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The Hobby-Eberly Telescope Natural Ventilation System Upgrade

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ABSTRACT

The Hobby-Eberly Telescope (HET) enclosure is receiving a series of modifications to improve dome seeing, including removal of residual heat loads from the optical path, increased insulation of the enclosure, and ventilation of the enclosure ring wall and dome. Analysis indicates that the contribution of dome seeing with the new system will be less than 0.05 arc seconds. The design of the HET enclosure lends itself to very large ventilation openings in the stationary portion of the enclosure also referred to as the "ring wall", with supplementary openings in the rotating dome. The ventilation design implemented has opened approximately 58% of the ring wall, and will open 8% of the dome, in the coming year, in order to achieve natural ventilation of 22 air changes per hour at the minimum design wind velocity of 3.5 mph. A system of ventilation louvers similar in design to the Kitt Peak Observatories 4-meter telescope was determined to be the most practical and cost effective design for use in the ring wall. Conventional off-the-shelf louvers are proposed for the dome, due to constraints in its design. Special considerations for retrofitting an operating facility included a custom hoist mounted on the dome for installation of the louvers (5000lb./ea.), and an inflatable curtain to protect the telescope during foul weather. The ring wall ventilation system has been in full operation since early April 2002 and is part of a program in progress to substantially improve the HET dome seeing.

Keywords: Hobby-Eberly Telescope, dome ventilation, dome seeing, telescope enclosure

1. INTRODUCTION

The HET is a 9.2-meter pupil segmented mirror telescope, which is fixed in declination at 35° from zenith. The telescope is positioned in azimuth on the sky and remains stationary during an observation. Tracking is performed at the secondary where the focus from the spherical primary roves about a region approximately 13 meters above the primary mirror surface. The HET enclosure (Fig. 1) is a 26.2 meter 5/8 spherical dome rotating on a 24.4-meter diameter stationary ring wall. The ring wall extends 9.26 meters above the floor of the HET.

The HET enclosure was originally designed for forced ventilation by means of 6 ventilation fans distributed radially around the ring wall. Due to a number of factors including high active heat loads in the optical path, poorer than expected fan performance (12 changes per hour instead of 20), and the lack of dome insulation, dome seeing was determined to be unacceptably high. This was conclusively demonstrated by interferometric images taken from the center of curvature alignment system (CCAS), and infrared imaging of the enclosure interior. While consideration was given to upgrading fan performance, analysis indicated that air flushing velocities necessary to maintain the structure/primary mirror temperature within 0.4C of ambient, or less, could not be generated by fan systems of reasonable size. This was especially true considering an ambient temperature drop of 1° C/hr, typical at McDonald as well as the active heat loads present in the optical path.

In response a team was formed to assess the HET enclosure thermal requirements and determine their priority. M3 Engineering and Technology, Inc., Tucson, AZ, was hired as an engineering consultant to perform a feasibility study for natural ventilation louvers. As a result the HET is receiving a series of

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modifications to improve dome seeing, including removal of residual heat loads from the tracking secondary, the addition of insulation and low emmissivity coatings to the dome, and ventilation of the enclosure ring wall and dome. The ring wall ventilation system (RWVS), determined to have a significant impact on dome seeing, and be the most expensive and difficult to implement, has been undertaken first, and is the principal subject of this paper. The remainder of the modifications will be implemented in the coming year. Radiative cooling of the dome presents a particularly significant impact on the interior seeing. However, the addition of insulation greatly complicates the installation of dome vents and thus, will be implemented immediately following their installation.

Figure 1: Western view of HET Enclosure with Ring Wall louvers and view of louver hoist.

The RWVS was fully implemented in less than one year, from June 2001, when the detailed design was initiated, to May 2002, when the project was completed. As work progressed, louvers were put into operation as they were installed, beginning in February 2002, and noticeable improvements in the image quality were noted immediately (Ref. 1).

The ventilation design implemented opens approximately 58% of the ring wall, in order to achieve natural ventilation of 22 air changes per hour at the minimum design wind velocity of 3.5 mph. The next phase of enclosure ventilation will open approximately 8% of the dome. Ventilation louvers on the ring wall promote thermal equilibrium of the primary mirror and concrete pier, while louvers in the dome will supply flushing winds at the level of the tracker/secondary assembly located at the top of the telescope structure. Insulation and recoating of the dome will minimize radiative cooling and greatly increase the efficiency of air-conditioning during the day. In addition, as part of the overall thermal management strategy, problematic active and passive heat loads interior and exterior to the enclosure will be enclosed and ducted to an Eastward location about 100 meters from the facility.

2. THERMAL ANALYSIS

While the dome currently has no insulation and is quite inefficient, the cooling capacity of the HVAC system is able to cool the interior to the evening opening temperature with minimal stratification. This performance will only be enhanced by dome insulation. Therefore, for the purposes of analysis, the passive

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elements of the enclosure are assumed to be at steady state from the beginning of the night under most circumstances. The typical nighttime thermal gradient at the HET is 1° C/hour.

Sources of passive heat inside the enclosure deliver a total heat load of 24,700 Watts, and include the following sources:

1. An insulated concrete floor.
2. The concrete telescope pier.
3. The ring wall structural steel.
4. The insulated ring wall skin.
5. HET structure.
6. HET Tracker steel.
7. HET Primary and truss.

Sources of active heat inside the enclosure deliver a total heat load of 3000 Watts, and include:

1. Tracker drive electronics.
2. Primary mirror segment drive electronics.
3. Structure azimuth drive.
4. 80 ft. hydraulic man-lift.

Active heat loads will be removed by means of cooling jackets and ducted enclosures, in subsequent efforts. Thus, the total heat load inside the enclosure excluding cooling by the dome and active heat sources is 24,700 Watts. The internal volume of the enclosure is $13{,}520 m^3$. The cooling capacity for the ambient air at 2000 meters elevation is 1kw/°C per $1 m^3$/sec. The maximum desired temperature differential from ambient air is 0.4°C, in order to limit the dome seeing contribution to 0.05 arcsec (Ref. 2). If the assumption is made that the air is uniformly heated as it passes through the enclosure the heat flow is given by;

$$P_v = C_a \Delta T \, dV/dt$$

Thus the airflow required is, $dV/dt = 61.75 m^3/sec$, and the number of enclosure air changes per hour is 16.4, or one air change every 3.65 minutes. Our chosen minimum wind velocity (see Ref. 3) is 1.56 m/sec (3.5 mph), so the required opening to supply 61.75 cubic meters/sec is 39.5 m^2. Flow studies of Siegmund (Ref. 4) demonstrate that natural ventilation only enters dome vents which face +/-30° from the incoming wind, thus the total vent area required in the building to make up for this inefficiency is 237 m^2, and the panel size per section in the building should be 14.8 m^2 (a clear opening of 3.85 m x 3.85 m).

Clearly the assumption that all ambient air entering the enclosure is evenly heated before exiting the enclosure is inaccurate, thus it is important to substantially exceed this theoretical value by maximizing the ventilation openings and further minimize all heat loads. Since the geometry of the ring wall lends itself to larger openings, the panel size was chosen to fill the distance between support columns in the ring wall (4.75 meters) and to increase the vertical dimension as far as practical without introducing boundary layer air into the interior. To this effect the ventilation panels were sized to be 4.5m wide x 5.4m high, producing a panel area of about 20 m^2 (accounting for loss of area due to framing and open panels) or about 35% greater than the area calculated as necessary to hold the temperature differential to 0.4° C, and the dome seeing contribution to 0.05 arcsec. The result is 22 air changes per hour at the minimum wind velocity of 1.56 m/sec.

3. LOUVER SYSTEM DESIGN

The HET benefited greatly from the many ventilation designs implemented and proven at other Observatories, and primarily those at the Kitt Peak National Observatory (KPNO), whose elevation (~2000 meters) and climatic profile are very similar to that at The McDonald Observatory. The KPNO 4-meter enclosure ventilation design was found to be the best combination of economic design, effective aperture, weather tightness, and adaptability to the HET ring wall.

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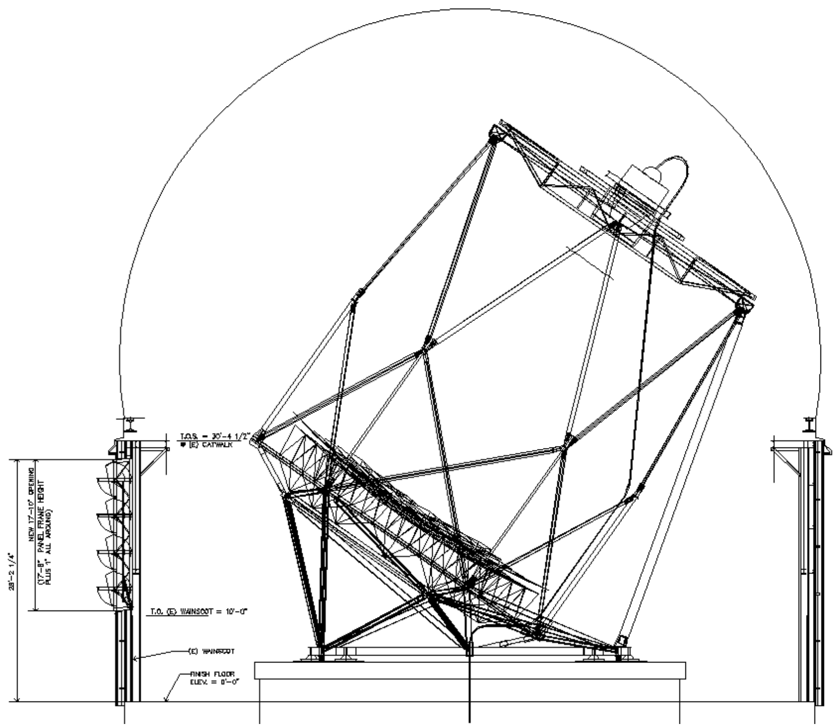

Figure 2: Sectional view of the HET enclosure with new louvers on left side and original wall on the right.

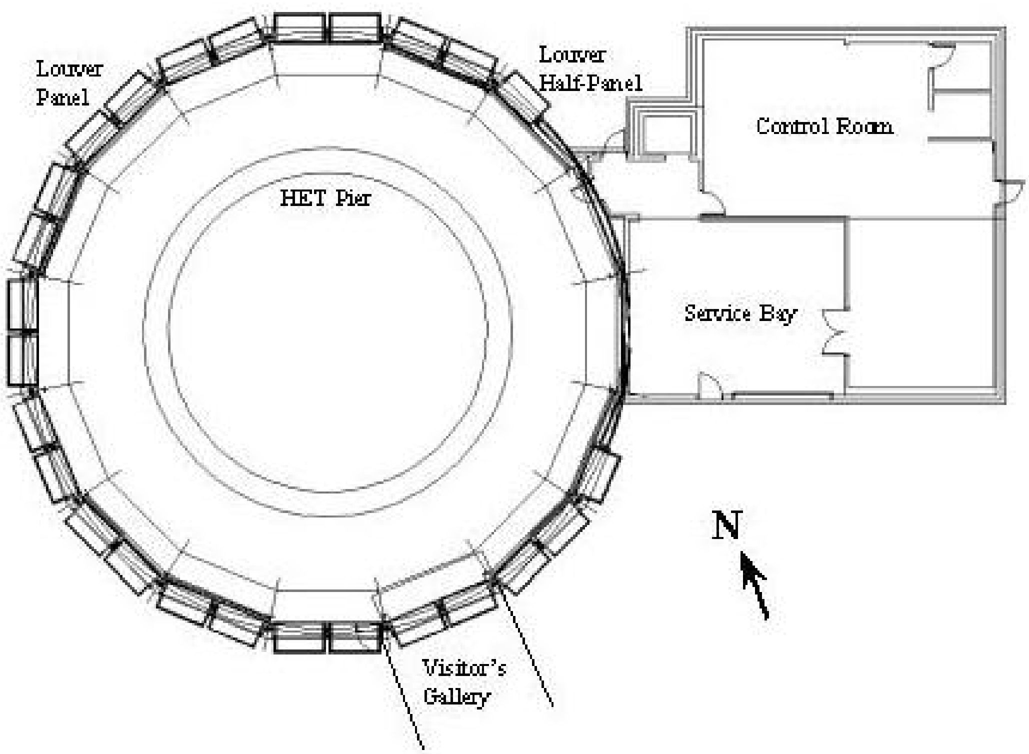

Figure 3: Plan view of HET enclosure with location of new louvers.

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The HET enclosure ring wall is segmented into 16 sections. The Control and Service Building occupies 2 of these sections to the East-Southeast (Fig. 2 and 3) of the enclosure to minimize thermal impact due to prevailing winds (predominately from the Southwest). A visitors viewing gallery occupies an additional section to the South, however room is available above this facility for ventilation openings. A large garage door opening (3 meters x 3 meters) between the enclosure and the Control & Service Building service bay can be opened to allow exhaust air flow from vents on the opposite side, but is not useful for air entry. Thus approximately 330° of the stationary portion of the enclosure can be opened to take advantage of most of the usable prevailing winds occurring over 300° from the Southeast, clockwise to the Northeast. The remaining blocked winds are typically not open dome conditions for the McDonald site.

Due to interface issues with the walls of the Control & Service Building, louvers could not economically be installed to fill all possible space on the ring wall. Therefore, 12 full louver panels, and 2 half panels were installed. In order to standardize the size of individual louver doors, and to ease shipping, the louver panels were manufactured in half panels and then bolted together prior to installation. The overall dimensions of the louver panel (two half panels assembled) are 4.78 meters wide by 5.38 meters tall. Each half panel contains four louver doors, 2.08 meters wide by 1.22 meters high. Thus the actual vented area of the ring wall is 264.1 m^2.

The horizontally pivoting doors of the louvers are mounted in a steel frame with about 6.4 mm clearance around the edges. This gap is sealed by a continuous bronze spring strip, which is available commercially. A hood is mounted around each louver door to complete the seal. Since there was no impact on the structural integrity of the ring wall due to removal of the wall material, the steel frame (Fig. 4) of the louver module was sized only to resist the maximum survival wind loading of 53 m/sec (120mph), and resist sagging under its own weight.

The control system for the louvers is manually switched with a master control for simultaneous control of all the louvers, or individual switches for selective actuation of selected sections of the enclosure. The time required to fully open/close the louvers is about 10 sec. The drives (Fig. 5) used are electrically driven screw actuators (Duff-Norton®), which exert 1500 lb of force on eight louver panels. A system of die springs interposed between the drive link and the louver panels allows an even distribution of force from the drive train to each panel, in order to avoid binding.

Figure 4: Interior view of louver structure.

Figure 5: Detail of louver drive mechanism.

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4. LOGISTICS & INSTALLATION

The RWVS project was placed on a very aggressive schedule and budgetary requirement. Development of large projects in a remote location such as McDonald (3.5 hours from major population centers and the nearest Home Depot®) has historically resulted in bid prices of 1.5 to 3 times projected costs. Contractors, wary of being held to a fixed price, and facing risks and requirements unique to an Observatory often pad the bid to insure against losses. Those that don't often have hidden problems and cost cutting solutions that only become apparent after they have been accepted as the "low bidder". Further compounding the risk to anyone considering the job was the liability inherent in remodeling a building surrounding a multi-million dollar instrument, the unpredictable nature of the weather, and difficult access to major portions of the building. The substantial time delays resulting from an unsuccessful bid process were unacceptable, and "value engineering", by reducing the scope of the project in order to save money, was not an option. Therefore, a significant management achievement of the project was convincing a justifiably wary administration that the Observatory had the necessary manpower, skill and time to do the job in-house. Complete control of the project allowed us to fully accommodate HET operations, divert installation crews to their normal duties at the Observatory in the event of poor weather, and have critical control over the performance of contractors fabricating the louvers and weather flashings. It also allowed the implementation of unique and cost saving solutions to problems that would likely not be available to outside contractors. Examples include the mounting of a custom crane on the dome and the design and use of a quickly deployable and inflatable weather curtain.

To minimize the skill level and time required during installation the louvers were designed as a self-contained appliance, complete with drives, and ready to use once welded into place. Reasonable tolerances were established for the positioning of louver modules and minor errors in positioning and wall removal were mitigated by the generous overlap of weatherproof flashings. Also key to the installation effort was the rental of two man-lifts, one of which was significantly oversized, to allow safe access from firm level ground.

4.1 HVAC DUCTING MODIFICATIONS

Original construction of the enclosure included a circular air conditioning manifold, which evenly distributed air near the top of the ring wall. Installation of the new ventilation system required accepting the ducting as an obstruction (about 8% of the ventilated area), or modifying it to function below the new openings. An additional problem with the ducting concerned stratification in the dome. While the cooling capacity of the HVAC system is well within the requirements for the interior, heat build-up in the upper elevations of the dome was contributing to the seeing problem. While the lack of insulation greatly exacerbated this problem, the original ducting system was clearly failing to evenly distribute air. One option, also borrowed from the KPNO 4-meter, was to install an upward directed fan on the enclosure floor to force air into the top of the dome. However, it was discovered that the same effect could be accomplished, removing the manifold and truncating the supply duct, which was already directed upward. The result was complete dispersal of the hot air bubble in the upper dome, a 125% increase in the flow rate of the air-handling unit, and the added benefit of complete removal of the obstruction to the new vents. The addition of mixing fans has since been determined to be unnecessary.

4.2 LOUVER HOIST

The louvers were manufactured in two sections for ease in shipping and handling on the site. Once positioned at the staging area by forklifts, an assembled set of louvers weighed 5000lb (2270kg), and thus required a crane for positioning. Access to the outer perimeter of the building is complicated by its close proximity to the edge of the mountain and the location of large equipment such as air handlers. Thus, if a crane was procured for lifting the louvers, it would have to be quite large to reach over the dome to extreme locations from firm level ground, and would add substantial cost to the project (quotations were received of $7000/week). For an installation period initially projected to last a minimum of 5 months the cost predicted was in excess of $150,000. Detailed analysis for the dome was available and it was determined

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that the shutter rail could safety support a hoist. Load testing was performed on the dome and it was determined that the hoist load would be only 25% of that seen by the structure when supporting the dome shutter.

Figure 6: The custom hoist permitted accurate and safe positioning of the louvers for installation.

Radial positioning of the louvers during installation was accomplished by rotating the dome (Fig. 6). Once the louver was positioned over the opening it was drawn into the building by means of "come-along" type hand winches. Shims were placed between the louvers and the columns to establish their position to specified tolerances. The louvers were lifted and installed in the open position to reduce the sail area, and minimize the effect of wind.

4.3 WEATHER CURTAIN

A key difficulty in the retrofit of louvers was accommodation of an operating facility and protection of the interior from precipitation and high winds once an opening was created. Estimates of the time required to prepare and install a louver were 3 to 4 days, and involved at least one over-night period in which a section of the exterior wall was completely removed. The timing of the project was also difficult since installation began in the peak of the winter season, and extended into the period of highest seasonal winds, some of which can reach 53 m/sec (120mph). Further compounding the problem was the difficulty in predicting when poor weather would occur. This necessitated a solution, which would cover the 5m x 4.5m opening, be easily and safety deployable in relatively high wind conditions, and resist high wind loading. Consideration was given to using a rigid plywood "lid", which would be lifted and held in place by the louver hoist. However, this option was considered unsafe to deploy and store due to the large sail area and significant weight.

The design implemented utilized a fiber reinforced vinyl curtain, which was sewn to a "cargo net" constructed of conventional seatbelt webbing (Fig7). The combination produced a very strong waterproof membrane. D-rings were sewn on the ends of the seatbelt webbing on all four edges of the curtain for anchoring to rollers and the ring wall exterior. Deployment of the weather curtain was accomplished by mounting it on a rail attached to the sheet metal remaining at the top edge of the opening. The original plan also called for a rail located along the bottom edge, however, this proved to induce a great deal of friction during deployment and was abandoned quickly.

Forces on the curtain were calculated to be substantial, since the entire surface could potentially encounter pressures of 2400N/m^2 (50lb/$ft^{2)}$. Since this force is transferred to the perimeter of the curtain, attachment to the sheet metal exterior by means of sheet metal screws would be completely inadequate. Thus a method had to be devised to convey this load into the structure of the building. This was accomplished by attaching an air bag (Fig. 8) to the back of the curtain, which when deployed over the open hole was inflated to

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equalize the pressure on both sides of the weather curtain. A system of straps attached to the columns and spanning the gap horizontally between them on either side of the opening, provided back up for the air bag. Once the curtain was inflated the outer membrane of the curtain experienced only minor forces, and the system proved to be quite stable (Fig. 9).

Figure 7: Weather curtain (back side) prior to mounting, showing cargo net sewn to vinyl curtain.

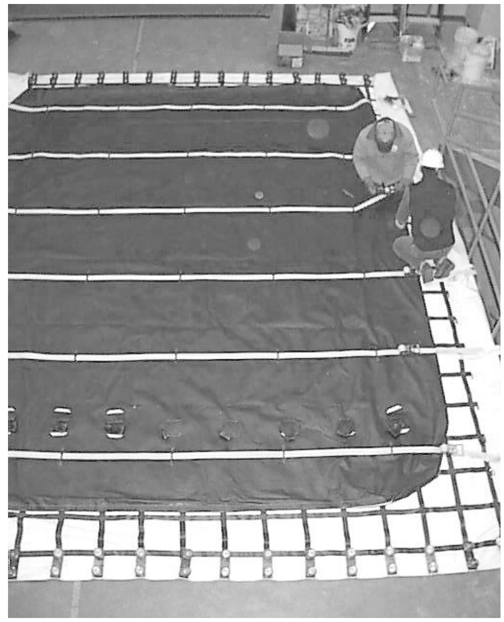

Figure 8: Weather curtain with air bag (deflated) and rigging.

Figure 9: Weather curtain in place over opening.

Figure 10: Wind damage from weather curtain while in stow position.

The weather curtain was important as a safety measure for the telescope and allowed the installation crew to take the necessary time to safety install the first louvers. Once experience was gained, however, the wall

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removal and installation sequence was refined to the point that both operations (wall removal & louver installation) could occur on the same day, making deployment of the curtain unnecessary. At one point the curtain became a liability while it was in its stow position and not being used in its designed mode. Figure 10 shows the damage to a louver just installed when the curtain came partially loose from its moorings in 83 mph (37 m/sec.) winds.

4.4 THE EFFECT OF WIND ON INSTALLATION

There was much concern for the safety of personnel, and the impact of wind loading on the installation operations. Whenever possible work was scheduled in the "wind shadow" of the dome, which allowed all construction operations in winds up to 13.5 m/sec (30 mph). Generally speaking, operations involving the removal or replacement of sheet metal required wind speeds less than 7.6 m/sec (15 mph). Louvers could be lifted into place in winds up to 8.0 m/sec (18 mph). Installation of weatherproof flashings was generally limited to wind speeds less than 5.4 m/sec (12 mph), due to their flexibility and sail area. Due to the fact that the wind speed increased as it flowed around the cylindrical wall, special care had to be taken in deploying the weather curtain to avoid waiting until winds got too high. Curtain deployment became unacceptably hazardous in winds over 11.2 m/sec (25 mph).

5.0 COSTS & SCHEDULE

The total project cost was about $450k. The cost of the louvers including shipping was $216k US, or about $3.33 US/lb of fabricated, painted and delivered steel (drives included). Weatherproof flashings cost about $20k US. The weather curtain cost was about $5k. The custom hoist and accompanying rigging was about $14k. Engineering/Design and consultation during the project was about $40k. Additional costs included rental of two man-lift platforms as well as tooling. Labor for the installation was by the McDonald Observatory Physical Plant.

Actual installation of the louver assemblies took 11 weeks including delays due to weather totaling 7 days. Fabrication of the louvers took 11 weeks from initial contract to final delivery.

6.0 CONCLUSIONS

Retrofit of louvers to the HET ring wall required careful planning to control costs and mitigate risk to the telescope. Procedures and techniques necessary in the beginning of the installation evolved or were abandoned as the job progressed, and the crew became more experienced and confident. The RWVS project is a significant step toward the reduction of dome seeing to the targeted budget of 0.05 arcsec. Subsequent steps will be taken in the coming year to greatly reduce cooling loads from the dome, active heat sources in and around the optical path of the HET, and passive heat flow from the basement. Booth, et al, (Ref. 1) describe the specific performance improvements of the HET as a result of this and other efforts aimed at bringing the HET to specified performance levels.

7.0 ACKNOWLEDGMENTS

The project is greatly indebted to the members of the Kitt Peak National Observatory, including Antony Abraham, for the fundamental design of the louver system and for his consultations regarding its adaptation to our enclosure. Similarly, we wish to thank C. F. Claver (NOAO), and C. P. Cavedoni (Gemini), for their experience and guidance in how to improve HET seeing. The project wishes to acknowledge the engineering expertise of Daniel Neff, of M3 Engineering and Technology, and the contribution of Hollywood special effects man, Steve Wolf, of Wolf Stunt Works, Inc., Austin, Texas, for his imaginative concepts on the weather curtain. The performance of The McDonald Observatory Physical Plant staff and HET operations personnel was key to the success of the installation of the louvers. The project installation team, completed the job 6 weeks ahead of the projected schedule, did a high quality job and most importantly, did it safely. We are grateful to The University of Texas Physical Plant Architectural & Engineering Services for their consultations and helpful insights. Also instrumental in the speed at which the project developed was The University of Texas Purchasing Department, who did much to expedite the

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purchasing contracts while maintaining a fair and open bidding process. A major key to the success of this project was the work of the two major fabrication shops, Industrial Fabrication and Machining (IFMI), of Waterloo, Iowa, (louver assemblies) and Oneto Metal Products Corporation, of Sacramento, CA (sheet metal flashings). Both contract shops exceeded project requirements and schedules, and made contributions to improve the design of the system. The ring wall ventilation project was funded largely by a private donation from Mr. and Mrs. Louis Beecherl. We are grateful for their generous support.

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