual-loop process controllers.

The processor communicates with each of the controllers by polling the controller and requesting specific items of information. These include current values of controlled variables and current setpoints. The processor may also influence the operation of the controller by sending new setpoints values and controller tuning parameters.

The Control Room computer system is made by Synergistic Business Systems. The central processing unit is an NCR model 0112 with keyboard and two 1.2-Mbyte floppy diskette drives and a 40-Mbyte nonremovable hard disk drive. A VEGA Deluxe graphics card feeds an NEC model JC-1402HMA monitor. A dual drive, 20-Mbyte/drive Bernoulli removable cartridge disk drive completes the system.

Communications between the LSCS computer system and the Control Room computer system are provided to permit exchange of process information between the two systems. The type of information exchanged includes the sending of current point values from the LSCS computer to the Control Room computer for remote viewing and the sending of new point values from the Control Room computer to the LSCS computer to influence current point values or control action.

This communication is accomplished through the use of the COM-2 serial port on the LSCS computer and the COM-1 port on the Control Room computer. This link is a standard RS-232 serial link operating at 9.6-Kbaud with even parity, 7 data bits and 1 stop bit.

2.2.5.2 Software configuration

The software for overall system operation is provided in the form of a single main program with an additional program for database loading. Special provisions have been made in the overall systems software to accommodate querying and placement of database values from a remote system. A memory resident common database is used to pass variables between programs.

While there was, at the time of system installation, an abundance of software available for the IBM PC/AT and compatibles, a survey of the market failed to find software that was appropriate for this specific application. The decision to develop customer software was based on the following criteria:

- Need to communicate directly with the Research Industries, Inc., Micristar controllers
- Need to be able to enhance or modify the program structures and/or functionality without having to rely on non-Roof Research Center staff, e.g., outside vendors or other divisions within the Laboratory.

The software is written completely in the BASIC programming language using the Microsoft QuickBASIC Version 3.0 implementation of BASIC. This implementation operates in a compiled environment rather than an interpreted environment. This operation provides a much more responsive software environment and provides much better real-time system response.

The system provides the ability to copy both test and graphics information directly from the CRT screen to the printer. This transfer is accomplished by a program named EPSON that is installed and initiated during system start-up. The program was obtained from the public domain software sources. In order to use the screen copy function, the printer must be loaded with paper and in the "ON-LINE" mode. Pressing the "Print Screen" key on the keyboard when the desired information is on the screen produces a hardcopy of the information.

The system software uses several disk files to process database definition, static display information, and dynamic data display information. These files are discussed in detail in the following paragraphs. How data in these files are presented and stored is discussed in Sect. 2.2.5.3.

Process database files: The process database files are sequential access, ASCII formatted text files with one record for each process point defined in the system. The files are formatted as ASCII text to permit easy editing with almost any text editor program. The maximum number of records is defined within the main program to accommodate the largest needed. A file is opened at the time that the program is executed, the records are read, and the point data tables are configured. The records are essentially free format with commas used as field delimiters. The exact field definition will vary based on the point type (i.e., analog input, analog output, digital input or digital output). The field definitions for analog input points are shown in Table 6.

Static information files: The information presented on the display screen consists of both static and dynamic data and information. Static information is defined as those items that do not change after the display is initially called up. These include screen headings, column headings, options, and similar items. In order to simplify the definition of the static elements of a screen image and conserve memory, files have been defined, with each correponding to a particular display screen. They contain ASCII test formatted records that specify text to be placed on the screen. The records also define the coordinates for the placement of the text on the screen and a code for the color of the text when it is displayed. The fields within the record are essentially free format with commas serving as the delimiters for each field. The field definition for these records is shown in Table 7. These files are identified by filenames of the form "SCRNxxx.SCN", where "xxx" is a numeric designation corresponding to the display "screen" number as defined within the program.

Table 6. Field definitions for analog imput points

Field	Function	Allowable/expected contents
1	Point type	ANI-Analog Input
2	Point name	Alpha-numeric characters (10 maximum)
3	Engineering Units	Any reasonable units designation (e.g., gal/min, °F, % humidity)
4	Point origin	Point source designation (how does it get into system) (e.g., MIC=Micristar communications; ADC=analog to digital convert)
5	Input unit	Numeric value of point origin unit (e.g., 1)
6	Input channel	Numeric value of channel on input unit (e.g., 1)
7	Conversion type	Symbolic conversion type designator (e.g., T=type "T" thermocouple; LIN=linear conversion of form: y=bx+c (see below); QUAD=quadratic conversion of form: $y=ax^2+bx+c$
8	"a" coefficient	Second degree term coefficient
9	"b" coefficient	First degree term coefficient
10	"c" coefficient	Constant coefficient
11	Low limit	Low alarm limit in engineering units
12	High limit	High alarm limit in engineering units
13	Sample interval	Interval (in seconds between analog input samples)

Table 7. Field definitions for data presentation

Field	Function	Allowable/expected contents
1	Row number	Numeric value of row on screen; should be <20
2	Column number	Numeric value of column on screen; must be 1 to 72
3	Color code	Numeric value of color code in accordance with the standard color codes
4	Displayed test	Alpha-numeric text to be displayed

Dynamic information files: The dynamic data presented on the monitor consist of process point values. The specification of the points and the corresponding location on the screen are defined by the records contained in the dynamic information files. These files are identified by filenames of the form "SCRNxxx.PNT", where "xxx" is a numeric designation corresponding to the display "screen" number as defined within the program. The fields within the record are essentially free format with commas serving as the delimiters for each field. The field definition for these records is shown in Table 8.

Table 8. Field definitions for the dynamic information files

Field	Function	Allowable/expected contents
1	Row number	Numeric value of row on screen; should be <20
2	Column number	Numeric value of column on screen; must be 1 to 72
3	Color code	Numeric value of color code in accordance with standard color codes
4	Point name	Alpha-numeric name of the point whose value is to be displayed

2.2.5.3 Data presentation/storage

The system software directs the collection of data into the process database files. These data are combined with data in the static and dynamic information files and presented on the LSCS computer monitor screen.

Each screen contains a STATUS, QUERY, and INPUT line and is selected from the MAIN MENU. The MAIN MENU screen comes up automatically upon start of the program.

The STATUS line provides the operator or observer with the condition of the data acquisition and control system, printer logging status, and disk logging status. SYSTEM RUNNING indicates that data are being gathered; otherwise, SYSTEM STOPPED is displayed. PRINTING ENABLED means that information is being logged by the printer; otherwise, PRINTING DISABLED appears. DISK STORE ENABLED means that information is being logged to the active disk drive; otherwise, DISK STORE DISABLED is displayed.

The default QUERY line shows valid keyboard inputs for a particular screen. If an incorrect response is input and echoed on the INPUT line, the QUERY line changes to "NOT A VALID SCREEN OPTION" for a few seconds. Then it changes back to the default, the INPUT line clears to blank, and both wait for the next response. If a correct response is input, the screen changes, the QUERY line goes to its default for the next screen while the INPUT line is again blank waiting for a new response. A carriage-return-only response will always return the operator or observer to the previous menu. Thus, repeated carriage-return-only responses brings up the MAIN MENU, providing a path to any of the screens is available.

The choices on the master menu include the following:

- START sends instructions to poll the high- and low-level A/D converters and the Micristar controllers for data from the sensors defined as active in the process database file. The polling continues at programmed intervals.
- STOP means to stop gathering data (i.e., no longer poll the data acquisition hardware or serial communications port for updates on data).
- GRAPH allows presentation of data in the current buffer (data from up to 22 h of the most recent system operation) in one of various formats. DIAG is an overall system diagram with a few values from each part of the system. BAR presents a bar chart for a selected group of variables. TREND shows one selected variable's trend every 5 min for up to 22 h with axis minima and

maxima automatically selected or manually entered. The choice of one of the three formats DIAG, BAR, or TREND is made from the GRAPH submenu. Once a choice is made and it is on the screen, the data presented are updated each time the system scans.

- CONTROL shows the present values and setpoints of variables controlled by the Micristar controllers. The operator can change any setpoint through this menu.
- DATA dynamically displays data on all points defined in the system. The format is a scrollable table. Any particular point can be moved to the top of the list for special emphasis.
- DISK allows the current disk file to be closed and a new one opened for collection of data into one file to document the response to a particular sequence of controlled variable values during a run. The file is identified by the date and time at which it was opened, and a one-line, operator-input identifier unique to the data.
- PRINT displays the printer control menu screen. It allows printer logging to be enabled or disabled and the logging interval to be set.
- QUIT terminates the data acquisition and control program in an orderly fashion by stopping all data acquisition and/or logging, closing open files, and returning to the operating system environment. Control of the LSCS continues under the direction of the Micristar controllers at their current setpoints.

2.3 DIAGNOSTIC PLATFORM DESIGN

Diagnostic Platforms are multipurpose devices that, in their most basic configuration, are reusable roof test specimen holders with provisions for sensors and data acquisition. However, the Diagnostic Platforms can also provide operational features which enhance the flexibility and range of experiments that can be carried out in the LSCS.

A primary feature of each Diagnostic Platform will be instrumentation terminal boxes that contain multi-pin quick-disconnectors for the thermocouples as well as other instrumentation. The design of the Diagnostic

Platform is based on multiple 55-pin connectors which are commercially available. Therefore, after the Diagnostic Platform is placed in the Climate Chamber, the instruments can be quickly connected to the data acquisition system using the multi-pin connectors. Each terminal box can accommodate about 220 individual instrument wires. Multiple boxes will be used as required to meet the needs of each experiment. This feature will be particularly useful in the more complex experiments that are estimated to contain up to 300 data channels.

A separate data acquisition station is provided in the experiment assembly area so that all instruments can be checked operationally in advance to assure compatibility with the data acquisition software and hardware. This precheck will also reveal, in advance of operation, any wire reversals and open or poor electrical contacts in the instrumentation system. The end result will be improved quality control of the instrumentation prior to experimental use. A sketch of a simple Diagnostic Platform and its related quick-disconnect panel is shown in Fig. 27. As noted earlier, some experiments will have more than one quick-disconnect panel depending on the number of instruments. The quick-disconnects are mounted on stand-offs in a thermally insulated water-tight gasketed aluminum enclosure to keep the connectors and their related thermocouple wire junctions near isothermal conditions to minimize potential thermocouple errors. Key thermocouples will be field calibrated to determine that required accuracies are obtained.

A cross-sectional drawing of a Diagnostic Platform is shown in Fig. 28. The simple Diagnostic Platform is a rather massive device, weighing about 12 kN (2700 lb). The main structural member is a square framework that is fabricated from 25-cm (10-in.) square carbon steel tubing. Figure 28 also shows one of the eight adjustable height support points that are mounted on the Climate Chamber floor to support the Diagnostic Platform within the chamber. Removable hoist rings, shown by dotted lines in Fig. 28, are used whenever the Diagnostic Platform is moved. After the Diagnostic Platform is installed, the hoist rings are removed and the hole in the flashing is temporarily sealed or waterproofed as required. The flashing, which extends over the Diagnostic

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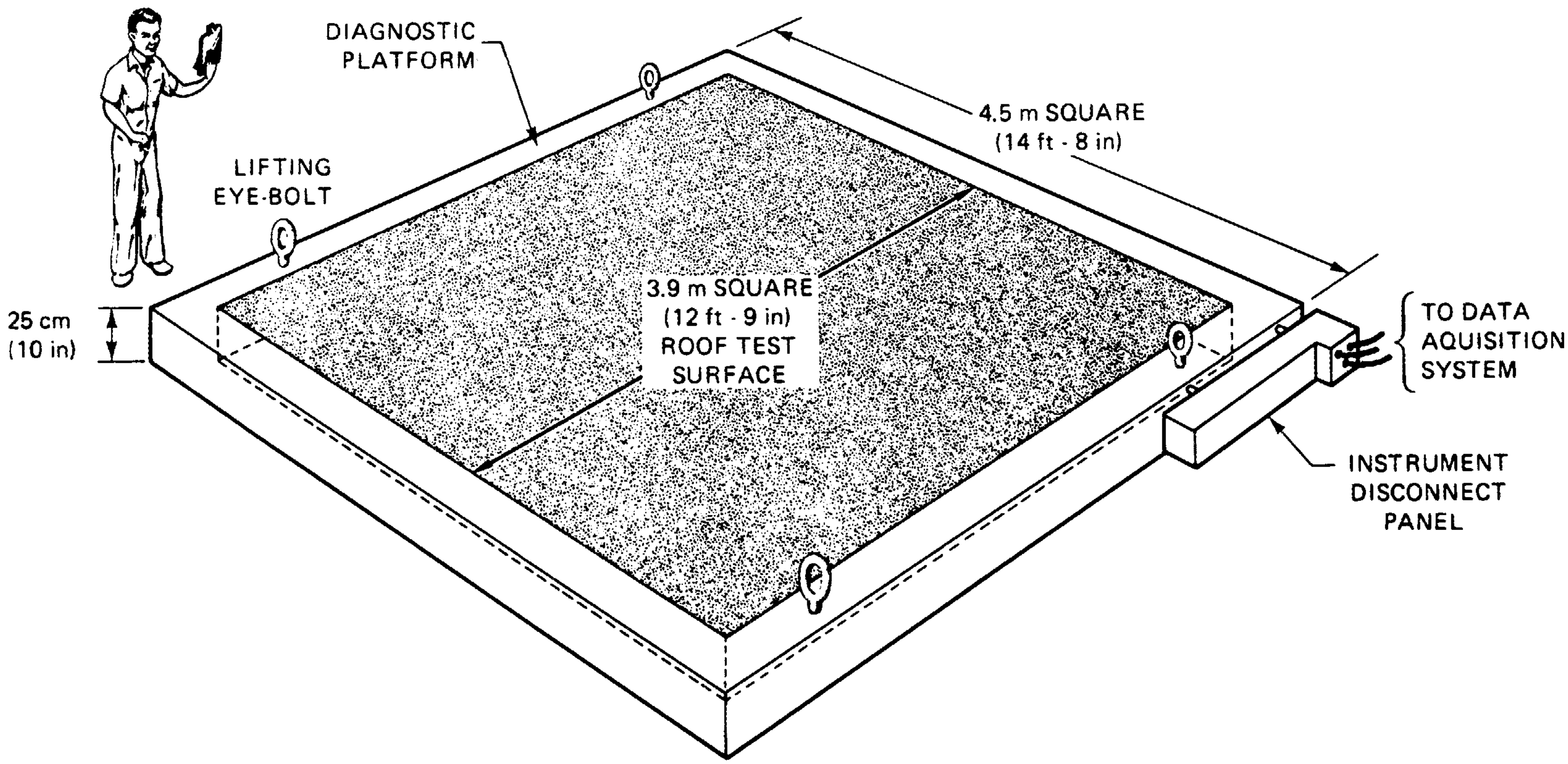

Fig. 27. A typical Diagnostic Platform with instrument disconnect panel installed.

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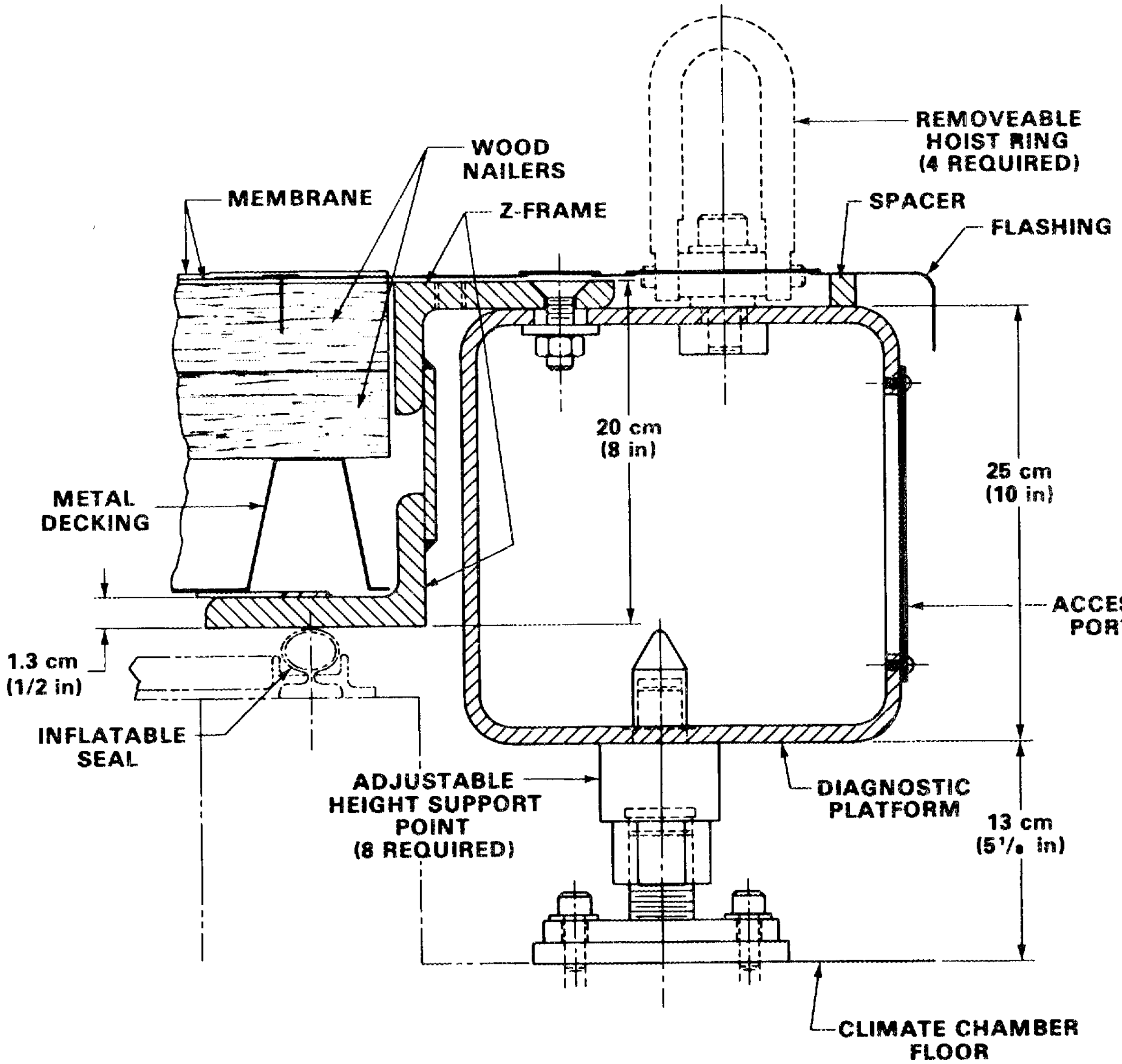

Fig. 28. Cross-section drawing of the Diagnostic Platform and Z-frame.

Platform, provides two functions. It will carry away any simulated rainfall from the membrane, and it provides a radiation baffle to reduce radiant heating of the upper surface of the Diagnostic Platform. Radiant energy from the infrared heating lamps will tend to bend the platform because more radiant heating will occur on its upper surface. The flashing will reduce this bending effect.

The Z-frame was provided as a separate part within the Diagnostic Platform to allow rapid removal of a particular roof test specimen from the platform. The Z-frame was designed to accommodate roof specimens with concrete underlayments and is, therefore, structurally adequate for test specimens weighing up to 61.4 kN (13,800 lb). The device provides a structural framework to allow removal using the lifting fixture and overhead crane. The Z-frame also is used during storage of roof test specimens in a storage rack that is described in Sect. 2.3.2. The same removable hoist rings are used in either the Z-frame or Diagnostic Platform whenever lifting is done.

As shown in the cross-sectional drawing of Fig. 28, the Z-frame consists of two carbon steel angle irons that are joined by welding to a flat carbon steel strip, thereby creating a Z-like cross section. The length of the vertical flat strip may be varied in future Z-frames to meet specific experimental requirements. The initial Z-frames have been fabricated with an overall height of 20 cm (8 in.). It is noted that the position of the inflatable seal in Fig. 27 is at a fixed elevation. Therefore, if the overall height of the Z-frame is varied in the future, the position of the Diagnostic Platform must also be raised or lowered accordingly. This movement of the Diagnostic Platform is done with the adjustable support that can vary ±1.3 cm (0.5 in.) in height. Two sets of support collars have been provided for the eight support points so that Z-frame heights ranging from 16.2 cm (6-3/8 in.) to 21.6 cm (8.5 in.) may be accommodated.

A thin flat carbon steel strip is attached to the horizontal upper surface of the lowermost angle iron of the Z-frame. The purpose of this strip is to assure that the vertical load bears on the surface of this strip and not, for example, at the outermost edge only. Load bearing at the outer lip of the angle iron would create excessive bending moments for maximum design loads which are expected to occur in tests with concrete substructures. However, this will not usually be a factor because test roof specimens featuring wooden or metal roof decking weigh less. Test specimens exceeding 40 kN (9000 lb) in weight should be reviewed with the Energy Systems General Engineering design staff to assure that proper load distribution is maintained on the Z-frame.

Figure 29 is a photograph showing a Z-frame being lowered into a Diagnostic Platform with the overhead crane. Three Diagnostic Platforms and five Z-frames have been fabricated to support the initial operation of the LSCS. This photograph also shows the lifting fixture, which may be used for either the Z-frame or the Diagnostic Platforms. The lifting fixture has an "X" configuration with two different lift points at the four ends to match either the Z-frame or the Diagnostic Platform dimensions. The lifting fixture was designed and fabricated in accordance with ANSI Specification B30.20: "Below the Hook Lifting Devices." The fixture is designed for lifting uniformly distributed weights up to 80 kN (18,000 lb). The fixture has been tested at ORNL with a 25% overload of 100 kN (22,500 lbs) in accordance with ANSI specification B30.20.

As noted earlier, Diagnostic Platforms add to the range of possible experiments because they serve as mounts for special experimental equipment. Two artist's conceptual drawings of such platforms are shown in Fig. 30. The upper half of Fig. 30 depicts an apparatus for producing a uniform flow of air over a roof surface at the ambient temperature in the chamber. Variable speed exhaust fans could be used to create a range of velocities from zero to the maximum permitted by size and power constraints. The rolling door could be remotely retracted if desired to expose the roof surface intermittently to simulated weather conditions within the Climate Chamber such as rain or infrared heating.

The lower half of Fig. 30 shows an artist's rendering of a "vacuum dome" to expose roof test membranes to large uplift forces. Such a device would be used only in cases where the desired pressure difference

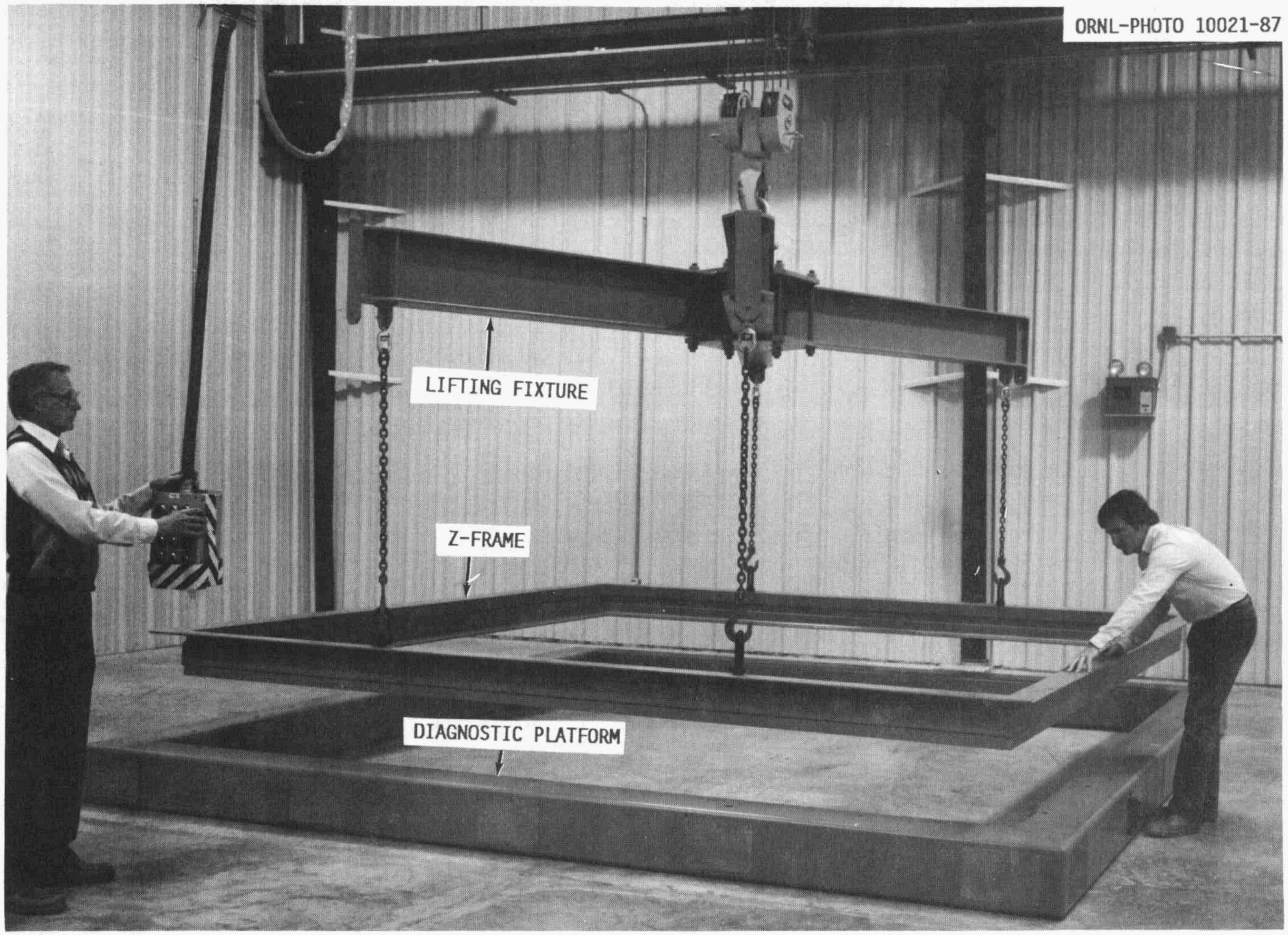

Fig. 29. Using the lifting fixture to install the Z-frame into the Diagnostic Platform crane.

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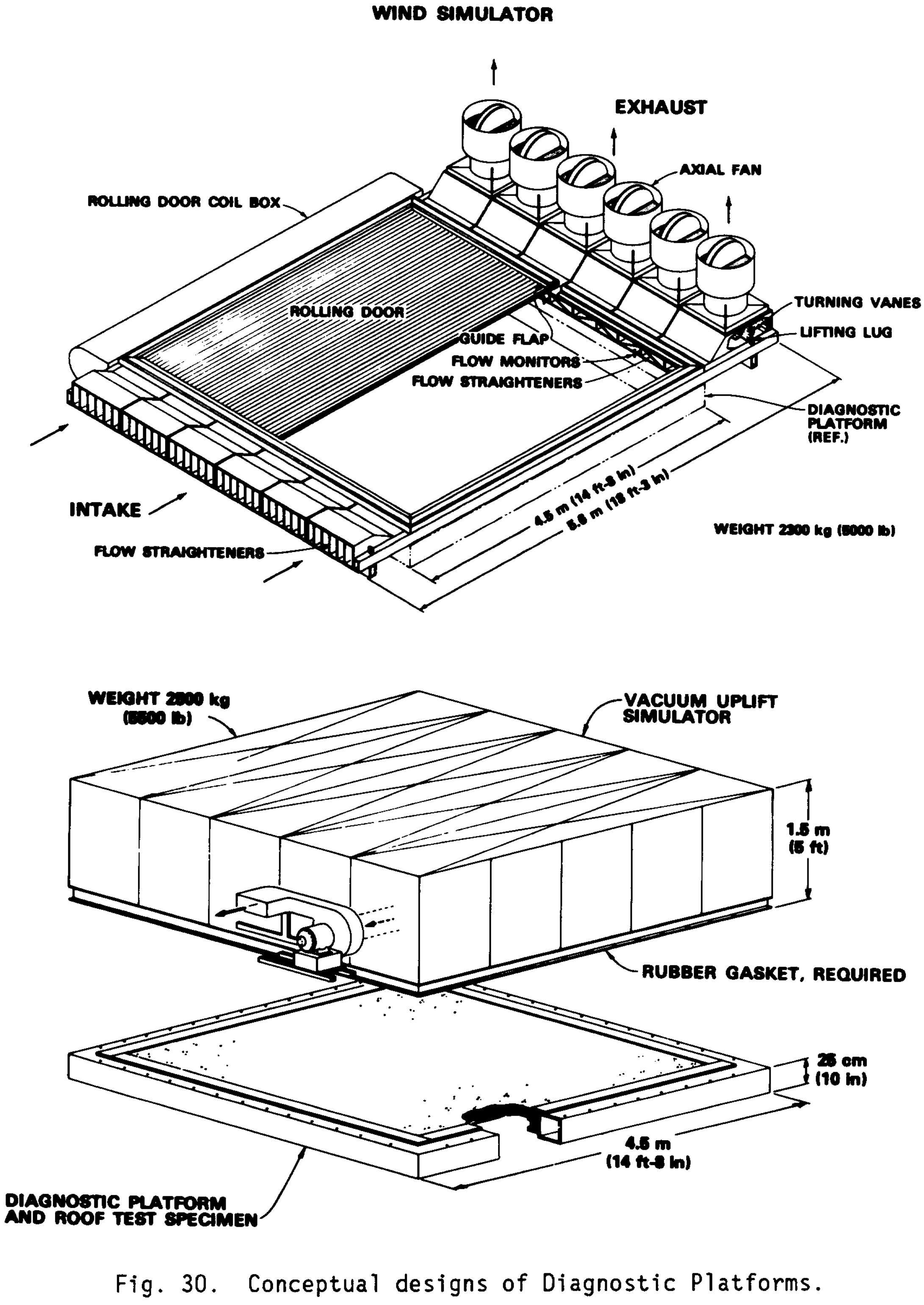

Fig. 30. Conceptual designs of Diagnostic Platforms.

exceeds the design vacuum uplift capability of the Climate Chamber, which is 1.44 kPa (30 lb/ft^2 loading). The vacuum dome is sealed to the Diagnostic Platform by a rubber gasket while the interior pressure is lowered with a suitable evacuation device. Based on a recommendation of the RRC Advisory Panel, the height of such a vacuum dome should be about 1.5 m (5 ft) to allow for significant membrane ballooning in tests where a relatively flexible single-ply membrane is being tested (without mechanical fasteners).

2.3.1 Membrane Tensile Testing

It is expected that some type of membrane tensile testing will be done in the LSCS. Conceptual designs for such experiments were considered but no detailed designs were completed because a definite experiment has not been defined yet. The discussion of these design considerations that follows is to record these thoughts for future reference.

A tensile stress situation could be set up on a specimen by holding an exterior boundary around the roof membrane in a fixed position while the membrane is subjected to temperature cycling within the Climate Chamber. This behavior would be similar to that of a building in which the perimeter of the roof remains relatively fixed while the membrane undergoes considerable temperature cycling and resultant stresses. One approach to simulating this structural behavior is shown in Fig. 31. The basis of this Diagnostic Platform design is to provide a rather massive I-beam structure at constant temperature within the Guard Chamber such that its dimensions will remain constant. Thermal insulation is located between the I-beam structure and the test membrane to isolate the two from severe temperature cycling within the Climate Chamber. For such a test the Metering Chamber would be kept in the lowered position. Figure 31 shows a scheme for a simple undirectional stress test, but the concept is applicable for other more complex testing as well. Tensile tests by others in the roofing industry indicate that such a device should be designed for maximum tensile loading up to about 670 N per lineal centimeter of membrane (150 lb per lineal inch of membrane).

A second method of maintaining a rather fixed boundary at the Diagnostic Platform was also conceived. This method would involve the use

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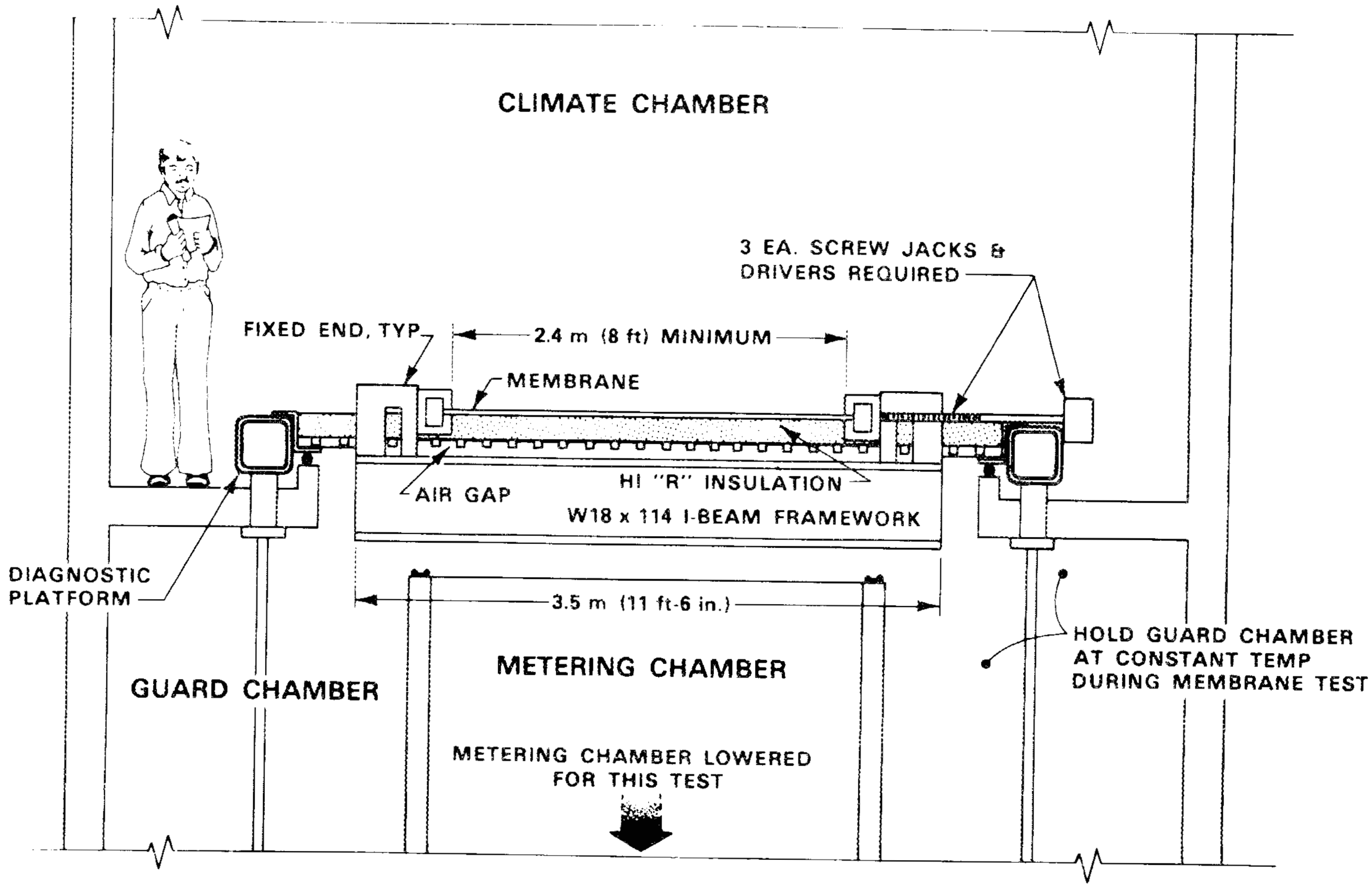

Fig. 31. Conceptual design of a membrane tensile testing Diagnostic Platform.

of the alloy "Invar," which has an exceptionally low coefficient of expansion over the range of temperatures employed in the Climate Chamber (see Fig. 32). Invar is a trademark of Societe Crensot-Loire (METALMPHY), France. It is a 36% nickel-iron alloy used in surveyors' measuring tapes. The alloy has strengths that generally exceed those of carbon steel. The major disadvantages for use of the alloy are that costs are high and delivery times are lengthy. A supplier, Ed Fagan Incorporated, Mahwak, New Jersey, quoted delivery times of five months and 1986 costs of $18/kg ($8/lb). The engineering data on Invar alloy are on file at the RRC (item 6 of Appendix A).

2.3.2 Storage Rack Design

Storage racks for roof test specimens are provided to make more efficient use of available floor space in the RRC building. Only one storage rack is initially being built. Space is available in the northwest corner of Bldg. 3144 for a second storage rack that may be built if operating experience demonstrates that the added storage space is needed.

The design of the initial storage rack that will hold five different Z-frames and their related roof test specimens is shown in Fig. 33. The lower rack is reserved for heavy (e.g., concrete) test specimens weighing up to 71.2 kN (16,000 lb). The four upper racks are designed for specimens not exceeding 35.6 kN (8000 lb).

The upper racks will have adequate capacity to store typical wooden or metal roof test deck specimens. The overhead crane will be used to set the uppermost specimen directly on top of the storage rack. Crane access to the lowest storage rack is obtained by moving this unit out from under the rack with four large wheels which roll directly on the concrete floor. Removable extension rails and an end support structure are required so the overhead crane can have access to the three specimens at the intermediate levels. The end support structure and the extension rails will be stored on the side of the storage rack when not in use to make the space in front of the storage rack available for other purposes.

2.4 ROOF TEST SPECIMEN DESIGN

There are two categories of test specimen designs for the LSCS, depending on whether the test program calls for use of the Metering

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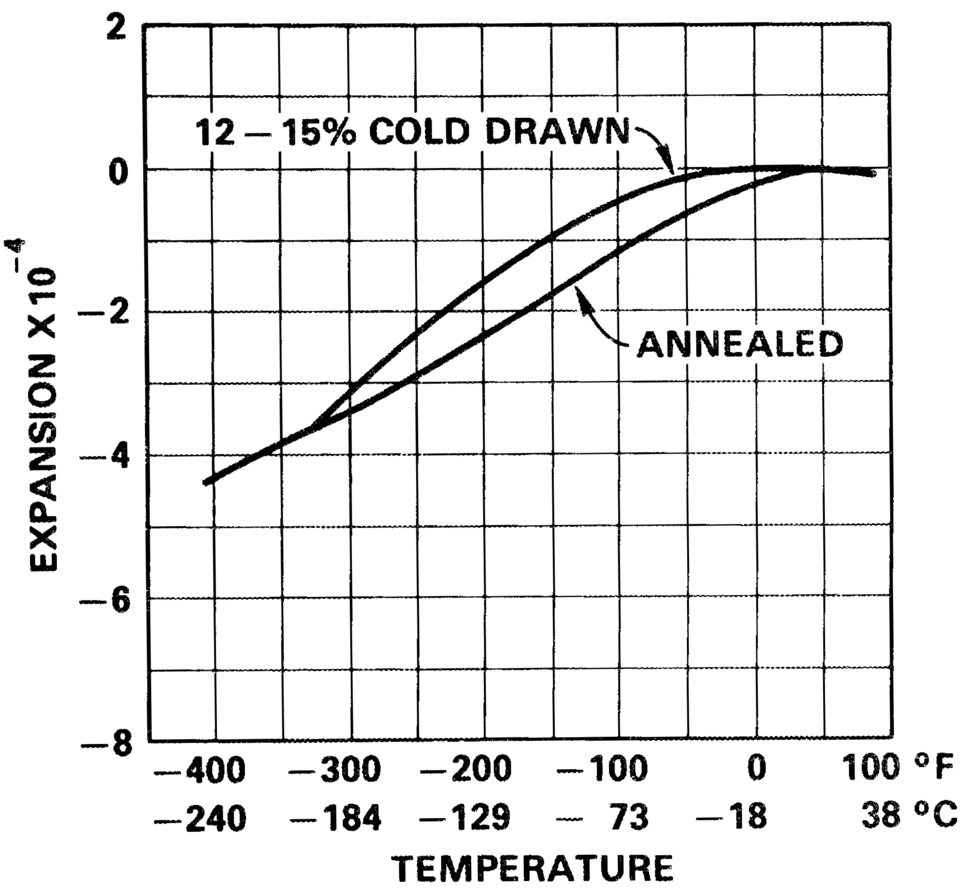

Fig. 32. Thermal contraction of cold drawn and annealed at 36% Ni-Fe alloy from 70°F (21°C).

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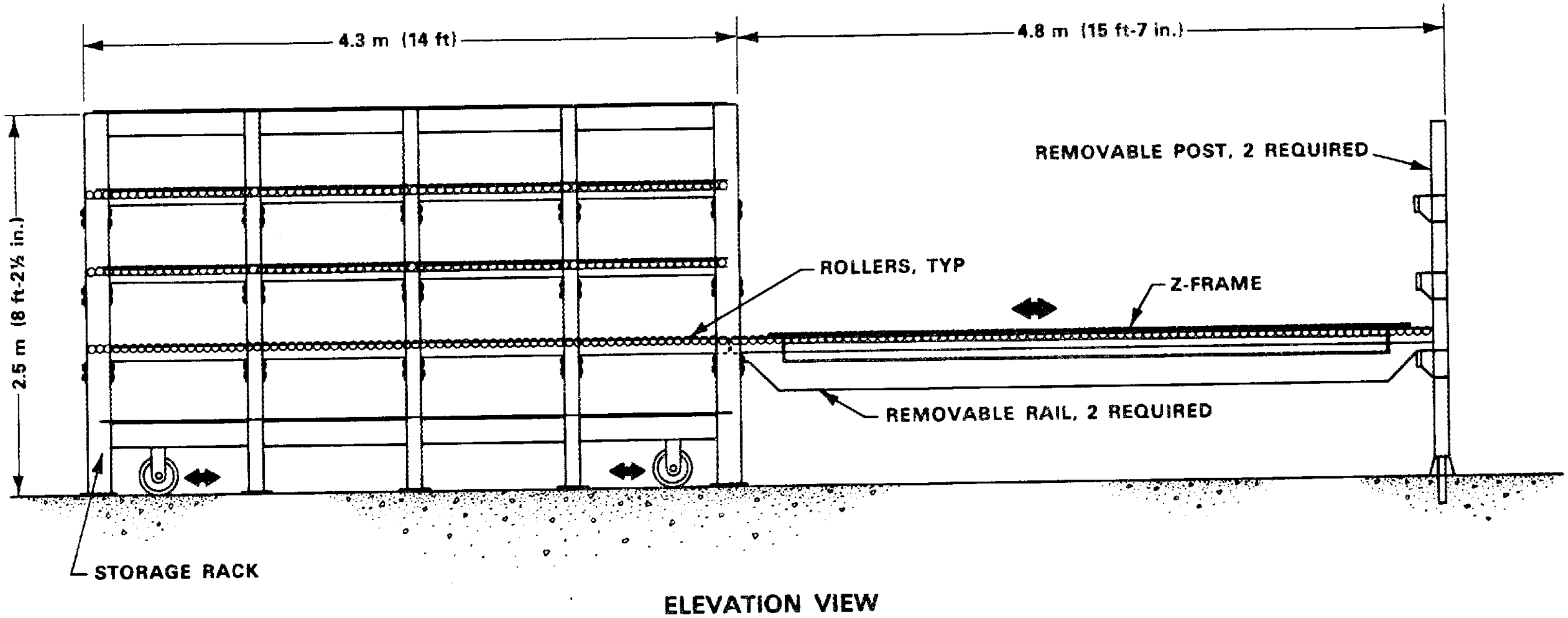

Fig. 33. Storage rack for Z-frames and related roof test specimens. The rack holds up to five specimens.

Chamber. For example, the first test series planned for the LSCS involves dynamic temperature cycling to duplicate real weather effects. The Metering Chamber is to be in the lowered position and not be in use. Results from outdoor exposure tests conducted at the ORNL with the roof thermal research apparatus (RTRA)will be used to correlate LSCS climate conditions and measured weather data. The results of the RTRA tests are to be extended to extremely cold climates using the capabilities of the LSCS. Four 1.8 × 1.8 m (6 × 6 ft) roof test specimens are to be tested side-by-side on a single Diagnostic Platform. Three of these are conventional insulated roof systems using fiberglass, expanded polystyrene, and phenolic foam insulation, respectively. The fourth examines heat flow measurement techniques for cavities insulated with reflective barriers. Metal roof decking spans the full 3.9-m (12-ft 9-in.) dimension of the Z-frame structure with added reinforcing from wooden rafter-like members that divide the roof specimen into four quadrants. A single-ply membrane of modified bitumen covers all four quadrants of the test specimen.

The design of a roof test specimen for use in conjunction with the Metering Chamber (i.e., for guarded hot-box operation) is more complex than the specimen described above. A more complex design is necessary because such a roof test specimen must provide a sealing surface on its underside for the double-P rubber gasket, which is located at the top of the Metering Chamber. The double-P gasket is deformed to effect a seal as the Metering Chamber is hydraulically raised into position against the bottom of the test specimen. Therefore, a flat, air-tight sealing surface is required on the bottom side of the specimen to mate the rubber seal on the Metering Chamber perimeter. An exploded view of a typical guarded hot-box test specimen is shown in Fig. 34. An added structure is needed for a guarded test specimen, which is identified in Fig. 34 as the specimen support. The inner 2.4-m (8-ft) square framework of the specimen support matches the perimeter of the Metering Chamber and provides the flat sealing surface.

The inner framework of the specimen support must be designed so that it provides thermal insulation as well as structural strength. It becomes a vertical extension of the insulated Metering Chamber walls.

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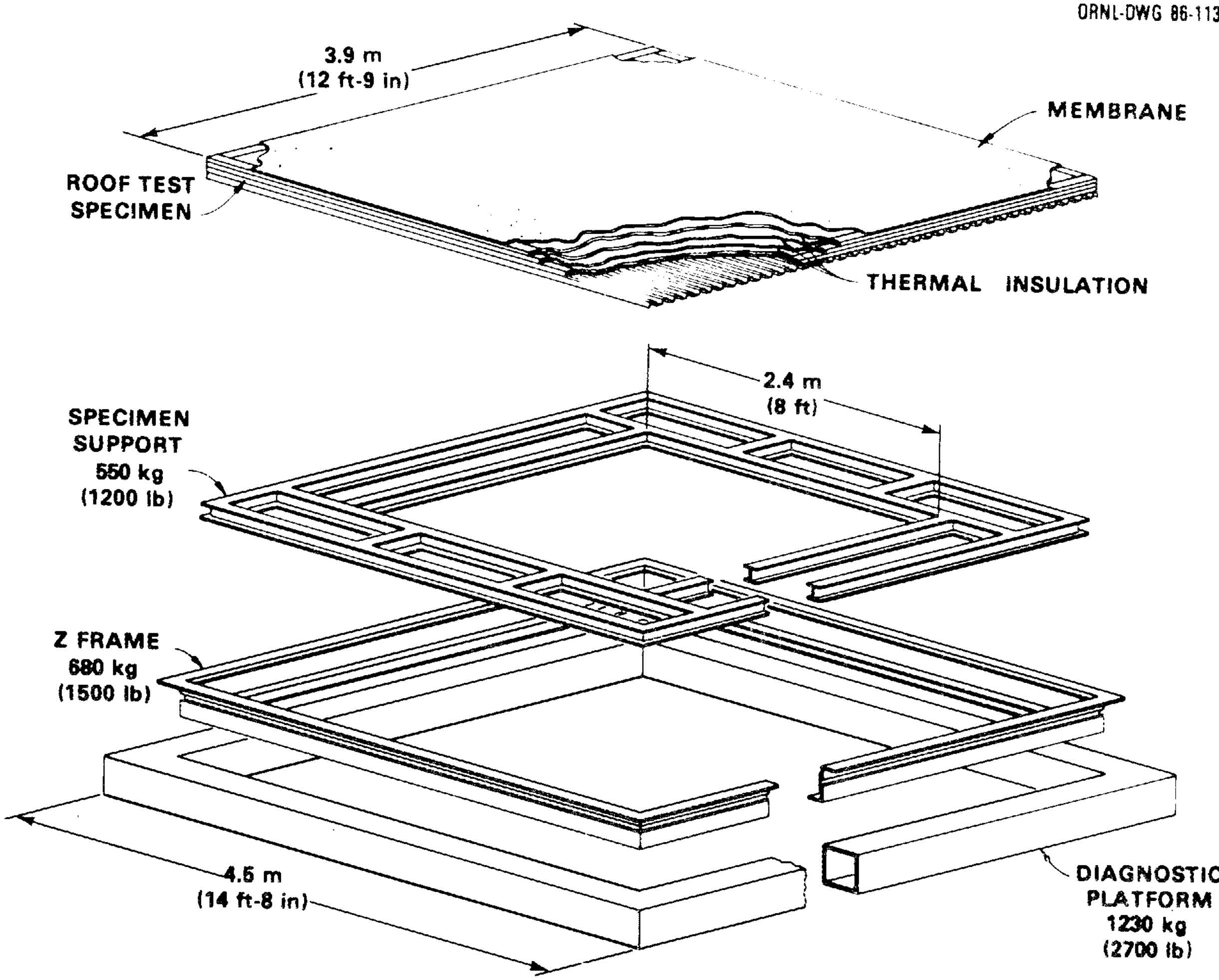

Fig. 34. Exploded view of a guarded hot-box roof test specimen.

Fiberglass-epoxy I-beams spray-coated with foam insulation may be candidates for this application. Fiberglass-epoxy beams are available from local suppliers such as J. T. Ryerson & Sons, Inc., in Chattanooga, Tennessee.

The specimen support is also needed for guarded hot-box test specimens to interrupt the high thermal conductivity heat path that is created by the metal decking such as that shown in the roof test specimen of Fig. 34. The thermal conductivity of the metal decking is about 2,500 times that of the insulation in the walls of the Metering Chamber and it, therefore, would provide a significant thermal bridge from the Metering Chamber to the Guard Chamber unless it is interrupted at the double-P gasket area. The Specimen Support framework would allow such a thermal break to be made in the metal decking while still providing the needed support of the roof test specimen.

3. OPERATION

The successful shakedown and operation of the LSCS was demonstrated during an acceptance test period that started in September 1987 and lasted about 4.5 months. The acceptance tests were completed and the chamber and its related systems were formally accepted from Vista Scientific Corporation in mid-January 1988. In the author's opinion, the acceptance tests were completed in a reasonable time period for a machine of this complexity and of original design.

No major revisions were found to be necessary during the shakedown and acceptance testing of the LSCS. However, as might be expected on new equipment, the vendor did make a number of system revisions to replace defective components or to improve system performance to meet the specified requirements. The system requiring the most attention was the chilled water circuit, which provides ambient heating or cooling for the Metering and Guard Chambers. To improve dynamic system response, a larger heat exchanger was installed to transfer heat from refrigerant 502 to the chilled water. Also, it was necessary to move control valves and bypass circuits closer to the Metering Chamber to shorten response times. It was also necessary to provide three separate water return lines to the chilled water expansion tank so that flow rate changes in one water circuit would have lessened effects on the others. Refer to Fig. 19 in Sect. 2.2.3.1 for a schematic drawing of the final, as-built piping configuration for the Metering Chamber chilled water systems.

The final construction contract effort of vendor personnel was a two-day operator training session that was performed after the acceptance tests were completed. The "hands-on" operator training was performed in conjunction with use of a vendor-prepared instruction and maintenance manual. The operator training was completed on January 28, 1988, and the contractor left the job site at that time.

3.1 SYSTEM LIMITATIONS AND PRECAUTIONS

A complete understanding of each component's limitations in the LSCS can only be obtained by perusal of the individual component catalogs and the LSCS Instructions and Maintenance Manual. These documents are available at Bldg. 3114 of the RRC as listed in Appendix A. There will be no attempt here to duplicate the detailed information they contain but some of the major precautions will be reviewed.

The two refrigeration compressors for the Climate Chamber are the most expensive mechanical components in the system and as such deserve special attention. The most likely cause of damage to the compressors would be from loss of oil lubricant or from return of liquid refrigerant to the reciprocating compressors (i.e., "liquid slugging"). Particular care must be used in early operations to ensure that the lube oil system is checked and recorded daily for proper oil levels and oil pressures in both single- and two-stage operation.

In order to protect the compressors from liquid slugging, the systems are equipped with automatic pumpdown circuits and crankcase oil heaters. The crankcase heaters are energized anytime the main power to the facility is on as indicated at the main control panel. To avoid expensive damage to the compressors, the main power should be left on at all times. If the crankcase heaters are turned off due to maintenance or a prolonged electric power outage, the heaters must be activated for approximately 8 h before start-up of the compressors.

The automatic pumpdown systems operate every time the compressors are shut down. When the refrigeration switch on the main control panel is turned off, all solenoid control valves close and the compressors continue to operate until the refrigerant is pumped out of the compressors. When the suction pressure reaches the setting on the low pressure cutout, the compressors will then turn off.

Concern for safety of personnel within the chamber is noted again here for emphasis. Prolonged exposure to the temperatures near either the high or low operating temperature limits of the chamber could be life threatening. Therefore, entry into the chambers must be carefully controlled and administratively accounted for. The telephones located within the chambers must be periodically checked to assure that the ORNL fire department would respond quickly in the unlikely event that someone is unable to exit from either the Guard Chamber or the Climate Chamber.

Automatic fire sprinklers have been installed in both the Climate Chamber and Guard Chamber to meet requirements of the ORNL fire department. These sprinklers, though necessary, provide a small measure of risk to the chamber if they were to accidentally activate when no one was present and the water could not drain out of the chambers. It is recommended that the drain lines from both chambers be modified to remove the shut-off valves in the drain lines so that the lines will be open at all times. The valves could be replaced by small nonsiphoning liquid traps that accommodate the normal range of operating pressures within the chambers. These new traps would provide automatic drainage of water from either the fire sprinklers or from a rain simulation system within the Climate Chamber.

Precautions should be taken to assure that fume build-up does not occur in the Climate Chamber from out-gassing of membrane products, particularly during tests at the higher operating temperatures. The hydrocarbon detection system, which is located near the personnel access door at the southwest corner, will automatically alarm if significant hydrocarbon levels occur. The Climate Chamber exhaust system may be used to purge the Climate Chamber with fresh air prior to personnel entry if there is any concern about contaminate levels in the air within the Climate Chamber.

Full-flow filters are provided in the chilled water circuit primarily to provide protection for the water-lubricated bearing in the turbine meter that measures water flow rates to the Metering Chamber. Two parallel 20-μm filters are provided at the main water pump inlet, and a finer filter is provided just upstream of the turbine meter. (Refer to Fig. 19, Sect. 2.2.3.1, for the flow schematic of this water system.) These filters did become restricted and develop excessive pressure drops during the system clean-up and shakedown. Therefore, the filter pressure drops will require surveillance during initial operation of the LSCS to assure that plugging does not occur again. It is noted that the filters upstream of water pump PMP-1 reduce the suction pressure of the pump if they become restricted. Restricted filters here can cause a sudden and near total loss of flow in the water circuit by causing the pump to cavitate when the filters become partially clogged. If this feature proves to be troublesome, it may be necessary to relocate the 20-μm filters to the pump discharge line of centrifugal pump PMP-1 from their present location in the pump inlet line.

An 18-kW steam generator is provided on the equipment skid at the south wall of the LSCS pit to add humidity to the Climate Chamber and Guard Chamber, as required. Steam generators require careful operation to assure that proper feed water is maintained and that no excessive pressures occur due to overheating. The system is equipped with the required safety devices such as a pressure relief valve, sight glass, and low water cut-off. It will be necessary to develop boiler blow-down procedures and schedules based on local water hardness conditions and the amount of boiler use in accordance with the operating instructions listed in the Instruction and Maintenance Manual, item 8 of Appendix A.

3.2 SYSTEM START-UP

The LSCS is designed with five separate Micristar process controllers to provide greater flexibility for system start-up. Each of these five individual controllers control two different parameters, and the desired profiles of these ten parameters are programmable. Programming and operating instructions for the Micristar controllers are available in the catalog file as listed in Appendix A. The Micristar controllers may be operated either as the primary means of system control or, alternatively, can be operated in conjunction with the computer of the data acquisition system. The individual Micristar controllers can accept repeatable programs of up to 49 straight-line ramp increments. In addition to overall coordination of the operating sequences of the individual controllers, the LSCS data acquisition computer system will be used for control whenever test programs require test sequences more complex than line ramps can perform or for tests where straight-line parameter ramps are unacceptable. It is noted that the flexibility of this system was particularly useful during acceptance testing where individual systems could be controlled and tested before the entire data acquisition system was operable. Likewise, this flexibility should be useful in future operations as the overall computerized control system is made operational, reprogrammed, or maintained.

System start-up is begun only after the compressor crankcases have been properly preheated for about 8 h. As a general rule, the crankcase heaters will be energized at all times to allow instantaneous start-up when required. After programming and energizing the control systems, the refrigeration systems may be activated. Once started, the compressors for the Climate, Metering, and Guard Chambers operate continuously because hot-gas by-passing is used for temperature control purposes. A defrost system is provided on the expansion coil within the Climate Chamber for use as required. If operating conditions require periodic defrosting, the electric-heated defrost system is energized by a timer system that is located within the control panel in the Control Room. During defrost, the air circulation within the Climate Chamber is automatically interrupted.

During start-up, the operator must decide on air circulation rates desired in the Climate Chamber and in the Metering Chamber. Only the Guard Chamber has a fixed air circulation rate. The Climate Chamber has two air flow rates that are regulated from the control panel by operating either three or six of the circulating fans, which are mounted in parallel above the expansion coil. For most testing only three of the fans are required. All six fans may be needed to provide the maximum refrigeration capacity or the maximum temperature ramping capability in the Climate Chamber. Individual louvers are placed on the six blower discharges to provide uniform air flow distribution across the Climate Chamber.

Start-up of the humidity control systems of the Climate and Guard Chambers is initiated by turning the steam generator to the "on" position. This steam generator supplies steam to both chambers as needed. Micristar controller No. 2, Channel 2, controls air moisture in the Guard Chamber; and controller No. 3, Channel 2, controls the Climate Chamber's humidity. Dehumidification is accomplished by refrigeration coils in both chambers that are supplied from their respective refrigeration systems.

Precision dew point hygrometers have been added to the system to provide accurate moisture readings in both the Climate Chamber and Guard Chamber. These hygrometer systems are controlled from separate control panels located on the west side of the chamber. The systems are started by energizing the two air sampling pumps to pump air from the chambers to the sensing heads of the hygrometers. The sampling pumps, filters and sensing heads are mounted in temperature-controlled, insulated boxes so that moisture condensation will not occur, particularly when there are high humidity conditions within the chambers. The temperature of the thermostatically controlled boxes should be selected depending on expected air moisture content of a particular test series; the sensing heads should not be operated in an ambient temperature more than 33°C (60°F) above the dew point temperature that is to be measured.

The requirements of each test program will determine if it is necessary to start the Climate Chamber pressurizing or evacuation system, as many tests will not require the use of this system. When required, the system selector switch on the control panel must first be manually moved to either the "pressure" or "vacuum" position. If the pressurized mode is selected, the control valves on the blower will be automatically positioned so that the blower discharge is directed into the chamber to maintain the Climate Chamber at the desired pressure level above atmospheric pressure. The pressure in the chamber can then be programmed and controlled to desired levels by Micristar controller No. 5, Channel 2. If the test program requires operation of the Climate Chamber below atmospheric pressure, the selector switch must be manually moved to the "vacuum" position. This positions the blower control valves to connect the Climate Chamber to the suction of the blower, creating a negative pressure within the chamber when needed.

Start-up of the Metering Chamber will be the most complex procedure because of the great flexibility of this system and because this system requires the greatest accuracy of operation. The double-P seal must be inspected to assure that it seals effectively to the bottom surface of the test specimen. By positioning the vertically adjustable air baffle and selecting the fan speed, the desired air velocity under the test specimen is set. Continuously variable air flow rates are available within the Metering Chamber with the variable speed dc powered fan motor. The fan speed is controlled by a potentiometer that is located on the control panel. Air flow rates up to 0.29 m^3/s (605 cfm) were demonstrated at the maximum fan speed of 3000 rpm during acceptance tests with the Metering Chamber in the "up" position.

The heat load in the Metering Chamber will vary greatly depending on the thermal resistance of the test specimen and the operating temperatures. Based on the specific test, the operator will select the desired temperature of the circulating chilled water systems. The operator must also select either one of six passes in the chilled water coil by means of the manual valves within the Metering Chamber. The flow rate through the chilled water coil can also be varied greatly using by-pass valve RGC-2. (See Fig. 19 in Sect. 2.2.3.1.) The flow rate must be low enough to obtain a significant temperature difference in the water as measured by the differential RTD, TDE-1. It is noted that there could be tests, such as simulation of extreme outdoor winter weather, where there would be continuous heat loss from the Metering Chamber. For such tests, the simplest and most accurate heat balances would be obtained by using only the dc powered heater for temperature control. In such a case, the chilled water coil would be drained at valve VW-15 to remove this unwanted mass from within the chamber. The decision must also be made to use either the full 6-kW capability of the dc powered trim heater or the 3-kW capability. In most tests, it is assumed that the Metering Chamber air leakage system will not be in use and for such cases the 4-in. PVC pipe penetration must be insulated and sealed to prevent air leakage.

The detailed start-up instructions of the LSCS Instruction and Maintenance Manual give added information on start-up procedures. This document is available at the RRC as listed in Appendix A, item 8.

3.3 SYSTEM SHUTDOWN

A typical shutdown of the system would proceed in the following manner:

1. Turn the Climate Chamber refrigeration and chilled water refrigeration system selector switches to the "off" position. Both refrigeration systems will go into an automatic pumpdown mode and continue to run until refrigerant pumpdown is complete.
2. Turn Climate Chamber main chiller pump selector switch to the "off" position.
3. Turn Metering Chamber and Guard Chamber chiller pump selector switches to the "off" position.
4. Turn Guard Chamber steam generator selector switch to the "off" position.
5. Turn Climate Chamber exhaust fume and pressure/vacuum selector switches to the "off" positions.
6. Turn Metering Chamber trim and fixed heat, Guard Chamber chiller heat, and Climate Chamber air heat switches to the "off" position.
7. Turn Metering, Guard, and Climate Chambers circulation blower switches to the "off" position.

NOTE: **The power selector switch should remain in the "on" position to keep the compressor crankcase oil heaters activated.**

3.4 UNATTENDED OPERATION

The LSCS is designed for unattended operation on nights and weekends. Protective circuits will keep the system in a safe condition if temperature, pressure, or level indicator limits are exceeded. The affected system may then be diagnosed and restarted when operators return.

Examples of such protective circuits are:

- High refrigerant pressure cutout
- Low refrigerant pressure cutout
- Oil pressure safety switches for compressors

- High membrane temperature
- High chamber temperature
- High temperature at chilled water heater
- Low water level in steam generator

A common operational problem for continuously operating experiments in the southeastern United States occurs in the summertime due to severe electrical storms, which can cause momentary electrical power outages. When a momentary outage does occur, the entire system is shut down and will not restart automatically. This non-restarting feature is required because in such situations the refrigerant compressors cannot complete their normal automatic refrigerant pumpdown cycles. Therefore, an automatic restart might damage the compressors. The crankcase heaters in the compressors, of course, will correct this problem automatically over an extended period after they are re-energized. However, the operators are cautioned to obtain special instructions from the vendor during any unusual restart situation because procedures may vary depending on outdoor temperatures, length of the power outage, etc.

3.5 PERFORMANCE TEST DATA

This section of the report will show typical performance data taken during the acceptance tests of the LSCS. The acceptance tests demonstrated that the equipment met the specified performance requirements. During these tests a dummy test section was installed that had an R-value of about 10. While tests were under way the various systems were under the control of their respective Micristar controllers. There was no supervisory control of the Micristar controllers by the data acquisition system computer, because the programming for this system was not yet available. However, the data acquisition system and printer/plotter was operational and the subsequent data plot was taken from this equipment.

The following typical test data have been selected from the three different chambers of the LSCS: the Climate, Guard, and the Metering Chambers. Ambient temperatures in all three chambers are monitored by platinum RTDs, and each chamber was specified to be capable of steady-state operation within ±0.1°C (±0.2°F). Figures 35, 36, and 37 show that each of the three chambers met or exceeded this criterion.

The temperature ramping capability of the Climate Chamber is shown in Fig. 38. For this test, about 8.9 kN (2000 lb) of steel weights were distributed around the floor of the Climate Chamber. The added mass was installed because the dummy test specimen was not mounted on a Diagnostic Platform during the acceptance tests. The steel weights provided thermal mass effects similar to those of a Diagnostic Platform during dynamic acceptance testing. The Climate Chamber temperatures was varied in straight-line increments because this is the normal mode of programmed control for the Micristar controllers. It is noted that both the setpoint and process variable are plotted in Fig. 38 and in all subsequent data plots of temperature ramping capability. Excellent tracking of the Climate Chamber ambient temperature with the setpoint is demonstrated. The specified maximum Climate Chamber heating rate of 53°C (95°F) per hour was also demonstrated in this particular test.

The temperature ramping capability of the Guard Chamber is shown in Fig. 39. The agreement between the setpoint and the Guard Chamber ambient temperature was excellent until control conditions were intentionally altered near the end of the test. This test demonstrated that the maximum specified Guard Chamber heating and cooling rates, which are identical at 11°C (20°F), per hour are achievable. The test also proved the system's ability to operate reliably and unattended during this overnight test sequence.

An upward temperature ramp of the Metering Chamber's ambient temperature is shown in Fig. 40. The agreement between the setpoint and the ambient temperature was not as good as in the other chambers but the test does demonstrate the chamber's ability to meet the specified maximum heating rate of 11°C (20°F) per hour. As has been noted earlier, the Metering Chamber's temperature control system and flexibility are the most complex of any in the LSCS and will require more operator experience to obtain optimum performance. For example, the gain and reset of the Micristar controller for the Metering Chamber's ambient temperature must

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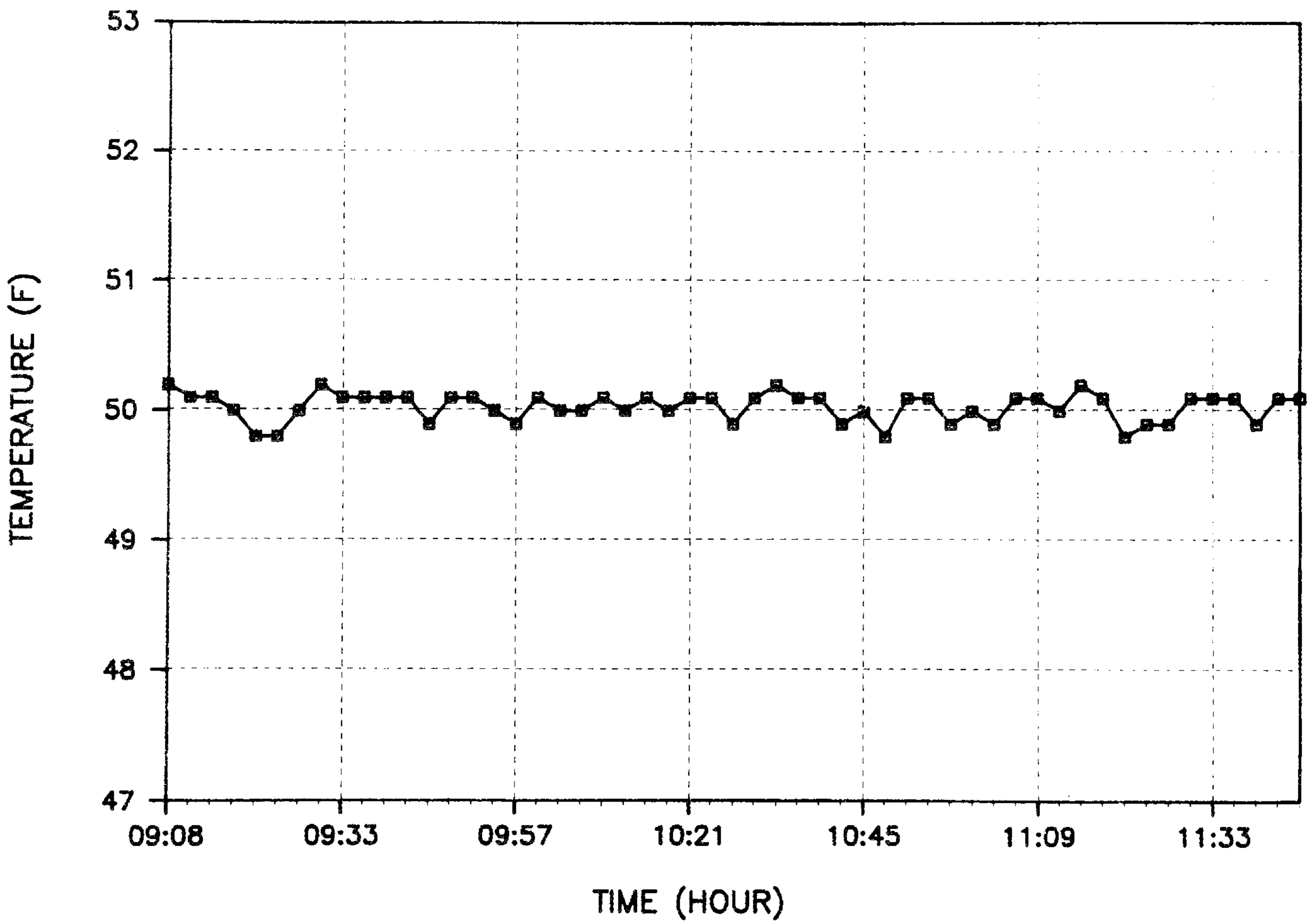

Fig. 35. Acceptance test for steady-state control of Climate Chamber dry bulb temperature, December 16, 1987.

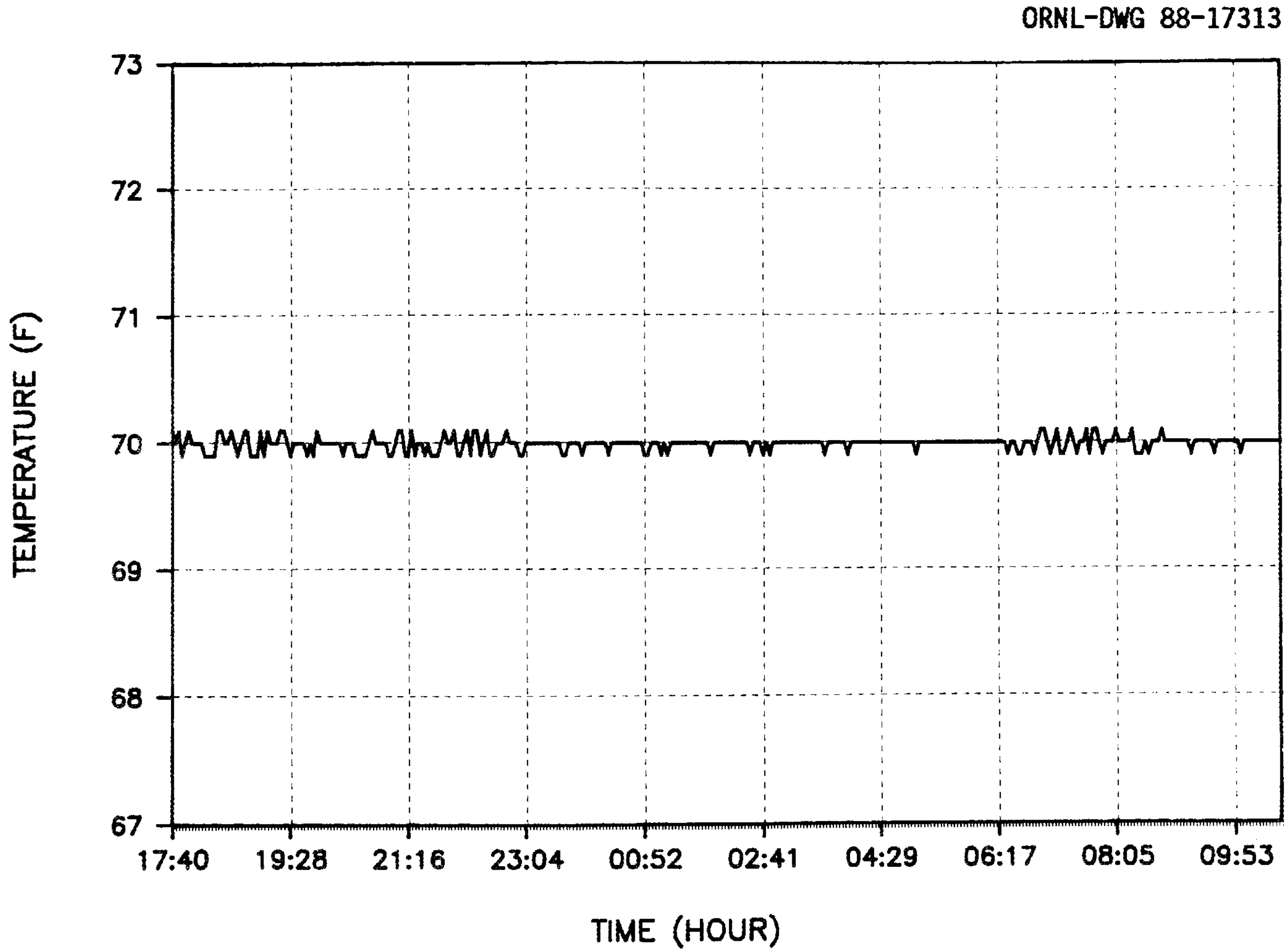

Fig. 36. Acceptance test for steady-state control of Guard Chamber dry bulb temperature, November 13-14, 1987.

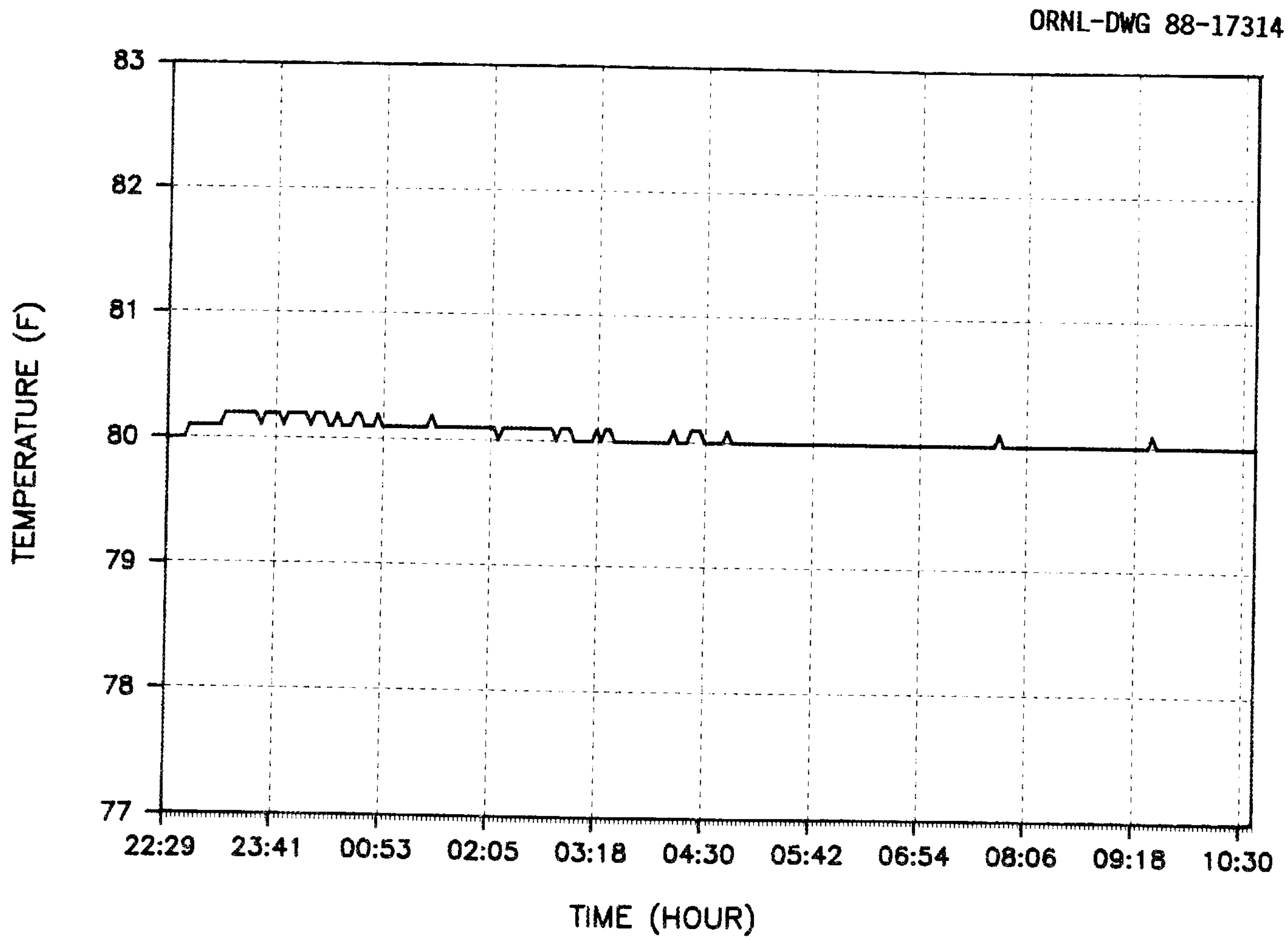

Fig. 37. Acceptance test for steady-state control of Metering Chamber dry bulb temperature, November 12–13, 1987.

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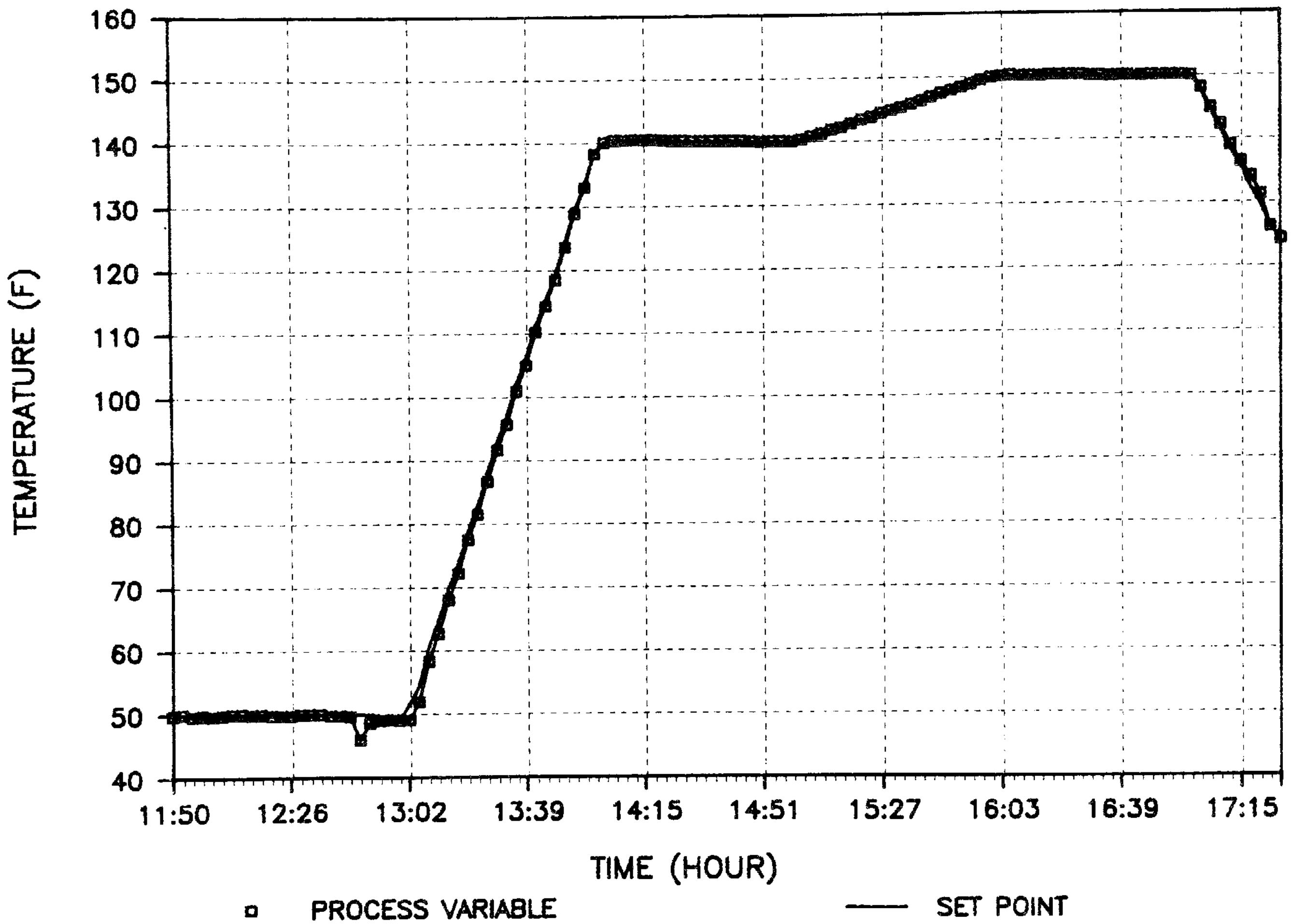

Fig. 38. Acceptance test for ramp control of Climate Chamber dry bulb temperature, December 16, 1987.

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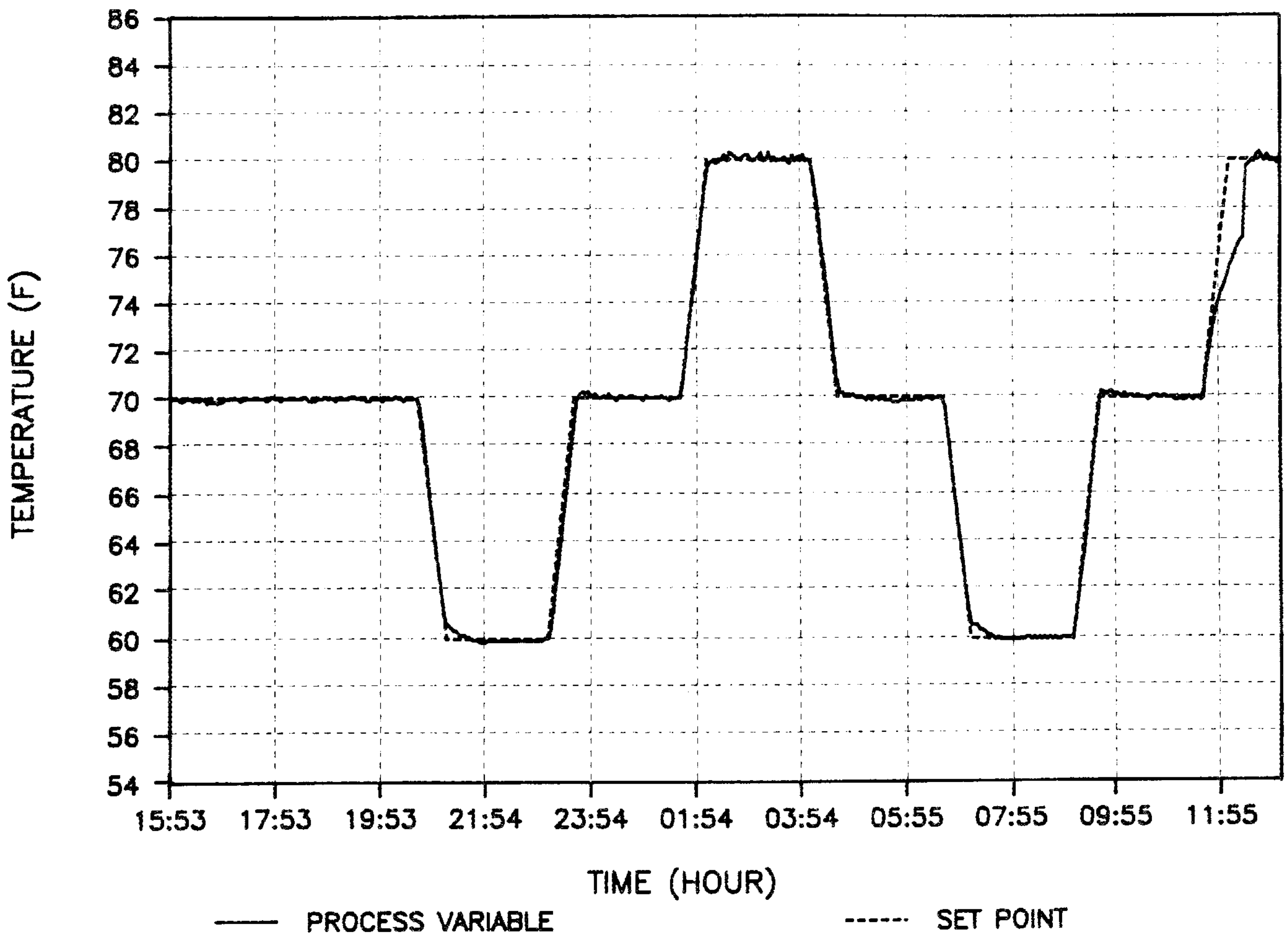

Fig. 39. Acceptance test for ramp control of Guard Chamber dry bulb temperature, November 23–24, 1987.

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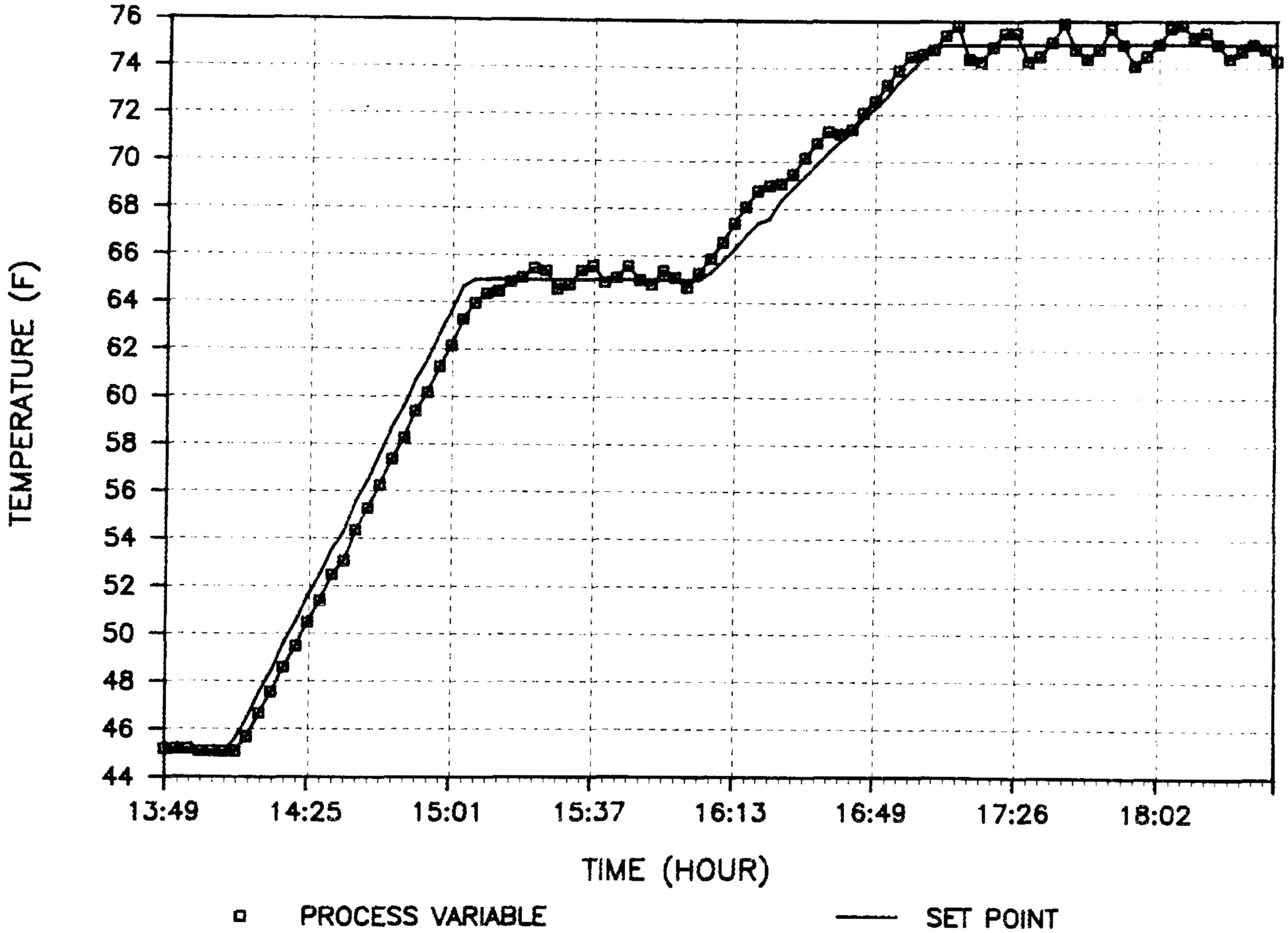

Fig. 40. Acceptance test for ramp control of Metering Chamber dry bulb temperature, December 17, 1987.

be changed when going from optimum steady-state operation to a temperature ramp. This alteration can be done automatically by the overseeing computer of the data acquisition system, but it will require experience as well as the programming software; neither was available at the time of this acceptance test.

Humidity control is provided in the Climate and Guard Chambers over the limited dew point range of 3 to 50°C (37 to 122°F) with a specified dew point tolerance of ±0.5°C (±1°F.) Figures 41 and 42 show typical performance data as the controls were adjusted to obtain relatively stable moisture conditions at steady-state ambient temperatures. The data are plotted as relative humidity because the moisture controller measures air moisture content in this manner. By use of a psychrometric chart, it can easily be shown that the humidity control was well within the specified dew point tolerance after initial control adjustments were completed.

The operators are forewarned that precise dew point or humidity control can be maintained only during steady-state temperature operation within the chambers. For example, during sharp upward ambient temperature ramps the surface mass within the chambers lags behind the air temperature. At such times, these relatively cool surfaces act as large condensing areas that temporarily overwhelm the moisture control capabilities of the system.

This section on performance test data has reported only a small portion of the data accumulated during the LSCS acceptance tests. For further information, see the Acceptance Test Report, which was prepared by Vista Scientific Corporation at the completion of acceptance testing. This internal report is available at the RRC (see item 9 in Appendix A of this report). Completion of the acceptance testing of the LSCS was a major milestone for the Roof Research Program at ORNL because the operational phase of roof testing could then begin in the LSCS.

4. SUMMARY

This report describes the design and construction activities which occurred during a 2.5-year period at ORNL. The result of this effort is

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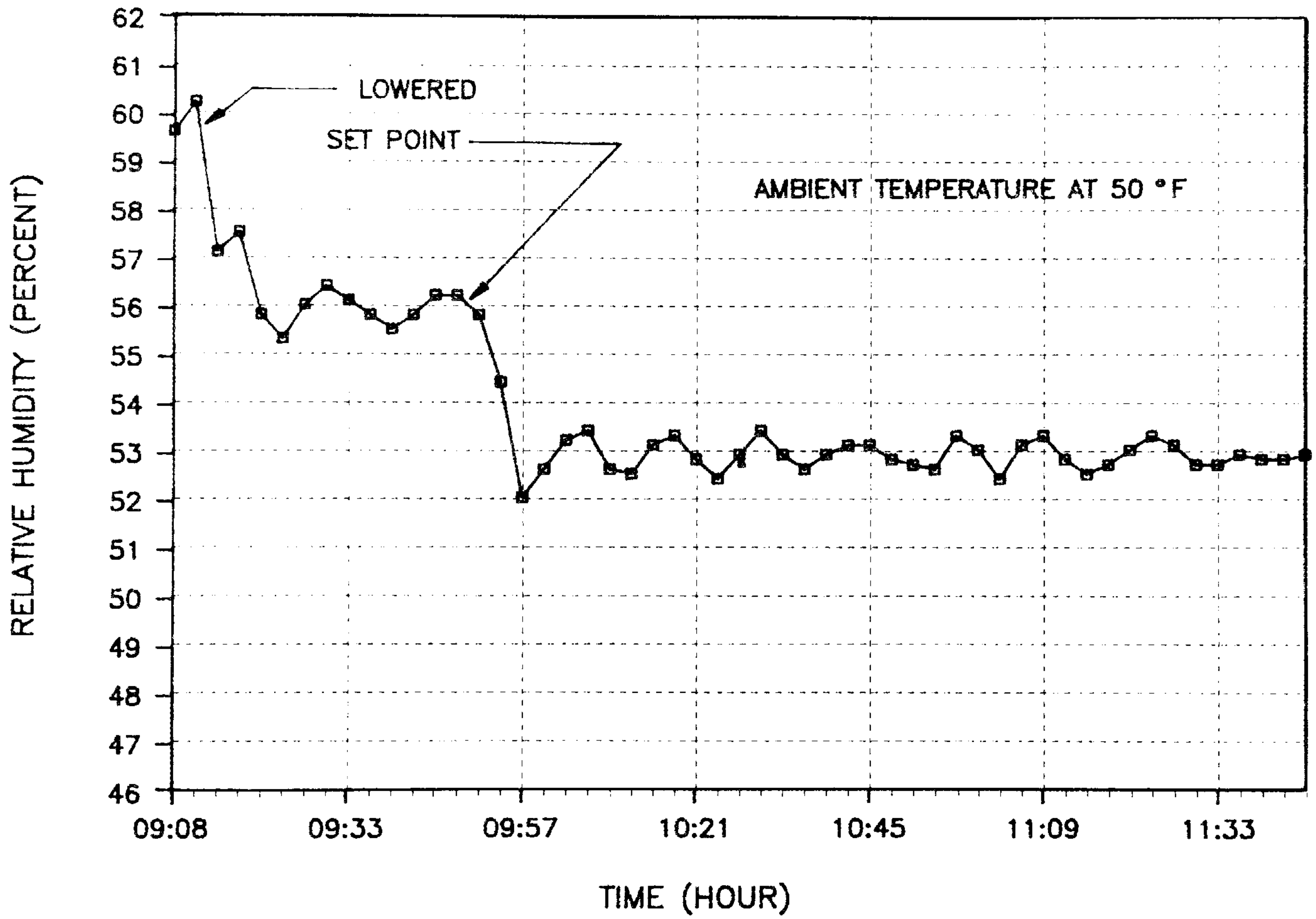

Fig. 41. Acceptance test for humidity control of the Climate Chamber, December 16, 1987.

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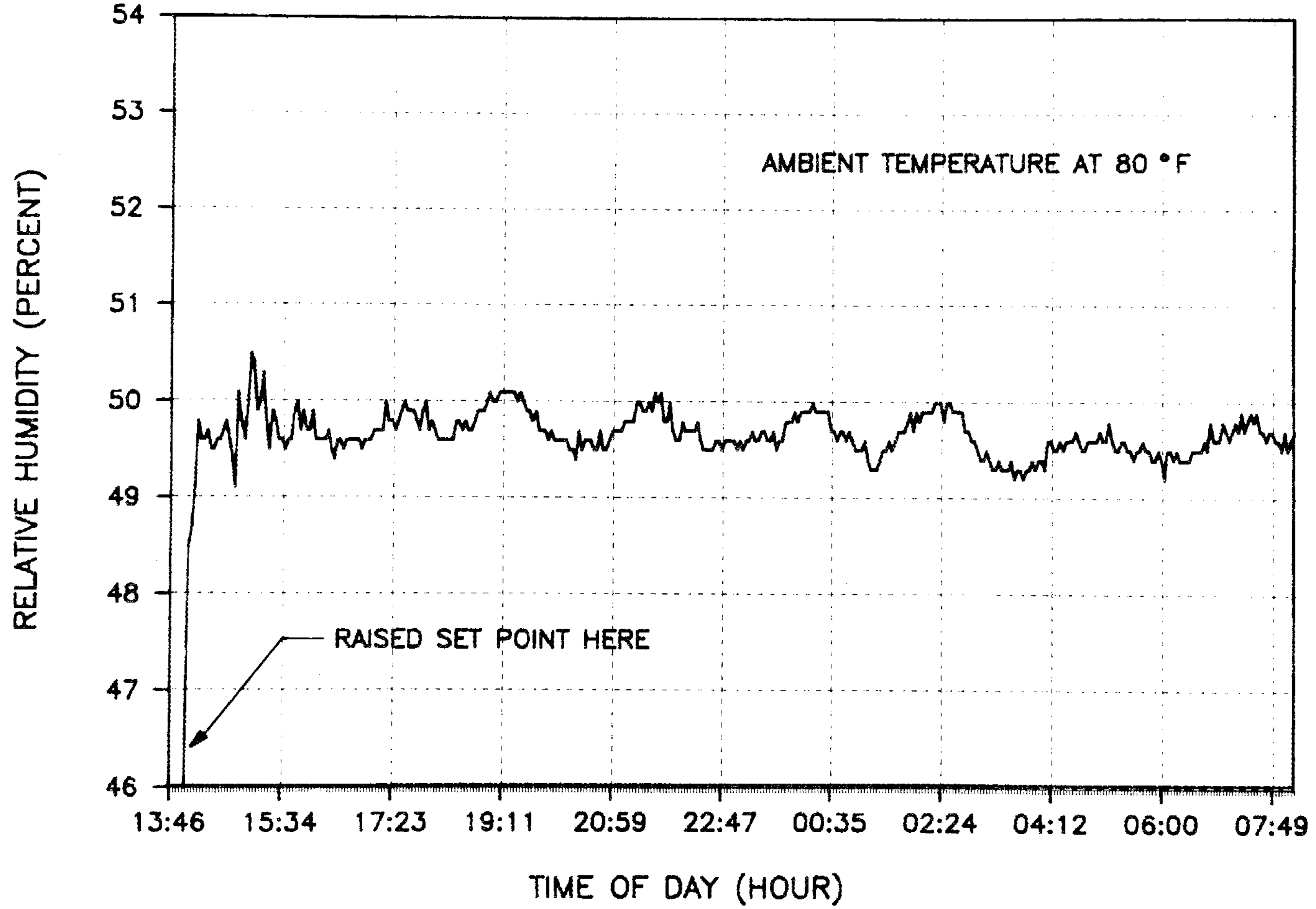

Fig. 42. Acceptance test for humidity control of the Guard Chamber, December 22–23, 1987.

a new building containing the LSCS for use in future roof research work by industry, academia, and goverment agencies.

This report has been prepared in the hope that it will serve as a reference document to aid future users of this complex facility. As a national user facility, it is expected that a portion of the LSCS experimental staff will be constantly changing throughout its useful lifetime. Therefore, the information herein related to test capabilities, features of the data acquisition system, detailed design features, system limitations, etc., should be of interest to each new experimenter. The author, who recently retired from ORNL, wishes success to the researchers as they enter this challenging arena to provide practical, thermally efficient, long-lived roofing systems for the United States.

5. ACKNOWLEDGMENTS

The Large Scale Climate Simulator has involved many people at Oak Ridge National Laboratory and the writer is indebted to a host of co-workers. Also, the advice from the members of the Roofing Industry Research Advisory Panel was invaluable throughout the entire project. The author particularily thanks George Courville, Program Director, for his guidance throughout all phases of the work. L. A. Klein, J. M. Morrison, Oakland Adams, and E. P. Sothman, all of Energy Systems Engineering Division, provided excellent assistance in specification preparation, cost estimating, and the design and construction of the facilities. The author is indebted to J. A. McEvers and co-workers in the Instrumentation and Control Division for the design and installation of the data acquisition system. T. W. Petrie, Marquette University, provided many editorial comments and contributed Sect. 2.2.5 of this report. Special thanks are given to Sherry Samples, Kim Grubb, and Gabrielle Coleman for preparing this draft manuscript, and to Mary Upton for final manuscript preparation.

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APPENDIX A

LSCS INTERNAL DOCUMENTATION ON FILE AT THE ROOF RESEARCH CENTER OAK RIDGE NATIONAL LABORATORY

Item		Description	Date of preparation	Approximate number of pages
1.	a.	Roof Test Chamber Procurement Specification ES-A4145A-1 prepared by MMES Engineering at ORNL	June 14, 1985	63
	b.	Amendment No. 1	July 18, 1985	3
2.		Vista Scientific Corp. Proposal with Design Calculations, Volume I	Sept. 5, 1985	100
3.		Detail drawings as prepared by subcontractor of each wooden panel which makes up the chamber walls, floor, and ceiling as prepared by subcontractor	August 1985	200
4.		Integrated System Test Plan prepared by Vista Scientific Corporation	July 1987	40
5.		Calculations for Infrared Lighting System by J. P. Sanders of ORNL	May 1985	60
6.		Engineering Data on Invor Alloy from International Nickel Company	1976 to 1986	40
7.		Vendor Catalog Data for individual components	Aug. 3, 1987	n/a
8.		Instruction and Maintenance Manual Rev. A prepared by Vista Scientific Corp.	Jan. 19, 1988	29
9.		Acceptance Test Report prepared by Vista Scientific Corp.	Jan. 25, 1988	40
10.		Interim Users Manual Roof Reserch Center prepared by ORNL	April 10, 1987	20
11.		Recommended Spare Parts List prepared by Vista Scientific Corp.	Jan. 1988	4

APPENDIX B

LSCS DRAWING LIST, VISTA JOB NO. 599

Size	Drawing Number	Rev.	Description
B	599-5-01 (3 sheets)	B	Single Line Power Diagram
D	599-1-04 (1 sheet)	E	Test Chamber & Pit Layout
D	599-1-05 (1 sheet)	G	Roof Test Chamber
C	599-2-07 (2 sheets)	D	Column Locations
C	599-2-10 (3 sheets)	D	Guard Chamber Arrgt.
D	599-6-11 (1 sheet)	D	Flow Schematic, Metering & Guard Chamber
D	599-6-12 (1 sheet)	D	Flow Schematic, Climate Chamber
D	599-6-13 (1 sheet)	D	Refrig. Schematic, Climate Chamber
D	599-2-25 (1 sheet)	F	Pit Layout Elevations
D	599-2-26 (1 sheet)	C	A.C. Unit Layout, Climate Chamber
B	599-3-29 (1 sheet)	-	Metering Chamber Baffle Frame
D	599-1-31 (2 sheets)	C	Metering Chamber Assembly
A	599-3-32 (1 sheet)	-	Metering Chamber Dischrg. Plenum Front & Back
A	599-3-33 (1 sheet)	-	Metering Chamber Dischrg. Plenum, Bottom
A	599-3-34 (1 sheet)	-	Metering Chamber Adjustable Slot Diffuser
A	599-3-35 (1 sheet)	-	Metering Chamber Dischrg. Duct, Top, Front
A	599-3-36 (1 sheet)	-	Metering Chamber Dischrg. Duct, Top, Back
A	599-3-38 (1 sheet)	-	Metering Chamber Dischrg. Duct, Support Frame
A	599-3-39 (1 sheet)	-	Metering Duct Support Frame
A	599-3-40 (1 sheet)	-	Press Screws Mounting Channels
A	599-3-42 (1 sheet)	-	Metering Chamber Intake Plenum
B	599-3-44 (1 sheet	-	Baffle Skin
B	599-2-45 (1 sheet)	-	Metering Chamber Dischrg. Duct Assy.
C	599-3-47 (1 sheet)	C	Chamber Support Frame & Load Point Details
D	599-3-52 (3 sheets)	C	Locking Pin Assembly
D	599-2-53 (1 sheet)	B	Water Drain Layout
C	599-1-54 (1 sheet)	B	Control Console Arrgt.
D	599-3-55 (2 sheets)	F	Roof Test Chamber, Freezer Box Details
B	599-3-56 (5 sheets)	A	Compressor Skid
D	599-5-57 (8 sheets)	B	Distribution Panel
D	599-3-58 (1 sheet)	D	Roof Test Chamber Details
B	599-5-59 (10 sheets)	C	Loop Diagrams (Control)
D	599-3-60 (1 sheet)	A	Refrigeration Layout, Climate Chamber
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C	599-3-63 (2 sheets*)	-	Pressure/Vacuum Frame
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D	599-2-66 (2 sheets)	A	Gasket Layout, Roof & Jamison Door
D	599-2-68 (2 sheets)	B	Lifting Mechanism, Roof Door
D	599-2-69 (2 sheets**)	A	Rain Simulator
C	599-3-71 (1 sheet)	-	Removable Infrared Lighting Section Lifting Harness
D	599-3-73 (1 sheet)	A	Fire Protection System
D	599-3-74 (4 sheets)	C	Support Steel
D	599-3-75 (1 sheet)	A	Sensor Locations
B	599-1-76 (1 sheet)	-	Roof Door Operating System

*1 sheet is a "B" Size
**Sheet 2 is an "A" size w/2 catalog pages attached

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