Australian National University

Environmental Subsystem Design

Prepared For

Advanced Instrumentation and Technology Centre

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Contents

List of Tables

List of Figures

Acronyms

ANU Australian National University.

EOS Electro-Optic Systems.

GSL Guide Star Laser.

1 Introduction

The laser enclosure has several components within it that produce heat, which has a direct impact on the temperature and turbulence air within the enclosure. This is partially mitigated through the usage of liquid-to-air cooling systems attached to the components, however it is not entirely removed. Additionally, the dome is not a controlled environment due to both vents in the walls and the shutter being open during operation, meaning the environment surrounding the enclosure varies significantly. This means that the air quality within the enclosure must be controlled to ensure the propagation of the laser beams is not negatively impacted.

For these reasons, the laser enclosure is required to be a closed system, ensuring that the temperature of the various components will be controlled, as well as controlling the air quality around the laser beams. This has the secondary effect of ensuring that the air inside the dome, specifically around the primary mirror, will be free from turbulences introduced by heated air from the system.

The following sections detail the specifics of the three subsystems, focussing on the control of air quality through filtration, the control of air temperature within the enclosure, and the cooling of laser components.

2 Air Quality Control Subsystem

The air quality subsystem relates to the air quality within the laser enclosure. For adequate laser propagation, the air needs to filtered to remove particulate matter, and have air flow sufficiently low so as to not introduce turbulence.

2.1 Requirements

The requirements for the design of the laser enclosures air quality controls are taken from the system subsystem document [1], and are reproduced here. These requirements are listed in table 1.

Table 1: System Requirements

Reference	Description
2.5.5	The Electro-Optic Systems (EOS) Guide Star Laser (GSL) requires air quality to ISO class 7 clean room standards.
3.2.2	The Australian National University (ANU) GSL requires air quality to ISO class 7 clean room standards surrounding the laser-head
1.5.5	The telescope dome dictates that the System shall exist within a dirty and dusty environment.
1.5.2	The telescope dome dictates that the System shall not produce excessive hot air turbulence within the dome
1.5.5	The telescope dome dictates that the System shall exist within a dirty and dusty environment

2.2 Design Details

To ensure that the air quality is maintained at ISO class 7 clean room standard, we utilise design components from other pre-existing systems. Testing of such as design is unable to be completed without the unit being assembled, so assumptions have been made, however these have been detailed where necessary.

The standard design for a clean room utilises positive air pressure, an area of HEPA filters that the air travels through, and airflow controls to make it as laminar as possible [2]. This is necessary due to the large volume of the room, and the regular traffic that is seen in them. On a smaller scale we see laser enclosure systems similar to this one utilising different combinations of the components. The typical arrangement is a dry-air input valve passing air through a HEPA-filter, maintaining positive pressure [3]. Due to the components, we do not typically see a laminar airflow, however the low air velocity and temperature uniformity mitigate this issue [4]. Additionally, due to the size and structure of the system, turbulence within the enclosure is of little concern [5].

The two possible options for the air intake are an open loop or a closed loop system. The open loop system proved to be largely inferior in design, so was removed from consideration.

2.2.1 Closed Loop System

The closed loop system is preferred, due to the simplicity of the system. By placing a HEPA filter and fan on the air intake at the top of the enclosure, with a return-air pipe at the base of the enclosure running the air back through the filter, we remove the need to constantly filter outside air.

This limits the work requirement from the filter, extending its maintenance cycle substantially. For a filter with only a small workload, the effective life can be indefinite [6].

The closed loop system has a second advantage, in that the heating and cooling of the enclosure is easier. With the air circulating within the enclosure, the main consideration for heat exchange is through convection from the surface of the enclosure to the dome (or vice versa), and does not need to include the heat lost or gained by taking in outside air constantly.

The single advantage that the open-loop system had over the closed-loop was by venting out air away from the dome (piping the air externally). This had the benefit of removing the heated air at a location away from the system. The fall back of this, however, is that more heat is required to be produced, and the convection of heat from the closure is the same, regardless of the loop chosen. This was further supported by the proposed enclosure cooling design (see section 3.4.2, where the heat will be extracted with the rest of the system heat through the chillers on the entry level.

2.3 Air Flow Requirements

The required air flow for good performance from a HEPA filter is approximately 0.45m/s [7, 8]. Using a filter size of approximately 120mm × 120mm, we get a flow rate of $6.48\times10^{-3}\text{m}^3/\text{s}$, or 6.48L/s.

With an enclosure volume of approximately 1.824m^3 [9], we see that it takes approximately 282 seconds to fully cycle the air within the enclosure, allowing 12 full air cycles per hour. This is approximately one third of the number that is recommended for a class 7 clean room [10], however, this is likely to be sufficient for an enclosure that is mostly closed to the environment [5].

If the performance proves to be insufficient, it is recommended to include a second filter in parallel with the first, increasing the number of cycles to 24 per hour, however this is likely to be unnecessary.

3 Enclosure Temperature Control Subsystem

This section looks at different methods for control of the ambient air temperature within the enclosure. This is important to control due to high temperature variation, as well as temperature critical components such as the components of the cooling system that lie within the enclosure. Specific temperature control systems for individual components are detailed in section 5.

3.1 Requirements

The interior of the dome sees large fluctuations in temperature, due to the high seasonal variation of temperature that is seen at Mt. Stromlo, paired with relatively poor insulation on the dome. The peak interior temperature observed is 30±2° [11], and the minimum temperature is predicted to be below zero [12].

The requirements for the design of the laser enclosures temperature controls are taken from the system subsystem document [1], and are reproduced in table 2.

Table 2: Enclosure Temperature Control Requirements

Reference	Description
1.5.3	The telescope dictates that the System shall account for temperatures up to 30±2°C.
2.5.1	The EOS GSL requires ambient temperature between 0°–40°C, but could work in lower temperatures.
3.2.3	The ANU GSL requires an operating temperature of 10° - 30°C
3.2.4	The ANU GSL requires a non-operational temperature of greater than 5° C, unless anti-freeze is used

The temperature requirements for the ANU GSL lies within that of the EOS GSL, so we use this as our guideline for temperature control. The required temperature while operating is between 10° and 30°C [13], with a non-operating minimum temperature of less than 5°, without introducing antifreeze to the cooling system [13]. Due to the recommended chillers being unable to operate with antifreeze [14], we set the minimum temperature to 10°.

To maintain these temperatures, there are three proposed solutions. These are utilising installation around the enclosure, introducing a temperature control system for the enclosure air intake, or a hybrid of the two. These are detailed in sections 3.2 to 3.4.

3.2 Enclosure Insulation

Utilising an insulating material for the side panels was one of the recommended approaches for temperature control [5]. We begin by analysing the system if insulation is not used, to determine if it is feasible to not use.

This is is dependent on which air-flow model is used. If option A is selected, we can find an approximate solution for the temperature by taking the heat loss through the enclosure walls. If the heat entering the enclosure from the heating element is greater than that leaving, we can conclude that this device will be able to heat the system.

One of the proposals for enclosure walls was the Kentek Blackout Windows [15], which are a polymer based compound. These panels have a thickness of 6mm, and will have a total surface area of approximately $9.52m^2$ **Cite Mechanical Report**. The thermal conductivity is not provided by the manufacturers, however similar materials have conductivities of between 0.15 and 0.5 $(W/m \cdot K)$. We take the higher value for this, setting it at $0.5(W/m \cdot K)$.

Using an internal temperature of 10°C and an external of 0°C, we get:

$$\begin{aligned}
\dot{Q}_c &= -\kappa A \left(\frac{T_2 - T_1}{L} \right) \\
&= -0.5 \times 9.52 \times \left(\frac{10}{0.006} \right) \\
&= -7.94kW
\end{aligned}$$

The volume of the air within the enclosure will be approximately 1.824m^3. The properties of the air within the enclosure are a specific heat of 1.004 $(kJ/kg \cdot K)$ [16], and a mass of $1.275kg/m^3$. This gives us a total air mass of 2.33kg. From this, we can calculate the total energy that can be lost before the enclosure has dropped to the external temperature:

$$\begin{aligned}
Q &= c_v m (T_2 - T_1) \\
&= 23.38kJ
\end{aligned}$$

This gives us an approximate time of 3s for the system to equalise temperature with the dome. This is not suitable, indicating that insulation is required.

One of the proposed insulation materials is provided by Askin [17], which offers various width panels, giving different heat loss values. Again, we used the surface area of 9.52m^2, and temperatures of 10° internal and 0°C external.

This gives us a set of thermal loss for different thickness's, listed in table 3.
From these values, we determine that insulation significantly reduced the heat loss from the enclosure.

Table 3: Heat Loss by Thickness

Thickness (mm)	Heat Loss (W)
50	65.66
75	45.34
100	34.62
125	28.00
150	23.50
175	20.24
200	17.80

Unfortunately, we note that this is by no means sufficient to maintain the temperature. Repeating the same calculation as above for the temperatures to equalise, we find that the equalisation time for 50mm is slightly under 6 minutes, and slightly over 20 minutes for 200mm. As temperatures below zero would likely be maintained for several hours, we note that insulation on its own is insufficient.

3.3 Enclosure Active Temperature Control

Active temperature control requires both heating and cooling capabilities. The preferred method is to utilise a small heating heating element as part of the air intake system (detailed in section 2), as well as a liquid-air cooling unit connected the the main component chiller units (detailed in section 5).

The heating and cooling will be controlled by a simple temperature sensor and controller device, such as [18]. This will ensure adequate operation of the system.

When looking at the size of heater required if no insulation is present, we immediately see that it is impractical. 4kW of heating is required to maintain the temperature, which would require installation of 2 separate 2kW heaters inside the enclosure (this is due to the 2.4kW limitations on single phase power). A 2kW heater is sizeable, and would make the design far more complex than simply introducing insulation.

3.4 Hybrid Insulation and Heating

The most practical solution is that of using a small heating element, a small cooling radiator, and insulation on the enclosure walls.

3.4.1 Heating

To calculate the performance, we take values from one of the proposed devices, the Pfannenberg 10-30W heater [19]. It is noted that there are 3 models, at 10,20, and 30W, however the physical dimensions do not differ between models. The surface area of the device is approximately 0.06074m^2, and the maximum operating temperature is 140°. The deviceS have duty-cycles of 100% when operating.

We note that for using the 30W model, we are able to sufficiently maintain the heat for insulation of 125mm or greater, so we select the 30W model, and a minimum insulation thickness of 125mm. Due to 1.1.2 enclosure requirement limiting the overall depth of the system to 1000mm [1], it is preferable to limit the insulation width to 75mm. This limits the total depth to approximately 950mm. To achieve the heating requirements, we include a secondary 30W heating element, which ensures heating can be achieved with the 75mm insulation, as well as including a buffer for any inaccuracies in the measurements.

It is further noted that these two heaters could be replaced by any number of heaters up to 60W power, provided the total surface area is equal.

To ensure that the device is capable of operating without error at maximum temperature, we must ensure that it does not exceed its maximum temperature. Using the previously calculated values, we use *Newton's Law of Cooling* to calculate the surface temperature.

$$\dot{Q}_C = hA(T_b - T_f) \tag{1}$$

where

h :	Convection Heat Transfer Coefficient
A :	Surface area of device
T_b :	Temperature of the surface
T_f :	Temperature of the fluid

For a slow moving gas, we use the model of free convection, giving a value for h of between 10 and 20 $(W/m^2 \cdot K)$ [16, 20], which could potentially be increased if needed, however it is ideal to minimise this to both reduce air turbulence, as well as to decrease the vibrations caused by the fan.

As the device temperature will be dependent on the heat exchange with air, and that the temperature will be maintained using PID control at a minimum of 10°C, we calculate the body temperature assuming maximum supplied power. Putting these values into equation 1 for maximum and minimum h, we find:

$$T_{(B,30W,\min)} = 108°\text{C} \qquad\qquad T_{(B,30W,\max)} = 60°\text{C}$$

These temperatures are all below the device maximum of 140°C, indicating that it is capable of providing the maximum rated power without issue.

From this, we determine that the device is capable of heating the enclosure sufficiently.

3.4.2 Cooling

Active cooling is required to keep the internal temperature below the maximum possible dome temperature of 32°C. This can be achieved by the use of a radiator, connected to one of the chillers detailed in section 5. As the temperature requirements of the components has not yet been specified [13], the temperature of the chiller has not yet been determined.

The radiator proposed [21] does not list a surface area for the component, however due to the design of the radiators, this will be greater than that of the heating element. Additionally, as the warmest of the coolers is likely to have a greater temperature differential than for the heating element, the cooling efficiency will be further improved, suggesting that such a design would work.

3.5 Temperature Control Design Proposal

The proposed design for the system consists of a HEPA filter, fan, cooling radiator, and heating element in sequence in the air intake. The heater and cooler will be activated when the temperature whenever it is needed.

This will ensure that the enclosure stays within the 10°C to 30°C requirements imposed on the system.

4 Air Intake Design

The air intake is system, including HEPA filter, fan, radiator, are to be in series at the top of the enclosure. The design ordering can be seen in figure 1. The arrangement is shown connected to the enclosure in figure 2.

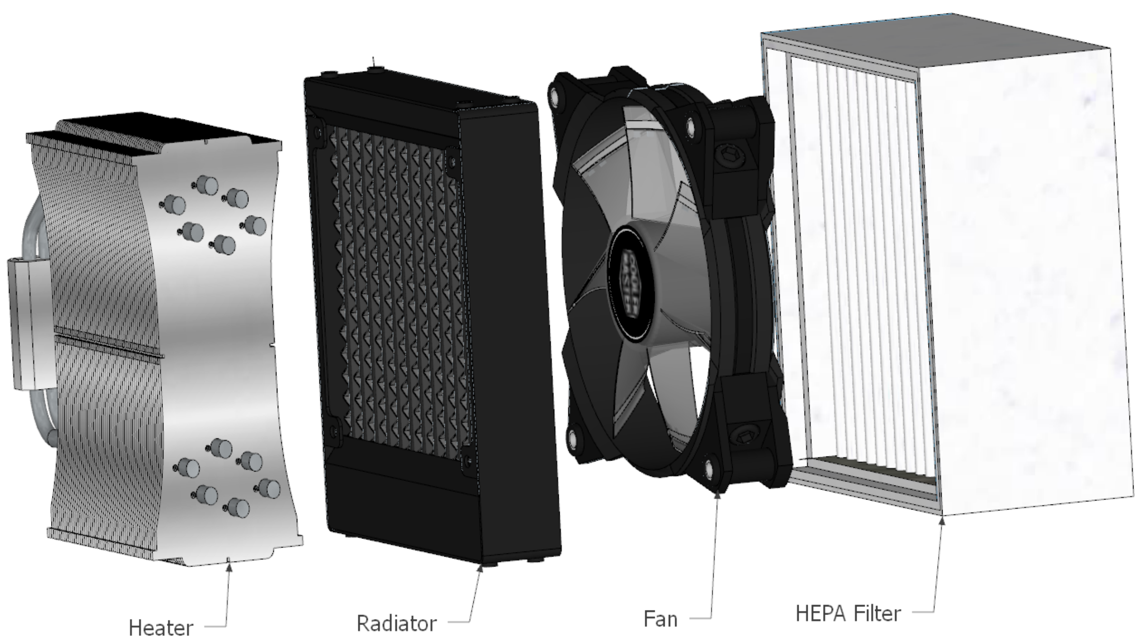

Figure 1: Air Intake Design

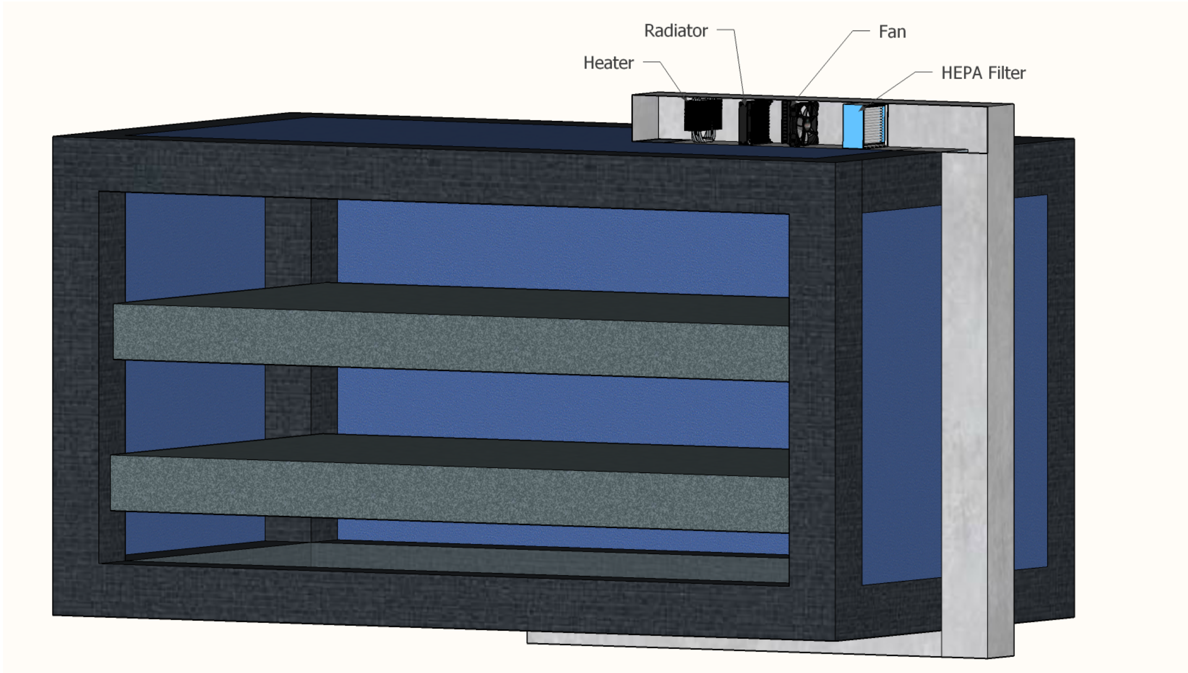

Figure 2: Air Intake Design

5 Component Temperature Control Subsystem

The EOS and ANU Guide Star Lasers have several components within them that require specific temperatures, namely the amplifiers and oscillators. While the exact operation of the lasers is outside of the scope of the projects, the EOS and ANU lasers both require consistent inputs of water at the specific temperatures for the lasers to operate, through the installation of nearby chillers to cool them, and dispose of waste heat.

5.1 Requirements

The EOS and ANU GSLs both require a certain volume of water at two specific temperatures, for their oscillators and amplifiers, resulting in a total of four potential temperatures [14, 13]. This means that it is possible that a total of four different chillers or heat exchangers will need to be installed, as each can only maintain a single temperature. However, it is likely that the oscillator components will be mounted in the clean room outside of the telescope [22], which has its own cooling systems, reducing the number of required temperatures to three. In the case that the ANU laser components both require the same temperature, or the same temperature as the EOS GSL, then this number could be even further reduced. Therefore, several different cooling designs are needed, to be chosen from when the final specifications for the lasers are provided by both EOS and the ANU vendor.
The following tables illustrate the cooling-related requirements for both lasers.

Table 4: Laser Cooling Requirements

Reference	Description
2.1.11	The EOS GSL requires that 10±2 cooler pipes must enter the EOS GSL breadboards collectively.
2.1.12	The EOS GSL requires The EOS GSL requires that coolers be attached to the System at a distance constrained only by the size of the telescope dome, and the vibrational impact on the lasers.
2.1.15	The EOS GSL requires that a deionised water and OptiShield Plus solution be used as a coolant.
2.1.16	The EOS GSL requires that any coolant additives be 100% soluble in de-ionized water.
2.1.17	The EOS GSL requires that the cooler is re-filled with ≤2.8L of water as necessary.
2.5.9	The EOS GSL requires that the amplifier components of the 1342nm laser assembly be kept at a temperature of 17±1°C.
3.2.1	The ANU GSL requires less than 800W of cooling.
3.2.5	The ANU GSL requires a combined flow rate of 8L/min.
2.1.19	The EOS GSL requires that Ethylene Glycol is not used in the coolers.
3.2.7	The ANU GSL requires cooling at potentially two different temperature points, for the amplifiers and the oscillators.

Table 5: Laser Cooling Requirements

Component	Temperature	Cooling	Location	Other
EOS GSL Oscillator	Unknown, possibly 17±1°C	Combined with amplifier, ≤400 W, possibly as low as ≤30-50 W	Likely to be placed in the clean room, out of scope	OptiShield Plus solution, no ethylene glycol
EOS GSL Amplifier	17±1°C	Combined with oscillator, ≤400 W, possibly as low as ≤30-50 W	Laser enclosure, telescope third floor	OptiShield Plus solution, no ethylene glycol
ANU GSL Oscillator	Unknown	Combined with amplifier, ≤800 W. Combined with amplifier, flow of 8 L/min	ANU electrical cabinet, first floor, or laser enclosure, third floor	Unknown
ANU GSL Amplifier	Unknown	Combined with oscillator, ≤800 W. Combined with oscillator, flow of 8 L/min	Laser enclosure, telescope third floor	Unknown

5.2 Chiller Selection

The EOS GSL requires that the chillers be able to use the OptiShield Plus solution, a corrosion inhibitor which is added to the water in the cooling loop. Two different families of chillers, compatible with the Optishield solution, are currently being used by EOS to cool the laser in the lab, the Bayvoltex and Termotek Chillers, and it was suggested [14, 23] that these were the most suitable to be used in the

telescope dome as well, due to their proven history in cooling the lasers so far, and meeting all the requirements.
No similar requirements have been provided so far for the ANU laser, due to the early stage of its development. It is assumed however that it will require a similar system as the EOS laser, due to the similarly delicate nature of its design, as well as for ease of installation and maintenance.
The following are the chillers and heat exchangers considered for use in the design, both those currently being used by EOS for the GSL in the lab, and other recommended models.

Table 6: Chillers and Heat Exchangers

Chiller	Cooling	Power Usage	OptiShield Compatible	Other Notes
Termotek P-300 Series [24]	Liquid-Liquid or Liquid-Air 10-35 degrees, 0.1 stability 300-3500 W cooling 0.5-16 l/min flow	575-2000 W 240 V Single-Phase 50 or 60 Hz	Yes	$8000+, the most expensive model.
Bayvoltex Rack-Mounted Chiller [25]	Liquid-Liquid or Liquid-Air 5-35 degrees, 0.1 stability 500-1700 W cooling 8.3 l/min flow	720-1800 W 120 V Single-Phase 60 Hz	Yes	The most widely-used model by EOS
Bayvoltex Fluid to Fluid Heat Exchanger [26]	Liquid-Liquid 5-50 degrees, 0.1 stability 20,000-100,000 W cooling 8.3-37.8 l/min flow	600-2300 W 120 or 230 V Single-Phase 60 Hz	Yes	Heat-exchanger, so incapable of cooling on its own and requires chilled water input.
Thermo Scientific Polar Series Chiller [27]	Liquid-Air -25-80 degrees, 0.1 stability 500 W cooling 21 l/min flow	500 W 220 V Single-Phase 50 or 60 Hz	Unknown	Very low noise and vibration output, can also heat in addition to cooling.

5.3 Heat Exchanger Loop Design

It was recommended [23] that the design in the telescope dome incorporate the use of Bay Voltex heat exchangers; this was suggested because they are very reliable at maintaining a specific temperature, as well as meeting the other requirements of the cooling system.
Figure 3 is a design involving the use of three Bay Voltex Heat Exchangers to maintain individual temperatures, with a chiller on the first floor to provide the liquid cooling. The first floor of the telescope is partially insulated from the upper floors, making it an idea place for the liquid-air chiller to be placed without affecting the air temperature of the upper floors.

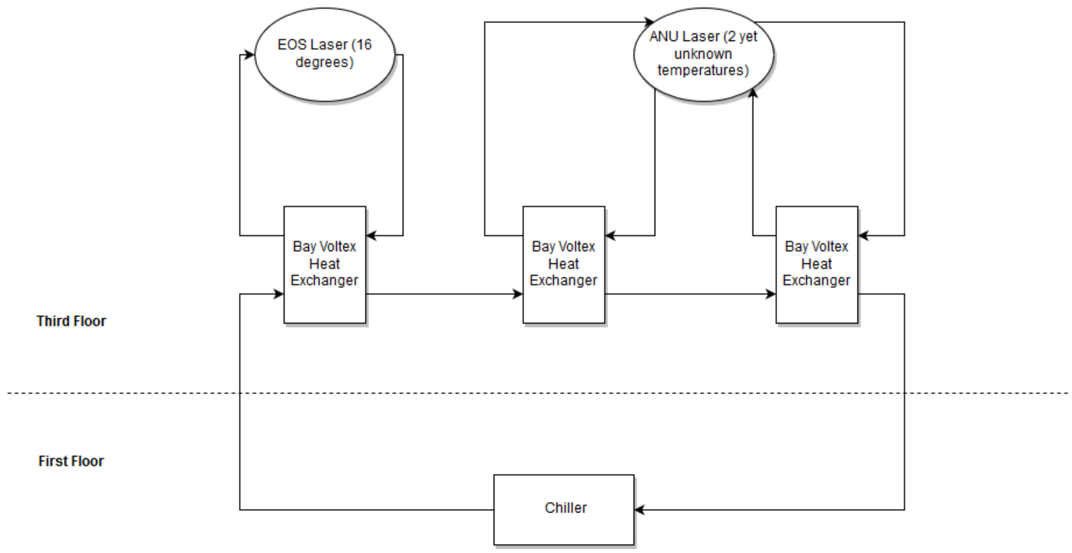

Figure 3: Design with Heat Exchangers and First Floor Chiller

The chiller depicted in this design could be a EXC-800 chiller (or two, if both lasers are required to operate at the same time), or any other chiller capable of providing water at a low enough temperature in a liquid-air system. The inputs to the ANU laser also might be different; it is possible that the oscillator of the ANU laser will be instead placed in an electrical cabinet, separate from the laser enclosure, requiring the cooling to be distributed there instead.

Figure 4 is a design showing another recommended variant, this time without the chillers and instead with a connection from the observatorys main cooling loop; note that this will require an expensive installation procedure.

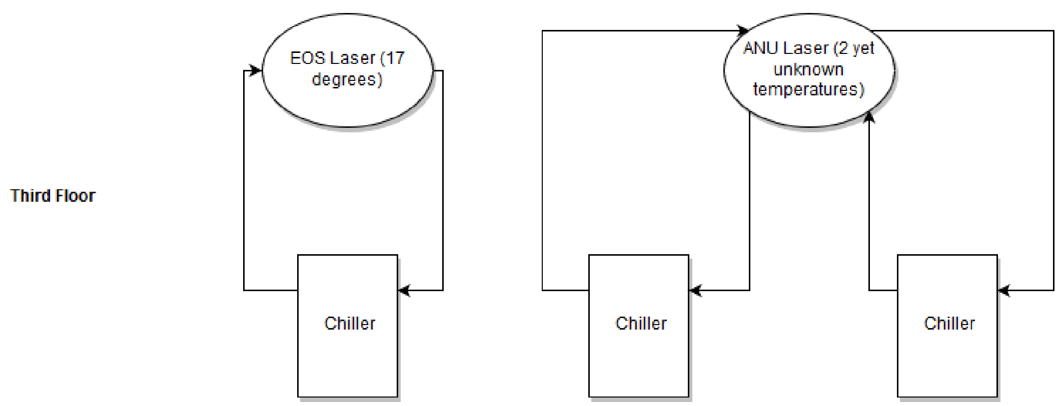

Figure 4: Design with Heat Exchangers and Main Loop

There are several drawbacks with this design when compared to the design above; the piping required to connect to the observatorys main loop to the 1.8m telescope is likely to be difficult and expensive, more so than installing a chiller on the first floor. Additionally, the water will have to be piped up the cable wrap, which has not been done before and will require the use of very thin pipes [23], significantly limiting the amount of water available for cooling. This design should only really be considered if there are other projects planned for the 1.8m telescope that are also likely to require large amounts of liquid cooling.

5.4 Direct Cooling Design

An alternative system proposed [14] is to use the same cooling system as that which is currently in the EOS laser lab. This is seen in figure 5. The Termotek and Bay Voltex chillers also meet all of the necessary requirements, and a system with individual chillers for each is easier to implement, install, and maintain, if more expensive due to having to purchase and install three individual chillers.

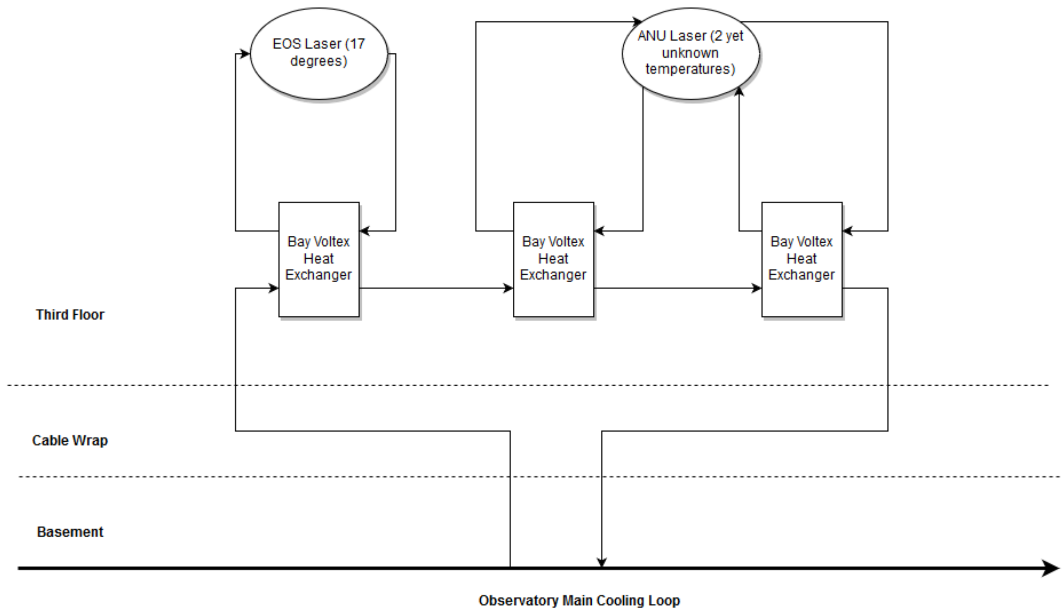

Figure 5: Design with Individual Chillers

Due to the fixed temperatures set in each chiller at installation, even if only one of the lasers were operated at a time, it is not possible to create a system to reuse the chillers for both lasers. The chillers that can be used for this system are the Termotek and Bay Voltex, with the appropriate thermal cooling power for each application (≤400 W, ≤800 W), cooling solutions, and flow rate. In addition, if the final design of the ANU or EOS lasers have very sensitive vibration or heating requirements, the Thermo Scientific Chiller could be used instead.

This is the preferred system, due to the strong thermal stability, small space requirement, minimisation of cables to be routed, and general design simplicity. This draw back is price, however, this is a valid trade-off.

6 Flooring around Enclosure

The enclosure is required to have anti-static, non-conductive flooring surrounding it. This is to ensure no damage will occur to the components during maintenance when the covers are removed.

The requirements for this is shown in table 7.
A mat, such as [28] will meet these requirements. To ensure that the mat covers a sufficiently large area, the recommended size for the mat is seen in figure 6. This will ensure that nobody is able to touch the

Table 7: System Requirements

Reference	Description
2.5.6	The EOS GSL requires that the area in which the System is located has an anti-static floor
2.5.7	The EOS GSL requires that the area in which the System is located has a non-conductive floor

inside of the cabinet while not standing on the mat.

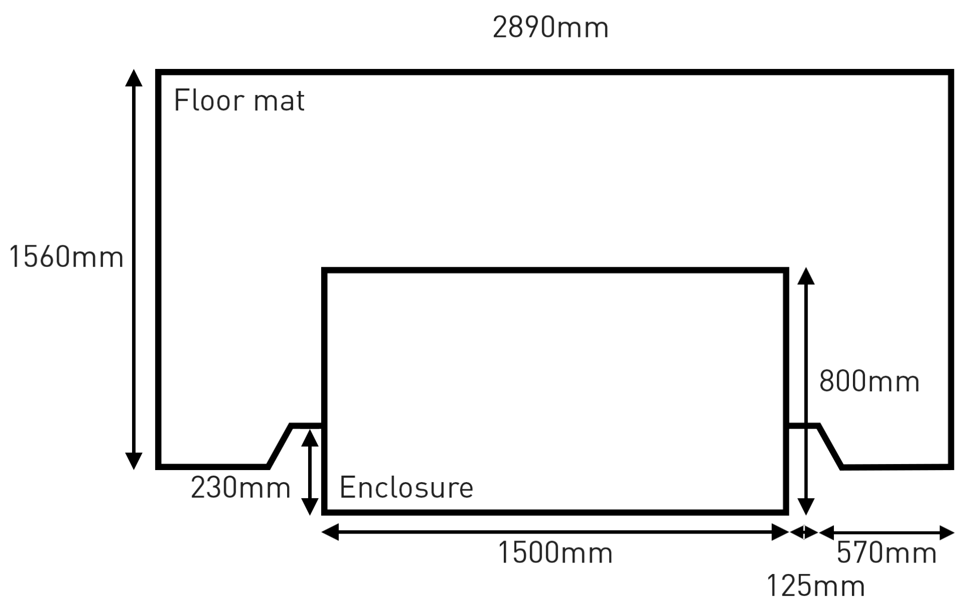

Figure 6: Anti-Static, Non-Conductive Floor Mat

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