Conceptual design study of the GMT enclosure

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ABSTRACT

The Giant Magellan Telescope (GMT) is a collaborative effort between universities and research institutions to build a next-generation extremely large telescope for astronomical research at optical and infrared wavelengths. The GMT enclosure is cylindrical in shape and stands approximately 65 meters high. The telescope rotates independently of the enclosure down to a minimum elevation angle of 25°. This paper covers the decisions made during the conceptual design phase of the GMT enclosure, including an understanding of the facilities systems.

Keywords: Rotating Enclosure, Control Building

1. INTRODUCTION

Various enclosure concepts were considered during the initial phase of the project. The Carousel design shown in Figure 1 was selected for the GMT baseline. The shape of the structure is roughly cylindrical with vertical walls. Also considered were spherical domes (e.g. Keck), co-rotating cube enclosures (e.g. MMT, LBT), roll-off structures, and the calotte concept. The Carousel was chosen based on its (a) efficient use of structural material and insulated panels, (b) use of standard and universal construction techniques, (c) ease of implementing shutter and ventilation door concepts, and (d) the ability to accommodate an overhead crane which is necessary for servicing the off-axis primary mirror segments.

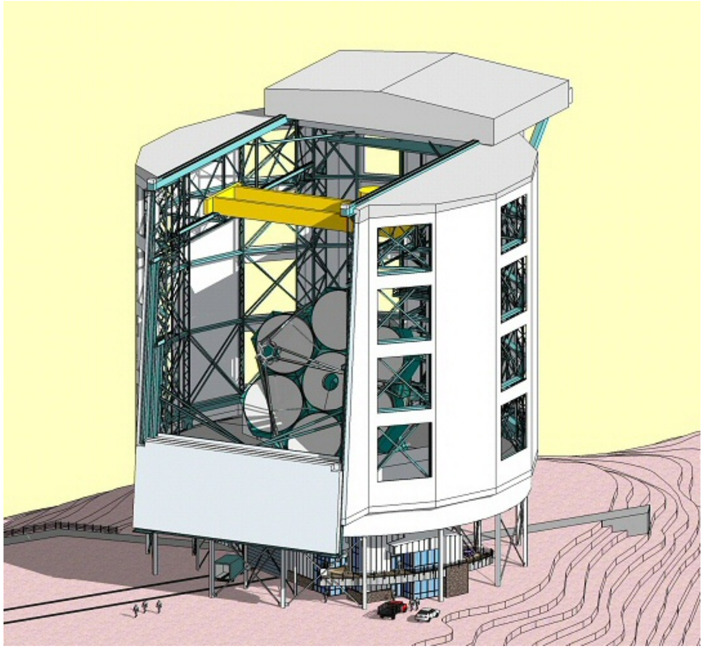

Fig. 1. Giant Magellan Telescope (GMT) Enclosure Concept

The baseline concept consists of:

- The stationary Enclosure Base structure that supports the Carousel rotation rails and the Observing Floor at a level even with the top of the telescope azimuth platform. Elevators and lifts in the base will provide equipment and personnel access to the Observing Floor and Mezzanine level below. Open structure at ground level allows air to flow below the Observing Floor and around the Pier to encourage the boundary layer to remain below the height of the shutters and vent opening.

- The Pier in the center of the base that supports the GMT but is mechanically decoupled from the enclosure. The center mirror assembly and Gregorian instruments will be serviced with a lift in the center of the Pier.

- The upper Carousel structure that rotates independently of the telescope. The telescoping main shutter doors open up to provide an unobstructed view down to a minimum specified telescope elevation angle of 25°. The doors will be partially deployed and tracked to shield the telescope from wind and stray moonlight during observing. Windows in the walls of the upper structure will provide roughly 25% open area for ventilation of the telescope chamber. A bridge crane mounted at the top of the Carousel will be used for telescope assembly and to remove the outer six primary mirror assemblies for mirror recoating.

- A Control Building located below the Observing Floor that communicates with the upper levels via an elevator and stairway but is otherwise thermally isolated from the Enclosure structure.

- A cart and rail system for transporting instruments between the Enclosure and Auxiliary Building for service. This will also be used for moving the primary mirrors during recoating.

2. SITE PLAN

For the purpose of the conceptual design, the baseline site is Las Campanas Peak located in the northern region of Chile approximately 160 km north of La Serena, Chile. The site is within Las Campanas Observatory owned by The Carnegie Institution of Washington.

The elevation of Las Campanas Peak is 2524 meters. Access to the site is currently provided by a dirt road that begins on the southern face of the mountain and ends at the northeast section of the proposed site.

The top of the mountain is to be excavated to 2516 meters altitude, providing a level platform with adequate space for the GMT enclosure, support facilities and a future possible second telescope.

Las Campanas Peak site characteristics determine the site layout of the enclosure and support facilities. The prevailing winds are generally from the north northeast with views of the mountains predominately to the north and east and Las Campanas Observatory to the west. The buildings are aligned along the mountain ridge with access to the buildings along the northern edge minimizing travel between the buildings. The orientation of the buildings is 90° from the prevailing winds and downwind of the observatory. (See Figures 2 and 3).

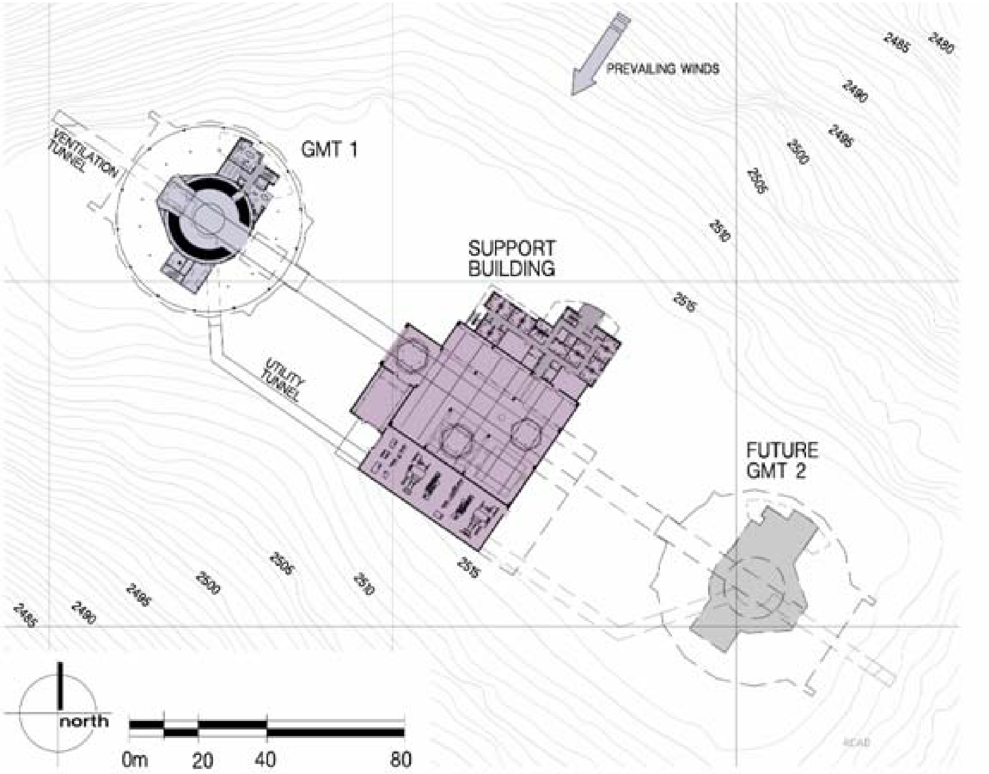

Fig. 2. Cerro Las Campanas with the GMT enclosure ("GMT1"), support buildings, and a possible future second telescope.

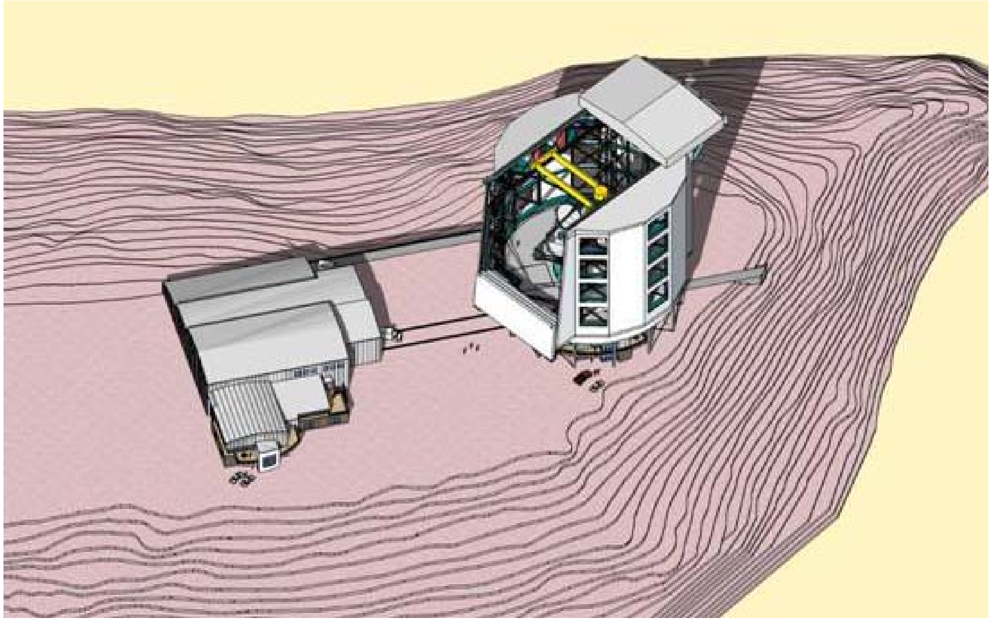

Fig. 3. Aerial view of the GMT Site

Fixed tracks connect the observatory and the auxiliary building allowing the primary mirror cell and instruments to be transported between the buildings on wheeled carts. The auxiliary building is centered and on-axis between GMT and any future telescope, connecting the three buildings in the future.

Along the southern edge of the site is a concrete utility tunnel going between the equipment building and the enclosure providing an accessible route for the utility lines. This maintains the primary heat-generating equipment away from the enclosure and downwind from the site.

3. LAYOUT AND FLOOR PLANS

The GMT Enclosure consists of three parts: the pier, the enclosure base and the rotating carousel.

Enclosure base

The enclosure base supports the rotating carousel and extends to the observing level located 14.72 m above finish grade elevation. A steel structure surrounds the telescope pier providing a thermal barrier and protection against wind buffeting. Adjacent and to the south of the pier is a utility chase, electrical room and emergency exit stairs from the observing level. (See Figure 4).

North-west of the telescope pier is the instrument staging area accessible from the pier. The fixed tracks extend into the space providing temporary storage and staging area for the mirror cart and instruments. The staging area's current function does not include instrument servicing, however it may be expanded for that purpose.

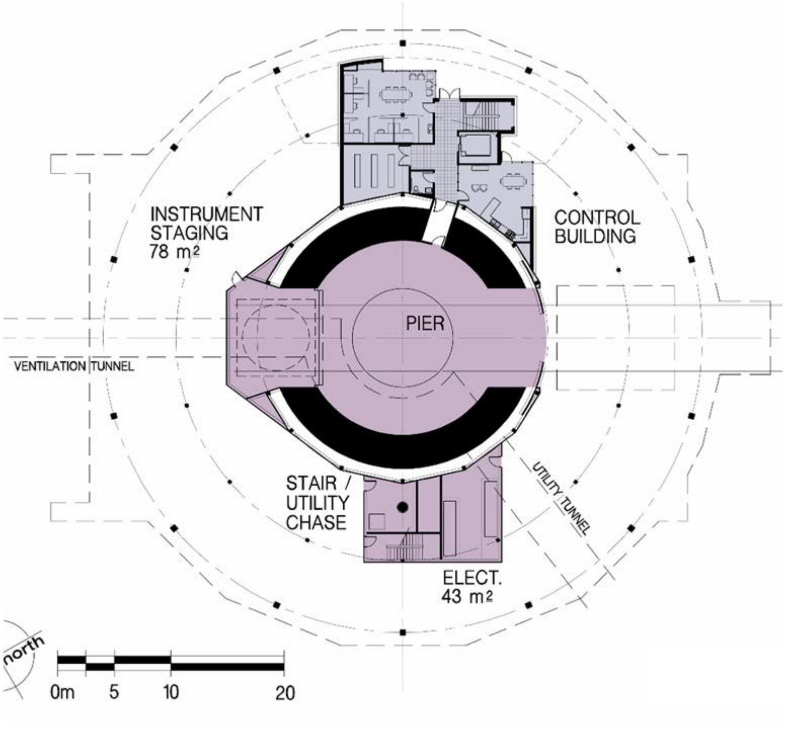

Fig. 4. Grade Level Plan

The lower level spaces are designed to minimize wind turbulence underneath the carousel. The instrument staging area that does extend from the pier in the cross-wind direction is kept small for that reason. The width of the utility chase and control building are within the pier diameter and in line with the prevailing wind.

The mezzanine level is at 11.0 meters above finish grade and is directly below the observatory floor. This space evolved during the conceptual design due to the depth of the steel structure required to support the rotating carousel above (See Figure 5). The structure is approximately 3.75 meters deep creating a shallow space that can be used for storage or as equipment space. At night it will be kept at the ambient outside temperature.

The total area of this level is undefined at this time. During the next phase of the design a study is needed to determine whether the added space below the observatory level creates any wind turbulence.

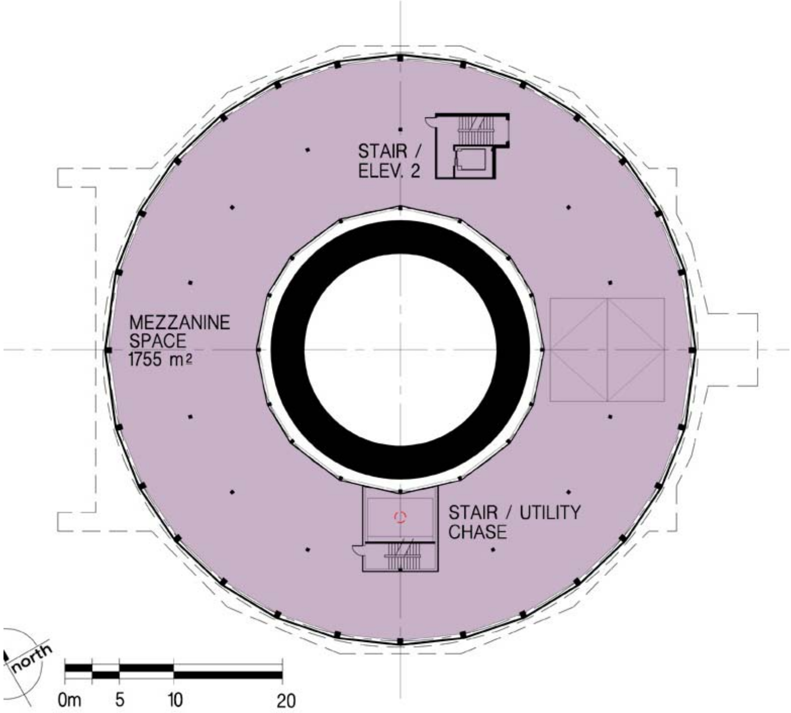

Fig. 5. Mezzanine Level Plan

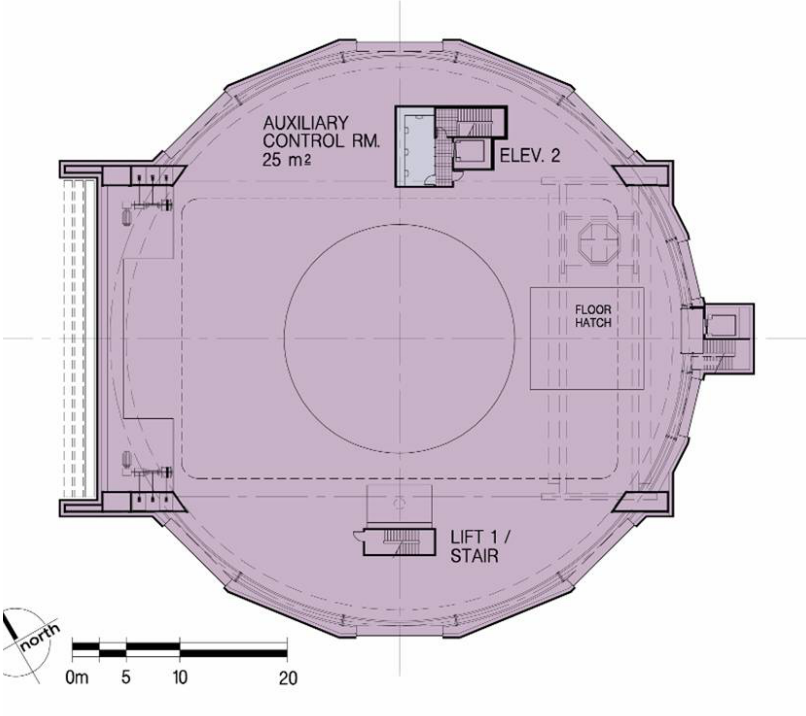

Fig. 6. Observing Level Plan

The observing level floor is at 14.72 meters above grade with the exterior, perimeter wall at 26.76 meter radius. This is the highest level of the lower fixed enclosure and the interface point with the rotating carousel. Located along the perimeter of the floor is a double rail for the rotating carousel and bogies and a circular seal. Service to the bogies and the seal is from the interior side at the observing level (See Figure 6).

The observing level flooring consists of steel plate decking with a floor loading of 1600 kg/m^2. The decking is insulated from below to prevent heat conduction from the lower levels.

Centered in the space is the telescope mount and rotating platform. The observing level is flush to the telescope platform and has a continuous seal along the perimeter edge. In line with the axis of the ground-level rails and the other buildings is a 9.5 meter by 10.5 meter hinged, bi-parting floor hatch flush with the observing level. All large instruments and equipment in the telescope chamber are hoisted through the floor hatch with a 100-ton capacity overhead bridge crane mounted on the rotating carousel.

Primary access to the observing level is via a stairwell and elevator (Elev. 2) from the control building directly below. The elevator is a 5000 lb. capacity, service type elevator for personnel and small instruments. A second stairwell is located on the opposite side of the observing level for emergency exit requirements.

Adjacent to the elevator is a 25 meter^2 auxiliary control room. This room is primarily used while servicing the telescope or preparing for the night's observing. It is not the main control room and it is not envisioned to be used during observing. This space is well insulated on all sides maintaining a thermal barrier to the telescope chamber and windows provide visibility to the telescope.

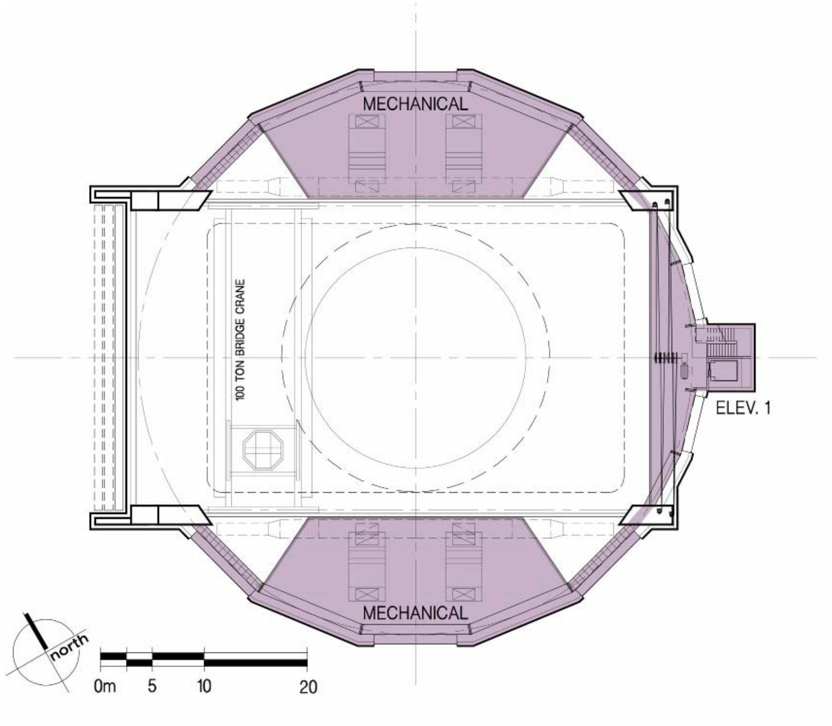

Fig. 7. Mechanical Level Floor Plan

Lift platform 1 (Lift 1) is located adjacent to the south stairwell and is used to lift instruments and equipment onto the telescope. It extends up to the level of the telescope Instrument Platform. The hydraulic lift is a 4-ton capacity with a 4 meter by 5 meter platform. The hydraulic piston extends below the observing level in a shaft adjacent to the stairwell. This lift can also extend down to the mezzanine level if the space remains in the next design phase.

4. CAROUSEL

The carousel is the upper rotating portion of the GMT enclosure and is centered on the azimuth axis of the telescope. The height of the carousel is approximately 60 meters above finish grade elevation to the upper shutter door rails and 65 meters to the top of the shutter (See Figure 8).

The carousel provides the telescope a 26.2 meter wide clear viewing path from 25° to 90° elevation angle. The telescope swing clearances are 2 meters minimum on the sides and 1 meter to the overhead bridge crane hook. The telescope elevation axis is 25.39 meters above grade. Openings through the carousel's exterior walls promote wind-forced ventilation of the inner structure and telescope chamber.

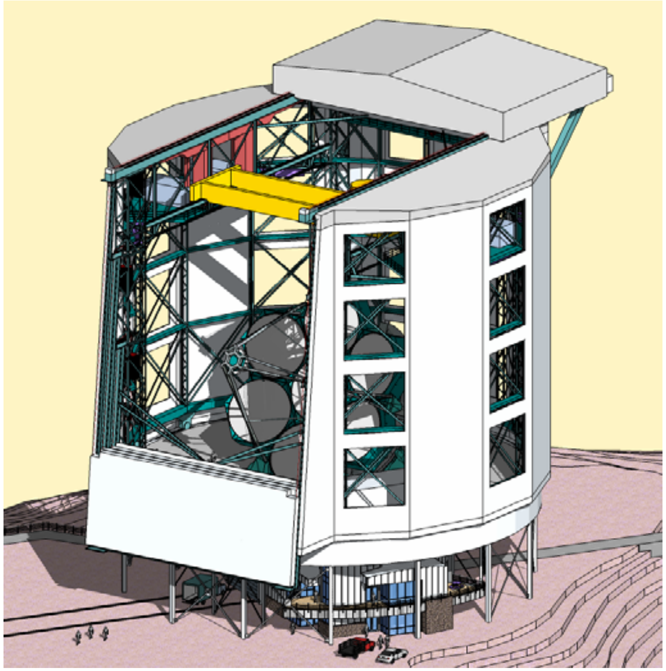

Fig. 8. Enclosure w/ shutter doors open, overhead crane deployed.

The carousel has unlimited range of travel in azimuth and rotates on 12 bogie assemblies and a double rail attached to the observing level. Mounted on the bogies is a circular ring-beam which supports the steel structure. At 54 meters above grade are the mechanical levels which house the upper shutter door drives and the HVAC equipment for the dome cooling system. The equipment platforms are on the back and sides of the carousel connected by catwalks.

4.1 Shutter Doors

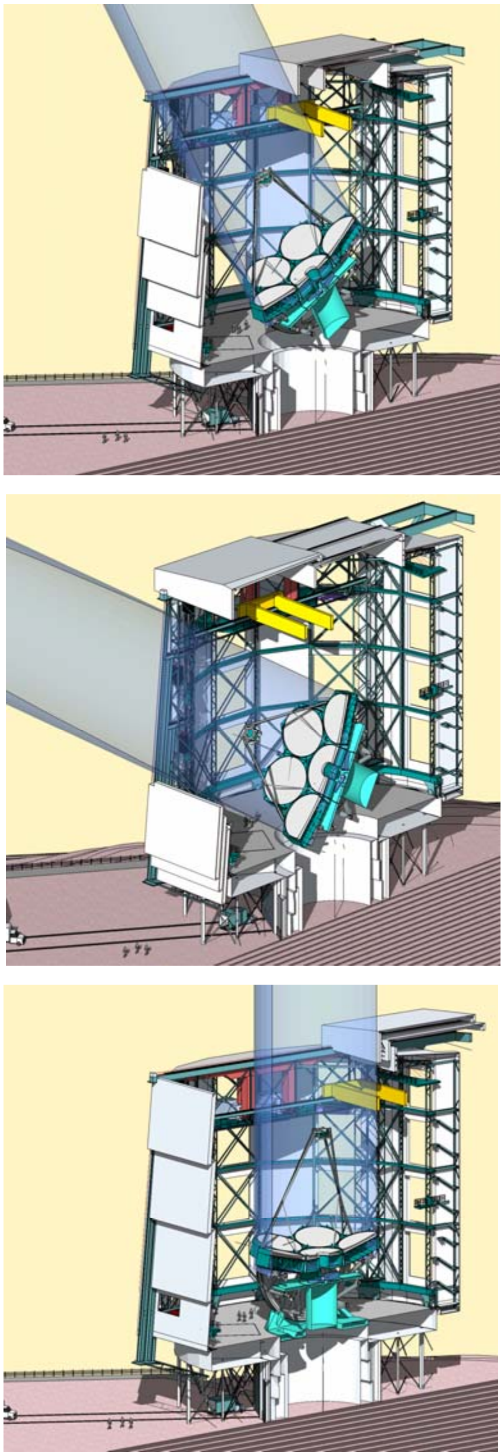

Fig. 9. Shutter doors deployed at 30°, 60° and 90° telescope elevation angle as wind and moon screens.

The shutters consist of a pair of horizontal roof panels and three vertical front panels. The structure around the shutter openings provide 1.5 m of clearance on either side of the optical path. When the roof panels are fully retracted there is 0.76 m of clearance at the back of the optical path when the telescope is pointed to the zenith (See Figure 9).

The nested panels of the upper shutter run on a pair of double rails fixed to the Carousel structure on either side of the top opening. The rails extend beyond the back of the carousel cylinder and are supported at the rear by an exposed steel structure. The lower nested panel rolls on the rails with four bogeys. The two front bogeys of the upper panel also roll on the fixed rails. At the rear, the upper panel is supported by the lower panel and rolls on rails attached to the top of the lower panel.

The upper shutter layout is designed to have the doors act as a moon screen by having the front edge of the door follow the telescope aperture in elevation. As a fail-safe system the doors are closed manually with a separate hand crank or drill driven winch and cable that is independent of the shutter door mechanism. This provides a safe, emergency closing procedure in case of both power and/or mechanism failure.

The vertical shutter doors consist of three nested panels that run on sets of vertical rails mounted on the carousel steel structure. The steel panels are approximately 120,000 lbs each and have a 100,000 lb. steel counter balance (approximately 10% less than the panel weight) located in the two front carousel columns. The system promotes a gravity assist downward movement and also provides wind and stray light shielding by creating a square observing aperture by coordinating deployment with the upper shutter doors.

The drive mechanism for the vertical shutter doors is located on a platform that is approximately 3 meters above the observing level and at the front of the carousel. Access to the platform is via a ships ladder from the observing level. The drive mechanism for the upper shutter doors is on the mechanism level located 40 meters above the observing level. Access to this level is via a stairwell and a 5000 lb service elevator (Elev. 1) located at the back of the carousel structure.

4.2 Structure

The enclosure structure consists of a steel carousel rotating on rails supported by a fixed steel base structure. The carousel is 55 meters in diameter and 50 meters high and rotates independently of the telescope.

The fixed base structure consists of perimeter steel columns that support a steel ring girder (55 meter diameter) and carousel rails. Steel bracing is provided around the perimeter except at the portals to allow access to the center of the pier. Two interior rings of steel columns support the observing level floor. Columns are braced in both radial and circumferential directions; Concrete foundations for the fixed base structure are independent of the telescope pier. The structure is designed to carry the static and dynamic loads from the carousel and seismic and wind loads.

The carousel structure consists of two steel arch girders that support the rails for the roof shutter panels, the front shutter panels and overhead crane. Steel framing forms the multi-faceted carousel walls that contain the ventilation openings. The carousel walls are braced for lateral wind and seismic loads. The bracing system incorporates access catwalks into the design (See Figure 10).

The typical cross section of the arch girder consists of a 2 m x 4 m column at each end and a 10 meter deep truss along the roof. The columns are 200 mm steel angles or wide flange sections at each corner braced with steel angles. The thickness of the steel is 19 mm, minimizing the thermal properties.

The roof shutters consist of two movable steel framed panels that nest over the elevator shaft at the rear of the structure during observing. The panels are 30 m wide by 23 m long and retract over five rails with the upper panel supported by the lower panel. The drive system coordinates the movement of the two panels so that they arrive at the open or closed position simultaneously.

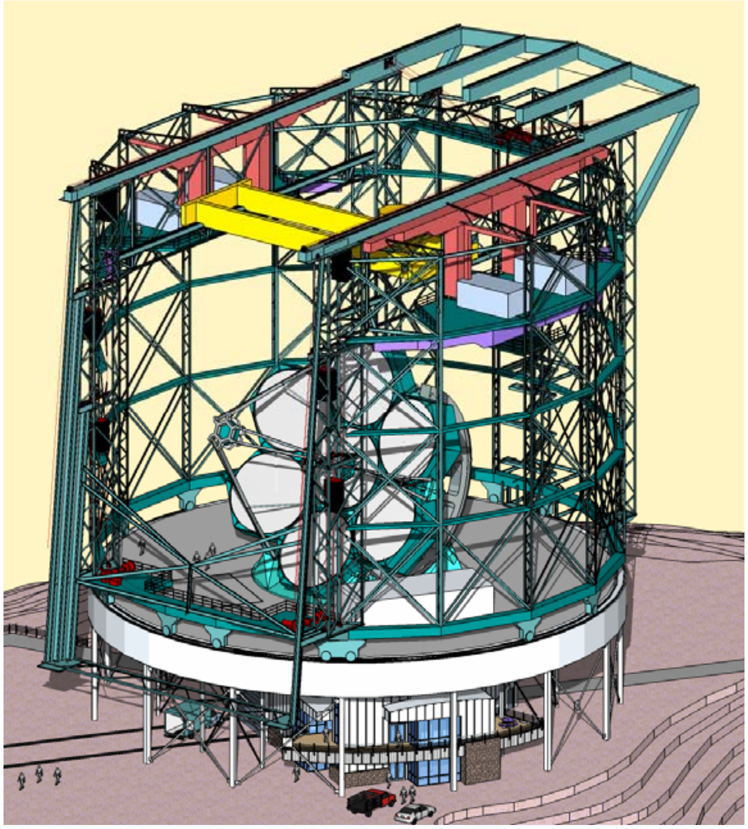
Fig. 10. Carousel Steel

The front shutters consist of three movable steel framed panels (30 m wide x 12.5 m high) that nest at the lower end of the shutter opening. The nested panels clear the aperture of the telescope. The drive system coordinates the movement of the three counterweighted panels so that they arrive at the open or closed positions simultaneously. Aluminum could be used for the front shutters to reduce counterweight requirements if necessary. The front shutters can also be used for a wind screen in a partially closed position. Independent control of each shutter leaf is an option which would allow screening of the secondary mirror from wind while allowing ventilation at the lower part of the telescope.

5. WALL SYSTEMS

The proposed exterior wall system of the enclosure is an insulated metal panel that is screwed in place to the secondary steel structure. The panel is a 36 inch modular width panel with an off-set double tongue- and groove-joint. The panels are sealed at the joints with a factory installed continuous seal in the groove and field applied sealant on the opposite side of the joint.

The panel has a smooth 22-gauge steel exterior face and a slightly fluted, 24-gauge interior surface for rigidity. The core is 3 inch thick foam-in-place polyurethane with R-24 insulation value and the following structural properties:

The metal panel has a factory applied G-90 galvanized finish with a 20 year warranty. It is the most reflective finish on a steel metal panel commercially available. Aluminum foil tape can be applied directly to the panel if needed to control radiation to the night sky and over-cooling of the skin.

The roof panels are similar to the wall panels in material and thickness but have rolled formed overlapping rib exterior for water tightness. The interior joint is the same as the wall panels.

The metal panels are precut in the factory and trimmed onsite. All panel edges are trimmed with either sheet metal flashing or a two part extruded aluminum trim piece that snaps in place. The trim finish matches the metal panel finish.

6. MECHANICAL SYSTEMS

6.1 Main doors

The concept for the vertical shutter is three individual steel framed panels that can be raised or lowered so that each panel arrives at the open or closed position simultaneously. As an option, the panels could be controlled independently to allow partial wind shielding. The panels could also be constructed of aluminum thereby reducing the weight and drive requirements.

Each of the three panels is 30 m wide by 12.5 m high. The estimated weight is 54.5 metric tons if constructed with steel and 18.1 metric tons if constructed of aluminum.

The drive system concept consists of a pair of 7/8 inch wire rope winches and a 24 inch diameter pulley system. The project requirements specify that the shutters open within three minutes and close within six minutes. Counterweights (1.8 m x 1.2 m x 20 mm thick with 12 mm space in between) are provided to reduce the power requirements of the winches and to facilitate manual closing of the panels in case of a power failure. Total winch power is estimated to be 80 horsepower. Lead could be substituted for steel in the counterweight to reduce the thermal load from cooling by 70% if that is shown to be significant.

The winches are controlled by encoder feedback with appropriate safety mechanisms to keep the panels from racking. Differential gearing of the winch drums controls the speed of the shutter panels as the outer panel must travel three times the distance of the inner panel and 1.5 times the distance of the intermediate panel.

Elevator drive and safety technologies such as failsafe braking in case of cable failure are provided. The drive winches are mounted on the observing floor to facilitate maintenance access.

If independent control of the three panels is required, six winches instead of two are necessary. However, louvers could be incorporated into the lowest panel if ventilation is required while shielding the secondary mirror from wind.
The concept for the upper shutter is two individual steel framed panels that open to nest over the top of the enclosure elevator. The roof panels are controlled by wire rope winches so that the two panels arrive at the open or closed position simultaneously. Each of the two panels is 30 m wide by 23 m long.

The drive system concept consists of a pair of 19 mm wire rope winches and a 521 mm diameter pulley system to pull the shutters open and closed. The roof shutters can be partially opened to double as a moon roof.
The winch is a single unit with differential gearing that controls the shutter panel speeds. The upper panel must travel twice as far as the lower panel.

The winch drive system is accessible from the top of the service elevator or stair. The technology is modeled after movable roof systems used for new sports stadiums. The estimated power requirement for the winch is 50 horsepower.

6.2 Rotation drives and bogies

The enclosure is rotated by four bogie drives. The total rotating weight of the Carousel including steel structure, sub-framing, wall panels, overhead crane, shutters and counterweights is 1,689 metric tons. The requirement of the specification is to accelerate the enclosure at a maximum $0.2°/sec^2$ with a maximum speed of 1.5°/sec. At the maximum rate the bogies are traveling at 0.72 meters/sec.

The bogie drives are located at the four main bogies that support the enclosure arch girders. Each bogie assembly consists of a weldment that contains four 1 m diameter canted wheels and a lateral restraint wheel between each pair of bogie rails. The four wheels ride on two rails (171 pound/yard crane rail).

Each four wheel bogie will be driven by two 75 horsepower (estimated) variable speed drive motors (600 horsepower total estimated). The drive motors will be connected to the wheels by a gear drive or chain and sprocket. The drives will be sized to move the enclosure with four out of the eight motors.

The bogies will be mounted to the enclosure structure with roller and/or flexible connections to allow for alignment tolerances and thermal expansion of the structure.

6.3 Ventilation windows

The carousel has four rows of ventilation windows along the front, side and back walls. The total window opening area is approximately 31% of the carousel wall surface (See Figure 11).

The ventilation windows are individually actuated with electric motors which are only energized during the time the vents are in motion. The windows operate through a PLC system and absolute proximity sensors control the exact location of the window and opening size.

The ventilation windows are insulated roll-up doors rated for 150 mph wind at the site elevation and have a 6.25 R-value. The door slats are 18-guage steel exterior surface and a 20-guage steel skin on the interior with a polyurethane core. Rubber seals along the jambs and a compressible bulb seal at the sill provide the required weather stripping. Replaceable seals will be specified for long-service life at the site elevation.

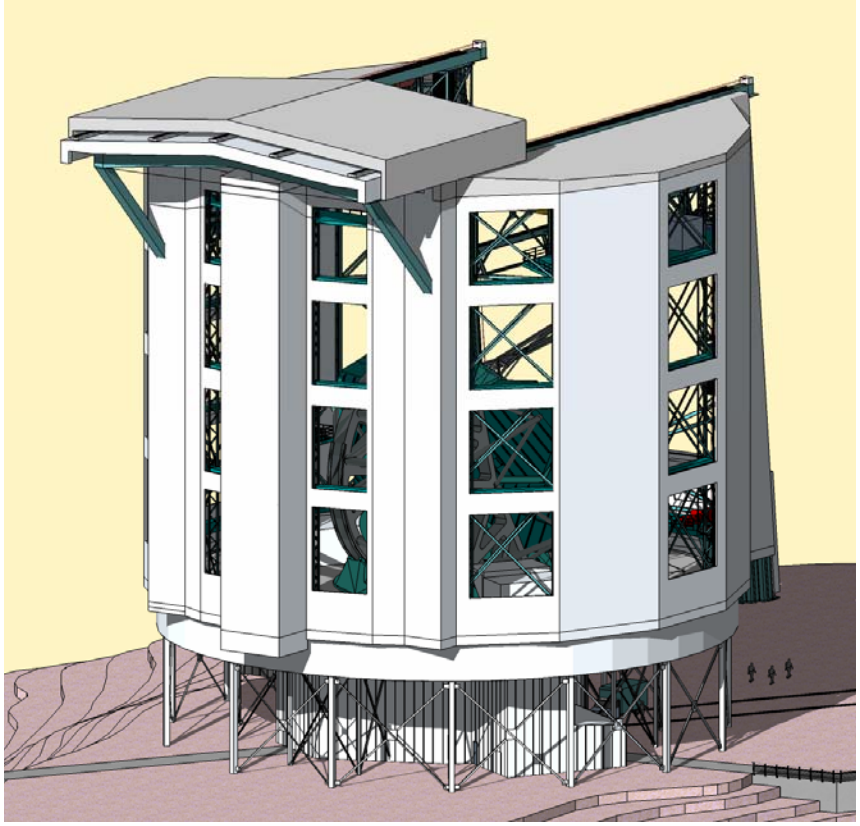

Fig. 11. Enclosure with vent doors open

7. THERMAL DESIGN

Dome seeing

The thermal environment inside the telescope chamber can degrade the imaging performance of the telescope if not carefully controlled. The effect is called “dome seeing” and is caused by turbulent mixing of air at different temperatures in the telescope beam. In the most detailed empirical study of dome seeing to date, Racine, et. al. (1991) derives a relationship between image quality and dome air temperature relative to outside air temperature, of the form $(0.1'' \pm 0.05'')/K^{6/5}$ FWHM, based on temperature and seeing measurements at the Canada, France, Hawaii Telescope (CFHT). This implies that the air inside the enclosure during observing should never be warmer than the outside air by more than 0.22 K in order to satisfy the 80% encircled energy image budget of 0.025″ (0.017″ FWHM) for this source of error. Colder temperatures were found to be less damaging in that study.

The thermal management system will operate 24 hours a day. During the day the enclosure will be sealed up and the inside air will be actively cooled to maintain the interior air temperature at the predicted ambient values at the start of the night. The air at different levels within the chamber will be mixed with fans to reduce stratification. The stratification will be monitored by a network of thermometers and used to control fans and louvers. In the late afternoon the air conditioning will be turned off and the enclosure will be opened up to the early evening sky. The thermal control system for the primary mirror will be turned on if not already operating and set to follow the ambient temperature. Wind driven ventilation through the shutters and ventilation windows will then be relied on to bring the rest of the enclosure and telescope structure to equilibrium with the ambient air and to track changes through the night. Cooling systems for active sources such as electronic racks will operate continuously day and night.

Potential nighttime heat sources include (a) cooling of the telescope and enclosure structure, (b) waste heat from electrical/electronic equipment, (c) waste heat from electric motors, (d) heated oil for the hydrostatic bearings, and (e) entrainment of air from the outside boundary layer. The cooling mechanisms at night include (a) active cooling of heat producing motors and electronic equipment and the primary mirror assemblies, (b) wind-forced ventilation of the telescope chamber and (c) radiation to the cold night sky.

Another potential source of dome seeing comes from air in thermal contact with the sides and top of the enclosure that is carried by the wind in front of the shutter opening. Depending on the exterior skin temperature, the air could be either warmer or colder than ambient. The wall and roof panels are made of insulated panels with a thin steel face sheet. In the absence of radiation cooling, the panel surfaces will rapidly equilibrate with the surrounding air. Radiation to the night sky however can drive surface temperatures up to 3.6 K below the ambient temperature (Good 2004) depending on factors including cloud cover, wind speed, conduction to the panel, and emissivity of the surface. The strategy adopted by Magellan and other telescopes to address this problem has been to apply low emissivity tape to the areas around the shutter. In the case of Magellan the whole dome was covered with tape. The much greater surface area of GMT makes this approach, while possible, not as practical as on smaller domes but local application around the shutters is still possible. Other low-emissivity surface treatments will be investigated in the design development phase and the effect of a cold outside surface will be modeled.

The GMT plan for dealing with dome seeing involves a number of measures:

- Raising the telescope above the boundary layer and providing for flow below the observing floor to prevent the heated boundary layer from entering the telescope chamber.
- Reducing the thermal mass and time constant of the steel structures within the telescope structure by the efficient use of steel truss members in the enclosure structure and thin cross section steel plates in the telescope,
- Maintaining the inside air during the day at the expected early evening temperature and mixing the air to prevent stratification,
- Insulating the observing floor to prevent conduction from below,
- Providing maximum wind-driven ventilation through the structure at night to expel pockets of warm air and promote rapid thermalization,
- Actively cooling heat producing motors and equipment with a chilled liquid system to capture and extract waste heat,
- Insulating and sealing the wall structure, shutters, and ventilation windows to reduce infiltration of heated outside air during the day,
- Cooling the hydrostatic oil,
- Actively cooling the primary mirror segments and cell assemblies,
- Applying low-emissivity surface treatments to the upper portion of the telescope to prevent overcooling from radiation to the cold night sky.

The results of this section do not represent a full analysis of the thermal performance of the GMT enclosure but do show that, at this stage of the development, thermal management of the structure using a combination of active cooling during the day and wind-forced ventilation at night is a viable strategy. A significant increase in the cross-wind ventilation could be achieved by installing windows on the four vertical wall panels that are currently solid. The trade-off is cost, more seals to contend with and a small reduction in the insulating value of the wall.

The major issues that must be confronted during the design development phase include

- Non-uniform heating and cooling of the interior structures of the enclosure and telescope including the effects of radiation to the night sky,
- Elimination of vertical temperature stratification of the inside air during the day,
- Treatment of the enclosure outside surface to prevent over-cooling of air around the shutter caused by radiation to the night sky,
- Behavior of the boundary layer at the selected site and its interaction with the enclosure structure,
- Prevention of heat infiltration from below the observing floor,
- Cooling of active sources, and
- Trapping the heat from equipment and structures with long thermal time constants (e.g. the bridge crane, arch girder structure, counterweights, etc.).

These will be investigated with a combination of analytical modeling and measurements at the site to better characterize wind and thermal conditions.

8. HVAC REQUIREMENTS

During daylight hours the enclosure will maintain the interior at the expected sunset temperature by actively cooling the air in the telescope chamber. The thermal environment on LCO is relatively benign. The median difference between the daytime high temperature and the temperature at sunset is 1.9 °C with a range of 0.9 °C to 2.8 °C between the first and third quartiles. The median difference between the closing temperature in the morning and the ambient temperature late in the afternoon at opening is 0.8 °C with first and third quartile values of -0.3 °C and 1.8 °C respectively. Weather predictions will be used each day to obtain the late-afternoon target opening air temperature in the dome.

The inside air temperature will be controlled by a set of four air handling/heat exchanger units (AHU) in the top of the enclosure supplied with a solution of chilled glycol. Coolant will be piped to the heat exchangers from a remote chiller unit.

The enclosure cooling load is calculated at 204 kW (58 tons). This load can be broken down into four basic components, 13% to environmental, 14% to infiltration, 11% to internal loads and 62% to waste heat produced by the fans themselves. Environmental loads are governed by the wall and roof R-value and the maximum temperature difference between the interior and exterior spaces. In this case the interior space is set at 19.5 °C while the exterior daytime high is 24 °C. Infiltration loads are influenced by the air tightness of building construction and average wind velocity. The internal loads are from electrical equipment such as lights and equipment. Fan heat is the brake horse power required to move 75.5 m^3/s (160,000 CFM) at a pressure differential of 0.87 kpa (3.5 in. wg).

Four 18.9 m^3/s (40,000 CFM) air handling units (AHUs) are located at the mechanical level. Two air handling units without heaters and humidifiers are placed on each side of the enclosure. The air handling units consist of a filter mixing box, cooling coil and fan section plus several smaller access sections. The air is filtered to an ASHRAE dust spot efficiency of 25-30%. The air discharges from the two units into a common supply duct located below the platform level. The supply air is discharged down the building interior walls creating an air swirl where the cold air falls down the interior walls while the hot air will rise in the enclosure center. The return air duct is located centrally as high as possible in the enclosure to capture this rising hot air. A relief air vent is located high in the enclosure to vent warm air above the return air ducts. Sufficient air is brought in from the outside by each air handling unit to make-up for the air that is expelled through the vents.

Temperature stratification is a concern with this enclosure. With a height of approximately 50 meters it is difficult to achieve a uniform vertical temperature distribution in the enclosed volume. The air handlers move 75.5 m^3/s (160,000 CFM) of air but that only represents 2.5 air changes per hour and air circulation at that rate will be relatively slow. To help reduce the potential for stratification the mixing of air may have to be increased with additional fans. Further analysis will address this issue.

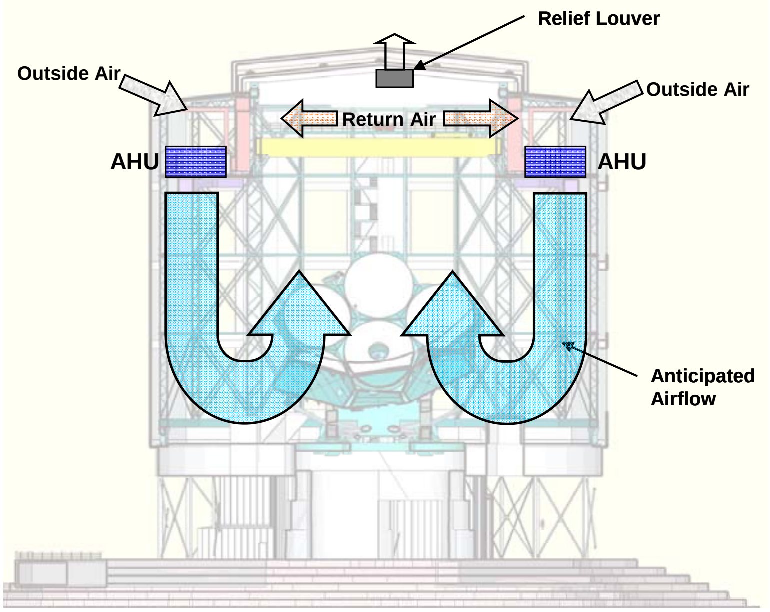

Fig. 12. Carousel Air Flow Diagram

A nominal 246 kW (70 ton) screw chiller is remotely located near the equipment building, with 100 mm (4 inch) diameter distribution piping routed in the utility tunnel to the telescope enclosure. For the distribution piping to cross over from the fixed to the rotating portion a flexible hose with a quick disconnect coupling is required. Safety interlocks are provided to prevent enclosure rotation while the chilled water piping is connected. 30% ethylene glycol is used as the brine to prevent freezing of the pipes during cold weather operation. The expected maximum operating temperature of the brine in the summer will be 10 °C and a minimum of -6.5 °C in the winter. With this range of brine temperatures the enclosure can be maintained at 18 °C in the summer down to 1.5 °C in the winter.