# The enclosure for the European Solar Telescope (EST)

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## ABSTRACT

The European Solar Telescope (EST) is a 4-m class solar telescope, which is currently in the conceptual design phase. EST will be located in the Canary Islands and aims at observations with high spectral, spatial and temporal resolution of the solar photosphere and chromosphere.

The main purpose of the enclosure is to protect the telescope and instruments from severe weather conditions. An enclosure is also often needed for reducing wind buffeting on the telescope and primary mirror cell, but on the other hand enclosures are generally considered to degrade local seeing. In this contribution we will present the conceptual design of the enclosure for EST. Two different concepts have been studied in more detail: the first being a dome concept with vent gates to enhance local flushing, the other being a retractable enclosure, with an optional windshield. Technically both alternatives seem feasible, but we conclude that the retractable enclosure is the less risky solution, since it allows easier local seeing control and allows the use of a reflecting heat stop in the primary focus. A windshield is effective in reducing wind load on the primary mirror; although preliminary analysis indicate that there are feasible solutions to keep the deformation caused by wind buffeting within the requirements.

**Keywords:** Dome, solar telescope, CFD, local seeing, turbulence, kinetic energy, retractable enclosure, windshake.

## 1. INTRODUCTION

The EST (European Solar Telescope)[1] is a 4-m class solar telescope, which, as a pan-European project that involves 29 partners from 14 different countries, currently is in the conceptual design phase. EST aims at observations with high spectral, spatial and temporal resolution in the solar photosphere and chromosphere, using a suite of instruments (broad-band imagers, narrow-band tunable filter spectropolarimeters and grating spectropolarimeters), which together can efficiently produce two-dimensional spectropolarimetric information of the thermal, dynamic and magnetic properties of the plasma over many scale heights. EST will be located on the Canary Islands, at either La Palma or Tenerife.

For the enclosure, we can indentify three functions: 1) protect the telescope from harmful weather conditions; 2) protect the telescope from wind load on the telescope structure and (primary) mirror, 3) maintain the temperature of the telescope during night at the air temperature of next morning when observations resume.

These functions must be performed with minimal degradation of the local seeing conditions during operation, which requires the minimizing of temperature gradients in the optical path. We will in this paper adopt the general thought that an enclosure is always a source of seeing[2]. The challenge is how find the best compromise between local seeing and the three functions as mentioned above.
In particular a) local seeing and b) windshake have been identified as main design drivers in this conceptual design study, the first being studied in this paper, the latter in [3,4,5].

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Two different alternatives for the enclosure have been studied in more detail:

- a dome concept,
- a retractable enclosure concept, with or without windshield.

## 2. REQUIREMENTS

The maximum seeing degradation in the error budget of EST that is assigned to the telescope environment is 0.1 arcsec in image blur[3]. The telescope environment consists of the building, its surrounding area, the pier and the enclosure. We expect that the most dominant seeing degradation source originate from the enclosure, since it is closest to the optical path. Seeing degradation that is caused by the enclosure we divide, in a simplified way, in 3 different sources: shell seeing, dome seeing, and interior seeing[2] (Figure 1). Shell seeing originates from the outer shell of the enclosure, if it has a deviating temperature. Dome seeing is occurs when the air temperature is not equal inside and outside the dome. Interior seeing is the seeing source that is caused by all systems inside the dome, e.g. a warm dome floor, or equipment.
For the sake of simplicity we will divide the error budget equally over the subsystems pier, building and the three dome seeing causes. The image blur seeing degradation requirement of each of the 5 subsystems will then be:

$$\theta_i = \frac{0.1''}{5^{3/5}} = 0.038'' \qquad (1)$$

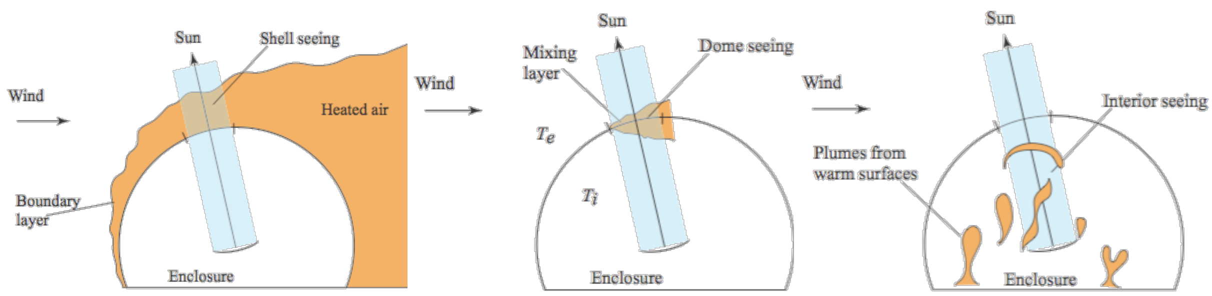


Figure 1: Main types of seeing around the enclosure: shell seeing, dome seeing and interior seeing [reprinted from [2]).

In case of a dome type enclosure, all three dome seeing causes are present. In the case of a retractable enclosure with the telescope operating in open air, both shell seeing and the dome seeing do not exist. Floor seeing is then however more dominant since the floor is now fully illuminated by sunlight, though this seems less severe when compared to shell seeing due to the location below the optical path and the larger distance.

## 3. THERMAL CONSIDERATIONS

### 3.1 Daytime seeing

Seeing originates from local changes in the index of refraction of air, which is caused by temperature differences. Daytime seeing is fundamentally different from nighttime seeing[6]. During daytime the ground is heated and generates warm air plumes that rise upwards, forming a heavily disturbed groundlayer. At night, a few hours after sunset, the ground sufficiently cools by radiation to the open sky, such that warm air plumes no longer rise up. Eventually, the ground becomes even colder than the air above it. The gradual increase of temperature from the ground upward permits a stable air mass and consequently, good seeing conditions can develop, which is impossible at daytime. Wind helps during daytime and limits the effective height of the ground layer; no wind (as considered on La Palma and Tenerife) leads almost always to bad seeing.
Below heights of 1 km the refractive index structure function $C_n^2(h)$, is typically 3 to 10 times worse than at night. From measurements[7] we have derived that at 15 m height the temperature fluctuations are, on average, 3 times worse than at night. Figure 2 shows as a random example a detailed graph of the temperature variations during daytime in a time span of 2 hours as measured on the DOT on La Palma[8], together with scintillation measurements, which are a good indication for the ground layer seeing[9,10]. It represents a day that the telescope was observing with reasonable conditions. The air temperature in the shown period varies between 8.5 and 12˚C and at the time that the best good conditions occur the

temperature varies between 10.5 and 12˚C. The average day-night temperature span at La Palma varies typically between 4 and 10˚C.

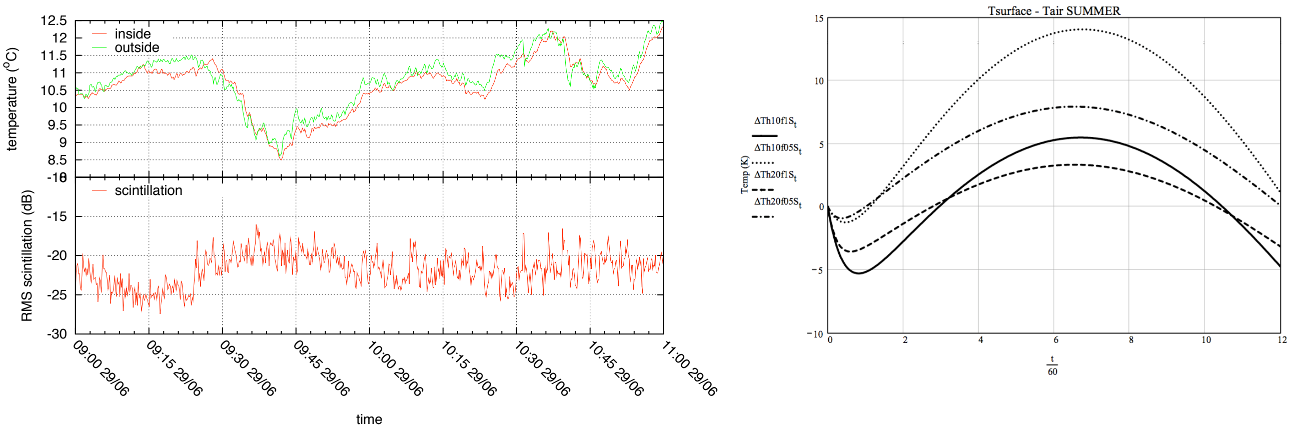


Figure 2. (Left) Random example of temperature fluctuations (top) and ground layer seeing (bottom) on a typical observing day as measured on the DOT on La Palma. In this period the seeing was reasonable (-20dB) to very good (-25dB). The plot uses a dataset with samples of 10 seconds (reprinted from [7]); (Right) Temperature difference between air and floor as function of time in mid-summer, for heat transfer coefficients of 10 and 20 W/m2K and sky emission factors of 1.0 and 0.5. A floor coating with emissivity of 0.87 and reflectivity of 0.75 has been assumed and floor surface mass of 50 kg/m$^2$ (steel); sky temperature 243K, air temperature 283K.

### 3.2 Dome interior seeing

Racine[11] published an empirical relation for estimating (night-time) dome seeing based on the difference between the inside and outside air temperature:

$$\theta = (0.1''\pm 0.05'')\cdot \Delta T^{6/5} \quad (2)$$

with θ – image blur [arcsec] and ΔT - difference between in- and outside air temperature [K].
Under the condition that we may use this night-time relation for daytime (Racine reported that ΔT was never much larger than 1K, hence quite good thermal equilibrium conditions), we obtain a maximum temperature difference of 0.3 to 0.8K in order to stay below the error budget value of 0.038”. Direct calculation of wavefront deviations from refractive index variations gives similar results.

### 3.3 Shell seeing

Air streaks over the shell of the dome, which in reality, will have always some different temperature than the ambient air. It is harmful because at the location of the enclosure shutter the airflow enters the optical path.
The actual seeing degradation depends on the properties of the boundary layer between shell and undisturbed air. Ford[12] and Dalrymple[13] did an integral analysis of the boundary layer (assuming that we are in the forced convection regime, with minor natural convection, or the Froude number *Fr* > 1) of the air stream going over a warm shell that passes the optical beam. The calculated difference in temperatures between shell and air they converted into seeing degradation with help of Racine’s relation (2):

$$T_p - T_0 = \frac{hL(T_s - T_0)}{\rho v \delta c_p} \quad (3)$$

$$\delta = 0.37\,\mathrm{Re}_L^{-0.2}\,L \quad (4)$$

$$h \cong \frac{k}{L} 0.036\,\mathrm{Re}_L^{0.8}\,\mathrm{Pr}^{0.43} \quad (5)$$

$$T_p - T_0 \cong 0.097\,\mathrm{Pr}^{-0.57}(T_s - T_0) \quad (6)$$

$$\theta = 0.15''[0.097\,\mathrm{Pr}^{-0.57}(T_s - T_0)]^{1.2} \quad (7)$$

with θ – image blur [arcsec]; $T_p$ – temperature in optical path [K]; $T_0$ – temperature of air [K]; $T_s$ – temperature at shell; *h* – heat transfer coefficient [W/m$^2$K]; *k* – heat conduction coefficient [W/mK], L – radius dome [m]; *ρ* – density air [kg/m$^3$]; $c_p$ –specific heat [J/kgK]; *v* – velocity [m/s]. Pr - Prandtl's number.
We can calculate then that for staying within the requirement of θ=0.038", we may allow temperature differences between the shell and air of 2.8K, and a difference between $T_p$ en $T_0$ of 0.3K.
There exist alternative methods for estimating the seeing degradation based on empirical and analytical relations (aero optical calculations[13], mirror seeing[14]), all giving results of the same order of magnitude, although simple approximations have been made, and not being always entirely correct. We use the result therefore as a first approximation, awaiting CFD work, although the variety of methods gives some confidence.

### 3.4 Interior seeing

Apparatus inside the enclosure can produce heat, which causes interior seeing. The main contribution is expected to come from the floor, but also other elements (e.g. telescope, auxiliary equipment) may contribute. We have to differentiate between two cases:

- Floor in an open telescope environment. In this case the floor receives solar illumination and is thus heated by the Sun. Secondly it radiates freely to the sky.
- Floor in a closed telescope environment. In this case the floor is not receiving solar illumination and is not radiating. But it might be heated by heat coming from the building below.

A floor that is too warm is the worst scenario, but also a floor which is too cold is to be avoided, since cold air can be transported upwards by large scale eddies or counter flows. This could be the case inside domes and also in retractable enclosures when the floor is located lower than the upper rim of the enclosure.

In principle the floor seeing can be considered as shell seeing, with the main difference that the floor is located further away from the optical path and that if the temperature disturbance remains below M1, it does not harm. This is different from shell seeing where the air stream *always* will pass the optical path. If we assume that the floor is 5 m below the M1 surface (based on the preliminary telescope model[4], pointed to zenith), we can compute from the vector sum of wind velocity and natural convection velocity (described in more detail in[15]) that the temperature may differ with 2˚C for wind speeds of 2 m/s, and 5˚C for wind speeds of 4 m/s before the convection reaches the height where M1 is located. This extra temperature budget we can add to the allowed temperature range for shell seeing, in order get a first estimate for the total temperature range for floor seeing. In case of a retractable enclosure, shell and dome seeing are even absent, which permits to allocate the total enclosure error budget to floor seeing.

Preliminary transient calculations have been done with a white painted steel floor (or shell), for different sky emission factors and heat transfer coefficients (Figure 2, right). This results in temperature differences between air and surface ranging between -5 and 13˚C relative to ambient, which is nevertheless larger than the temperature budget as indicated above. About half of the variation is caused by the daily variance of the air temperature (8 ˚C). The results are in agreement with measurements done at the Gemini dome[12].

### 3.5 Conclusions

We conclude that shell seeing and dome seeing seem to be the most demanding thermal problems. The required maximum temperature difference of the shell relative to the air is in the order of ±2˚C and the required maximum temperature difference of air inside and outside the enclosure is in the order of 0.5˚C. Temperature control of the shell, with the control system tracking the diurnal temperature pattern, seems unavoidable for staying within the requirements, since a passive shell exceeds the allowed temperatures easily. A critical issue is that the permitted temperature deviation of the shell is of the same order of magnitude as short-term (15 minute scale) air temperature deviations, which would require extremely fast control systems.
For shell seeing, we conclude that the only engineering parameters that exist and that can be optimized are the shell temperature (by a temperature regulating system), the shell contact length L or heat source area A (which can be minimized, thus a small dome and/or high porosity). Dome seeing could easiest be mitigated by introducing flushing by including a number of venting apertures in the dome. Floor seeing seems to require temperature control as well, but is much less critical since more temperature difference is needed before any disturbed air reaches the optical path. Floor seeing can be mitigated by maximizing the height difference between floor and optical path and allow maximal wind velocity.

# 4. CFD

CFD analysis has been carried out to study the impact of the wind flow on the enclosure, and also pier and building, which is reported in more detail in[15]. The main objective of these simulations was to capture the pressure distribution, velocity field and kinetic energy in and around enclosure, telescope, pier and building. Also forces and moments were calculated. Thermal aspects have however not been studied yet, and are planned for a near future follow-up analysis.

The discretized domain is a section of 200x800 m, with a height of 150 m; the wind speed 10 m/s and uniform. In total 22 different models have been analyzed, each with 1 to 3 different wind directions. More details about the simulations can be found in[15].

The results have been used to look at different aspects in both qualitative and quantitative way:

- Wind and pressure reduction, inside the dome,
- Study at areas of very low wind speed, so-called stagnant air areas. In these areas air remains relatively long in contact with telescope and/or enclosure parts, and thus can more easily adapt different temperatures,
- Homogeneity of the airflow, in particular inside the optical beam. The more homogenous the airflow is, the better temperature stability can be expected,
- Turbulence. Although turbulence in itself is not harmful, it is to be avoided if temperature differences are present.

We have studied domes with a hemispherical and octagonal (e.g. ATST[3]) shape. The most striking difference between the two types is that the hemispherical dome allows for free movement of the telescope in all directions, whereas in the octagonal dome the movement is restricted to the elevation axis: for movement in azimuth the dome has always to co-rotate with the telescope. Advantage of the octagonal dome in terms of seeing is that it has a smaller volume and its shell that faces the Sun can be more effectively minimized.

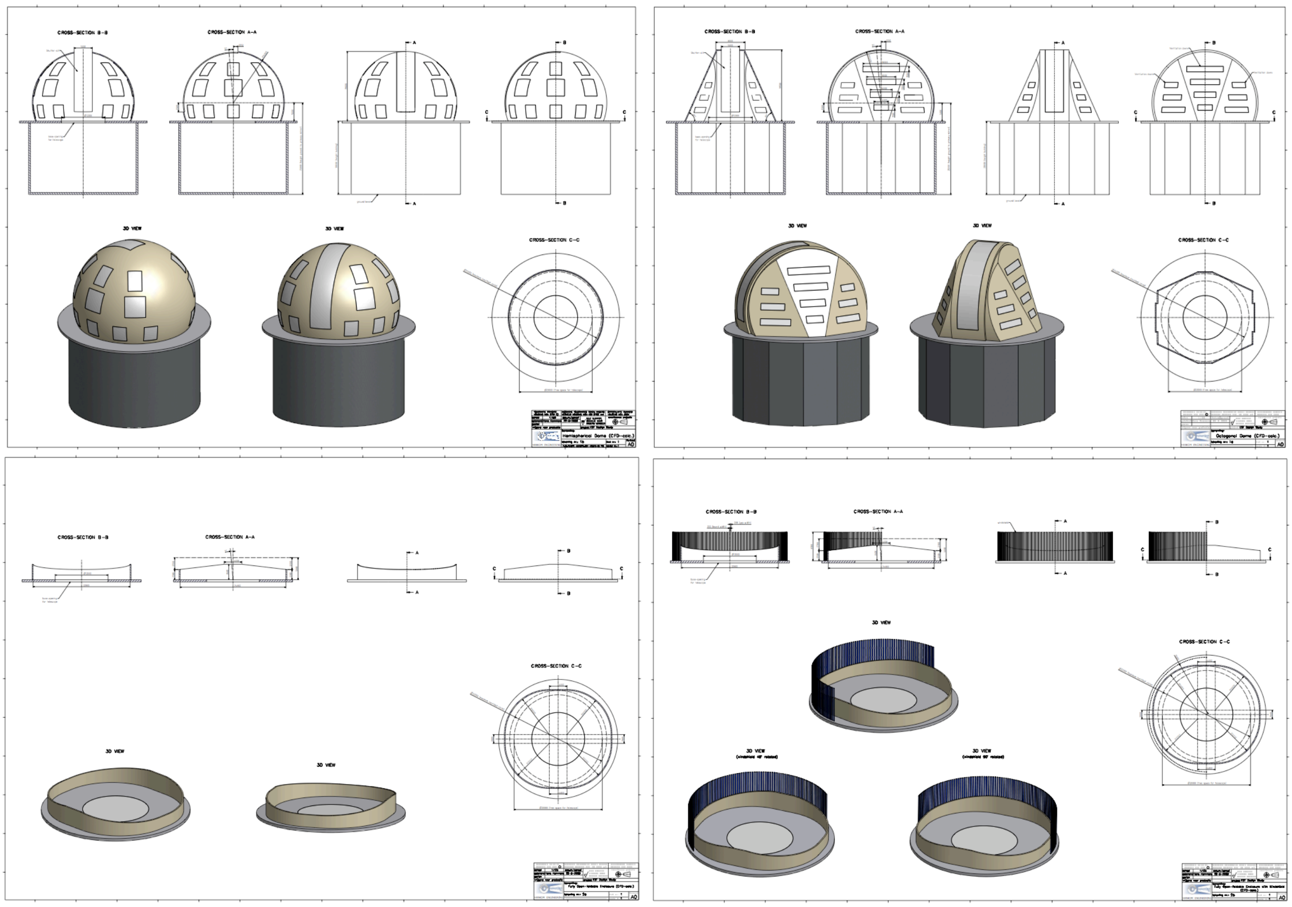

Figure 3. 3D concepts for a hemispherical dome (upper left) and an octagonal dome (upper right), retractable enclosure (lower left) and retractable enclosure with wind shield (lower right).

As derived from[16], the hemispherical and octagonal dome could be seen as two opposite types regarding flow characteristics, although our hemispherical dome is designed with more vent gates than the analysis carried out in[16] and also the octagonal domes are different. Figure 3 shows the different dome shapes and enclosures that we have used in our analysis.

Figure 4 illustrates the flow inside and around the hemispherical and octagonal dome. It is evident that the wind speed reduces, both for the hemispherical and octagonal dome; but for the latter it is slightly more effective: the wind speed reduces to ~5m/s inside the optical beam, whereas for the hemispherical dome it reduces to 'only' 7m/s. It is likely related to the larger vent openings that have been chosen for the hemispherical dome, which results in a less effective wind reduction. Since wind pressure scales with the square root of the wind velocity, a reduction from 10 to 7 m/s is equal to 50% reduction in wind load and a reduction from 10 to 5 m/s is equal to 25%.
The flow is not homogenous within the space between two vent gates, with de airflow being low, but kinetic energy (turbulence) higher. In the dome interior the wind speeds varies between ~8m/s and almost zero: around the optical beam it is closer to 8m/s, and in many other parts <0.5m/s. The kinetic energy seems to remain close to the shell, with the optical path relatively free of turbulence. The vent gates are of the order of several meters in width and height. From measurements on wind shields[17] we conclude that the mixing becomes fully effective at a distance behind the shield of about 20 times the venting gate distance, which requires many small openings instead of larger and fewer ones.

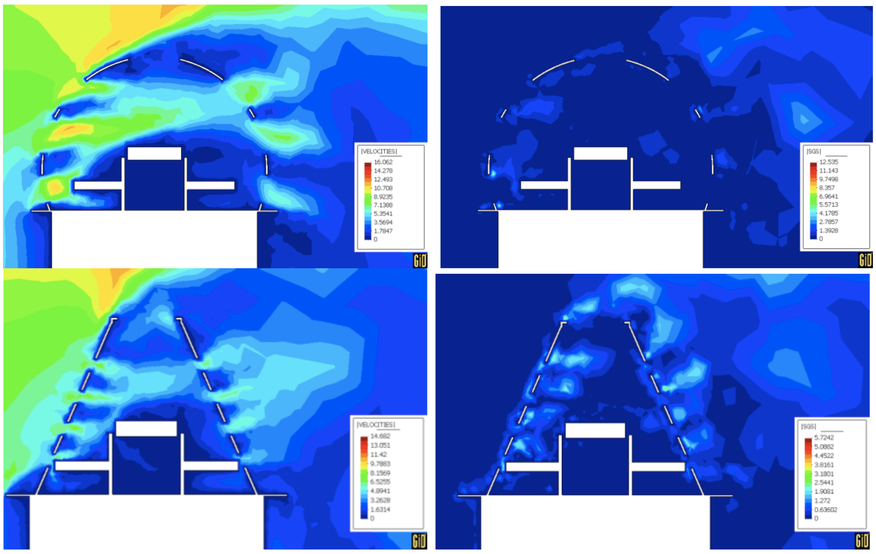

Figure 4. CFD snapshot of the hemispherical and octagonal dome. (From left to right): wind velocity in and around a hemispherical dome (colour range 0-16 m/s); kinetic energy inside and around the hemispherical dome (0-12.5); wind velocity in and around octogonal dome (0-14.6 m/s); kinetic energy of octogonal dome (0-5.7). Wind is coming from the left with 10m/s. The telescope points in perpendicular direction. Note that the color bars have different scaling.

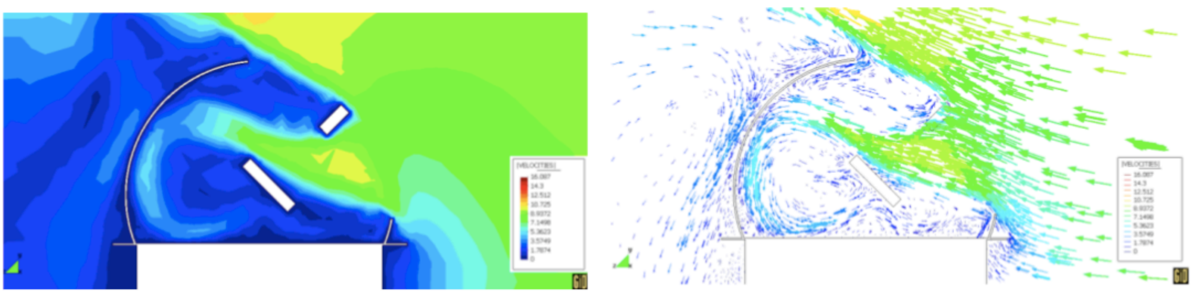

Figure 5. CFD snapshot of the hemispherical dome. Left plot: wind velocity; Right plot: vector plot of wind velocity. Both figures show that there is a large counter flow against the back shell of the dome.

Figure 5 shows a vertical cut through the center of the hemispherical dome. The slit of the dome is facing the wind direction. This probably most demanding wind direction produces a large counter flow in the form of a big eddy, formed with help of the back of the dome shell. Also the octagonal dome shows such a counter flow. In the case that a partial shutter covers part of the slit, this effect also occurs, both for hemispherical and octagonal dome, and even with slightly higher wind speeds. Although a counter flow could help in mixing the air inside the enclosure, it also increases the contact time of the air with the dome shell and floor significantly, before coming back to the telescope optics, and thus better should be avoided.

Graphical results of the CFD analysis of retractable enclosures is shown in Figure 6. High velocities occur inside the optical beam; on M1 it is somewhat tempered. It can also be seen that the horizontal flow is bended upwards. This is seen in all simulations, and reaches approximately a height of half the diameter of the pier at the center of the pier[15]. The volume below shows turbulence and low velocities.
The adding of a windshield (Figure 6, right) lowers indeed the wind speed, from 13 m/s to 5m/s. As expected[17] most kinetic energy occurs closely behind the screen. Likely the windshield needs further optimization since in-situ measurements[17] show even larger reduction factors. The windshield also eliminates the effect of the disturbance of the horizontal flow direction of the airstream and makes the flow more uniform.

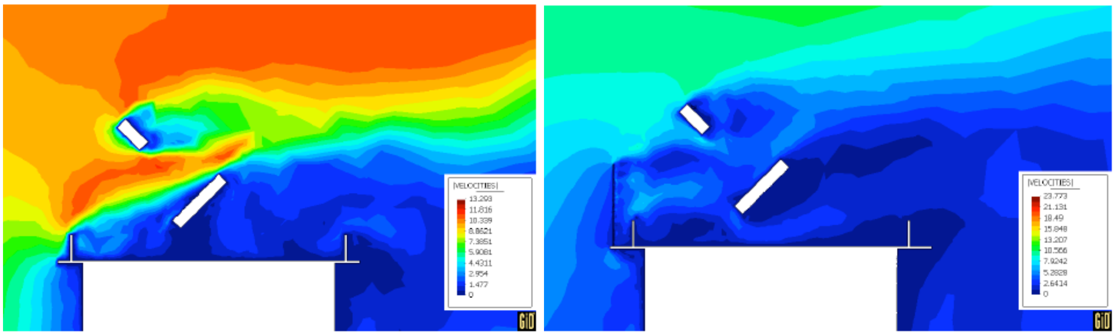

Figure 6. Wind velocity for the retractable enclosure without windshield (left, colour bar range 0-13.3 m/s) and including windshield (right, colour bar range 0-23.8 m/s). The windshield reduces the wind velocity on the telescope and makes the airflow more horizontal.

In order to obtain insight in the influence of the flow pattern on the seeing degradation of the telescope, for each simulated case the amount of turbulence inside a column of air that represents the optical beam above M1 (5x5 m wide and 20 m long) has been computed by adding up the turbulence values of all nodes inside the volume and dividing the total by the number of nodes. This amount of turbulence inside the optical path column is a first indication for the optical seeing we can expect (if we associate turbulence with temperature variations). A summary of the results is given in Table 1, which lists the computed mean turbulence value for a hemispherical dome, octagonal dome and retractable enclosure with and without windshield. They all show similar performance, although the octagonal dome seems slightly better. As mentioned before, we expect that the result depends on the design of the vent openings and we feel it cannot be concluded which design is to be preferred. The results indicate on the other hand that the kinetic energy in the optical beam changes much with the wind direction: when the telescope faces the wind the turbulence is almost twice as large compared to observing downwind.

Table 1. Mean turbulence value for different enclosure types and wind directions.

| Model # | Building orientation | Wind dir. | Mean turbulence value |
|---|---|---|---|
| Model 1 | Hemispherical dome | 0° | 2.48E-01 |
| | | 90° | 2.52E-01 |
| | | 180° | 1.57E-01 |
| Model 2 | Octogonal dome | 0° | 2.14E-01 |
| | | 90° | 2.31E-01 |
| | | 180° | 1.04E-01 |
| Model 3 | Retractable enclosure | 0° | 2.56E-01 |
| | | 90° | 2.14E-01 |
| Model 4 | Retractable enclosure /w windshield | 0° | 2.37E-01 |

As turbulence in itself is not harmful if no temperature differences are present, and awaiting the results of thermal simulations, a first approximation have been made to estimate the seeing degradation based on the computed turbulence, by adding temperature aspects. For all turbulence cells in the optical beam, the distance from its heat source (i.e. M2, dome shell, floor, dome, interior), its temperature deviation, size of the source, the local velocity of the wind have been taken account, which resulted in a weighting factor for each turbulence cell *i*:

$$W_i = \frac{\Delta T \cdot a}{d \cdot v} \tag{8}$$

with $W_i$ – weighting factor; ΔT – temperature difference heat source; a – surface heat source; d – distance heat source, v – local wind velocity.

In the analysis an identical value for the temperature deviation have been assumed. Table 2 shows the results for the hemispherical dome, retractable enclosure and retractable enclosure with windshield. It shows that for an upwind observing telescope in a dome and in retractable enclosures (with and without windshield) all behave very similar, which is due to the fact that M2 in all case is the main cause of the turbulence in the optical path. A downwind observing telescope in a dome behaves however worse, despite its lower turbulence, due to the large contact of the air with the dome shell before it passes the optical path.

Table 2. Temperature weighted mean turbulence values for hemispherical dome and retractable enclosures.

| Model # | Building orientation | Wind dir. | Temperature weighted mean turbulence value |
|---|---|---|---|
| Model 1 | Hemispherical dome | 0˚<br>180˚ | 0.069<br>0.157 |
| Model 3 | Retractable enclosure | 0˚ | 0.066 |
| Model 4 | Retractable enclosure /w windshield | 0˚ | 0.037 |

## 5. CONCEPTS FOR THE EST ENCLOSURE

### 5.1 Dome concept

The design that is proposed for the conventional type dome corresponds to a hemispherical dome with 25 m diameter. It allows for free movement of the telescope inside without the need to co-rotate the dome. Awaiting more detailed CFD optimization, eventually the hemispherical concept could evolve into an octogonal shape. The dome design includes vent gates, in order to reduce both dome seeing and shell seeing. In order to homogenize the airflow inside the dome efficiently we aimed at a large number of small vent openings, instead of fewer and larger, as outlined in Section 4. In order to minimize counter flows also the shutter obtained vent gates. Figure 7 (left) illustrates the concept. Instead of a hemispherical surface, the dome is divided in many flat surfaces that are used to accommodate the vent gates, which results in a simple and less expensive construction. We estimate the 'porosity' at 32% percent. If necessary, a porosity of 50% is could be realized (Figure 7, right). The shutter of each vent gate slides sideways over girders and is opened with a 0.55kW motor system. When opened, an area of 2x3m is available for flushing. The motors and all mechanical parts are located in the inside of the dome, to enhance robustness, and connected to the shutters with chains, driven from two sides. The design is such that no rain and ice can penetrate, with water stops and drains.

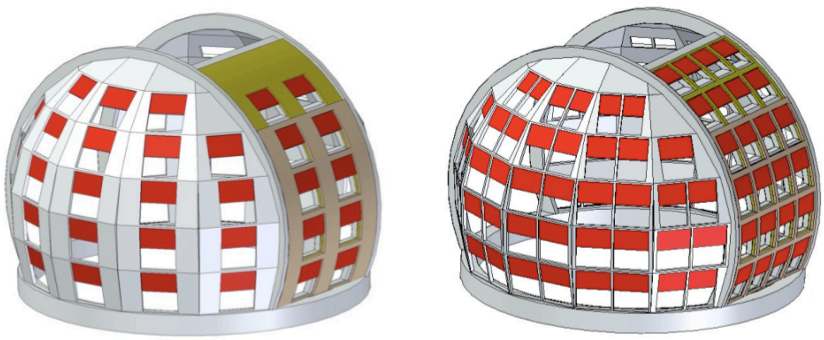

Figure 7. Two concept of 25 m hemispherical domes with 3x4 m vent openings for maximum wind flushing.

All dome panels and shutters will be cooled. In case of heavy ice deposition warm water can be pumped through the panels, avoiding the formation of ice. In the design the inside of the panels have 5cm thick insulation.
The shutter slit is 12 m wide, allowing in itself for generous flushing. If needed a windshield or shutter can be attached. A first estimate for the weight of the total dome is 400 tons with 160 tons for the skin and 240 tons for the structure.
The maximum heat absorbed by the dome shell is estimated at 50 kW. This heat load needs to be absorbed by the shell cooling system. Thermplate, composed of two, spot laser welded, plates, which are pressurized during manufacturing after welding, that creates a channel for water circulation in between, is considered for cooling the outer dome skin. The material is stainless steel. On the outside the panels will be coated with a white thermal or aluminum coating. All shutters and plating will be covered with Thermplate. The cooling will be done with cooling liquid (water-glycol mixture with additive). The connection between panels and equipment is foreseen with hoses. It is proposed to divide the complete dome in 12 vertical sectors for cooling, each one with each independent cooling circuit, which extract and return their cooling liquid from a ring supply reservoir in the base ring of the enclosure, just above the bogies. All cooling machinery should be located in an auxiliary building, located at some distance down-wind.
The aim is to have the cooling flow large enough that the heat load (and the variation in heat load and sky radiation cooling) does not vary much the cooling liquid temperature. The shell temperature follows then the temperature of the cooling liquid, which is contineously changed to track the diurnal air temperature variation. For this goal 3x100kW cooling machines are foreseen. The current design is able to pump 150 $m^3$/hr and has a reservoir of 30 $m^3$ (circulated every 12 minutes). The maximum temperature increase that can be tracked is 0.9˚C/hr. This is (just) enough for tracking the average daytime temperature span of 5˚C, but not for faster temperature changes, which requires (much) more cooling power.
The proposed design with many vent gates, keeps the telescope structure and the floor exposed to sun irradiation, with parts of the floor exposed to sunlight and other parts in shade. A similar cooling system as proposed for the shell will be implemented for the floor.

### 5.2 Retractable enclosure concept

For the retractable enclosure a concept has been developed based on the 7 m and 9 m retractable enclosures for the DOT and GREGOR solar telescopes[18]. Although novel in their construction, both enclosures are in operation for many years, with broad experience available. For EST, concepts with diameters of 23, 28, and 33 m have been studied, the first being the smallest enclosure possible, the second permitting full azimuthal movement of the telescope inside the enclosure but with limited elevation range, and the last concept permitting full movement. Technical details are published in[19].

The enclosures consist of steel bows with spanned cloth (membrane) in between. In all concepts two main bows are driven by a compact rotation system near the hinges of the bows with electrically driven actuators. The other bows between the different cloth segments are not driven. During opening and closing, the upper cloth segments are sufficiently tensioned because of the weight of these in-between bows. This construction avoids flapping of the cloth during opening and closing without the need of a complex drive system for the in-between bows. Clamps hold together the two main bows in closed position.
Calculations have shown that until ~30 m diameter no principal changes are necessary in the design[18]. For larger sizes more bows need to be motorized.
Each half independently can be opened with full motor speed to an arbitrary level from closed to fully open. The enclosure is designed to withstand 70 m/s, with maximum windspeed for closing at 30 m/s (or 10 min > 20 m/s, 1 min > 25 m/s). For opening and closing, 96kW motor power is available to close the enclosure in 2 minutes time.
The membrane will be double layer with an air gap in between to improve insulation[7]. Ice deposition during winter is minimal due to a PVDF coating on the membrane material. The total mass for the 23 m variant is 58 tons.
The design of the enclosure is such that when fully opened, the bows and membrane are 'stored' below the telescope platform, which enhances flushing and avoids the formation of air pockets with deviating temperature. In the smallest variant the telescope floor is 17 m in diameter.

Since the floor is illuminated by sunlight, the floor temperature should be maintained, as outlined in Section 3. Several options are being considered: 1) Installation of a cooling system. A light floor, with fast response time is preferred. Possibly Thermplate, as suggested for the shell of the dome concept, can be used. The cooling system has only to track the average daytime temperature to ensure seeing degradation to stay within the requirements. 2) Installation of suction openings that remove all directly air above the floor. 3) Use of a massive floor, with good conductance and large heat capacity. It should work as a large heat capacitor and maintains constant temperature during the day. With a temperature

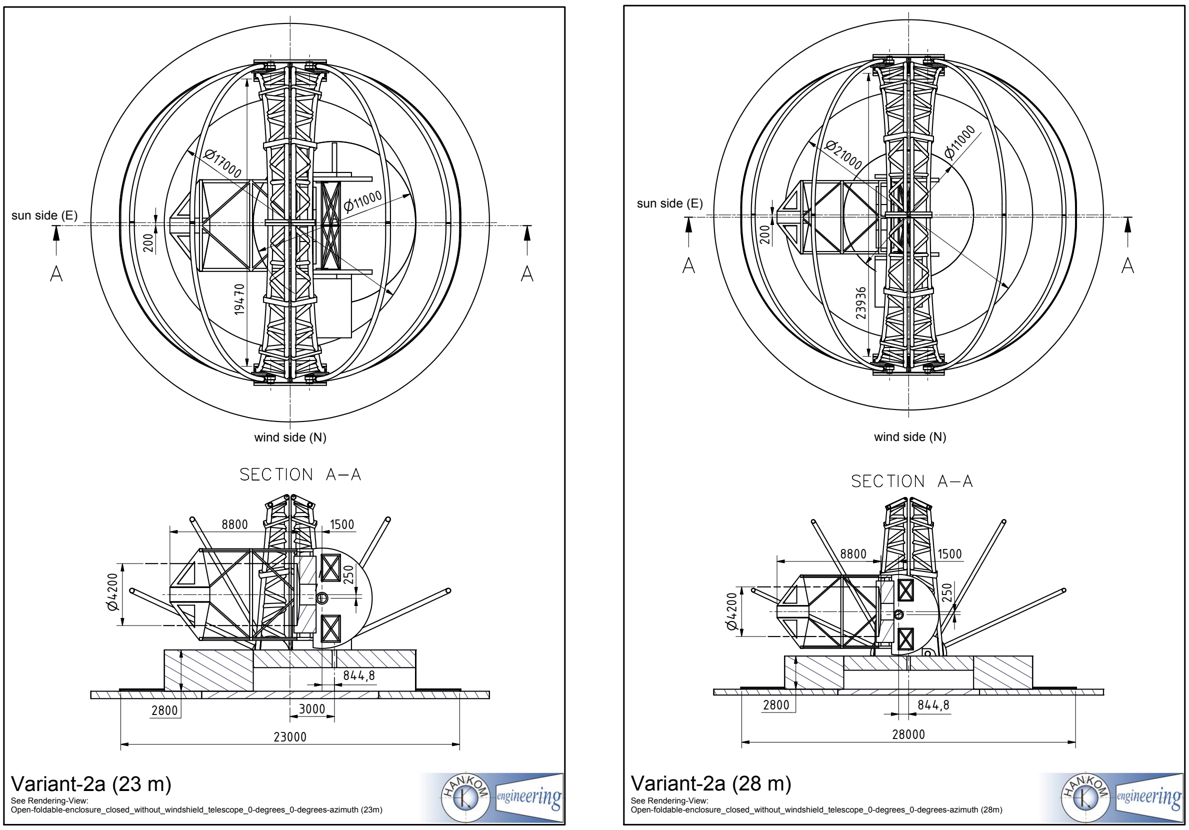


Figure 8. 23 m retractable enclosure (left); 28 m retractable enclosure (right).

span between day-night of approx. 6˚C, this should just be allowable. 4) No solid telescope floor, but metal grid floor instead. No floor seeing is generated.

A semitransparent windshield is implemented, mainly for reduction of wind load on the telescope structure if that is needed. The proposed design is composed of a screen of vertical poles placed on an 180º carrousel that can rotate on a circular rail in order to turn the shield towards the actual wind direction. The poles generate small scale eddies, formed directly behind the windshield that dissipate efficiently the kinetic energy, and the vertical pole orientation maintains the horizontally stratified air mass with a minimum of turbulence. The shield has a part that is 4 m and a part that is 6 m high, allowing for an optimal choice in relation to the pointing of the telescope (Figure 9).

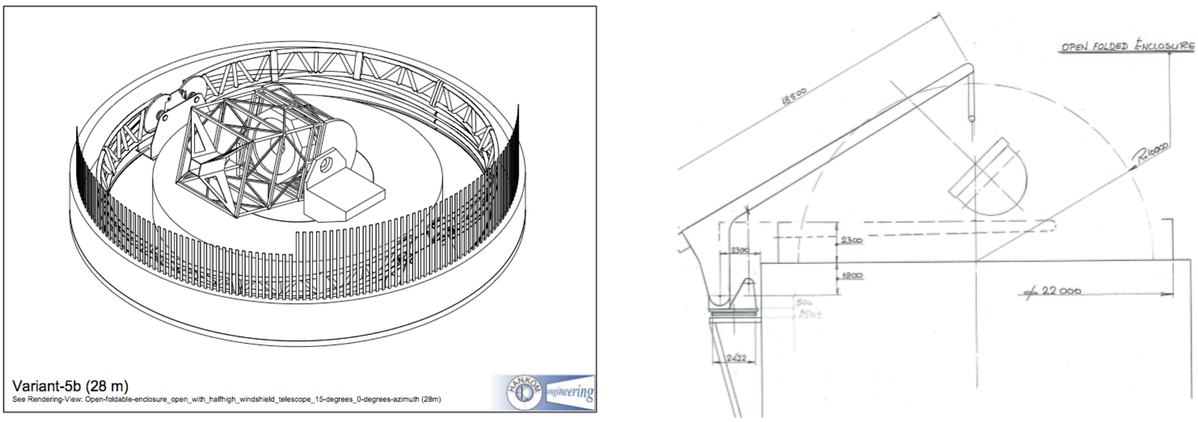


Figure 9. (Left) Windshield; (right) Proposed crane for handling of the M1 cell for periodic recoating.

Craning of heavy equipment (M1) is proposed with an outside crane, which lifts the M1 cell vertically out (Figure 9, right). More advanced methods are under study.

## 6. TRADE-OFF AND CONCLUSIONS

We conclude that both a cooled hemispherical and a retractable enclosure based on membrane are regarding technical considerations feasible. The strengths and weaknesses of dome and retractable enclosure are listed in Table 3.

Related to seeing, since shell- and dome seeing seem to be the most demanding thermal problems, with shell seeing the most critical, and floor seeing the easiest to mitigate, the retractable enclosure is preferred.

The main general drawback of a retractable enclosure is the windshake on the telescope structure and M1. A windshield turns out to perform well, and turns out to be similar in performance as a ventilated dome. Preliminary analysis have been done on the effect of windshake on the telescope structure and on the primary mirror for the open air configuration, which gave requirements for the telescope structure and primary mirror support and resulted in preliminary designs able to operate in open air with acceptable wind deformation[3,4,5].

Retractable enclosures are cheaper than domes. It has been estimated that a ventilated and cooled dome of equal diameter will be 2-4 times more expensive than a retractable enclosure, depending on the exact configuration. A significant part of the costs of a dome is needed for the shell cooling and gates. This cost difference is partly diminished by the fact that in case of an open air configuration, the telescope structure and primary mirror needs to be stiffer than in the case of a dome, in order to be able to cope with higher wind load. But, also considering this difference, the cost of a conventional dome with thermal control will be higher than for the retractable enclosure.

The retractable enclosure allows the use of a reflecting heat rejecter at the Gregory focus, while with a conventional dome it is necessary to absorb the heat inside the dome.

Disadvantage of the retractable enclosure is that a larger diameter seems required than for a dome, if a full movement range of the telescope is required inside. Craning facilities are more difficult to implement.

Table 3. Comparison of strength and weaknesses of the dome concept and retractable enclosure.

| | Ventilated Dome | Retractable Enclosure | Comments |
|---|---|---|---|
| Local seeing | - | + | Retractable always best. More effort needed in case of dome. |
| Wind shake | + | = | Stiffer telescope needed. Effect can be mitigated with windshield |
| Primary focus heat stop | - | + | Heat rejector possible. Safer. |
| Telescope mobility | + | - | For full range, larger diameter required for retractable variant. |
| Handling equipment | + | - | The dome can easily provide crane facilities. |
| Safety | = | = | Dome more complex system, due to cooling. Both need redundant safety systems |
| Cost | - | + | Dome more expensive, even when including extra costs for stiffer telescope |

Considering the above arguments, we conclude that the retractable enclosure is to be considered as the less risky alternative, since it allows easier local seeing control with less effort and it allows the use of the safer reflecting solution for the heat stop. The preliminary analysis of wind load on the primary mirror indicates that there are feasible solutions to keep the wind buffeting deformation within the requirements for open air configuration. A windshield can be implemented as backup.

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