Fighting the local seeing – Cooling and Venting

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Observational disturbances by air turbulence are an annoying side effect for astronomers. This so-called (optical) "seeing" is caused by turbulent air cells with a typical size of a few meters. They distort the parallel wave front of the incident light and increase the apparent diameter of point sources in the sky. Beginning at an aperture of about 15cm the resolving power of a telescope is not dominated by its diffraction limit but by the local seeing in the sky.

To eliminate or minimize this unwanted effect there are three possibilities for the astronomers:

1. Measurements from space - without any atmospheric effects each telescope operates at the diffraction limit.
2. Using adaptive optics – the correction of the disturbed wavefront by mechanically flexible telescope optics.
3. Special observing sites – Perfect atmospheric conditions reduce the seeing effect. (Fig. 1).

Fig 1: The Nordic Optical Telescope at La Palma (Wikipedia - Bob Tubbs).

Unfortunately, all three measures can normally not simply be implemented by amateur astronomers. Measurements from space are overwhelmingly expensive and will therefore remain an exclusive domain of professional research. The available adaptive systems in the amateur market do not deliver reasonable results for their prices. And measurements at the best observing sites are usually connected to high installation or travel expenses.

However, a well-known contribution to the natural seeing can be significantly reduced both by professionals and amateurs for a relatively low price - the local seeing. It is air turbulence near the observation station caused by the telescope and the associated building.

A detailed investigation

In 1995 Lorenzo Zago at the École Polytechnique Fédérale de Lausanne published a comprehensive work on the local seeing influences at astronomical observatories [1]. In his dissertation he considered different seeing effects at various professional observatories and provides a quantitative analysis, which can be directly transferred to amateur observatories. His central considerations include the so-called dome seeing, which is caused by structures in and around the observatory. This seeing portion can also be very effectively fought by amateurs. The four key issues are (Fig. 2)

a) Free convection from the floor which is warmer than the environmental air,
b) Turbulence at the dome slit,
c) Seeing from a primary mirror which is warmer than the environmental air and
d) Seeing from a secondary mirror which is warmer than the environmental air.

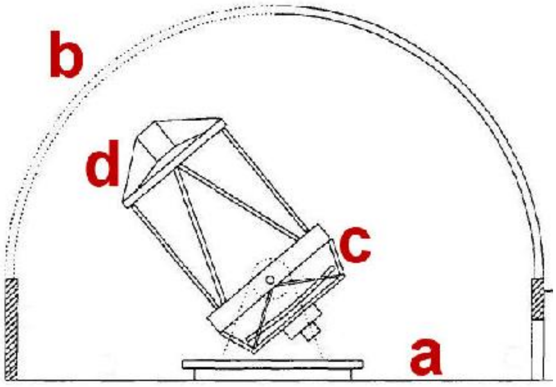

Fig 2: The most important sources of ~~the~~ dome seeing (Zago).

Natural and local seeing

The seeing disk, i.e., the „diameter" of the stellar image in the sky is described by its „Full Width at Half Maximum" (FWHM or Φ). It describes on the diameter of the intensity function in arcseconds of a point light source widened by air turbulence at its half maximum intensity level. Since the seeing consists of various effects and sources and since there are no techniques to distinguish these various seeing sources, one always needs to consider all seeing sources together. The natural seeing Φ_n and the local seeing Φ_l are connected by a power similar to Pythagorus [1].

$$\Phi^{5/3} = \Phi_n^{5/3} + \Phi_l^{5/3}$$

This simple equation shows that one can significantly improve the overall seeing by an improvement of the local seeing Φ_l alone. An example: If the local and the natural seeing are 4 arcseconds the overall seeing is about 6 arcseconds. However, if we improve Φ_l to 1 arcsecond the overall seeing is then 4.2 arcseconds! It is therefore understandable and desirable to attack the seeing where it is most easily possible for amateurs. And that is the local seeing at the observatory, which is in turn dominated by the four sources of dome seeing above.

Free convection from the floor~~n~~

When the European Southern Observatory had conducted seeing measurements at various telescopes on La Silla, they discovered something interesting. The seeing at the 3.6m telescope (Fig. 3) was significantly worse than that at the 2.2m Planck telescope (Fig. 4).

Fig 3: The ESO 3.6m telescope at La Silla with its oversize dome (ESO).

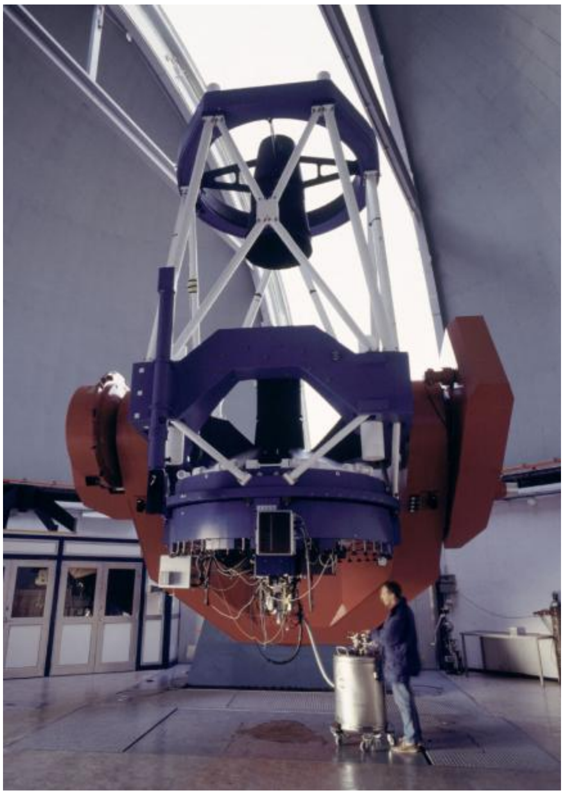

Fig 4: The ESO 2.2m Planck telescope at La Silla with its closely adapted dome (ESO).

That was by far unexpected since the dome of the 3.6 telescope was massively oversized with respect to the telescope structure. The idea was a large distance to the dome slit to avoid disturbing wind turbulence. Above that, the telescope building was relatively high to avoid seeing introduced by the local ground. In contrast, the Planck telescope is at ground level and in a dome of minimal dimensions. Nevertheless, its dome seeing was significantly better than that of the 3.6m. Similar negative influences had been noticed at the 3.6m Canada-France-Hawaii Telescope (CFHT) on Mauna Kea, which is also housed in a large building.

The decisive advantage of the Planck telescope building is its actively cooled floor. When the floor of the CFHT was also cooled, the median seeing of around 2 arcseconds improved to 0.6 arcseconds. The cooling of the floor affects the air turbulences in the telescope room and entirely eliminates the so-called floor seeing. This also applies in a similar manner for a floor and wall insulation without ventilation.

Turbulence at the dome slit

Generally, seeing is not only connected to the wave front of the incoming light but also deviations from ideal pointing and guiding accuracy. These deviations may be introduced by wind turbulence at the dome slit. The reason is velocity fluctuations due to stochastic velocity differences between the inner dome space and the outer environment. The geometrical sizes of these turbulent cells are of the order of the dome slit width. This in turn causes pressure differences and thus disturbances in the tracking with a typical frequency of 1Hz. A relatively large distance between the dome and the telescope can reduce this problem and the great 3.6m telescope at La Silla was designed accordingly.

One might argue that parallel walls and large telescope slits completely avoid such turbulence (e.g., buildings with sliding roofs). Many examples can be found in the amateur domain, much as we designed our own first observatory (Fig. 5).

Fig 5: Our first observatory (STScI).

Such a building can also be found at La Silla. It is the 3.5m NTT with an orthogonal housing. However, for specific azimut angles with respect to the wind direction, turbulence can even be increased. Wind shields can help, which then, however, imply a significant extra effort and act best only at limited azimuth angles to the wind.

Seeing from the primary mirror

A special and often neglected seeing source is the so-called mirror-seeing. This seeing source should be at the focus of all considerations with respect to the local and instrumental optical quality. After all, mirror seeing usually accounts for the largest share of the total local seeing! The cause of this disturbance is a main mirror, which is warmer than the surrounding air and thus generates thermal turbulence directly on the mirror surface. This is completely analogous to a dome space that is warmer than the surrounding outside air which causes thermal turbulence at the dome slit.

Extensive research by Zago has yielded results that can also be used by amateur astronomers. At first, mirror seeing takes place in a very narrow geometric area. The far greatest disturbances are caused by a 5mm boundary layer on the mirror (Fig. 6).

A quantitative analysis shows that a mirror that is warmer than its surroundings delivers additional seeing of 0.3 - 0.4 arc seconds per °C. If the main mirror is only about 5°C warmer than the ambient air, local seeing deteriorates by up to 2 arc seconds. According to the above equation, an excellent 1 arcsec Central European seeing is worsened to more than 2 arcsec if the mirror is warmed up to 5°C relative to the ambient temperature. This effect is well known in practice. Measurements in the morning, after the main mirror has cooled down to ambient temperature, provide significantly better results than observations in the evening when the main mirror is still warm. This problem is already taken into account by some telescope manufacturers through fans in the tube. If you don't have such fans, we recommend retrofitting them to improve cooling.

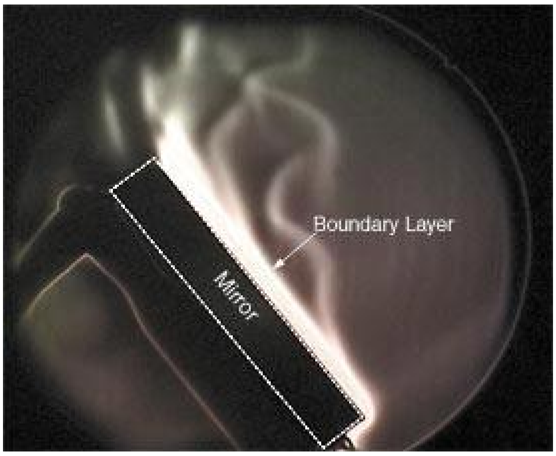

Fig. 6: Schlieren photography of a warm mirror (Zago).

It should also be noted that mirror seeing does not occur if the mirror is cooler than 3°K below ambient temperature.

Seeing from the secondary mirror

Another, albeit weaker, seeing source is the secondary mirror. With its small size, it does not dominate the entire system, but if you consider its position in the light path, you can recognize its significant influence on the wavefront of the incident light. If it is warmer than ambient temperature, a zone of warm and thus undesirable turbulent air stands above it, which disturbs the image (Fig. 7). It is therefore advisable to include the secondary mirror in the thermal concept by means of a fan or other cooling system.

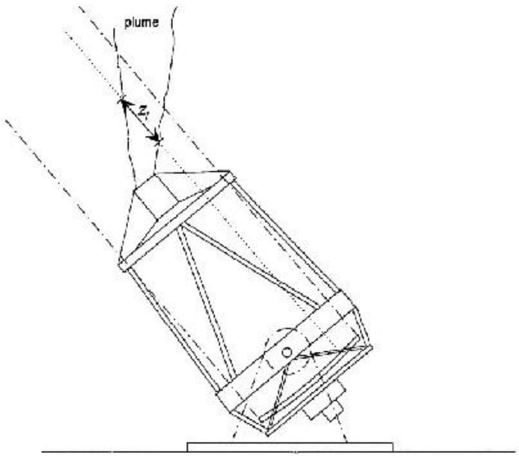

Figure 7: The secondary mirror with its indicated heat vane (Zago).

Other sources of interference

Zago discussed some other important points, which amateurs should also consider. These include the building material, vegetation around the building, and the local climate.

The building material

The above considerations about the telescope environment and the instruments can be transferred to the telescope building, especially to the building material. Before thinking about this topic, massive sandstone or even granite buildings with a correspondingly high heat capacity were widespread (Fig. 8). This has negative consequences for the heat balance and thus for the seeing.

There are two contradictory parameters in the choice of building materials.

- On the one hand, the interior should heat up as little as possible during the day, in order to keep the telescope and telescope room as cool as possible at night. That means the walls should be insulated.
- On the other hand, the amount of heat accumulated in the wall during the day should be as small as possible and should be directed outwards as quickly as possible. This means that the walls should be relatively thin and not insulated.

Figure 8: The historic Göttingen Observatory (Wikipedia - Patrick Hessman).

The art of selecting adequate building materials is therefore to find a sufficiently good compromise between the above requirements. Since only very few amateur astronomers have adequate knowledge of building physics, questions about the building material are often neglected. In times of the Internet, however, there is no longer any need for specialist knowledge and the corresponding equations no longer need to be known. For example, the website www.u-wert.net (English version available) uses a front-end to calculate relevant parameters for different building materials. This means that, for dozens of freely selectable standard materials and wall thicknesses a number of parameters can be caculated and displayed. These are the heat transfer coefficient in W/m²K, the condensate in Kg/m², the temperature amplitude damping, the phase shift, but also the dew point, the place of condensation and the temperature curve (Fig. 9).

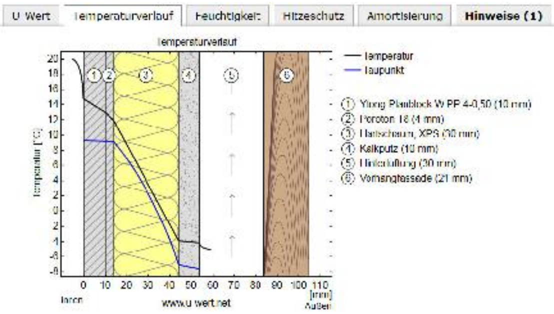

Figure 9: Sample graphic output of the temperature profile for a ventilated wall made of different building materials (www.u-wert.net).

Surprisingly for us, fired bricks turned out to be extremely advantageous for our needs. However, similar good properties could be achieved with much cheaper hollow blocks, so that we have chosen this material for our telescopic tower. In contrast, our attached service building is made out of a timber stud construction for maximum insulation.

Vegetation

During a discussion with the people in charge at Bayfordbury Observatory [2] in England a few years ago, we discussed the southern English seeing conditions at the local telescopes and their domes. I learned that one of the seven permanently installed telescopes delivers the best seeing in the long term. It is the Marsh telescope with a 50cm Cassegrain. The reason for the good seeing is the strong hedge growth on the outer wall of the telescope building (Figs. 10 and 11).

Apparently, the plant regulates the temperature by reducing the heating of the building through solar radiation. It also stabilises the local moisture, just as well known indoors.

Figure 10: Some dome buildings of the Bayfordbury Observatory in southern England. The Marsh dome with hedge growth can be seen halfway to the left (Bayfordbury Observatory).

Figure 11: Detail view of the Marsh Dome (Bayfordbury Observatory).

What you shouldn't do

Anyone who has ever worked at a professional observatory will not have much passion for measurements in urban environments. Too frustrating is the difference between a typical professional seeing of about 0.2 arc seconds and typical values 10 times greater. Nevertheless, when planning your own observatory (if you still have maximum freedom) you should also consider other conditions in order to achieve an optimal result for the local conditions. Unfortunately, I repeatedly see unfortunate amateur solutions, which in my opinion should be avoided as far as possible.

1. **A telescope on the roof of the house.** Any strategy at the Observatory against local seeing is useless if the largest part of the building is not taken into account.

As houses usually have an effect on the seeing up to several dozen meters above sea level, they even have an influence on the natural seeing. Get away from the houses or find appropriate arrangements!

2. **Observatories made of unfavourable material.** One should carefully consider the temperature adaptation (diffusion) and stability (isolation). Only then should one opt for the material after taking into account further boundary conditions (finances, location etc.). Once the building has become a "heat accumulator", it is difficult to correct this with other techniques (e. g. active cooling). So: check the building material first!
3. **An observatory near natural or artificial obstacles.** The key to excellent natural seeing is a laminar atmospheric air flow without turbulence. This is the only way to avoid turbulent seeing cells. This easily explains the good seeing conditions of some observatories in relatively flat terrain. So: Look for a wide open space without obstacles!

The overall package must be right

Modern observatories take full account of Zago's investigations, whose work is very detailed. He notes that a ventilated building can completely eliminate local seeing. He also notes that dome seeing is generally eliminated if the telescope optics are cooler than the indoor air and the indoor air is cooler than the outdoor air. Accordingly, at modern professional observatories, there are not only active cooling systems but also sufficiently large openable hatches dome walls which ensure optimum air exchange (Fig. 12).

Figure 12: The interior of the Gemini Observatory on the Mauna Kea (Gemini Observatory).

In addition, Zago has found that the wind flow and thus temperature balance is better in buildings with a rectangular ground plan than in those of circular shape. However, rectangular buildings can cause disruptive turbulence. These different problems are the reason why modern domes are no longer exactly spherical. They try to keep the wind flow as turbulence-free as possible.

This is quite frustrating for the amateur. The ventilation of the telescope can still be realised with relatively little means, but cooled telescope rooms (whether with cooling devices or fans) cause additional costs and inevitably include a separate control room (you don't want to be cold). Special building material can also be expenxive, not to mention extra costs for an observatory far away from any residential areas. Spherical domes are certainly not cheap, but special designs put even more strain on the finances. Compronises are needed!

Our own design

The above investigations and observations were the basis for the planning of our own observatory. Our main instrument is a professional 80 centimetre Ritchey-Chretien telescope of the American manufacturer DFM Engineering, which used to be located at the Wendelstein Observatory and whose construction has been installed more than a hundred times worldwide so far (Fig. 13). In order not to further degrade the performance of this telescope, as the German location per se already does, we had to carry out extensive investigations which take the Zago results into account as far as possible and are nevertheless financially realistic. Good thermal planning was a central part of these considerations because otherwise we would destroy the outstanding opto-mechanical properties of our instrument (active optics with actuators, temperature-stabilized focus through the use of Nickel-Iron alloy Invar elements, active fan cooling of the main mirror) already with the construction.

Figure 13: The STScI main instrument. Two of the four cooling fans for the primary mirror are visible on the mirror cell (STScI).

We would have used a dome that was optimized for seeing and had offered a diploma thesis at Aachen University. Unfortunately, no student responded to this complex work. The main hurdle, however, was the projected price of around 150,000 euros, so we decided to buy a used but very cheap traditional 6-metre dome.

We chose a KLB pumice stone for the telescope tower (Fig. 14).

Figure 14: The body shell of the telescopic tower for the STScI main instrument (STScI).

In high summer, even in direct sunlight without active cooling, the temperature of the telescope room is significantly below the outside temperature. The active cooling of the telescope room is carried out by a low-noise high-pressure industrial fan from dalap GmbH [3] (Fig. 15).

Figure 15: Low-noise high-pressure fan for ventilating the telescope room (dalap GmbH).

In view of the size of our telescope room of almost 100m³, we have opted for a fan diameter of 150mm, so that all the air in the telescope room can be evacuated within less than 10 minutes (Fig. 16).

Figure 16: Installation of the ventilation pipes in the telescope room. The system will be installed under a wooden ceiling.

In summer, however, this configuration would make no sense due to the inverse temperature gradient (high outside temperatures). In the warm season, ambient air will flow through several meters of earth ducts via the chimney effect due to warmer air in the dome. During this procedure the flowing air is cooled by the ground temperatures of typically 10°C. In winter, the cold air is thus actively led through the dome slit into the dome and then to the outside via open wall hatches.

In addition, we are considering actively cooling the floor of the telescope room, just as we are doing with the Planck telescope. This is relatively easy to achieve with cooling loops of an underfloor heating system and a heat exchanger. The dissipated energy can then be used to heat the service building in winter and to heat a tank for water in summer.

Summary - Cooling and ventilation

One should consider the consequence of the equation $\Phi^{5/3} = \Phi_n^{5/3} + \Phi_l^{5/3}$. One may find wonderful atmospheric conditions, but the local seeing can still ruin everything. Because the local seeing is composed of many sources of disturbance (dome, building walls, telescope etc.) it can grow quickly to a few arc seconds. Good observation conditions (e.g. 2 arcseconds in our area) can then be degraded to catastrophic values. Of course, the local seeing depends on the individual conditions and requirements of individual observers. However, sophisticated observatories anyway require extensive considerations about the local seeing. Considering the climatic conditions that amateurs usually have to deal with, appropriate considerations are a must.

[1] Lorenzo Zago, *The Effect of the Local Atmospheric Environment on Astronomical Observations* – http://www.stsci.de/zago.pdf

[2] Bayfordbury Observatory - http://www.herts.ac.uk/bayfordbury

[3] dalap GmbH (Olbernhau) - http://www.ventilatoren-belueftung.de