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Analysis of the requirements and their impact on the design of electronic cabinets for the current generation of ESO ELT instruments

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ABSTRACT

In the ESO ELT control electronics guidelines, the hardware devices are located in standard COTS cabinets, each equipped with an air-liquid heat exchanger and customized for the specific application. The customization is done in order to achieve compliance to the stringent thermal and vibrational requirements. The cabinet design must also fulfil the required earthquake protection. In this paper these requirements are highlighted and analysed. An alternative custom design of the cooling system is then proposed and analysed, with specific focus on the thermal and vibrational aspects. The custom solution also allows for the use of a different cabinet, optimized for the use of DIN rail electronic components. The possibility of not using fans for air recirculation inside the cabinet is also considered, in order not to introduce further vibrations to the system.

Keywords: ESO, ELT, Electronic cabinet, Thermal requirement, Vibrations, Cooling

1. INTRODUCTION

The European Southern Observatory is responsible for the construction of the ELT (Extremely Large Telescope). This telescope is being built in Chile and it will be the biggest telescope in the world, with a primary mirror of 39 meters in diameter. A higher level of image resolution will be achievable with the ELT class of instrumentation. The quality of observations will be also guaranteed thanks to the adoption of Adaptive Optics systems. In particular, one thin deformable mirror (M4), belonging to the main telescope optical path, will be employed. Additionally, MICADO and a future instrument will benefit from the action of the Multiconjugate adaptive Optics Relay For ELT Observations (MORFEO, formerly known as MAORY), an optical module with an additional deformable mirror [1].

Figure 1. Adaptive optics comparison, ESO.

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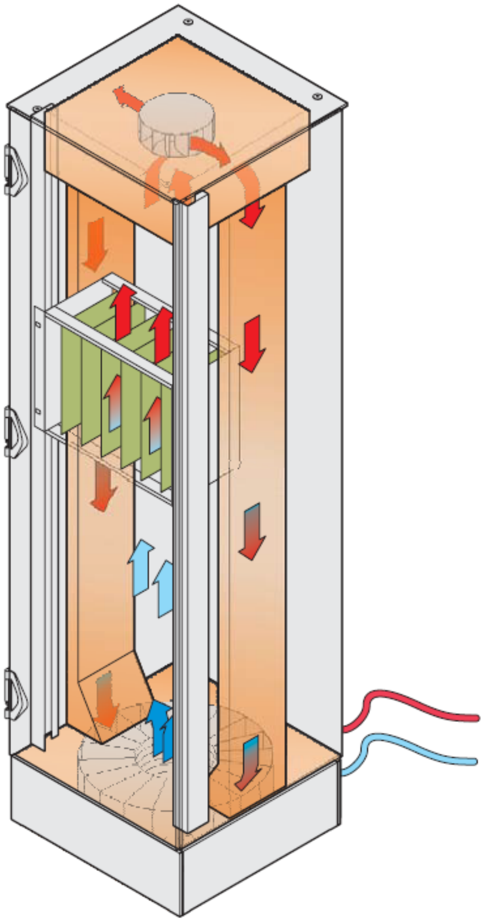
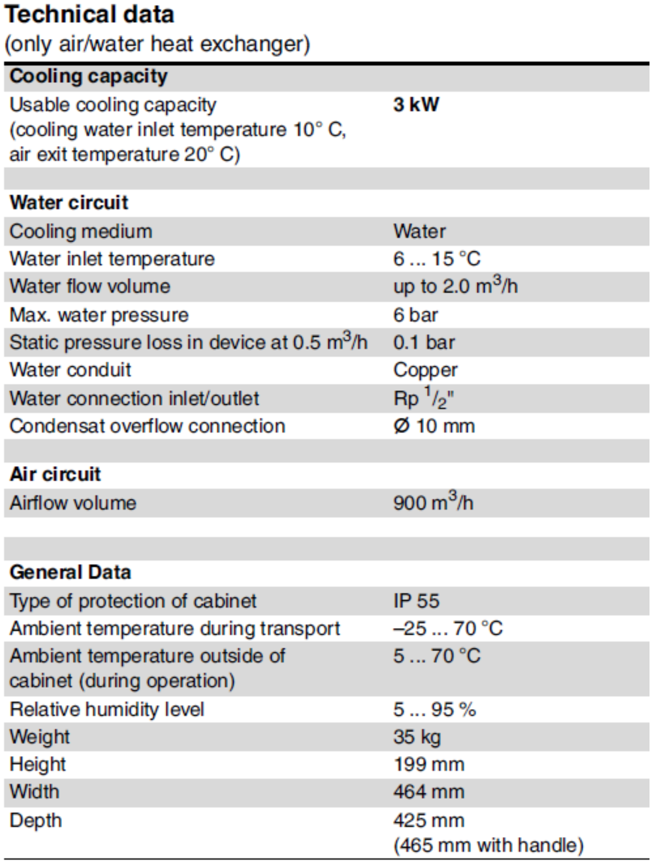
The high efforts done in order to compensate for the turbulence induced by the atmosphere could be thwarted if there are other sources of turbulence.

The temperature of the ELT instruments outer surface must be strictly regulated [2]. In fact, the difference between surface temperature of the items placed on the Nasmyth platform and the ambient temperature could induce natural convection phenomena that can alter the field of view and drastically reduce the potential of the AO under the resolution point of view. Special attention must be given to the cooling of the active sources of heat, mainly the control electronics [3][4].

2. CASE STUDY

The control electronics for the ELT instruments are hosted into standard 19" cabinets (Figure. 2). The COTS cabinet is already provided with a built-in heat exchanger taking a cooling fluid from the SCP (Service Connection Point provided by ESO) that is used as cooling vector to the ambient, and a fan that moves the air inside the cabinet in order to induce a forced convection. The assembly, as built, needs a customized damping system in order to eliminate, or at least reduce, the transmission of the vibrations arising from this system. In fact, due to these vibrations, the movement induced to the system could become another element of disturbance for a system as sensitive as the ELT [5].





Technical data

(only air/water heat exchanger)

Cooling capacity	
Usable cooling capacity (cooling water inlet temperature 10° C, air exit temperature 20° C)	**3 kW**
Water circuit	
Cooling medium	Water
Water inlet temperature	6 ... 15 °C
Water flow volume	up to 2.0 m^3/h
Max. water pressure	6 bar
Static pressure loss in device at 0.5 m^3/h	0.1 bar
Water conduit	Copper
Water connection inlet/outlet	Rp $^1/_2$"
Condensat overflow connection	Ø 10 mm
Air circuit	
Airflow volume	900 m^3/h
General Data	
Type of protection of cabinet	IP 55
Ambient temperature during transport	–25 ... 70 °C
Ambient temperature outside of cabinet (during operation)	5 ... 70 °C
Relative humidity level	5 ... 95 %
Weight	35 kg
Height	199 mm
Width	464 mm
Depth	425 mm (465 mm with handle)

Figure 2. Schroff Varistar LHX3 cabinet with cooling system, Schroff catalogue.

2.1 Solution

A fanless design of the cabinet cooling is under study, in order to achieve a system that can ensure the operative thermal conditions imposed by the ESO requirements, without the problem of the vibrations. In this study a cabinet placed on the Nasmyth Platform is used as an example, and the typical condition in which a cabinet belonging to the Instrument Control Hardware system of MORFEO works during operations, with an average power dissipation of 500 W, will be considered. These operative conditions are considered in a feasibility study, that represents the first milestone for the effective design of a fanless cooling system.

The first step is in fact to determine if, due the boundary conditions, a design that satisfies the thermal energy equilibrium can be made.

Table 1. Boundary operative conditions.

Item	Description
ΔT Surface/Ambient air	±1.5°C
h_e (external convection coefficient	5W/m2K
Temperature of coolant supply	T_{amb}-8°C
Temperature of coolant return	$<T_{amb}$
Air pressure	712mbar±50mbar
Air temperature (operational)	From 0 to 15°C
$\%\varphi_{avrg}$	42% (@ Paranal)
Coolant type	Water + 33% ethylene glycol
Internal heat generation	500W

2.2 Insulation strategy, a feasibility study

Most of the cold-plates available on the market are designed for a cooling power much bigger than 500W, so it could be taken into account that a commercial cold-plate is a cold sink for our application. In fact, if the hot power is much lower than the capacity of the cooling system, it can be estimated that the variation of temperature between the entering glycol-water mixture cooling vector and the exit is very small. In these conditions, after a transient period, the temperature of the powerful cold-plate should reach an equilibrium with the inside temperature of the cabinet.

Considering the worst case in which the inner temperature of the cabinet is the same as the temperature of the cold-plate, the difference between the internal temperature and the external ambient temperature can be, at most 8 ºC. Since the external cabinet wall can be at most at a temperature that is 1.5 ºC lower than the ambient air temperature, a thermal resistance must be introduced to keep the temperature difference between the internal walls of the cabinets and its external surface at 6.5 ºC.

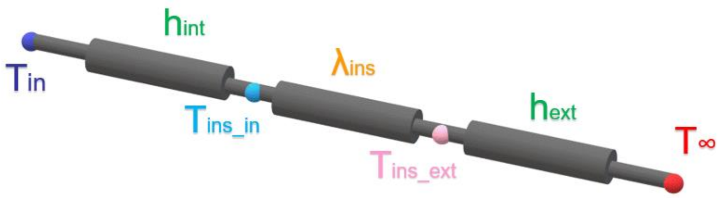


Figure 3. Equivalent electrical scheme. From left to right, the temperature of: electronics; internal walls of the cabinet; external insulated surface; ambient air.

To this end, the cabinet walls must be insulated. In this study, Armaflex® insulating material, with a thermal conductivity of 0.045 W/mK, has been considered. The needed thickness of the insulating material has been computed for the system to be compliant. From the analysis, an Armaflex thickness of 17 mm is needed.

With this information we have all the data to compute the function linking the thermal power exchanged between the cabinet and the ambient air and the internal convection intensity in the interval of ±1.5 ºC imposed by the requirements.

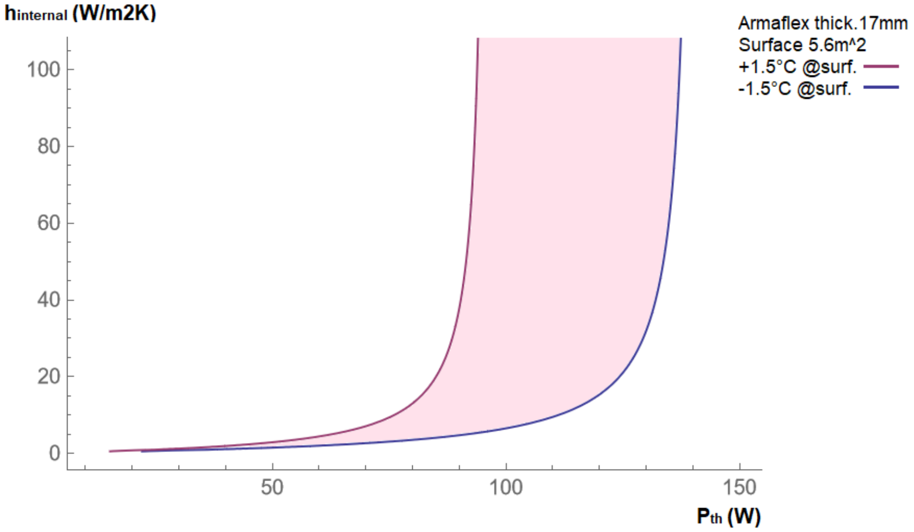


Figure 4. $h_{internal}$ vs thermal power in the range of interest.

2.3 Insulation strategy test, a zero-dimensional model

The data obtained has encouraged us to build a model to understand whether the most important actors of the actual physical phenomena work in the way it has been hypothesized in the previous considerations. This task has been performed through Simulink®. The has been almost entirely developed using standard components. A customized box was coded by us in order to compute the magnitude of heat convection factor of the system, as it is built.

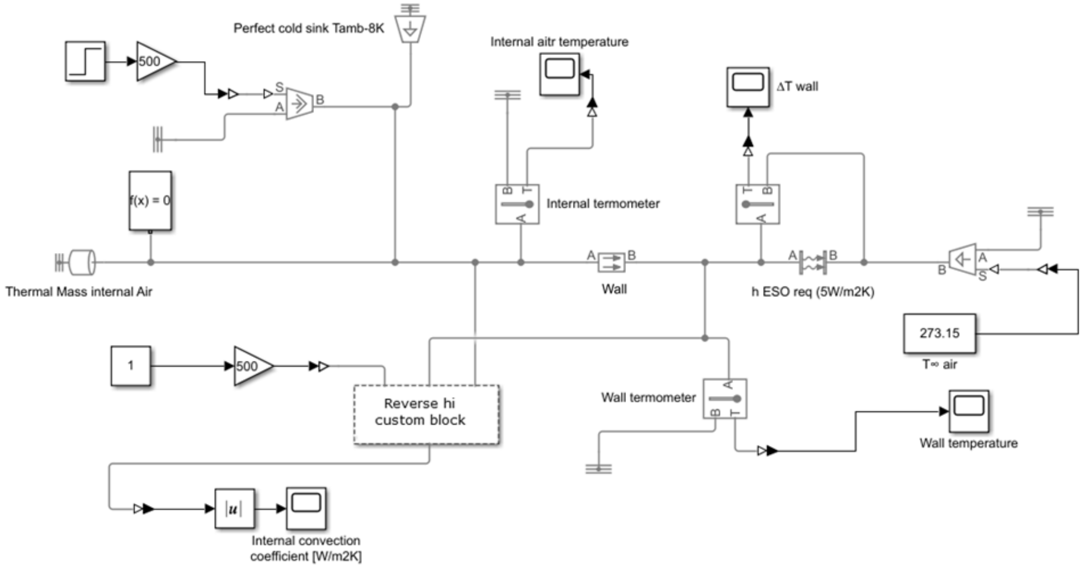


Figure 5. Zero-dimensional model of the cabinet.

The model is based on the following library:

Table 2. Simulink library.

Item	Description
Thermal mass	Simulates the mass of the internal air
Conductive heat transfer	Simulates the Arfmaflex insulation
Convective heat transfer	Simulates the external convection
Thermal reference	Simulates the external air (is used as reference for all the thermometers)
Temperature source	Simulates the cold plate as cold sink
Controlled heat flow source	Simulates the electronics as hot sink
Others	Thermometers, scope, gain, mathematical operators

What comes out is encouraging: as it can be interpreted from the temperature sensor, measuring the difference between the wall temperature and the external air temperature, the system as designed is not so far from the stringent requirements, that, according to the model, can be reached with an Armaflex insulation thickness of 39mm; in any case the solution gained by the models is in the order of tens millimetres.

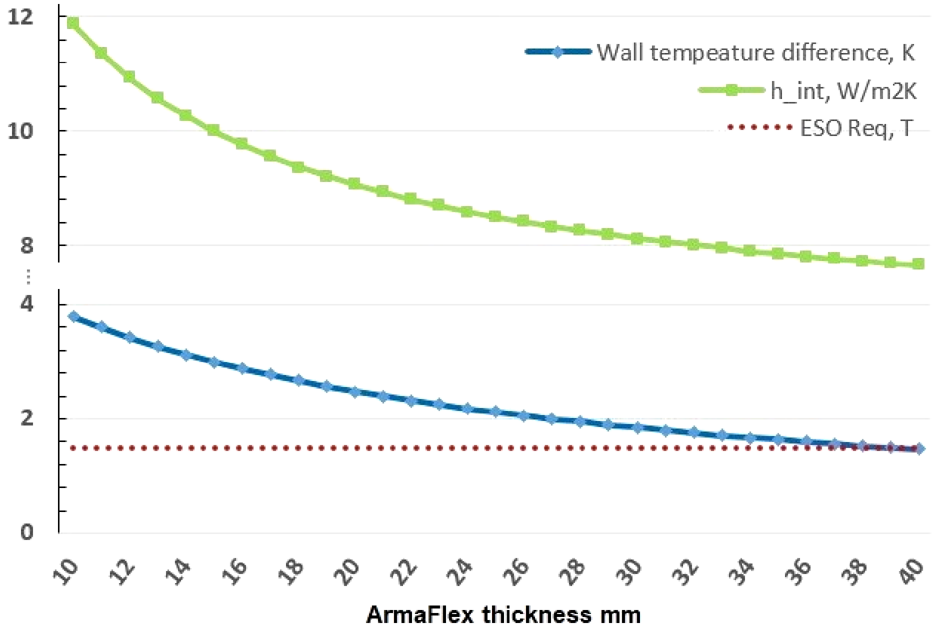


Figure 6. Wall ΔT and internal convective heat transfer coefficient vs Armaflex thickness.

Another good result is the heat convection factor, that, in both cases that have been analyzed is in the range of a typical natural convection (2.5-25 W/m^{2}K).

2.4 Next steps

In order to carry on forward this analysis, a model that is more faithful to reality must be realized, starting from a 2D model. In fact, on the side of natural convection one of the most important characteristics is the spatial orientation of the objects, according to the huge literature on the subject. Some first layouts have been designed, in order to reach a satisfying maturity level.

3. OTHER STRATEGIES: THE PELTIER CELLS

Another strategy that can be followed to create a design without potential sources of vibrations, like fans or other elements with periodic movements, is to use thermoelectric systems. A good option in this field is represented by the Peltier cells.

The Peltier cell is a thermoelectric device built using two semiconductor sheets of type-p and type-n respectively, with a different electron density and electrically connected in series, so that, when subjected to a direct current, the heat can be driven from one side to the other. Their efficiency improves thanks to the high electric conduciveness of this material versus a high thermal resistance.

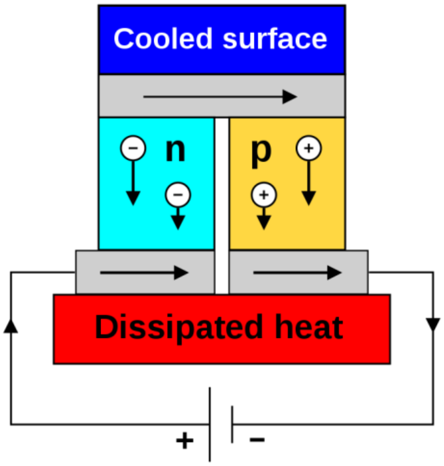


Figure 7. Thermoelectric Cooler Diagram, Ken Brazier, Creative commons license.

One of the strong points of the thermoelectric devices is that they are not subjected to the characteristics of the cooling fluid from the SCP, so the constraint of the cooling fluid at Tamb-8°C is overtaken. Another important point is that being an electronic system it can be powered and driven by an electronic control system, creating a loop that reads the temperatures of interest and govern the current through the cell to give the right intensity. Due to its versatility, this solution is already widely used in astronomy technology and informatics. Peltier cells are used where small amounts of material need to be cooled quickly. They are used, for example, to cool CCD sensors of telescopes and thermal cameras, in lasers to keep the working temperature stable and sometimes to cool the CPU or GPU using a heat pipe to cool the side of the cell that is heating. This solution could improve the reliability of the system, that is demonstrated already highly reliable [6][7]. In fact, the characteristic MTBF of a Peltier cell is of 100000 hours.

4. CONCLUSIONS

The model gives important information about the behavior of the system composed by the electronics, the cold-plate and the cabinet: natural convection can be a solution to implement the cooling of the cabinets. A good result can be achieved through an overcooling and exploiting the stationary condition created to have the insulation thickness as the only degree of freedom. What comes out is encouraging, because with an acceptable insulation the problem can be dealt with. This result deserves a deeper analysis in order to evaluate how much the physical phenomena behaves following the results of a first-order model. On this side, the study can be continued simulating a 3D cabinet and trying different spatial configurations for the electronics and the cold-plate based cooling system inside the cabinet, to further validate the model. 3D analyses to find potential hot spots on the surface of the cabinet, based on the internal layout, must be carried out.

A “fan-less” solution can be also the adoption of other types of cooling systems. In this case the case study would change radically. In our opinion the thermoelectric effect should be further investigated to understand if it fit the needs of the system under study. For this reason an experimental phase of the study is also foreseen.

REFERENCES

[1] Ciliegi, P., et al., “MAORY@ELT: general overview up to the preliminary design and a look towards the final design”, Proc. SPIE, 12185-40 (2022), in these Proceedings.

[2] Aliverti, M., et al., “MAORY@ELT: Thermal Control System preliminary design”, Proc. SPIE, 12185-176 (2022), in these Proceedings.

[3] Eredia, C., et al., "Design and analysis of an innovative distributed architecture for ESO instrument control hardware", Proc. SPIE 11449, 114490Q (2020).

[4] Cascone, E., et al., “MAORY Instrument Control Hardware: general overview", Proc. SPIE 11447, 1144735 (2020).

[5] Cascone, E., et al., “General overview of MORFEO (formerly known as MAORY) Instrument Control Hardware design”, Proc. SPIE, 12184-110 (2022), in these Proceedings.

[6] D’Auria, D., et al., “Hazard and failure modes analysis of the Instrument Control Hardware design for ELT class of instrumentation”, Proc. SPIE, 12187-53 (2022), in these Proceedings.

[7] Eredia, C., et al.., "Trade-off between different PLC based architectures of Instrument Control Hardware for ESO ELT class of instrumentation", Proc. SPIE, 12184-111 (2022), in these Proceedings.

[8] D’Auria, D., et al., “Mechanical and electronic design of the MORFEO (formerly known as MAORY) Calibration Unit selector”, Proc. SPIE, 12184-109 (2022), in these Proceedings.

[9] De Caprio, V., et al., “Mechanical design overview for the Main Structure of MAORY/MORFEO”, Proc. SPIE, 12184-106 (2022), in these Proceedings.

[10] Cianniello, V., et al., “Structural Analyses of the MAORY/MORFEO Main Support Structure at global level for Preliminary Design Review”, Proc. SPIE, 12184-138 (2022), in these Proceedings.

[11] Cianniello, V., et al “Global to Local FEA validation for complex geometries: submodeling technique applied to mechanical structures for ELT class of instrumentation”, Proc. SPIE, 12184-96 (2022) in these Proceedings.

[12] Cianniello, V., et al “Finite Element modeling technique: trade-off between two different FE models of a mechanical selector for Astronomical Instrumentation”, Proc. SPIE, 12184-97 (2022) in these Proceedings.