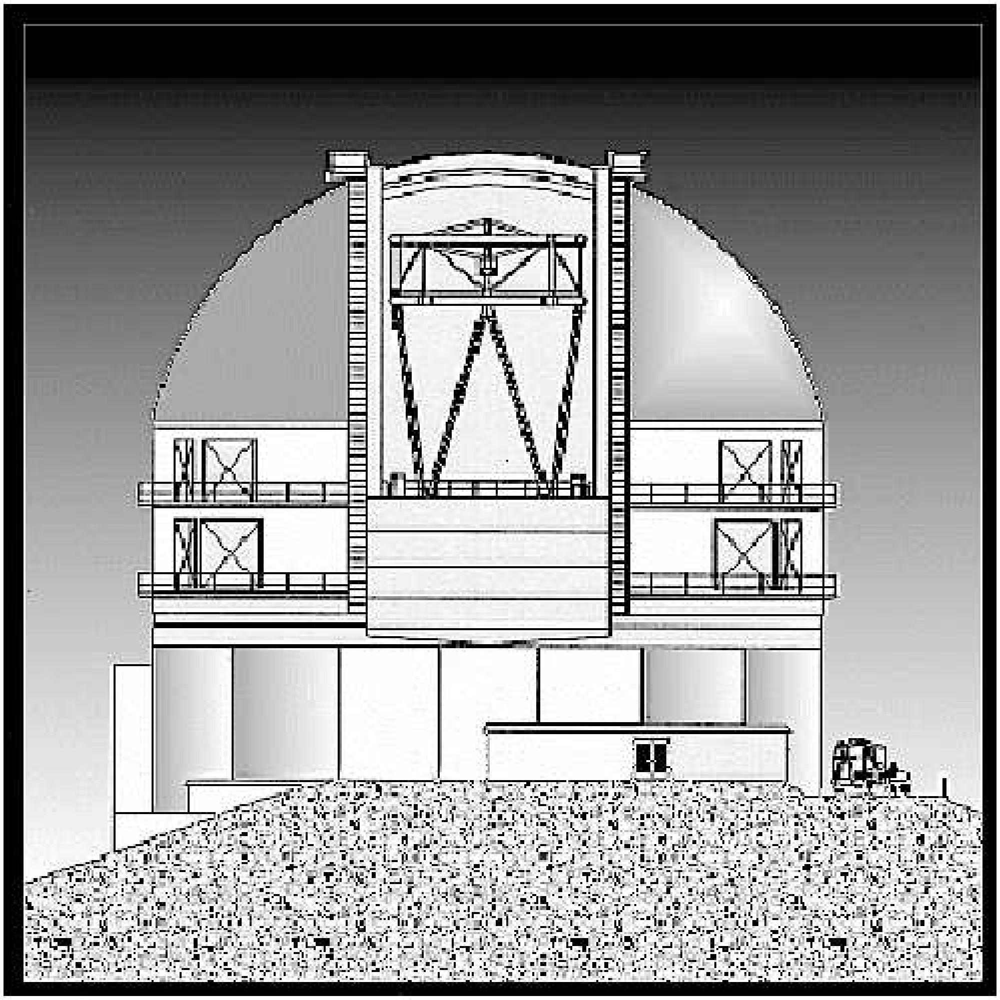
GEMINI
8-M Telescopes
Project

SPE-S-G0048

Facility Thermal Management System



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1. Introduction

This paper describes the implementation of the thermal management system used to control seeing for the Gemini 8 meter telescope facilities.

Seeing is defined as the integral effect of changes in the refractive index of the air contained within an optical lightpath. Seeing is produced by the heat released into the air within the lightpath by cooling structures and active electrical sources such as drive motors, lights, and electronics/instrumentation packages.

The Gemini facility will utilize both active and passive systems to alleviate seeing. Active thermal management systems include chillers and fans. The passive systems include surface coatings, insulation, chamber flushing vents, and flow control valves that allow ambient air to enter the space below the enclosure shell.

Thermal modeling was used to determine which combination of active and passive systems would best alleviate the local seeing effects produced by discrete structures including the shell, chamber wall, and floor of the enclosure, as well as the mount, truss, and top end of the telescope. The modeling included the effects of heat released by active sources operating within the enclosure chamber [Gemini Project Document No. RPT-TE-G0039].

An overall operational strategy for implementing day to day thermal management of the facility was determined by combining the individual control methodologies investigated with the modeling. The thermal operations plan also includes the operational contingency to be followed in the event of a local commercial power outage.

2. Systems for alleviating self induced seeing

2.1 Mechanical systems

Two principal categories of mechanical systems are used for the thermal management of the Gemini facility:

- a chiller system is used to produce cold fluid heat transfer media that is piped to various loads throughout the facility;
- an air handling system is used to draw ambient air through various air volumes within the facility.

2.1.1 Chillers

A total of four discrete vapor compression refrigeration chillers are used. Two large high capacity chillers and two smaller modular chillers are located within the facility exhaust tunnel. Figure I shows the piping schematic for the chiller system. The two high capacity chillers provide cold liquid to:

- condition the air of rooms within the support facility;
- control the temperature of oil exiting the hydrostatic bearing heat exchangers;
- condition the air within the enclosure chamber during the daytime hours;
- control the temperature inside electronics cabinets (VME crates);
- remove heat from instrumentation packages;

- remove heat from mirror support assemblies.

The two modular chillers are used to:

- cool helium compressors that supply instrument package cold heads,
- condition the temperature of the backside of the primary optic**.**

2.1.2 Air handling system

The air handling system is composed of four high capacity (120,000 cfm.) fans, an exhaust tunnel, a riser duct connecting the exhaust tunnel to the enclosure, and five sets of dampers. Two fans are mounted at each end of the exhaust tunnel. Depending on the time of day and the magnitude of the ambient wind velocity, the dampers can be set such that the source of make up air for the fans will be:

- one end of the exhaust tunnel;
- the enclosure chamber;
- the shell air volume;
- the chamber and shell air volumes combined.

2.2 Passive systems

Four different categories of passive systems are utilized in the Gemini facility to minimize the effects of seeing produced by environmental boundary conditions.

2.2.1 Surface coatings

Surfaces in close proximity to the optical lightpath that are well coupled to the sky utilize low emissivity coatings to prevent the surface from subcooling below the temperature of the surrounding air. These surfaces include:

- the outer structural shell of the enclosure;
- the telescope truss;
- the telescope top end.

Surfaces inside the chamber that are not well coupled to the sky (while the shutter is open) are covered with diffuse coatings of high emissivity (low reflectivity); this causes the surface to more closely track the ambient air by transferring more energy to the night sky and also helps minimize scatter and reflective effects inside the chamber cavity. These surfaces include:

- the mount;
- the floor;
- the inside chamber wall.

Surfaces on the Gemini facility distal to the enclosure utilize high emissivity coatings in order to force the surface to subcool. This prevents upward free convective flow that could drift over the open shutter from occurring during periods of low ambient windspeed. These distal surfaces include:

- the walls and roof of the support facility;
- the sides and roof of the exhaust tunnel;
- the vertical walls of the enclosure base structure.

2.2.2 Passive flow system for the enclosure chamber

The Gemini enclosure incorporates large vertically activated gates to flush the telescope chamber with wind while the telescope is in the observing mode. Figure 2 presents the physical relationship between seeing and chamber air velocity.

2.2.3 Passive flow system for the enclosure shell

The Gemini enclosure is designed such that an air volume exists below the outer structural shell and the inner insulated chamber wall of the enclosure. During the day, solar loading forces the of the enclosure above the ambient air temperature. Heat is then conducted into the structural truss which supports the shell. The modeling has shown that this beat then discharges back into the shell during the early nighttime hours and causes an elevated level of shell seeing. Figure 2 shows the system of remotely actuated flow valves located at the top and bottom of the shell that are opened to allow the passage of air into the shell air volume. This procedure will:

- minimize the amount of energy stored in the shell during the daytime hours;
- decrease the daytime heat load on the enclosure chamber air conditioning system.

2.3.4 Insulation

Urethane insulation is utilized in the chamber walls of the enclosure to:

- provide a low thermal time constant surface on the inside of the telescope chamber that will rapidly track changes in the chamber air temperature;
- minimize the heat load on the air conditioning system during the daytime hours.

3. Methodology for alleviating self induced seeing

3.1 Chamber seeing

Chamber seeing is caused by the temperature differential between the air volume inside the enclosure chamber and the ambient air. The thermal modeling has shown that it can be minimized by:

- conditioning the chamber air during the daytime hours such that at the commencement of viewing in the early evening, the temperature of the chamber air will approximate that of the ambient air;
- coating the walls and floor of the chamber with diffuse low emissivity coatings;
- force ventilating the air volume below the structural floor of the chamber;
- actively controlling the temperature inside control cabinets located in the chamber;
- actively controlling the temperature of the oil exiting the hydrostatic bearing plant.

Chamber seeing is further diminished by ventilating the chamber air volume:

- by allowing air to pass through open ventilation gates to sweep out the enclosure chamber;
- by using the chamber air volume as a source of make up air for the high capacity fans used in the facility air handling system.

During the nighttime hours, regardless of the windspeed, the chamber air is always used as a source of make up air for the exhaust fans.

3.2 Shell seeing

Shell seeing is caused by the temperature differential between the shell and the ambient air.
Wind will move the power flow produced by this temperature differential over the shutter slot.
The thermal model has shown that shell seeing can be controlled by:

- allowing passive flow to occur in the shell air volume during the day to reduce stored heat;
- using the shell air volume as a source of make up air for the air handling system during the night;
- using a low emissivity coating on the outside of the shell to prevent the shell from subcooling during the night.

3.3 Mount and upper structure seeing

Seeing produced by the mount is alleviated by:

- covering the mount with a high emissivity coating;
- forced ventilating the air volume within the mount during the nighttime hours-,
- conditioning the chamber air during the daytime hours so the temperature differential between the mount and the ambient air is minimal when observing commences.

Seeing produced by the upper structure (truss and top end) is alleviated by:

- covering the upper structure with a low emissivity coating;
- forced ventilating the air volume within the upper structure during the nighttime hours;
- conditioning the chamber air during the daytime hours.

3.4 Mirror seeing

The primary optic was not included in the thermal model of the enclosure and telescope. However, work by the Rutherford Appleton Lab [Gemini Report RPT-RAL-G0036] has demonstrated that mirror seeing can be controlled to acceptable levels by:

- controlling the temperature of the back surface of the optic via radiative heat transfer (utilizing a cold plate cooled by liquid media) such that at night the bulk temperature of the optic is always just below the temperature of the ambient air;
- heating the reflective coating of the optic back up to the ambient air temperature with electricity to minimize the optic surface to air temperature differential (optional).

3.5 Facility seeing

Facility seeing will be produced by the roofs and walls of the support facility, exhaust tunnel, and enclosure base structure. Because the pole of the telescope is located well above the boundary layer at the sites, heat moving off the roof and walls of the support facility will be swept away sideways during periods of high ambient windspeed. This argument is no longer applicable during times when the ambient air is quiescent or moving at low velocities, therefore:

- low emissivity coatings are used on the walls and roof of the support facility to force these surfaces to subcool- upward buoyant flow that could move into the telescope lightpath is thus prevented.

4. Implementation of the active systems

4.1 Daytime ventilation

Figure 3 shows the configuration of the air handling system for daytime operation.

- The shutter and vent gates are closed to seal the chamber (to minimize the outside air infiltration heat load);
- the chamber air is temperature is being conditioned to a value near the ambient air temperature at the shutter opening event;
- heat from the chiller condenser/compressor units (located in the portion of the exhaust tunnel directly adjacent to the support facility) is being rejected into the air of the exhaust tunnel;
- a single fan operates at the south tunnel end to remove the heat from the tunnel air;
- the makeup air enter the open damper at the from the north tunnel end;
- the riser damper is closed to prevent conditioned air from being drawn out of the enclosure.

4.2 Nighttime ventilation

4.2.1 Low ambient windspeed

Figure 4 shows how the facility air handling system is implemented at night during periods of low ambient windspeed.

- The riser damper is in full open position;
- all four high capacity fans are operating drawing equal volumes of air through the shell air volume and the chamber air volume;
- air in the chamber is drawn through surface grates (always open) in the rotating telescope floor, then moves radially through the stationary enclosure floor and enters the ring plenum, where the flow exits the enclosure through the exhaust tunnel riser;
- ambient air enters the shell air volume at the top of the enclosure through the open enclosure shell air valves and moves through the shell into the ring plenum;
- the lower shell air flow valves are closed to permit air flow only between the shell air and ring plenum, thus preventing "short circuit" flow between the ambient air (outside the base of the enclosure) and the ring plenum.

4.2.2 High ambient windspeed

Figure 5 shows how the facility air handling system is implemented at night during periods of high ambient windspeed.

- Ventilation of the shell air volume is not required;
- the upper and lower shell air flow valves are closed to prevent flow between the shell air volume and the ambient air (with the shell air flow valves in this configuration, the shell air volume is connected to the low pressure plenum air volume; heat can not escape from the shell air volume and drift through the light path);
- the operation of two fans only is required, and the two south fans are operated with the north tunnel damper closed;
- all makeup air moves through the enclosure chamber.

4.3 Chamber air conditioning

Coolant produced by one of the high capacity chillers is used for conditioning the enclosure chamber air during the daytime hours. The coolant is piped to heat exchangers at four distributed locations on the stationary chamber floor. A fan attached to each heat exchanger draws air in at the floor level and exhausts it out a nozzle system such that the conditioned air is directed towards the mount of the telescope.

4.4 Active temperature control

4.4.1 VME buss crates

VME crates are located in the enclosure chamber, the primary mirror cell, and in the HROS room located in the base of the telescope pier. The temperature of the air inside VME buss crates is constantly (24 hrs/day) controlled. The temperature control is accomplished by enclosing the crate in an insulated container and circulating coolant produced by the chiller system through a liquid to air heat exchanger. A small fan circulates the air within the box.

4.4.2 Instruments

Coolant from the central chiller system is used to control the temperature of instrument packages and drive servos associated with the Cassegrain instrument rotator. A piping network delivers the coolant to the devices via the telescope azimuth cable wrap.

4.4.3 Helium compressors

Helium compressors located in the mechanical plant are cooled by a modular chiller located in the heat exhaust tunnel. The chiller and helium compressors are backed up with the emergency generator so that in the event of a mountain commercial power outage helium delivery to cold heads located within instrument packages will not be interrupted.

4.4.4 Hydrostatic bearings

Two liquid to liquid heat exchangers for the hydrostatic bearing plant are located on the top of the lower pier access platform. One heat exchanger cools the oil for the telescope altitude bearings; the other serves the azimuth bearings. Low temperature coolant from the central chiller system is piped into the heat exchangers so the temperature of the oil exiting the bearing pads will always be just below the ambient air temperature.

4.4.5 Primary mirror radiation plate

A specialized low temperature modular chiller located in the heat exhaust tunnel provides coolant for the primary mirror cold plate located within the mirror cell. The coolant is delivered to the cold plate through piping located in the azimuth cable wrap.

4.4.6 Mirror supports

Supports for the primary optic are cooled by fluid supplied by the same piping used to service the VME buss crates.

5. Thermal management strategy

5.1 Control

Control of the active systems is implemented by a series of Programmable Logic Controllers at the following locations:

- on the stationary chamber floor adjacent to the elevator;
- in the mechanical plant room;
- in the telescope operations room.

Each P.L.C. is equipped with a CRT monitor and a keyboard for interface activity. Initially, the P.L.C. system will be programmed by the support facility contractor at a rudimentary level sufficient to satisfy commissioning operations. More advanced P.L.C. programming will be performed by the site operations staff.

A control interface is also supplied to the Gemini control system through an RS -232 interface. A P.L.C. at any of the above locations can remotely control the:

- shutter
- flushing gates
- fans for the air conditioning heat exchangers
- upper and lower shell air flow valves
- riser damper
- exhaust tunnel fans
- exhaust tunnel dampers
- central chillers
- modular chillers
- pumps and proportioning valves used to control the circulation of coolant throughout the piping network

5.2 Daytime operations

The following table summarizes the daytime operating conditions for the facility thermal management system.

Table 1- Daytime operating conditions for the facility thermal management system

Device	**Logic**	**Notes**
Shutter	1	Chamber is sealed to minimize infiltration
Flushing gates	1	
Chamber A.C. fans	1	chamber air is being conditioned
Upper shell air flow valves	0	allows passive air flow to occur in the shell air volume
Lower shell air flow valves	0	
Riser damper	1	prevents cold air moving out of chamber
North tunnel fan No. 1	0	make up air must enter this end of tunnel
North tunnel fan No. 2	0	
North tunnel dampers	0	allows make up air to enter tunnel
South tunnel fan No. 1	1	one fan only required to remove chiller exhaust heat from tunnel
South tunnel fan No. 2	0	
South tunnel dampers	1	prevents flow short circuit
Central chiller No. 1	1	services support facility, instruments, crates
Central chiller No. 2	1	cools chamber
Helium compressor chiller	1	serves helium compressor (constant)
Optic cold plate chiller	1	serves cold plate (assume constant)

5.3 Nighttime operations

Nighttime operating logic for both low and high wind velocities are summarized in Table 2 and Table 3, respectively.

5.3.1 Low wind speed

Table 2 - Nighttime operating conditions for the facility thermal management system: low wind speed

Device	Logic	Notes
Shutter	0	telescope in observing mode make up air enters chamber
Flushing gates	0	
Chamber A.C. fans	0	daytime only
Upper shell air flow valves	0	allows make up air to enter top of shell air volume only
Lower shell air flow valves	1	
Riser damper	0	connect chamber, shell, and floor to tunnel
North tunnel fan No. 1	1	all fans at both tunnel ends required to operate
North tunnel fan No. 2	1	
North tunnel dampers	1	prevents flow short circuit
South tunnel fan No. 1	1	all fans at both tunnel ends required to operate
South tunnel fan No. 2	1	
South tunnel dampers	1	prevents flow short circuit
Central chiller No. 1	1	services facility, instruments, buss crates
Central chiller No. 2	1	cools hydrostatic oil heat exchangers
Helium compressor chiller	1	serves helium compressor (constant)
Optic cold plate chiller	1	serves cold plate (assume constant)

During a period of low wind speed, telescope observing may be affected by the thermal plume exiting a tunnel end. An operational contingency exists whereby the fans responsible for the image degradation are switched off such that all air flow escaping the riser will be drawn off by the fans operating at the opposite end of the tunnel. Under these circumstances, the telescope operator must perform the following control operations:

- close the tunnel end make up air inlet dampers adjacent to the deactivated fans to prevent a flow short circuit (to efficiently operate all make up air must enter the shell or chamber);
- if the south tunnel fans are deactivated, some makeup air must enter one of the south tunnel dampers to allow efficient heat rejection from the chiller condensers located near the south end of the exhaust tunnel.

5.3.2 High wind speed

Operations under high wind speed differ from the low wind speed case only in that ventilation of the shell air volume is no longer required; only two of the tunnel fans are required to operate. it is preferable to operate the South tunnel fans so exhaust air is always moving past the chiller condensers.

Table 3 - Nighttime operating conditions for the facility thermal management system: high wind speed.

Device	**Logic**	**Notes**
Shutter	0	telescope in observing mode, make up air enters chamber, chamber wind ventilated
Flushing gates	0	
Chamber A.C. fans	0	daytime only
Upper shell air flow valves	1	no shell air flow required
Lower shell air flow valves	1	
Riser damper	0	connect chamber, shell, and floor to tunnel
North tunnel fan No. I	0	south tunnel fans required only
North tunnel fan No. 2	0	
North tunnel dampers	1	prevents flow short circuit
South tunnel fan No. I	1	draw 10 chamber volumes per hour of make up air
South tunnel fan No. 2	1	
South tunnel dampers	1	prevents flow short circuit
Central chiller No. I	1	cools facility, instruments, buss crates
Central chiller No. 2	1	cools hydrostatic oil heat exchangers
Helium compressor chiller	1	serves helium compressor (constant)
Optic cold plate chiller	1	serves cold plate (assume constant)

Table 3 Notes

1. The flushing gate openings may be modulated to limit telescope wind shake.

5.4 Power outage

During normal nighttime operation, the base electrical load of the Gemini facility will be about 350 kVA. Two 30kVA UPS systems and a 100 kVA emergency generator provide backup power for the facility in the event of a commercial power failure. Thus during a power outage, the facility base load may not be maintained. At Mauna Kea, power outage occurrences average about six episodes per year; average outage duration is 30 minutes.

Power outage operating procedure consists of

- maintain computer control of the facility;
- cover the primary mirror;
- stow the telescope (zenith pointing position),
- maintain helium supply to instrument cold heads-,
- seal up the enclosure;
- wait until commercial power is again available.

The only components of the thermal control system that will still be maintained in operation are the helium compressors and the modular helium chiller; this is because a one hour interruption of cold head helium supply will require 12 hours of subsequent supply to achieve the initial head temperature.

5.4.1 UPS system

The UPS systems will automatically provide power to the following:

- computer room and telescope operations room (computers and emergency lighting);
- VME buss crates power supplies;
- telescope drives;
- instrumentation packages;
- Cassegrain rotator servos;
- the telescope primary mirror cover servos.

After sensing the loss of mountain power, the computer control system automatically initiates the following shutdown procedure:

- close the primary mirror covers;
- orient and park the telescope in zenith pointing position.

A telescope operator then starts the emergency generator.

5.4.2 Emergency generator

After a power failure, all mountain- powered electrical motor loads will go off line and require manual restarting. After the generator has been started, the following procedure is followed:

- a manual interlock is activated to disconnect the facility buss from the commercial grid;
- the generator is connected to the to the facility buss;
- the modular chiller for the helium compressors is manually restarted;
- the helium compressors (up to four) are restarted in sequential fashion;
- the upper shutter of the carousel is closed;
- the lower shutter is closed;
- the ventilation gates are closed in sequential fashion.

The elapsed time for a team of operators to perform the above tasks is estimated to be about 20 minutes. If during the process, additional computer time is required, then one of the rotary UPS systems is manually started with generator power.

Figures

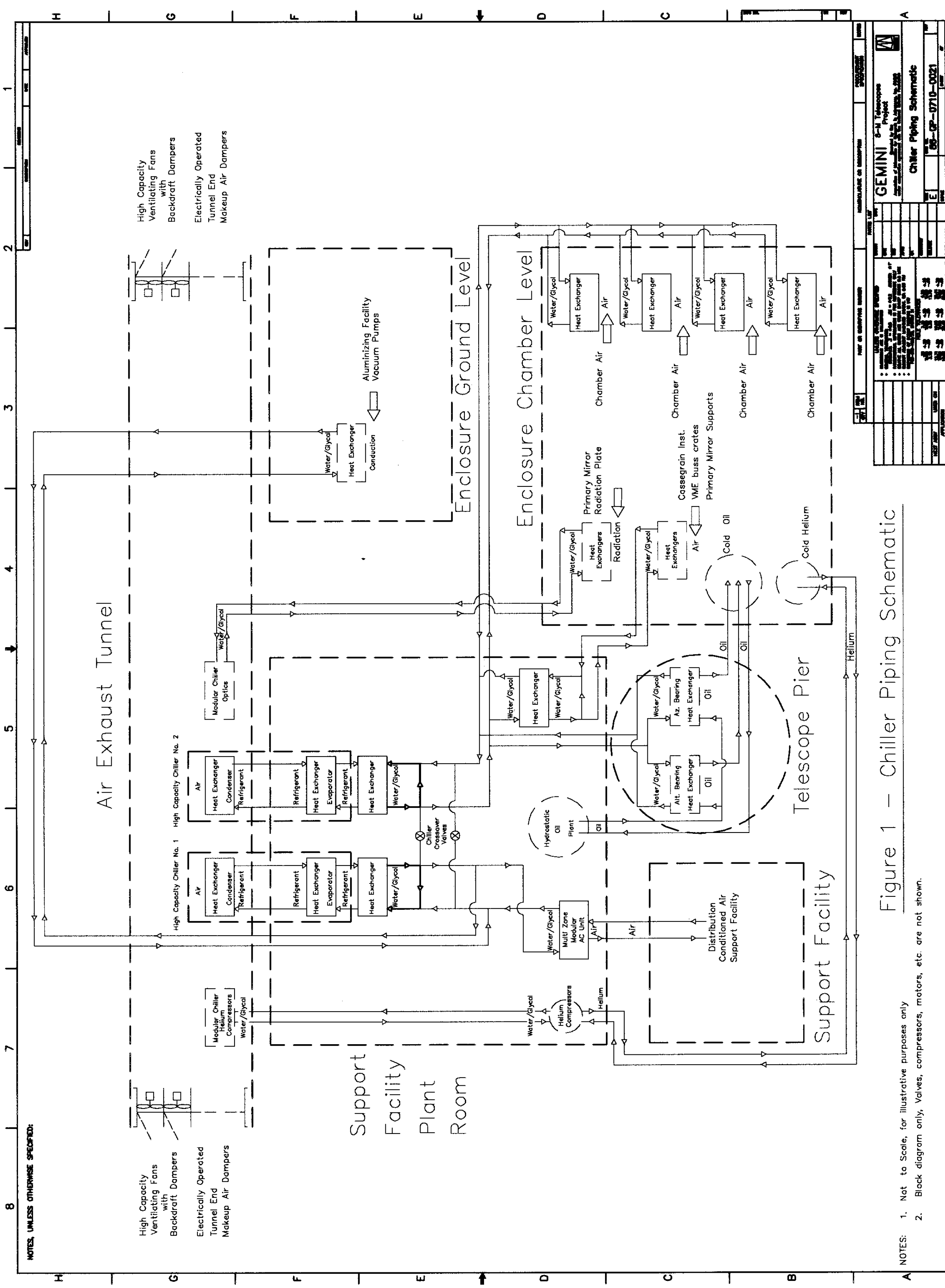
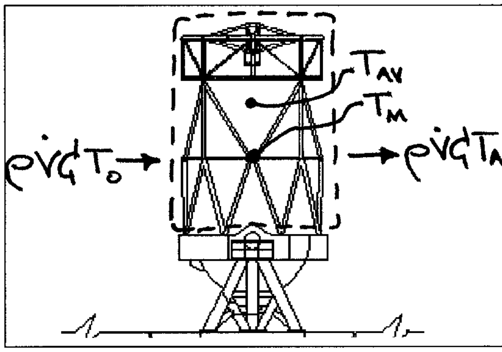


Figure 1 – Chiller Piping Schematic

Figure 2. Seeing as a Function of Air Velocity



1. Energy balance on air volume over primary optic:

$$\dot{E}_{FLOWIN} = \dot{E}_{CONVECTED} + \dot{E}_{FLOWOUT}$$

$$\rho\dot{V}\,CT_O + hA_S(T_M - T_{AV}) = \rho\dot{V}\,CT_{AV}$$

2. Solve for temp. differential between the air volume and the ambient air.

$$|\Delta T| = |T_{AV} - T_O| = \frac{h}{\dot{V}}\left(\frac{A_S}{\rho C}\right)\ |T_M - T_{AV}|$$

$$|\Delta T| = \frac{h}{\dot{V}}k\ \ |T_M - T_{AV}|$$

$$where: \qquad k = \frac{A_S}{\rho C} \qquad (Constnt)$$

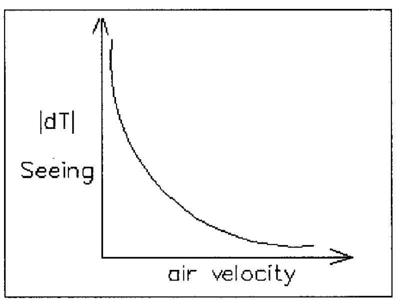
$$h = f(v)$$

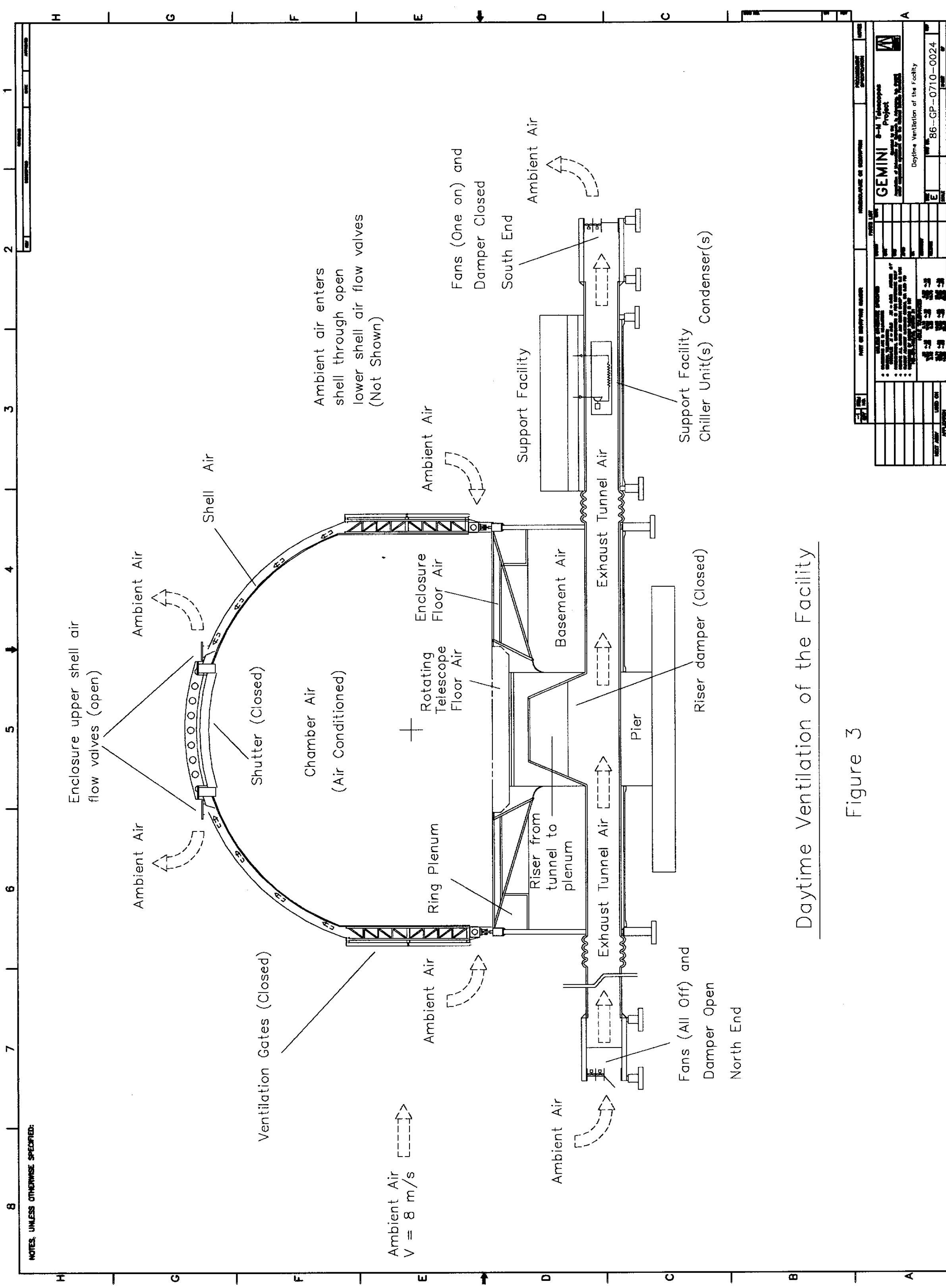
$$\dot{V} = f(v)$$

3. Look at the velocity dependent variables.

$$h \propto \sqrt{v} \ \ and\ \ \dot{V} \propto v;\ \ therefore\ \ \frac{h}{\dot{V}} \propto \frac{1}{\sqrt{v}};\ \ thus\ \ |\Delta T| \propto \frac{1}{\sqrt{v}}.$$

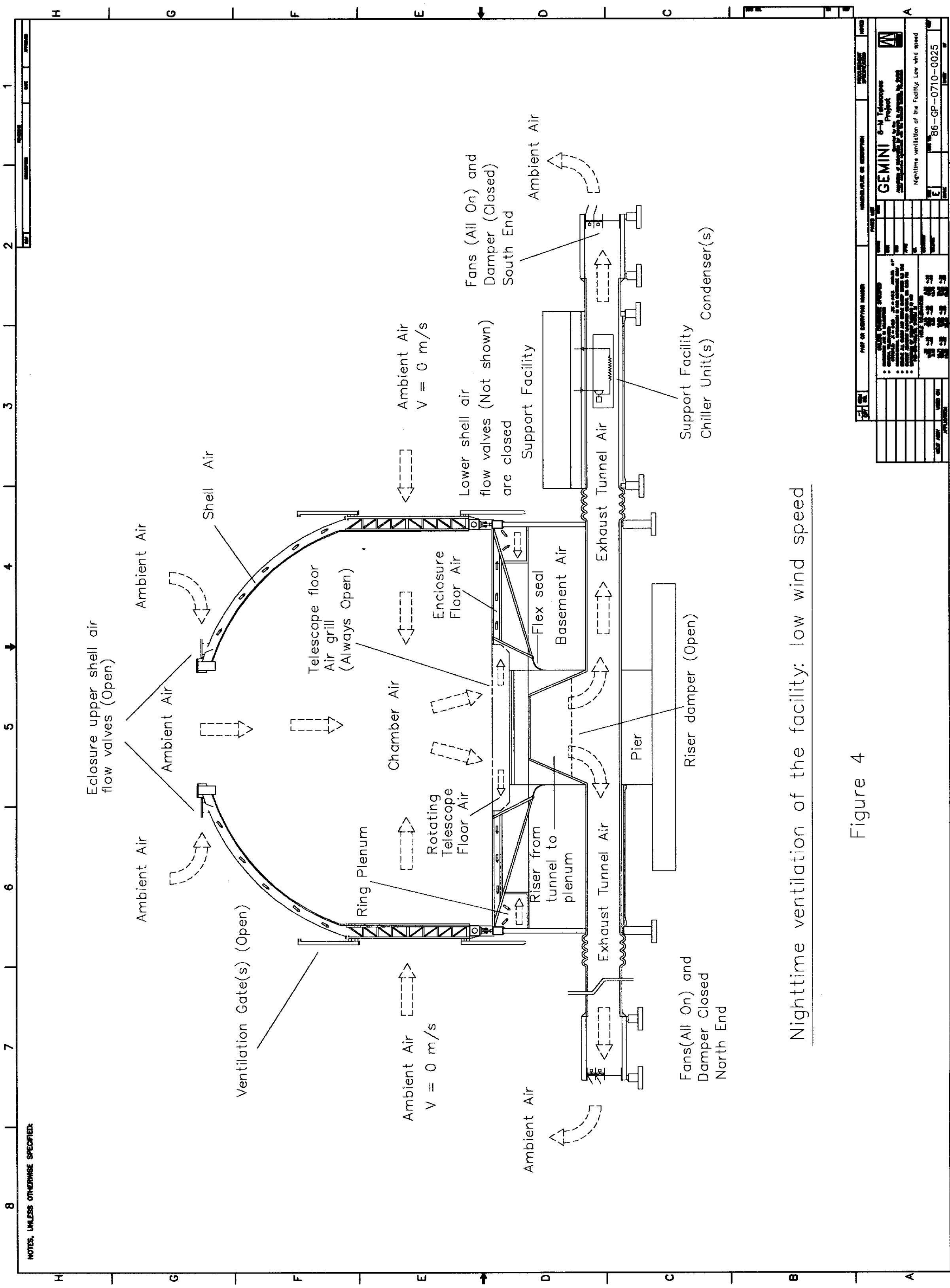
$$Since\ \ seeing \propto |\Delta T|^{6/5},\ \ seeing \propto \left|\frac{1}{\sqrt{v}}\right|^{6/5}.$$





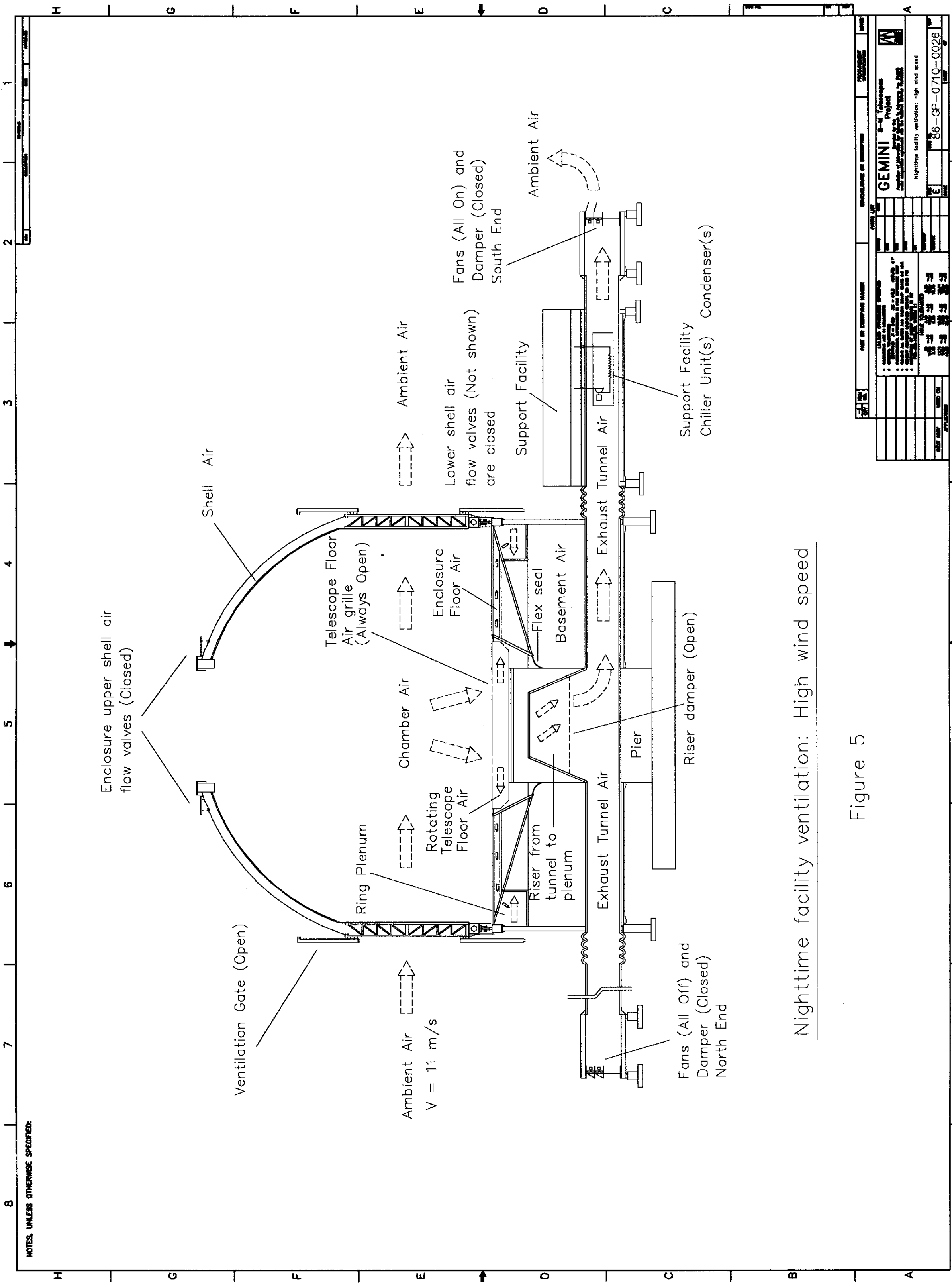
Daytime Ventilation of the Facility

Figure 3



Nighttime ventilation of the facility: low wind speed

Figure 4



Nighttime facility ventilation: High wind speed

Figure 5