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Paul Tom Worthington, James R. Fowler, Craig E. Nance, Mark T. Adams, "Thermal conditioning of the Hobby-Eberly Telescope dome," Proc. SPIE 4010, Observatory Operations to Optimize Scientific Return II, (25 July 2000); doi: 10.1117/12.392502

SPIE.

Event: Astronomical Telescopes and Instrumentation, 2000, Munich, Germany

Thermal conditioning of the Hobby-Eberly Telescope dome

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ABSTRACT

The Hobby-Eberly Telescope (HET) is an innovative, low cost 9-meter telescope that specializes in queue mode spectroscopic observing. Because of the HET's unique design, careful day-time and night-time thermal conditioning of the interior dome environment is essential to optimizing the telescope's performance on the sky during astronomical research operations. In this contribution, we describe the past and present thermal conditioning techniques that have been developed and employed at HET to optimize the telescope's scientific performance.

Keywords: Hobby-Eberly Telescope, thermal conditioning, scientific performance, HVAC

1. INTRODUCTION

Thermal conditioning of any telescope and telescope enclosure improves scientific efficiency by providing improved dome seeing. The HET efficiency, as it relates to science, is additionally improved by reducing the time required for initial mirror alignment at the beginning of nightly science operations. If the telescope and enclosure are conditioned to nearly outside air temperature at opening, the time required to perform the initial mirror alignment is reduced; thus, more of the nightly open hours are available for gathering science data.

This paper provides a brief description of the telescope, telescope enclosure and the thermal conditioning equipment. The descriptions below are detailed enough to provide an understanding of the task of thermally conditioning the telescope and telescope enclosure. Additionally, a discussion of the past and present thermal conditioning techniques that have been developed and used at the HET are presented. Finally, an evaluation of the thermal conditioning performance based on a 10-micron camera survey is presented.

2. DESCRIPTION OF THE HOBBY-EBERLY TELESCOPE, TELESCOPE ENCLOSURE AND THERMAL CONDITIONING EQUIPMENT

2.1 Telescope description

The HET primary mirror shown in Figure 1 is a 10 by 11-meter mirror consisting of 91 individual mirror segments mounted on a precision truss. Each mirror segment weighs approximately 250-pounds (114 Kg) and is one meter across flat side to flat side. The 91 mirror segments have three actuators each and the controls to allow alignment of the mirror. The mirror alignment process is called stacking. The quality of the mirror stack is quantified by enclosed energy 50% and 80% measurements. A well-conditioned and stable thermal environment is essential to the alignment process since heat driven convection air currents leaving the dome adversely impact the ability to align the mirrors.

The mirrors are mounted in a precision truss that is fixed at one support and the other two supports allow for motion due to thermal effects. The primary mirror, the truss and truss-supports, are shown in Figure 2. The telescope structure supports the primary mirror truss, the primary mirror and the tracker which is 13-meters above the primary mirror. The tracker[1] supports and moves the Spherical Aberration Corrector (SAC), Primary Focus Instrument Package (PFIP), Fiber Instrument Feed[2], guide and acquisition cameras, and the Low Resolution Spectrograph[3]. Figure 3 shows the tracker's reflection in the primary mirror.

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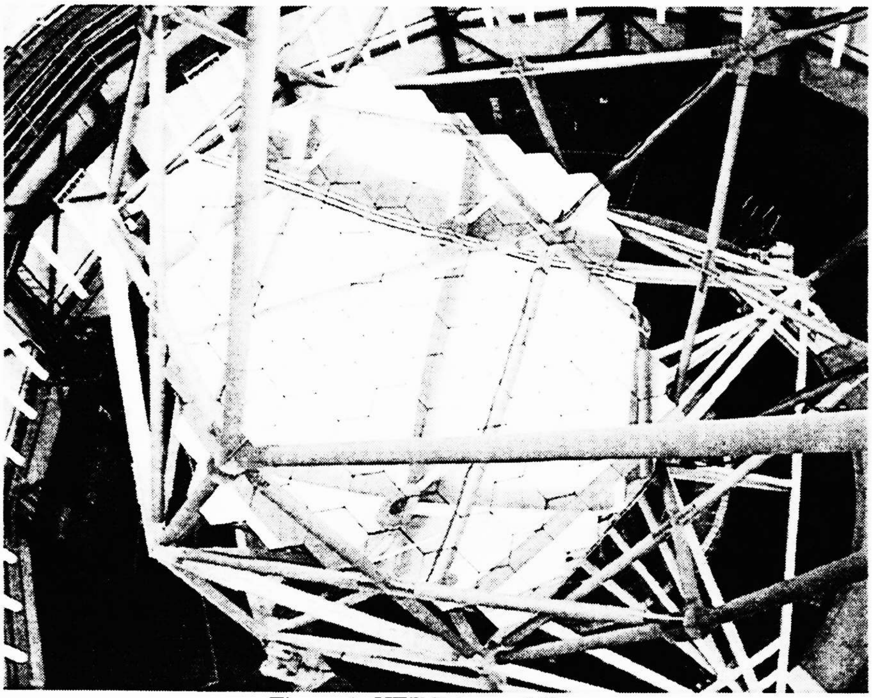

Figure 1: HET Primary Mirror

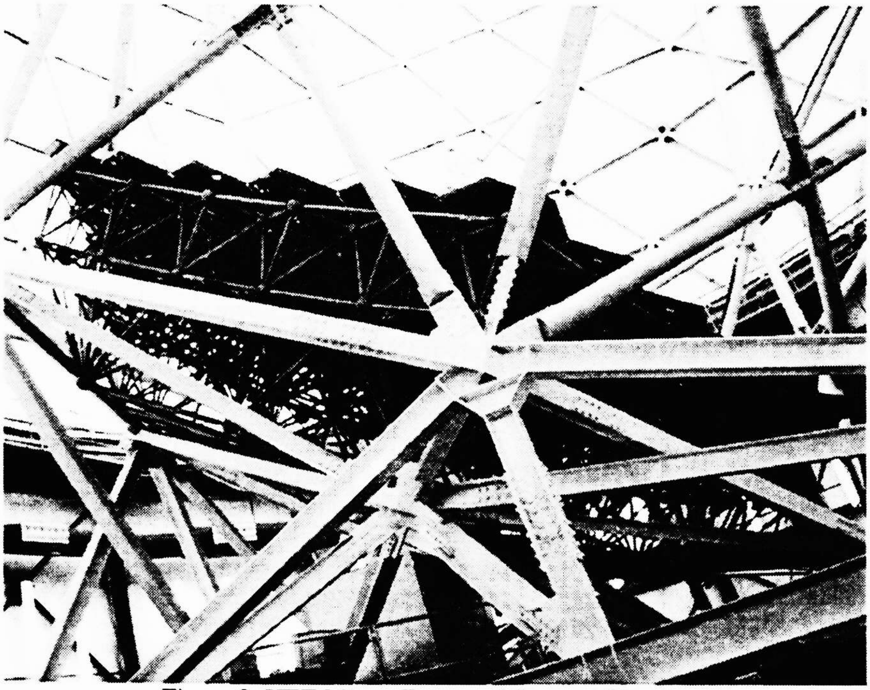

Figure 2: HET Mirror Truss and Support Structure

The 91-ton (82,554-kilogram) telescope is positioned to the required azimuth by lifting the telescope using eight air bearings. The air bearings have an effective diameter of 33-inches (83.82-cm). Two air bearings on either side of a telescope foot are shown in Figure 4. The air bearings are pressurized to an average of 26.6 pounds per square inch (0.2-Mpa) to lift the telescope. While floating on the air bearings, the telescope computer commands two drive motors to rotate the telescope to the commanded azimuth. When the desired azimuth is reached, the computer sets the telescope down by isolating the lifting air to the air bearings. After a sufficient time elapses for the telescope to set down on its feet, the remaining lift air is released by solenoid valves.

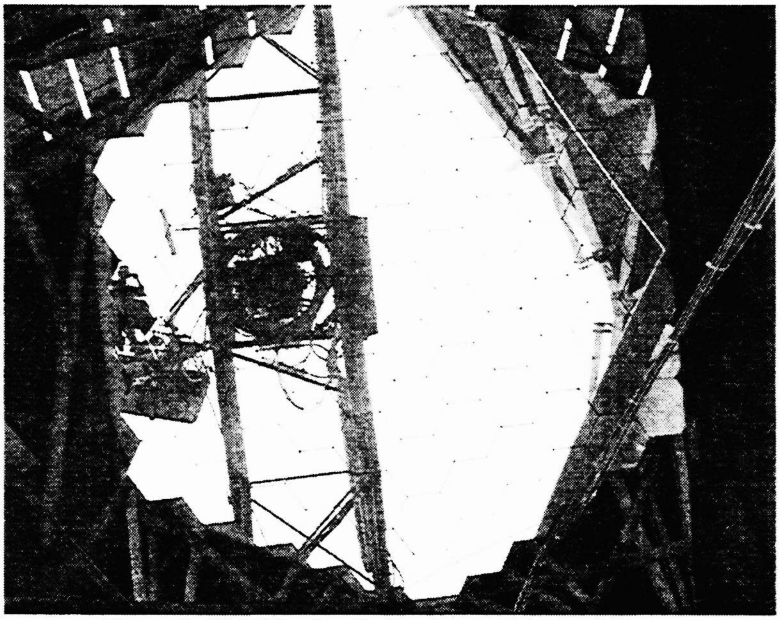

Figure 3: HET Tracker Reflection in Primary Mirror

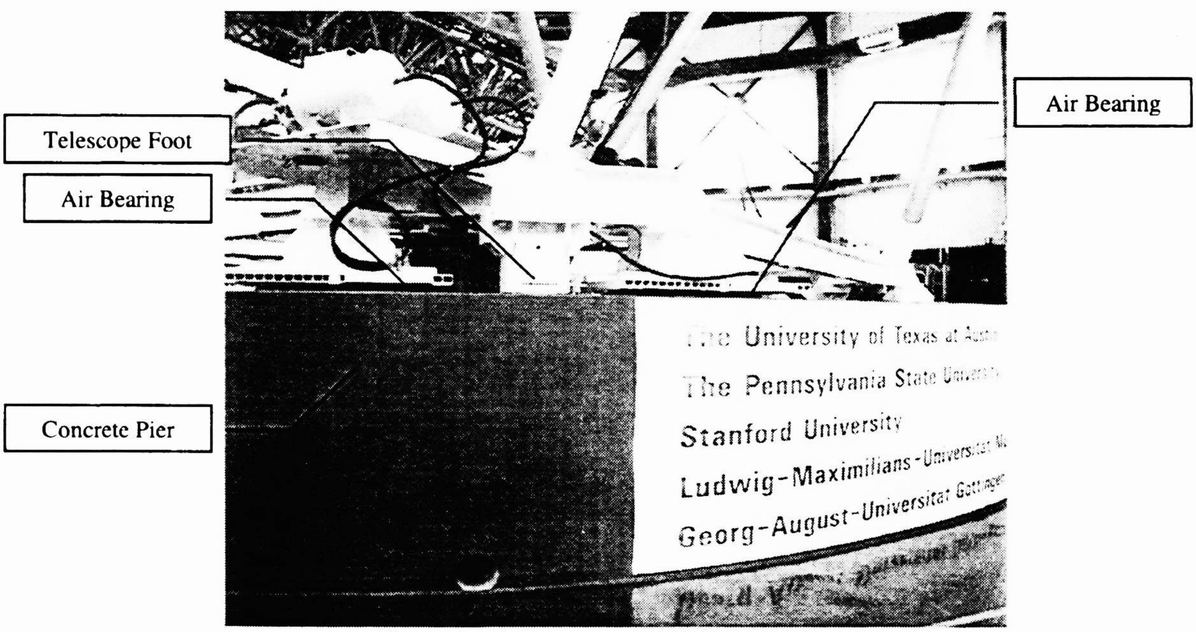

Figure 4: Air Bearings and Telescope Drive

The azimuth is controlled by two drive motors and an associated motion control computer. The air bearings and telescope structure feet rest on the concrete pier shown in Figure 4. The pier has a smooth finish on top upon which the air bearings operate. The pier extends approximately 55.5-inches (141-cm) above the enclosure floor and is approximately 39.6-inches (101-cm) thick. The telescope elevation is fixed at 55°; however, the ±6° ranges of elevations of interest are accommodated by the tracker motion.

After a target is selected, the trajectory is calculated by the telescope control computer and transmitted to the tracker shown in Figure 5. As the astronomical target transits across the primary mirror, the tracker moves the instrument payload according to the calculated trajectory, along the focal sphere to focus the target onto the instrument. The tracker positions the instrument payload moving in six degrees of freedom. This is accomplished using 10 motor operated drives and precision position encoders. The drive motors are jacketed with cooling coils to remove heat and are insulated around the cooling coils. The heat is removed by the telescope-cooler glycol system and rejected via an ambient air heat exchanger shown in Figure 9.

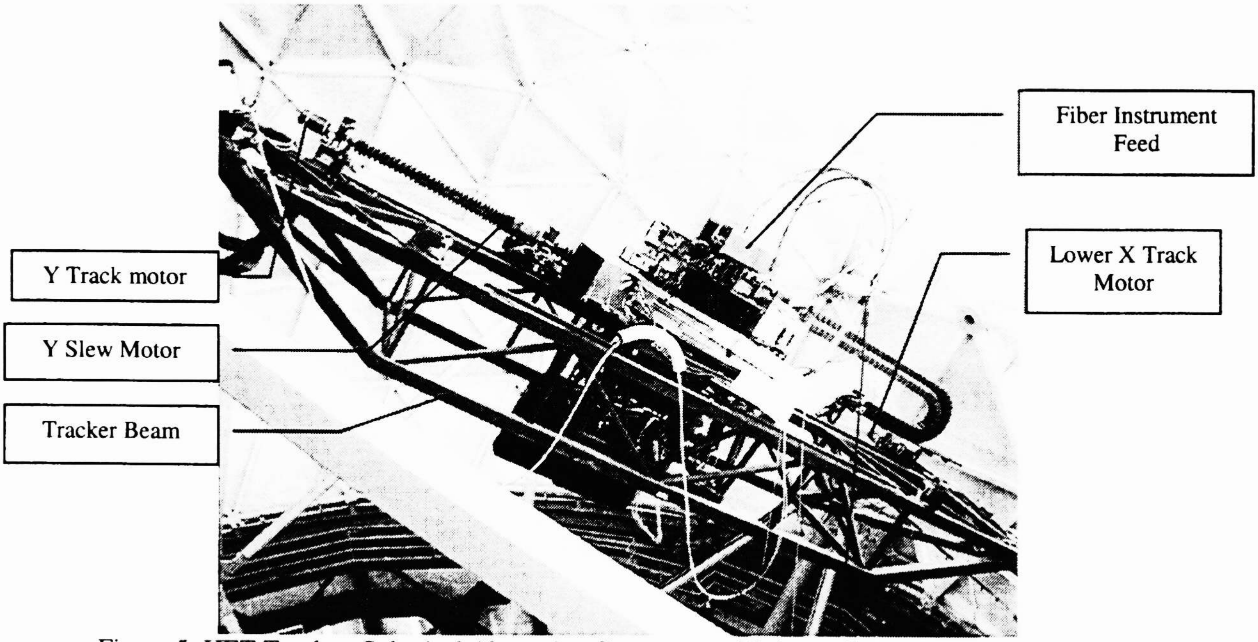

Figure 5: HET Tracker, Spherical Aberration Corrector and Primary Focus Instrument Package.

Owning to cable length limits for the drive amplifiers and position encoders, the electronics that control the drives and mirror segments are located below the primary mirror on the telescope structure platform. As shown in Figure 6, the heat from the electronics is trapped by an insulated cabinet and directed away from the mirror.

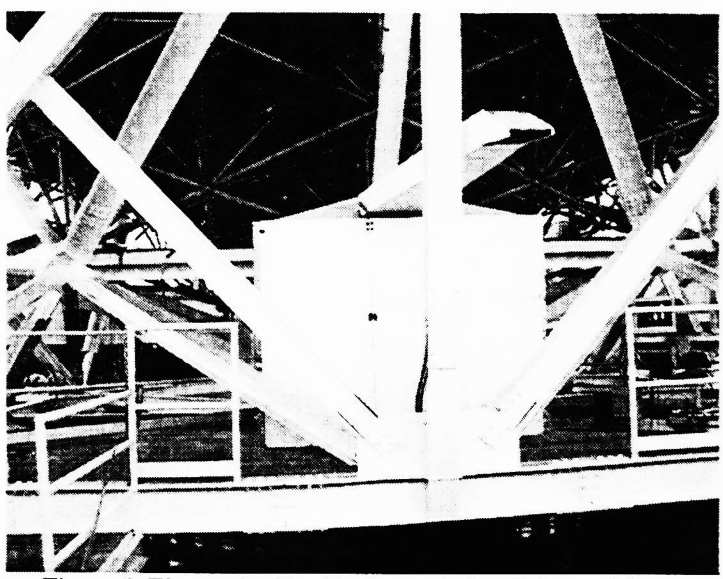

Figure 6: Electronics Bay Enclosure below Primary Mirror

2.2 Enclosure description

The telescope enclosure, as shown in Figure 7, is a geodesic aluminum dome constructed by Temcor of Carson, California. The dome is mounted on top of the enclosure wall that forms a right cylinder. The dome is 85-feet 10-inches (26.2-meters) in diameter. The dome is truncated by the enclosure cylindrical wall that is 79-feet (24-meters) in diameter and 30-feet (9.1-meters) tall. The dome extends 61-feet (18.6-meters) above the enclosure wall. The volume of the enclosure is over 427,000 cubic feet (12,091 cubic meters).

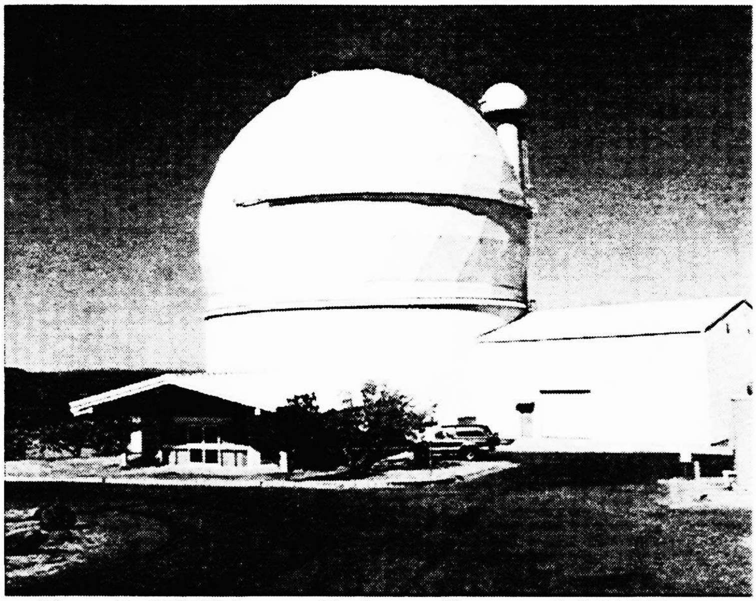

Figure 7: HET Telescope Enclosure, Shutter and CCAS Tower

The dome is rotated by two drive motors mounted 180° apart on the enclosure interior catwalk wall. One drive unit is shown in Figure 8. The dome weighs nearly 120,000-pounds (534,000-newtons). The enclosure wall is a structural steel frame with aluminum siding. The dome is not insulated; however, the enclosure wall is insulated to approximately R-19. Six downdraft fans, a 12 foot (3.7-meter) by 10-foot (3-meter) garage door, visitor gallery and two doors penetrate the enclosure wall, one on the west side and one on the east side.

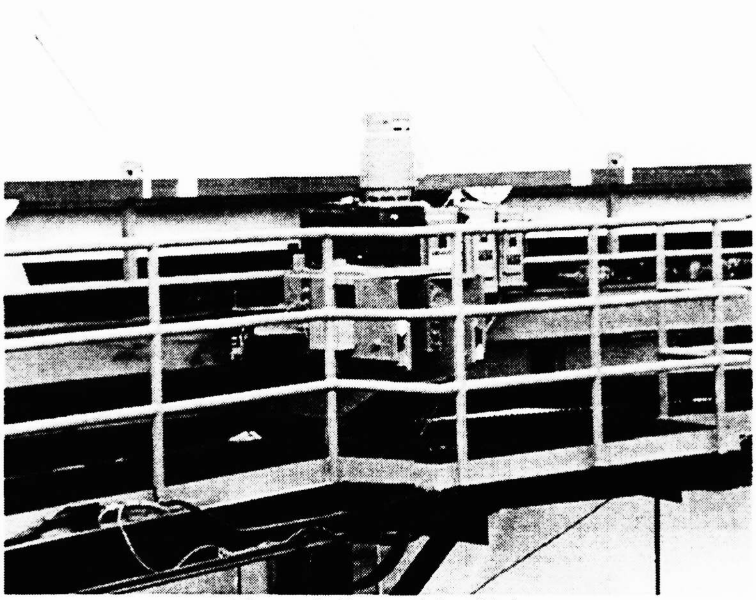

Figure 8: Dome Drive Unit

The dome shutter is 472-inches (12-meters) wide and 510-inches (13-meters) tall, and can be seen closed in Figure 7. The area of the shutter opening is 1167 square feet (108 square meters). The shutter is chain driven by a motor and helical gearbox assembly similar to the dome drives. The telescope is located at an elevation of 6634-feet (2012-meters).

2.3 Thermal conditioning equipment description

The HET has a single 50-ton (176-kilowatt) chiller shown in Figure 9. The chiller is capable of providing approximately 120 gallons per minute (454 liters per minute) chilled water with a supply temperature as low as 16°F (-9°C). The chilled water is a 60/40 mixture of ethylene glycol and water to prevent freezing. The chiller is air-cooled and is located on a chiller pad approximately 72-feet (22-meters) from the enclosure.

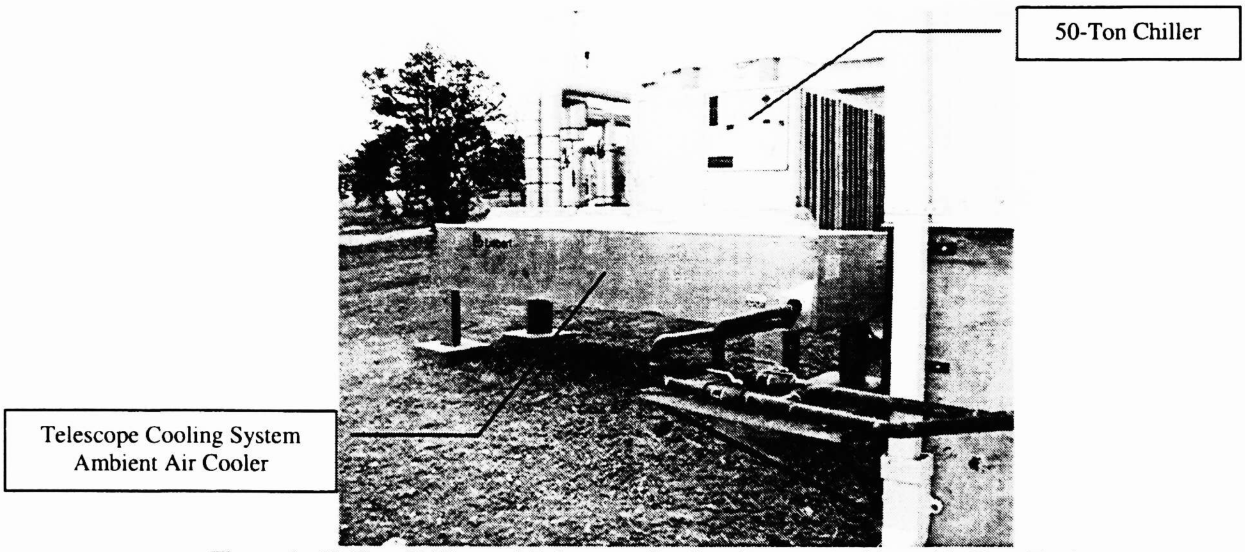

Figure 9: 50-Ton Chiller and Telescope Cooling System Ambient Air Heat Exchanger

The chilled water is circulated to two air handlers on opposite sides of the enclosure. One air handler is shown in Figure 10. The air handler supply fans deliver an airflow rate of 8250 cubic feet per minute (234 cubic meters per minute) each. Each air handler has a return fan with the same airflow capacity as the respective supply fan. The air handlers are a draw-through type. This means the fan is on the air outlet side of the cooling coil. The 5-horsepower (3.7-kilowatt) motors that drive the supply fans are located in the air stream. The return air fan motors are not in the air stream. Each air handler is capable of operating between 100% re-circulation and 100% outside airflow by adjustable dampers. Each air handler has filters on the inlet side of the coils to remove dust and dirt.

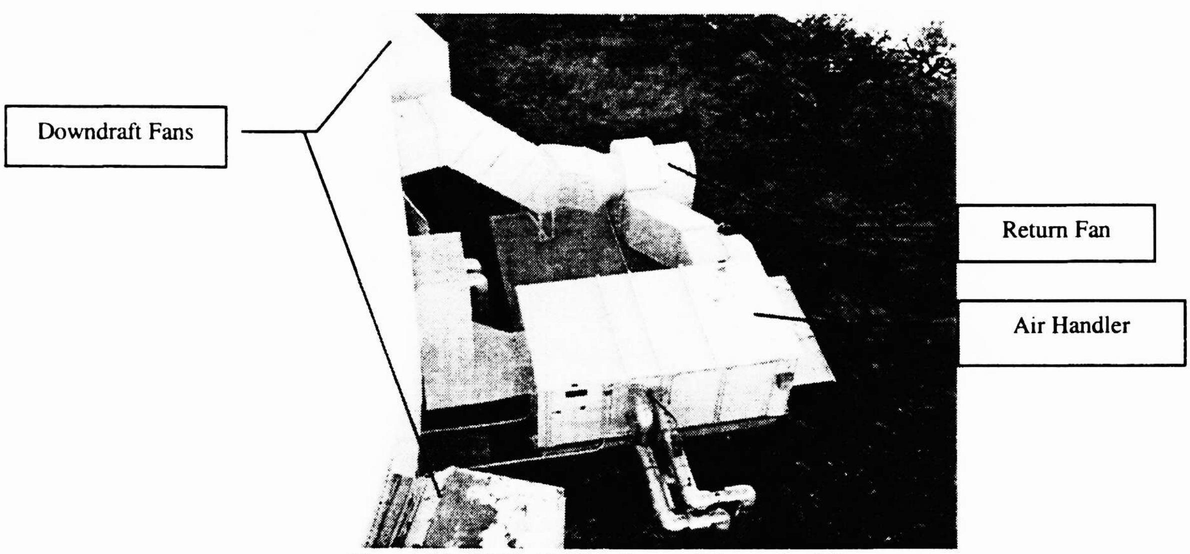

Figure 10: HET Air Handler and Downdraft Fans

As shown in Figure 11, there are five dampers in the top of the dome that allow ventilation of the dome. These dampers are called the dome vent dampers. The dome vent dampers are typically open in the 100% outside air mode and during night-time operations.

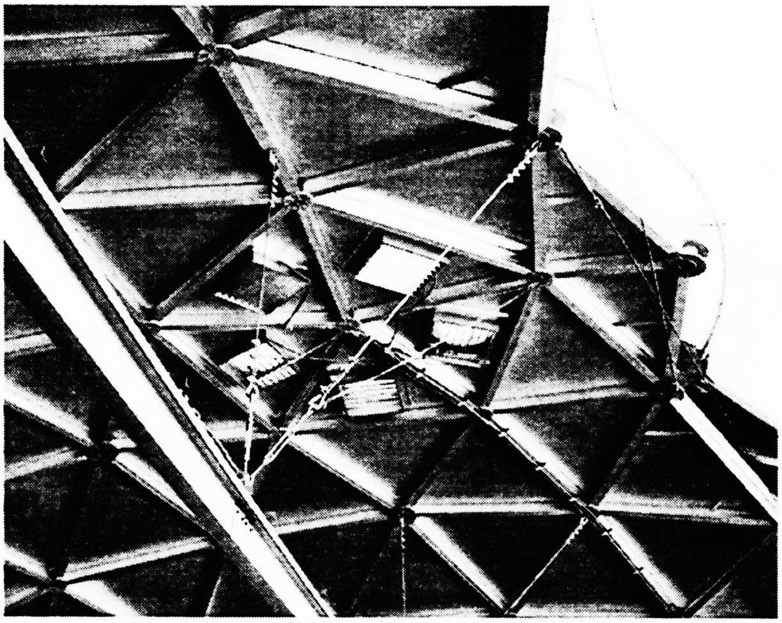

Figure 11: HET Dome Vents with Shutter Open

Installed in the enclosure wall are six downdraft fans and associated dampers. A single downdraft fan is shown in Figure 12. These fans have a measured airflow of approximately 14,500 cubic feet per minute (410 cubic meters per minute) each. When operated, these fans provide 12.2 air changes per hour for the enclosure. As mentioned above, the return fans for the air handlers have an airflow rate of 8250 cubic feet per minute (234 cubic meters). The return fans can be operated in conjunction with the downdraft fans for dome flushing. When the return fans are operated in conjunction with the downdraft fans, the total airflow is 103,000 cubic feet per minute (2916 cubic meters per minute). The air change rate in this mode is 14.5 air changes per hour.

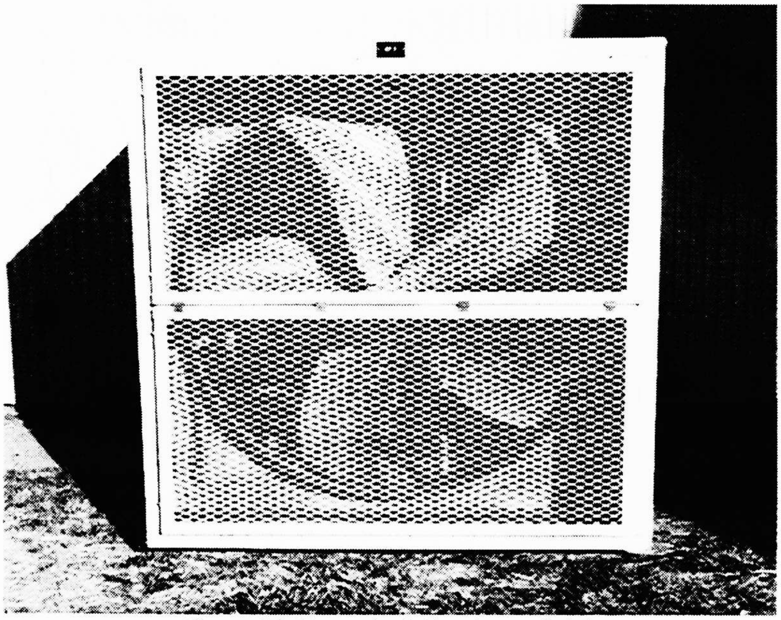

Figure 12: Downdraft Fan (one of six)

The thermal conditioning equipment with the exception of the dome vent dampers is controlled using a Metasys direct-digital control (DDC) system manufactured by Johnson Controls of Milwaukee, Wisconsin. Figure 13 shows a photograph of the control cabinet. Unfortunately, the DDC cabinet is presently installed in the telescope enclosure. To deal with the heat generated by this cabinet, an actively ventilated enclosure was built around it as shown in Figure 14. Plans are to relocate the DDC cabinet out of the telescope enclosure. This system uses a proportional-integral-differential control scheme. The controls system is operated from a facilities computer in the telescope control room. Inputs to the facilities computer can also be made using the telescope control system computer. The dome vent dampers are controlled from the dome control computer.

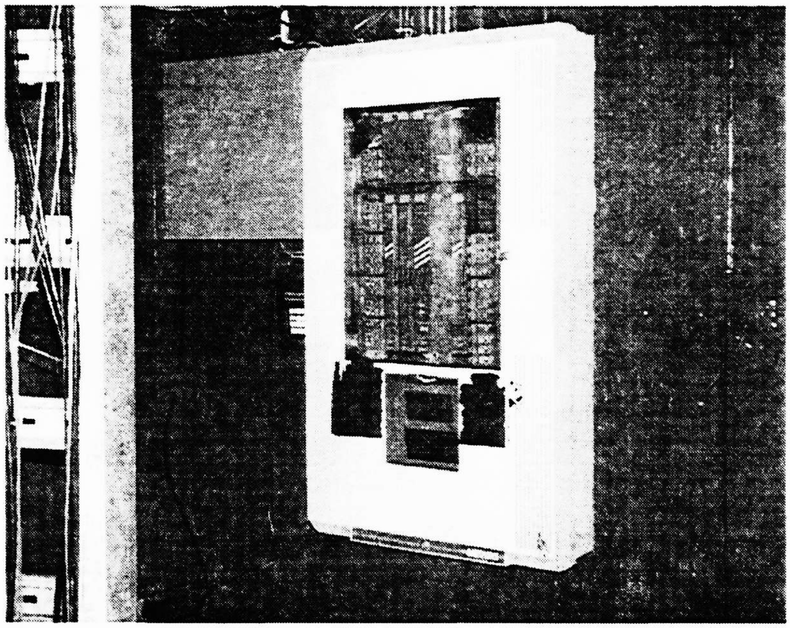
Figure 13: DDC System Control Cabinet (enclosure removed)

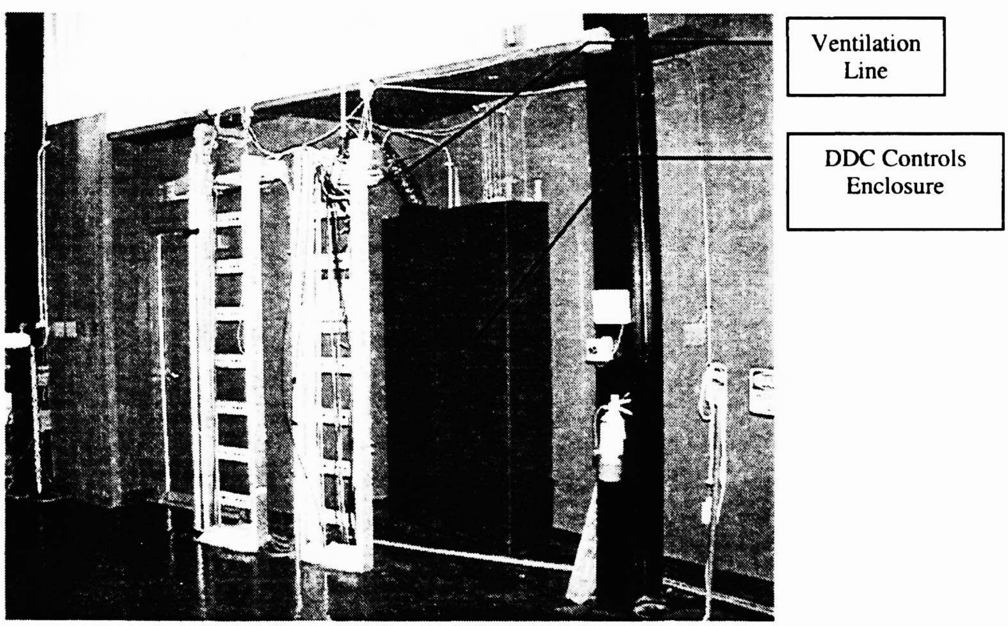

Figure 14: DDC Controls Enclosure

The final system used to condition the telescope is the Telescope Cooler System. This system uses an air-to-glycol heat exchanger shown in Figure 9, triplex plunger pump and glycol storage tank. Glycol is pumped from the storage tank to the telescope drive motors and electronics box heat exchangers. The glycol is then delivered to the air-to-glycol heat exchanger and returned to the storage tank via a filter. This system is not effective in preconditioning the telescope or enclosure; however, it does remove heat generated by the 10 drive motors and several electronics boxes mounted on the telescope.

3. PAST AND PRESENT THERMAL CONDITIONING TECHNIQUES

3.1 Past thermal conditioning techniques

The original technique used to condition the telescope for night-time operations was to open the telescope shutter, start the downdraft fans and turn telescope and dome to the Center of Curvature Alignment System (CCAS) tower. Mirror alignment would then begin. This was ineffective. A quality stack, or mirror alignment, was not achieved until after the telescope reached thermal equilibrium, as driven by outside air temperature several hours after sunset.

To condition the telescope and its enclosure for opening time (sunset), an estimate of the night-time outside air temperature at sunset is required. Initially, McDonald staff forecasted temperatures at sunset; however, Accu-Weather of State College, Pennsylvania now provides sunset temperature forecasts for the HET. The HET uses two forecasts per day. The first forecast is made 8 hours before sunset, and the second forecast is made 4 hours before sunset. The accuracy of the forecast is pivotal in conditioning the telescope and enclosure for night-time opening. The forecasted sunset temperature is the temperature used as the control setpoint for the DDC system that controls the air handling units and chiller. During the 4-month period October 1999 to January 2000, the Accu-Weather forecasts differed from the measured ambient temperature on Mount Fowlkes, in the mean, by –0.6°F (-.33°C). The standard deviation of the Accu-Weather forecast error, over the same period, was 4.0°F (2.2°C). This is approximately twice the performance that Accu-Weather hopes to achieve, long-term.

The second method of conditioning the telescope was to start the air handlers upon receipt of the forecasted temperature 8 hours before sunset, and operate them in 100% re-circulation mode with the dome vents shut. In this mode, both the supply and return fans are running. The forecast temperature is set as the room temperature setpoint for the air handlers. The air handlers controlled to room temperature as measured by thermocouples mounted near the enclosure wall. After receipt of the forecasted temperature 4 hours before sunset, the control setpoint is adjusted. This method was marginally effective if the forecasted sunset temperature was accurate and the actual heat gain of the enclosure was less than the capacity of the chiller. Opening the dome vents to relieve the hot air in the top of the dome was ineffective. In this configuration, the telescope enclosure pressure is neutral with respect to outside air, ignoring wind effects. If the wind is greater than zero, there will be a driving pressure for infiltration of outside air into the enclosure.

The re-circulation mode of operation allowed the buildup of a hot air pocket in the top of the dome. As discussed above, the velocity and capacity of the supply air fans are insufficient to cause mixing of air in the top of the dome so that the heat could be removed by the air-conditioning system. The air handler supply air ducts are located at the bottom of the dome catwalk which is approximately 30-feet (9-meters) above the enclosure floor. The top of the dome is more than 60-feet (18.2-meters) above the air ducts. Simply opening the dome vents was not effective in eliminating the hot air collecting in the top of the dome.

3.2. Present thermal conditioning techniques

Some of the problems associated with the accuracy of the forecast for sunset outdoor temperature were mitigated by assigning a duty operations Engineer to monitor outside air temperature and to adjust the thermal conditioning equipment. Given the Accu-Weather forecast accuracy achieved to date, the interior/exterior temperature requires careful monitoring as dome opening time approaches. Adjustments are made based on operator experience, weather reports via the Internet and local weather station data. The HET local weather tower provides outdoor air temperature, average wind speed, maximum wind speed, wind direction, and relative humidity. The aforementioned data is averaged over five minutes and displayed in the control room.

If the forecast is sufficiently inaccurate and adjustments to the thermal conditioning equipment cannot compensate, the following technique is used. The dome shutter is opened into the wind, the downdraft fans started, and the chiller and air handlers turned off. The return fans may also be started to increase the air change rate in the enclosure. Additional airflow is attained by opening a set of 10-feet (3 meter) by 12-feet (3.65 meter) garage doors (in series). Approximately 3600 cubic feet per minute (102 cubic meters per minute) of airflow is attained through the garage doors with wind speed at 10 miles per hour (16 kph). Outside air is flushed through the dome until stable thermal conditions are achieved. Stacking of the primary mirror could then begin.

The main component requiring thermal conditioning is the primary mirror truss. Therefore, the key parameter that should control the air handlers is the temperature of the primary mirror truss. Thermal effects on the truss or the truss behavior with changes in temperature are what causes stacking difficulties. The previous methods discussed above used room temperature thermocouples located near the enclosure wall to control the air handlers. The HET staff changed the system to use thermocouples located in the primary mirror truss to control the air handlers. With this change, the system is controlled by the parameter of interest. The result of the change is better control of the air handlers. Before this change, one air handler could be delivering warm air while the other is delivering cold air. This change, along with some software changes, eliminated this condition.

Both operating experience and calculations show that the heat gain of the telescope enclosure can exceed the capacity of the chiller and air handlers. Additionally, it should be noted that mechanical cooling equipment is limited as to the lowest temperature to which it can condition an enclosure regardless of equipment capacity. In the case of the HET, the normal chilled water setpoint is 20°F with a temperature trip setpoint of 16°F. Therefore, if the forecasted opening temperature is near or less than 20°F, the mechanical cooling equipment installed will not be effective in conditioning the enclosure. Under these conditions, the only option is to flush the enclosure with outside air.

Experience shows that a hot air pocket collects in the top of the dome during the day when the system is operated in re-circulation mode. Simply opening the dome vent louvers is ineffective at expelling the hot air.

To combat these conditions, the operation of the air handlers was modified as follows. The air handlers are configured for 100% outside air and the return fans turned off. This configuration positively pressurizes the enclosure and is very effective in expelling the hot air pocket in the top of the dome when the dome vents are open. The air handlers can expel the hot air in the top of the dome in approximately 26 minutes. The enclosure, in this configuration, is at a positive pressure relative to outside air. The advantage to this configuration is that a portion of the enclosure heat gain does not have to be removed by the air handlers and chiller. The limiting factor, however, to this configuration is the amount of energy that must be removed from outside air to cool the enclosure in addition to the enclosure heat gain that remains to be removed. While better than previous methods, the capacity of the air handlers and chiller can be overwhelmed by the enclosure heat gain. Calculations in accordance with References 4 and 5 show that the peak heat gain for the telescope enclosure can exceed 130-tons (457 kilowatts). Therefore, under the conditions where enclosure heat gain exceeds chiller capacity, a manual modulation mode is used. The air handler configuration is varied between re-circulation and outside air modes. Finally, if it becomes evident that the thermal conditioning equipment is not going to achieve a satisfactory opening temperature for the primary mirror truss, the shutter is pointed into the wind and the enclosure flushing method discussed above is used. Plans include slowing the return fans to provide positive enclosure pressurization in all modes of operation and remote control of individual dampers on the air handlers.

The chilled water supply temperature can be as low as 16°F (-9°C). The normal chilled water setpoint is 20°F. When outside air conditions are cold and relative humidity exceeds 90%, the air handlers and chiller are shut down to prevent ice build up on the cooling coil. Ice build up could damage the cooling coils and reduces airflow into the enclosure. This condition only occurs in wintertime, and the flushing method discussed above is again employed to achieve a satisfactory truss temperature for stacking the primary mirror.

4. EVALUATION OF THERMAL CONDITIONING PERFORMANCE BASED ON 10-MICRON CAMERA SURVEY

4.1 Instrument and instrument configuration

The 10-micron camera used for the aforementioned survey was loaned to the McDonald Observatory by the National Optical Astronomy Observatories (NOAO) at Kitt Peak. The camera is an AGEMA Thermavision 400-A8, software version 4.08. The camera is liquid nitrogen cooled. A video recorder documents the observations. The camera has an isothermal mode and a "spot" mode. In the spot mode, a crosshair appears on the screen. The temperature of the spot within the crosshair is displayed on the camera output screen. While the HET found the correlation between measured temperature and the temperature indicated in the spot to be within 1°F, the strength of the camera is in the measurement of differential temperatures (i.e., it effectively measures thermal contrast.)

4.2 Procedure

The camera was set up before each survey in accordance with the manufacturer's specifications and set to function in the "spot" mode. The temperature of the air discharge from the air conditioning ducts in the enclosure is known to within 1°F. The air temperature at the wall of the enclosure is known to comparable accuracy. The camera, in the spot mode, would be trained to the wall and ambient temperature set on the camera to correspond to the measured ambient temperature of the enclosure wall. The camera would then be trained to the air conditioning duct discharge to measure the air discharge temperature. This would be compared to the measured air discharge temperature of the air conditioning system. The temperature measured by the camera was within 2°F of the temperature reported by the air conditioning system. Observations were made on four separate nights covering the beginning of operations, i.e., during mirror alignment shortly after sunset, and after several hours of science operations during trajectories, i.e., during science operations between midnight and 0200 hours in the morning.

4.3 Results

The survey results indicate that the enclosure was well conditioned at opening if the forecast was accurate. The conditioning of the enclosure degraded during the night as outside air temperature dropped. The fluorescent lights were observed to be 32°F above ambient shortly after opening. The time required for the lights to cool to ambient temperature is between two and three hours. Operating procedures now include turning off these lights several hours before opening. The mirror truss air mixing fans (two are shown in Figure 15) were also 32°F above ambient. The telescope truss always appeared to be isothermal. Depending on the rate of outside air temperature decrease or increase, the truss was at outside air temperature. There are six air-mixing fans installed below and in the mirror truss. These fans were installed as a test of the concept and utility of such fans. The utility of these fans is still under consideration. The ambient air receiving area garage door and adjacent wall become a significant source of heat influx into the enclosure. The wall around the garage door and the door were at ambient temperature on the surveys conducted shortly after opening; however, later in the night this area was recorded to be 13°F above ambient. Additional results are as follows: Shutter control FM modem power, 10.3°F; Upper electrical room cable tray penetration, 9°F; Power cables at lower X, 8°F; Dome drive controller, 7°F; Electronics Bay Enclosure below Primary Mirror, 4°F; Downdraft fan variable frequency drives, 5°F; Dome drive motors, 5°F; Shutter Drive controller, 2.5°F; Overhead Crane, 2.3°F; Pier, 2°F; Base of columns, 1.8°F; Enclosure Walls, 0°F; Fiber instrument feed electronics box, -2.5°F.

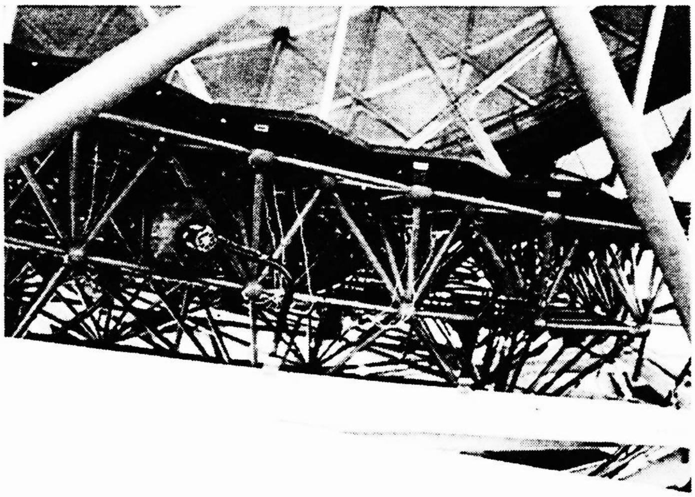

Figure 15: Mirror Truss Air Mixing Fans

Reduction and analysis of this initial 10-micron camera survey is continuing. An engineering plan is being drafted to improve the thermal conditioning of the HET enclosure and to eliminate all heat sources in the telescope enclosure. Our goal is the elimination of all significant sources by January 1, 2001.

5.0 CONCLUSIONS

As discussed in Section 3, occasionally the HET's installed thermal conditioning equipment capacity is exceeded by the enclosure heat gain. Therefore, it is concluded that careful consideration during design and construction is required to achieve optimum thermal conditioning capability for a telescope and enclosure. Equipment must be adequately sized by performing heat gain calculations, determining air flushing requirements and eliminating heat generating equipment from the enclosure to the greatest extent possible. Further, the thermal conditioning equipment must have a sufficiently flexible controls system to allow operations personnel to establish the operating modes suitable for achieving optimum thermal conditioning of the enclosure based on existing weather conditions.

The ability to positively pressurize the enclosure is an essential element in thermally conditioning the enclosure. A positive pressure in the enclosure not only provides a means of expelling heated air in the top of the enclosure, but also aids in maintaining the cleanliness of the optical surfaces by keeping dust out of the enclosure.

Night-time opening temperatures in the winter can be and have been lower than the ability of the HET mechanical cooling equipment to achieve. This would be true regardless of capacity. The HET's installed equipment can provide over 16,000 cubic feet per minute of conditioned air at 20°F (-7°C). Therefore, the lowest temperature achievable in the telescope enclosure is greater than 20°F. When this condition occurs, the remaining option is to flush the enclosure with outside air until the desired thermal conditions are met. This requires the ability to move a large airflow through the enclosure using natural or mechanical means.

ACKNOWLEDGEMENTS

We are grateful to George Jacoby and John Glaspey of the National Optical Astronomy Observatories (NOAO) at Kitt Peak, Tucson, Arizona USA for the loan of the 10-micron camera, and to Charles Carson who trained M^cDonald personnel to operate the camera.

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