Thermal Design of the WIYN 3.5 Meter Telescope Enclosure

Dan Blanco & Matt Johns

National Optical Astronomy Observatories†
P.O. Box 26732, Tucson, Az 85726

Abstract

The WIYN 3.5 Meter Telescope enclosure was designed to minimize the effects of dome seeing. A combination of strategies is being used to achieve this goal including a well ventilated telescope chamber, low thermal inertia construction, active ventilation using fans, and utilization of surface coatings to control radiation losses. This paper presents the design approach and preliminary thermal measurements of the facility.

1. Introduction

The WIYN Observatory is a joint project of the University of Wisconsin, Indiana University, Yale University and the National Optical Astronomy Observatories to build and operate a new 3.5 meter telescope on Kitt Peak, Arizona. A report on the project status is given by Johns and Blanco (1994).

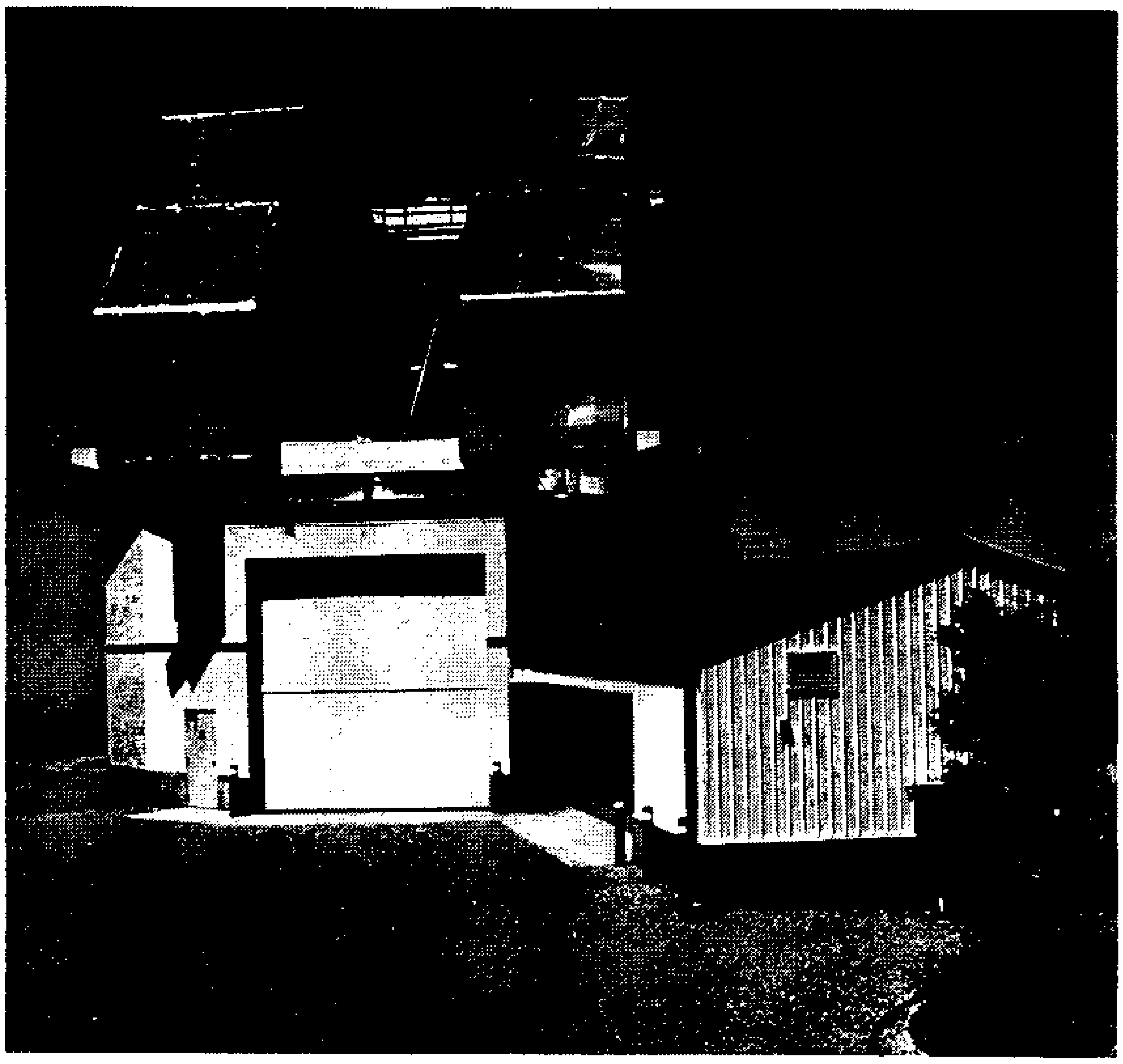

Figure 1 The WIYN 3.5 meter telescope facility.

The telescope enclosure houses the 3.5 m telescope and provides space for activities directly associated with the telescope operation. The building has three stories with the telescope imbedded in the center of the building and spanning the three floors. The rotating polyhedral dome opens up to allow the telescope to view all parts of the sky. The concept for the WIYN dome was adapted from the enclosure design for the Magellan telescope. The design provides a lightweight, thermally optimized structure by using space frame techniques. The polyhedral shape approximates the traditional hemispherical dome but uses flat panels for ease of fabrication and low cost.

The WIYN dome has an uninsulated internal skeleton of square structural tubing to support the skin and shutters. The skin is fabricated from commercially available insulated panels. The

†Operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation.

outer surface is covered with a highly reflective aluminum-mylar tape to reduce daytime heat gain due to insolation and to reduce nighttime over-cooling of the surface due to radiation to the sky. The steel frame and inner surfaces of the panels are painted.

Large bi-parting shutters open up during observing to provide a 4.25 meter wide slot for viewing. Seven motorized vents are incorporated into the vertical side walls of the dome to provide openings for air to passively flush the telescope chamber. The vents are made of insulated foam core panels and use commercial garage-door hardware. Sectional views of the enclosure are shown in Figures 2 and 3.

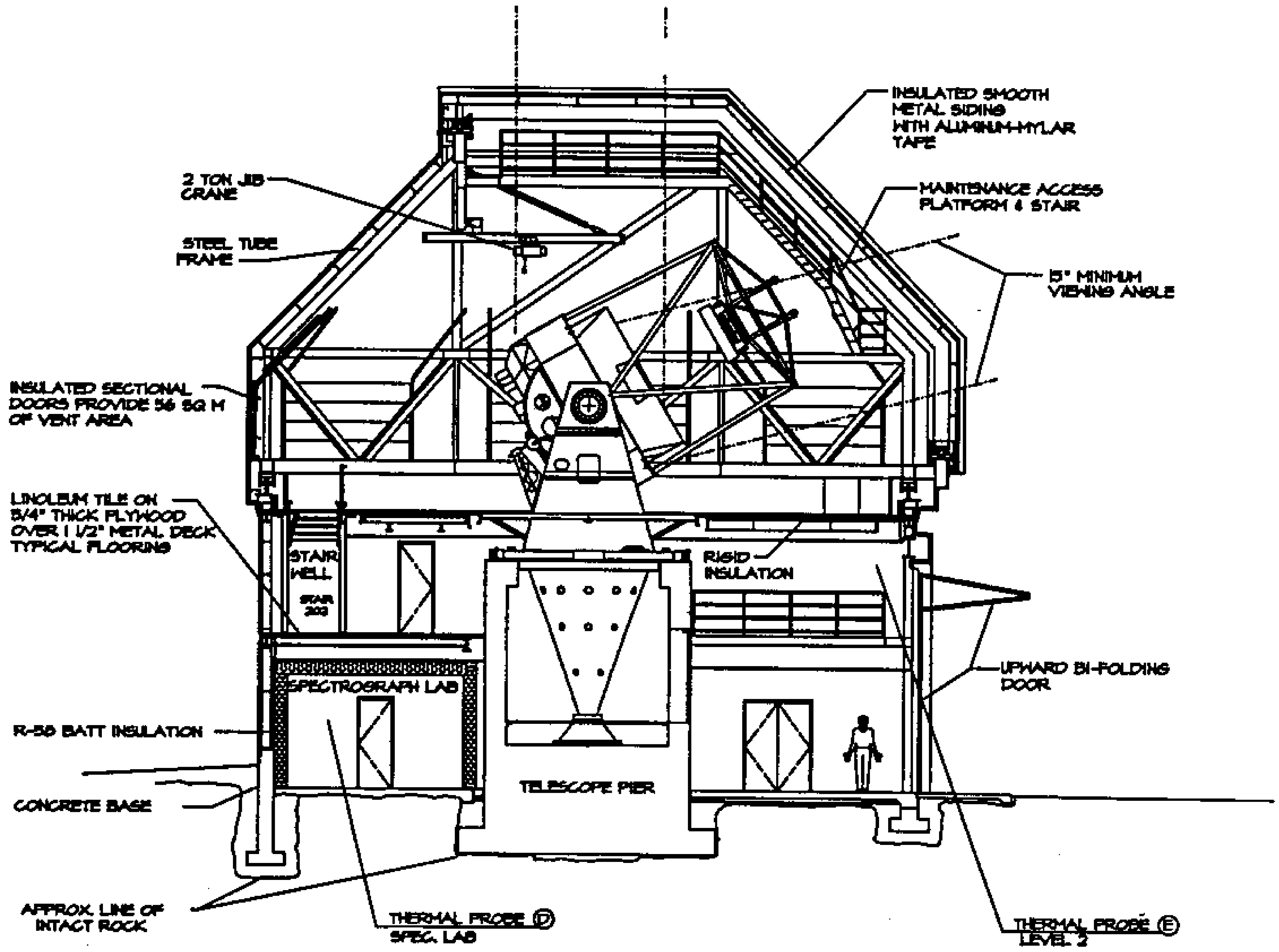

Figure 2 Sectional views of the WIYN telescope enclosure looking towards the north.

The observing floor provides access to the telescope optics support structure (OSS) and the instrument area. It is reached by an enclosed stairway from the mezzanine level. A door at the bottom of the stairway prevents air exchange with the lower levels. The telescope chamber is not air conditioned during the day and is exposed to the outside environment when the shutters are open. The observing floor is plywood over corrugated metal decking which provides low thermal mass and conductivity. The floor is covered with vinyl composition tile. Rigid insulation is attached to the under side of the chamber floor.

The stationary portion of the enclosure surrounds the telescope and pier and provides a base for the dome. The steel structure of the base is uninsulated and exposed to the inside air. The exterior walls are constructed from sandwich panels of a similar insulating value as the dome skin. The two lower floors have space for equipment storage and a well insulated, unheated, spectrograph lab. These floors are unheated and tend to follow the outside night-time temperature with a lag due to thermal inertia. The spectrograph lab has added thermal mass and is allowed to find its own temperature without active controls.

The mezzanine floor is constructed with the same materials as the observing floor but is uninsulated. A large opening to the ground floor allows a free flow of air between the two lower levels. The concrete floor and telescope pier are uninsulated.

Air is drawn through the enclosure base to force the inside temperature to follow the air temperature in the telescope chamber. The air pressure in the base is maintained slightly below the pressure in the telescope

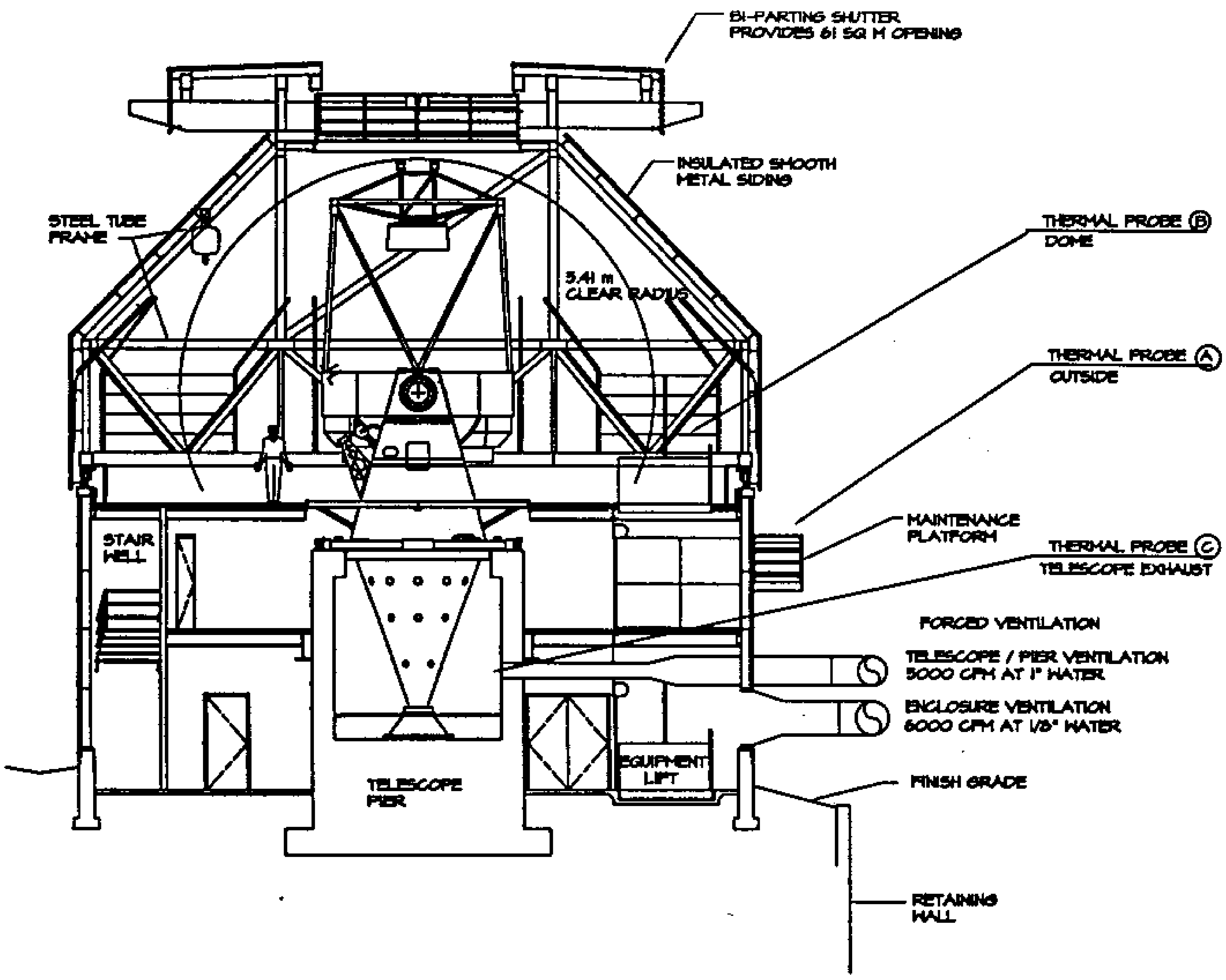

Figure 3 Sectional view of the enclosure looking towards the west.

chamber to insure a downward flow of air and prevent warm air from escaping upward into the telescope chamber. Make-up air enters through registers in the observing floor and through a wall vent at ground level.

A thermal buffer space is provided between the enclosure and the control building which contains all the heated spaces of the observatory. Conditioned areas are provided for an instrument lab, computer room, and telescope control room.

2. Ventilation

The telescope enclosure is provided with four ventilation systems for controlling the temperature in the building. One is passive and relies on the natural action of wind to force air through the telescope chamber. The other three systems use blowers to draw air through the telescope and lower floors of the enclosure and an adjoining equipment room. Air is exhausted at a fan house 38 m from the enclosure in the prevailing down wind direction.

2.1 Dome Vents

Seven vents are provided in the vertical walls of the rotating dome. Each has a clear area of 8 m^2 when fully opened. The shutter gives an additional 60 m^2 opening for ventilation. All combined they represent about 25% of the surface area of the dome. The shutter and vents will normally be open for observing. During times of high wind, the vents may be individually closed to reduce the flow. With all the vents closed, ventilation is provided primarily through the shutter with additional air being drawn through the telescope chamber by fan-forced systems.

Water tunnel tests using an acrylic scale model of the WIYN enclosure were conducted at the University of Washington Department of Aeronautics (Siegmund, 1990) to test the flushing of the telescope chamber. Dye was injected into the telescope chamber of the transparent model and the time for the dye to completely clear was recorded. Tests were run with a free flow velocity corresponding to 5.3 m/s when scaled up to the real building. This is consistent with normal conditions at the site where night time wind speeds exceed 5 m/s 90% of the time.

The tests indicated that flushing is least efficient with the dome pointed away from the flow. In this orientation air enters only through the three vents on the upwind walls. Assuming a wind velocity of 5.3 m/s, the volume of air flowing into the enclosure through the upstream vents is 100 m^3/s. Since the volume of the chamber is 1300 m^3 this produces a volume change every 13 seconds or 280 changes per hour.

The rate of heat extraction from the air exchange is given by:

$$P_v = C_a \, \Delta T \, \frac{dV}{dT} \tag{1}$$

where $C_a = 1.0 \times 10^3$ J/m^3 is the volume heat capacity of air, V is the volume of air exchanged, and ΔT is the temperature difference between the incoming and exiting air. With an air flow of 100 m^3/s, heat is extracted at 100 kW/°C . The average temperature rise in the air is 0.01 C per kilowatt of dissipated heat.

While this airflow might seem like overkill from the standpoint of heat transport, keeping the flow rates high through the structure lowers the thermal relaxation time of the telescope and dome for the reason that (1) the temperature of the air in contact with interior surfaces will be closer to the outside temperature and (2) heat transfer rates at interior surfaces will be greater with more air moving over the surface. High flow rates will also rapidly sweep hot air bubbles out of the telescope beam.

2.2 Enclosure Base Ventilation System

The enclosure base is ventilated by a blower that draws air through the lower two floors. Make-up air enters through registers in the observing floor, upper stairway and through a louver in the base. Additional air is drawn through registers around equipment on the chamber floor. The system performs the following functions:

- Extract waste heat from the chamber and equipment located on the lower floors.
- Extract heat from the around the dome ring beam.
- Remove heat from the dome rotation motors.
- Extract heat stored in the lower building structure.
- Prevent hot air bubbles from rising into the telescope chamber.

The system has a capacity of 6000 cfm at 1/8" water static pressure. Excluding the pier and spectrograph lab, the ventilated volume is 734 m^3 for an exchange rate of 13.8 building volumes per hour. This flow of air extracts 2.7 kW per 1°C air temperature rise.

The exhaust air is ducted away from the telescope enclosure to the fan house 38 meters downwind from the center of the enclosure. Since most of the make-up air comes through registers in the observing floor, the base ventilation system provides additional ventilation for the telescope chamber during rare times of dead calm wind.

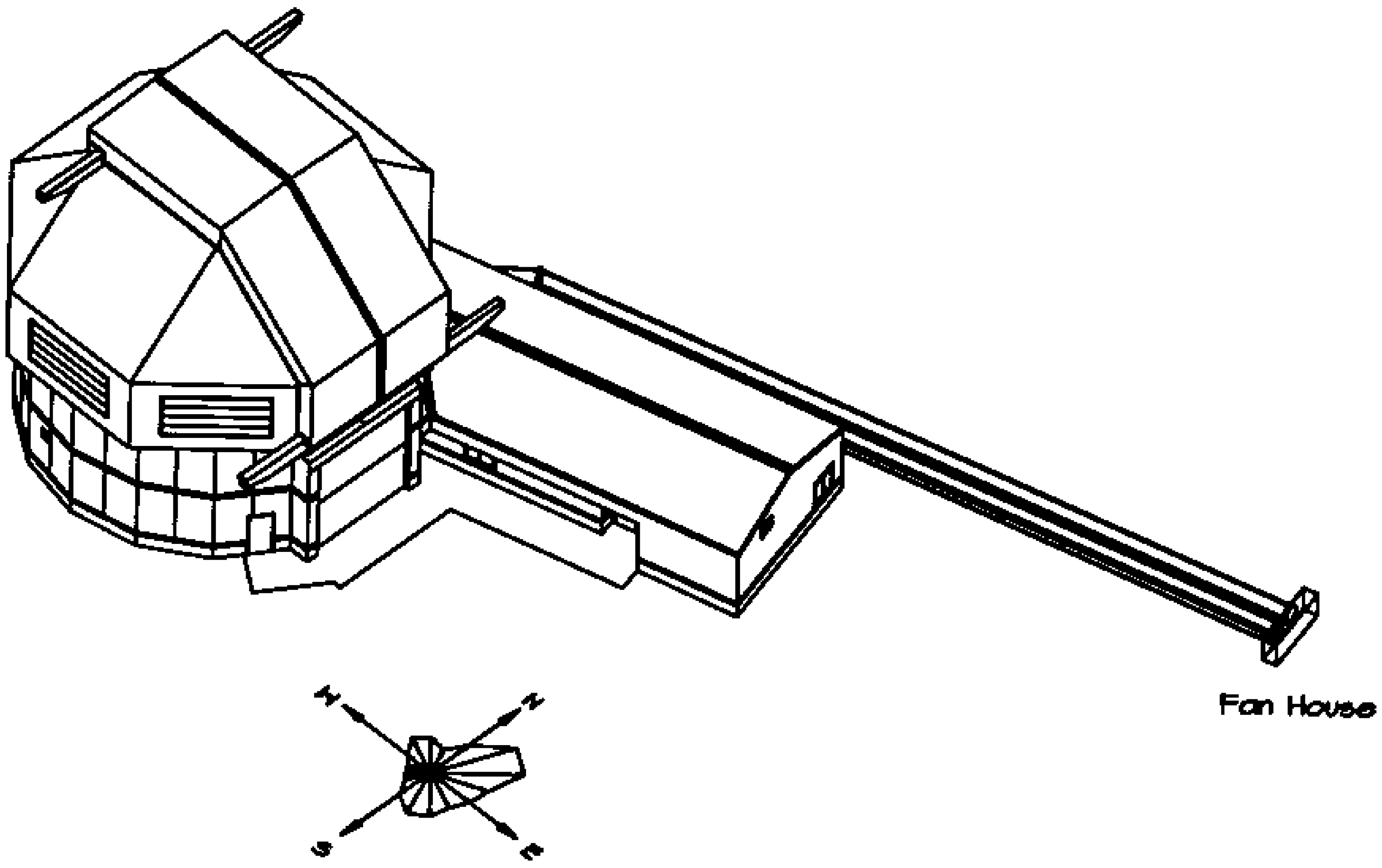

Figure 4 Quartering view of the facility showing the polyhedral dome, control building, ventilation ducts and fan house. The compass rose shows the prevailing winds.

2.3 Telescope & Instrument Ventilation System

A separate ventilation system is provided for the telescope and attached instrumentation. Air is drawn through the telescope structure into a plenum formed by the telescope pier. From there it is ducted away from the building. A rotating seal is provided between the telescope and pier just below the azimuth drive disk to prevent air intake from the lower levels of the enclosure.

Make-up air enters the mount structure through vent holes distributed over the surface of the telescope. Ducting is provided to connect instruments to the system. The system performs the following functions:

- Remove heat stored in the telescope structure & promote cooling
- Extract waste heat from instrumentation & electrical equipment.
- Prevent hot air from rising up inside the fork assembly.

The system has a capacity of 5000 cfm at 1" water static pressure and can extract 2.2 kW per 1°C air temperature rise. Exhaust air is released at the fan house. Like the enclosure base ventilation system, this system provides additional ventilation for the telescope chamber.

2.4 Equipment room ventilation and control building

Heat producing equipment needed to operate the telescope is located in an unheated room between the enclosure base and the control building. The equipment includes the heat pump used to condition the primary mirror and uninterruptable power supplies for the facility. The ceiling of this room is heavily insulated. Air is drawn into the equipment room through registers into the vestibule. Exhaust air is released at the remote fan house.

All heated space in the observatory is located in the control building. Waste heat produced by air conditioning systems that operate at night is ducted to the remote fan house. The walls and roof of the control building are insulated and the roof of the control building is painted to promote over-cooling by radiative coupling to the night sky.

3. Thermal Balance of the Telescope Chamber

Day-to-night temperature variations at the WIYN site are typically 11°C ± 4°C with the largest variations occurring during the day. The greatest temperature swings occur shortly after sunrise and shortly before sunset. The average rate of temperature change during the 10 hours from 8 pm to 6 am civil time measured on 61 randomly selected nights in 1986-1989 was 0.27°C/hr. In the analysis that follows we adopt 0.25°C/hr as a typical nighttime rate of temperature decline to be consistent with estimates by others.

Under this steady rate condition heat loads into the telescope chamber arise from (1) stored heat in structures, (2) conduction from outside the chamber, (3) radiation, and (4) active sources such as electrical equipment. The heat input is balanced by convective transport driven primarily by passive flushing.

3.1 Stored heat

Stored heat is released into the chamber from the telescope, the dome and from the chamber floor. The steady rate heat load into the telescope chamber from structures cooling at a uniform rate is given by:

$$P_T = \alpha \, C_T \, M \, \frac{dT}{dt} \tag{2}$$

where C_T is the heat capacity, M the mass, T the temperature, and t is time. α is the fraction of the structure mass that couples into the telescope chamber.

The total rotating mass of the telescope is 36,400 kg, about half of which is below the chamber floor level where it is ventilated by the telescope and enclosure forced air systems. The primary mirror and cell weldment, with a combined mass of 5,700 kg, have an internal thermal control system that will extract about half the heat given off by them. The net telescope mass that releases heat into the chamber is 22,000 kg.

The rotating dome has a mass of 36,400 kg. The steel skeleton with a mass of 30,000 kg releases heat directly into the chamber, while the 6,400 kg mass of foam core panels of the skin releases heat equally inside and out.

The chamber floor is constructed of plywood with rigid insulation on the bottom side. The floor releases all of its stored heat to the telescope chamber.

3.2 Heat conduction

Heat is transferred by conduction into the telescope chamber through (1) the dome skin, (2) the observing floor, and (3) by equipment that pierces the observing floor including the telescope. The amount of heat is given by:

$$P_c = \frac{A \, k_c}{l} \, \Delta T \tag{3}$$

where A is the boundary cross sectional area, k_c the thermal conductivity, l the boundary thickness, and ΔT the temperature difference across it.

Measurements of the temperature difference that develops between the exterior surface and the ambient air were made by Beckers and Ulich (1981) using insulated panels with aluminum-mylar tape coating similar to those used in the WIYN dome. The panels were mounted outdoors face upwards exposed to the sky. At night with a 10 mph wind the panels cooled 0.28°C below the ambient air temperature from radiation to the cold sky. Solar heating warmed the panel top to 11°C above the air temperature at noon with the same 10 mph wind.

The WIYN dome has a surface area of 613 m^2. The 75mm thick foam core panels have a thermal conductivity of 0.05 W/m°C. The heat transfer through the dome is 412 W/°C. If the entire surface of the dome were cooler than the inside by 0.28°C, the nighttime heat loss through the skin would be 115 W.

Conduction through the observing floor depends on the relative temperatures above and below. The structural steel, concrete pier and concrete floor in the enclosure base are large uninsulated masses that tend to stabilize the temperature. Because of this the lower floors are usually warmer at night than the telescope chamber.

The chamber floor has an area of 175 m^2 is constructed of 25 mm thick plywood with a conductivity of 0.12 W/m°C over 25 mm of polystyrene with a conductivity of 0.05. The heat transfer into the chamber through the floor is about 125 W/°C. With the ventilation fans running the average air temperature difference is no more than 4°C between the dome and the mezzanine level.

Conductive transfer through the telescope is negligible since the steel sections are thin, the distances large, and the flow is dominated by forced convection from the telescope ventilation system.

3.3 Radiational cooling

At night heat is removed from the telescope chamber by radiation through the open shutter. The upward looking exposed area is 47 m^2. We assume a night time radiational heat transfer rate of 80 W/m^2. The top end of the telescope and the upper end of the OSS is covered with aluminum-mylar tape to lower its emissivity and prevent sub-cooling due to radiative coupling to the night sky.

3.4 Active heat sources

Active sources of heat include the telescope and dome drives, electrical equipment, OSS functions such as mirror covers and counterweights, and science instruments. Active sources around the telescope can be particularly troublesome if they produce localized hot spots that find their way into the telescope beam. Ducts connecting into the telescope ventilation system are provided for the elevation drive motors, OSS control electronics, the Nasmyth instrument rotators, and for science instruments. Two dome drive motors which reside in the chamber are ducted into the enclosure base ventilation system.

3.5 Heat balance

The heat loads into the chamber during typical steady rate observing conditions are summarized in Table 1. This heat transfer results in a change in the temperature of the air inside the dome and is balanced by convective transfer to the ambient by passive flushing. We assume the 5.3 m/s minimum wind speed which prevails 90% of nights at the site.

Table 1. Heat balance for the telescope chamber.

Heat Balance on Telescope Chamber (Watts)			
Stored Heat			**2,025**
	Telescope	675	
	Dome	850	
	Floor	500	
Conduction			**385**
	Dome	-115	
	Floor	500	
Radiation Loss			**-3,760**
	Slit	-3,760	
Active Sources			**1,003**
	Primary supports	126	
	Primary thermal	200	
	Secondary	8	
	Tertiary	5	
	Elevation drives	13	
	Instrument rotators	20	
	OSS Controls	32	
	Science instruments	500	
	Dome drives	100	
Total			**-347**

Heat loads on the telescope chamber are dominated by cooling due to radiation to the night sky through the dome slit. The net air temperature change is calculated by solving equation (1) for ΔT. With a 100 m^3/s flow rate and the heat loads listed in Table 1 there is a net -0.004°C cooling of the air in the telescope chamber.

The degradation of the image size from "dome seeing" has variously been estimated (Coulman et al 1986, Le Poole 1990, Woolfe 1979) at 0.1 - 0.6 arcsecond per degree difference between the inside and outside air temperatures. Our error budget for dome seeing is 0.15 arcsecond so our goal is to maintain a temperature difference less than about 0.4°C. These results are well within that goal.

4. Preliminary Results

Since the completion of the WIYN enclosure and the installation of the telescope mount in the spring of 1993 we have attempted to characterize the thermal performance of the telescope enclosure in two ways; first by visual observations of the facility with a thermographic video camera, and second by logging the output of temperature probes at various locations in the facility.

4.1 Thermal infra-red observations

Infra-Red thermography has become a useful tool for assessing the thermal environment of observatories (Williams et al, 1986). It is particularly easy to identify heat sources, however, care must be taken to account for differences in the emissivity of the various surfaces. In our observations we used hand held temperature probes to verify surface temperatures. Prior to the observations the shutters and vents were opened and the ventilation systems were turned on.

The outside of the facility showed several features;

- The gravel parking lot cools rapidly to below ambient air temperature
- The roof of the control building also cools to below ambient.
- Concrete footings around the base of the enclosure exposed to sun during the day remain considerably warmer than ambient (about 6°C) at sunset.

Features noted inside the telescope chamber included;

- The inside surface of the dome skin was isothermal to 0.1° - the resolution of the thermographic camera.
- The steel skeleton of the dome was also very isothermal at 0.5°C cooler than the skin.
- The two large beams which support the shutter at the top and bottom of the slit were 3°C colder than the internal building steel. They had been cooled by evaporation in a recent storm.
- The outer surface of the plate structure of the telescope mount was isothermal within 0.5°C
- The inner surfaces of the telescope mount were 0.5°C warmer that the outside.
- The top end of the telescope showed evidence of radiative sub cooling. Surfaces covered with aluminum-mylar tape were very close to ambient while a few remaining painted surfaces reached 1°C below ambient .
- The chamber floor beneath the open shutter cooled to 1.3°C below ambient. Other areas of the floor closely followed ambient temperature.

We also noted a few "hot spots" in the observing chamber:

- The overhead cranes have a thermal overload protection box which dissipates a few watts.
- The elevation axis encoder uses an incandescent light bulb which warms the encoder housing 1.2° above ambient.
- The elevation drive housings were 0.5°C above ambient after running for 40 minutes.
- Two dome azimuth drive boxes were 3°C above ambient. Evidently the ventilation fans are not working effectively.

At the time of this writing we are installing the telescope control system which will add active heat sources to the chamber. We intend to continue these observations and deal with thermal problems as the telescope goes into commission.

4.2 Logged temperature profiles

Six thermocouple temperature probes have been installed at various locations within the facility. One probe located to the north of the enclosure and just below the chamber floor level serves as an outside temperature reference. Other probes are located in the telescope chamber, in the pier just in front of the telescope ventilation exhaust duct, on the mezzanine level, in the spectrograph lab, and at the intake to the building exhaust duct.

Once the telescope is in operation we expect to establish a normal routine in which the telescope chamber is opened only at night. During construction we have not followed such a regimen, so it has been difficult to gather temperature data under conditions which approximate normal. Day crews for example find it convenient to open the dome vents in good weather to let light and warm air into the chamber. In the few periods in which we were able to simulate normal operations the weather has been less than cooperative. Figure 5 shows temperature profiles logged over a two day period in November, 1993 during which conditions came close to normal. For clarity only three temperature profiles are shown; outside, telescope chamber, and the spectrograph lab. On the first night shown the weather was cloudy and only the dome vents were opened; the dome shutter was left closed

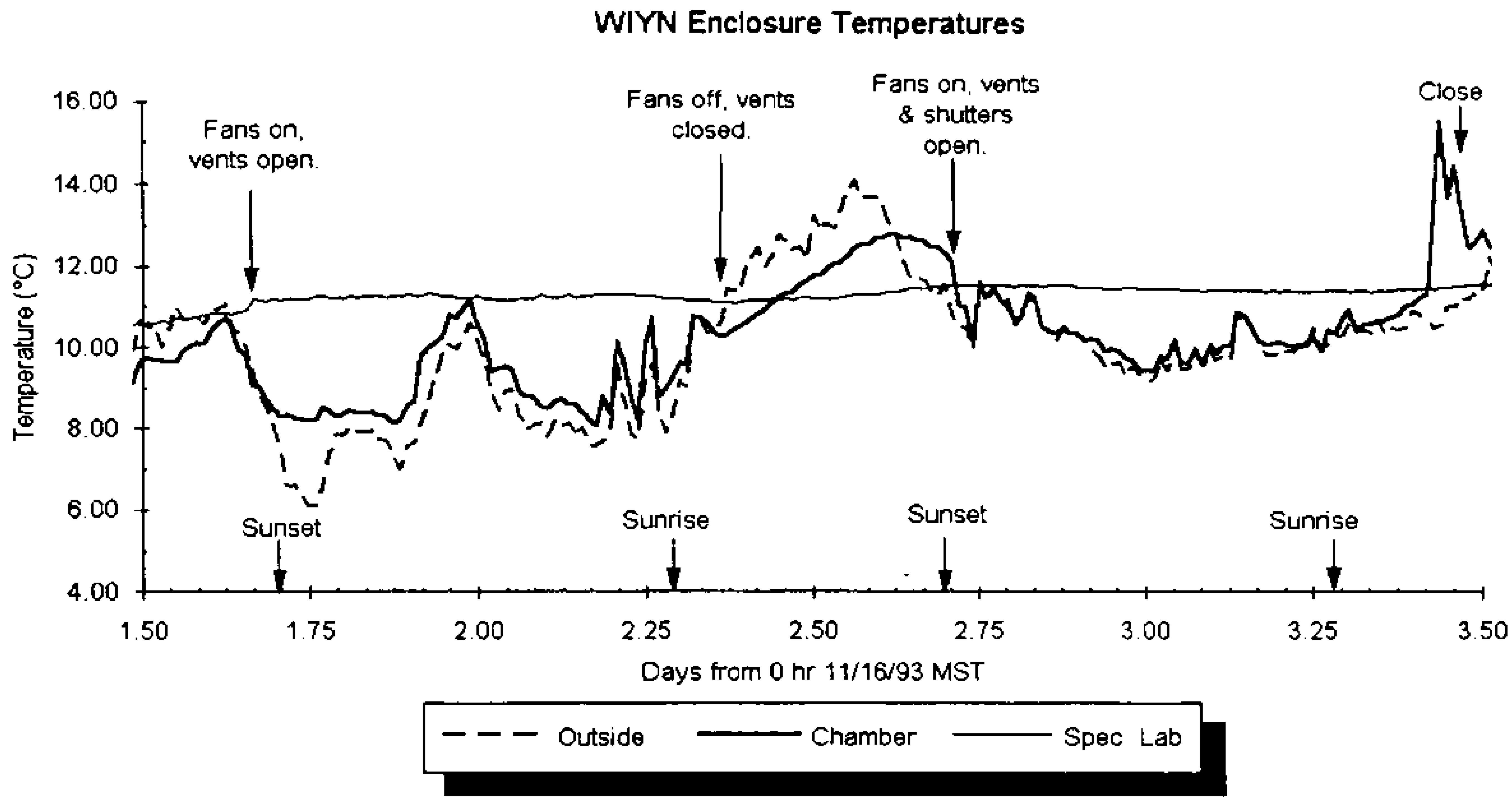

Figure 5 Temperature data taken through two days shows how the enclosure quickly reaches outside air temperature after opening, and tracks temperature variations through the night.

as a precaution against rain. The second night was clear and both the shutter and vents were open.

On opening the air temperature inside the chamber rapidly converges with the outside temperature and closely follows throughout the night. Over the period from one hour after sunset to one hour before sunrise the median temperature difference between the dome and outside was 0.62°C on the first night (shutters closed) and 0.15°C on the second (shutters open). By contrast the spectrograph lab sees very little diurnal variation and slowly follows the day to day temperature change. Over the period shown the temperature variation in the spectrograph lab was less than 0.3°C peak.

5. Summary

The WIYN enclosure makes use of several passive and active strategies to reduce dome seeing. The dome is a low mass, well insulated and very well ventilated structure with few heat sources in the telescope chamber. The enclosure and support building make use of appropriate coatings to control emissivity. The enclosure is designed to equilibrate rapidly and track night time temperature variations closely through the night.

Measurements of the thermal performance of the enclosure will continue, however, preliminary results indicate that under normal observing conditions the enclosure tracks outside air temperature within 0.4°C, the goal set by the imaging error budget for dome seeing.

6. References

1. M. Johns & D. Blanco,"The WIYN 3.5 meter Telescope Project", *Advanced Technology Optical Telescopes V*, vol 2199, SPIE, Kona, 1994

2. W. A. Siegmund, "Report on Flow Visualization of the WIYN Telescope Enclosure Design", 1990

3. J. M. Beckers and B. L. Ulich, "MMTO Technical Memorandum No. 81-1", 1981

4. C. E. Coulman, J. C. Andre, P. Lucamese, P. Gillingham, "The Observation, Calculation, and Possible Fore Casting of Astronomical Seeing", PASP 98, 1986

5. R. Le Poole, "Minimizing the Man-Made Deterioration of the Seeing at the 3.6-m Telescope at La Silla", PASP 91, 1979

6. N. Woolfe, "Dome Seeing", PASP 91, 1979

7. J. T. Williams, J. M. Beckers, D. Salmon, P. Kern, "IR Thermography and Observatory Thermal Pollution", *Advanced Technology Optical Telescopes III*, vol 628, SPIE, 1986