Toward a "green" Observatory

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ABSTRACT

Many of the modern observatories are located at remote sites, far from larger cities and away from infrastructure like power grids, water supplies and roads. On-site power generation in island mode is often the only choice to provide electricity to an observatory. During the 2008 petrol price rally, conventional power generation has received special attention and alternatives are being studied now in many organisations to keep energy prices at bay.

This paper shall outline the power generation at the ESO VLT/VLTI observatory at Paranal as it is now and a plan for a possible way out of the dependency on fossil fuels in the near future.

A discussion of several alternatives including wind energy, solar energy and heat recovery from a conventional power plant shall be analysed and compared.

Finally, a project is being proposed to equip the VLT/VLTI with a modern alternative energy supply, based on a novel concept: Solar cooling.

Keywords: Power Generation, Solar Power, Solar Cooling, Alternative Energy, Renewable Energy, Island Mode, Carbon Footprint, Observatory Operation.

1. INTRODUCTION

The aim of this paper is to analyse the present energy production at the ESO VLT/VLTI Observatory at Paranal, considering the recent development of world energy prices and to propose ideas for the implementation of alternative models and show the feasibility for a future application of alternative energies.

The VLT/VLTI Observatory has not been conceived originally with any alternative energy concept in mind. During the planning of the VLT/VLTI project, some ideas were studied but discarded afterwards due to the high additional investment that was not easy to justify considering the low energy prices at that time. The fact that Paranal is a very remote site, more than 130 km away from the town of Antofagasta, until 2009 only accessible via a dirt road, out of reach of any power grid and in the middle of the Atacama desert, did not leave many other choices to the VLT/VLTI project engineers than to produce its own power with Diesel generators.

As the environmental awareness has increased over the years and large companies and organisations are now more conscious about environmental issues, the conditions to study and implement alternatives to contaminating processes have also fundamentally changed. None of the novel technologies are cheap and they still have to compete with the ones that use fossil fuels. However, organisations are more open now to consider return on investments on a longer time scale than a short sighted 2-3 years, which opens possibilities to apply these new concepts economically.

2. PRESENT SITUATION

2.1 Development of energy prices

The two plots (Figure 1) show clearly how the prices for crude oil and natural gas developed over the last decades. Due to the higher demand worldwide, the ever-growing concern about resource depletion and increasing production costs, crude oil will not become cheaper again in the long term. As the natural gas price is still somehow connected to the crude oil price, this tendency is possibly also valid for this type of fuel. The recent discovery of new gas deposits and new extraction methods may well lead to a growing span between oil and gas and thereby put the latter at an advantage. But despite of that, renewable energies will become more and more competitive in comparison to fossil fuels. The break-even point, where renewables become effectively cheaper, depends however on different factors like initial investment costs and operating costs of the alternative power generation systems. These aspects will be discussed later.

Operating the observatory on fossil fuels alone will have an increasing impact on the operational costs in the near future. Mitigation of this risk is not easy and will require the observatory to change its energy policy.

A barrier that hampers the use of alternative energies in the host country of the organisation is the missing law framework that would allow feeding excess energy into the grid and oblige the large grid operators and utility companies to buy back energy produced by these decentralised and mostly smaller producers. Such laws are in place in many European countries already and largely facilitate the development of the alternative energy sector.

But in the absence of a connection to the grid, this is not an issue that needs immediate attention. If this would become a possibility in the future, Paranal could get electrical energy at nearly half of the present production costs, which would maybe relax the situation temporarily but certainly not in the long term. Energy prices are bound to rise and the only long-term solution is to embark upon renewable energies. This is particularly true for Chile where according to a 2009 OECD/IEA statistics 78.1% of the primary energy supply is based on fossil fuels and 21.9% is renewable (and thereof only 6.5% is hydro).

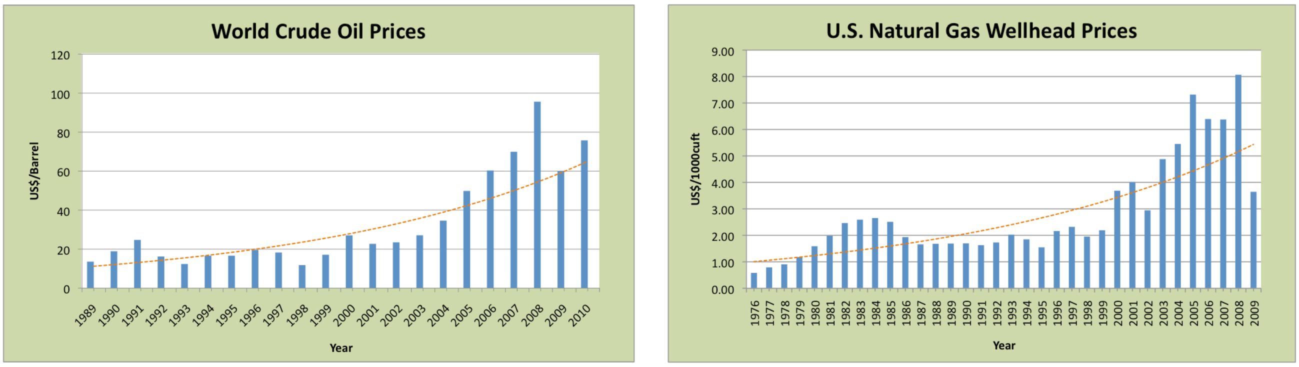


Figure1. U.S. oil spot prices (left) and natural gas wellhead prices (right). (Source: Energy Information Administration at: http://tonto.eia.doe.gov/)

2.2 The energy mix at Paranal

The primary energy consumption at the observatory consists of 95% liquid petroleum gas (LPG) to feed a 2.4 MW multi-fuel (Diesel and LPG) turbine for the electricity generation. This turbine is also enabled for natural gas (methane) operation. The remaining 5% go into gasoline and Diesel for local car commuting at the site (2%) and Diesel (3%) for the electricity generation with 3 back-up Diesel generators of 800 kW each, which are used during maintenance periods of the turbine. This shows that Paranal relies entirely on a non-renewable energy supply.

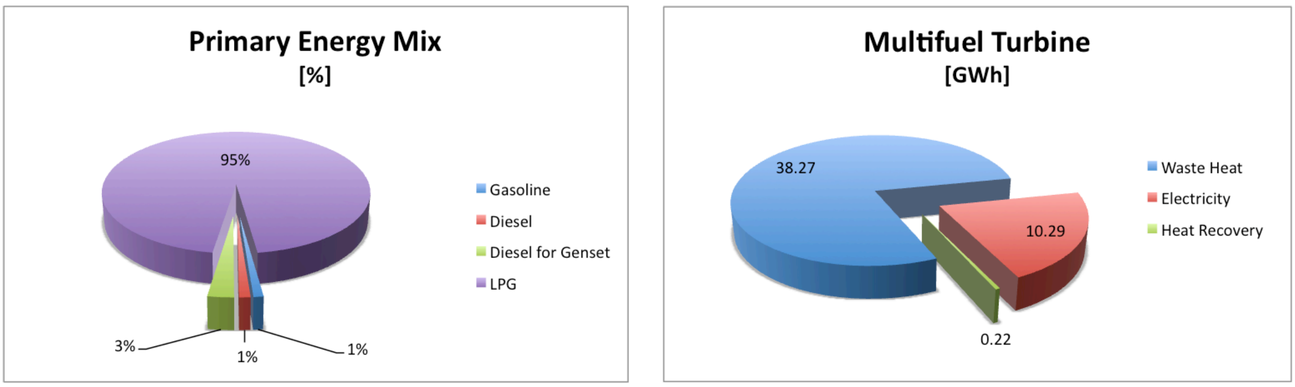


Figure 2. Composition of primary energy sources of Paranal (left) and energy efficiency of the multi fuel power generation with the heat recovery for the Residencia hot water supply.

Figure 2 shows that except for on-site commuting and transport, all energy consumption is in the form of electricity. A very minor fraction of the waste heat from the power generation is being recovered for the hot water heating at the Residencia. Here, the observatory would of course have an option to use this exhaust heat also for the room heating of the Residencia and the container camp.

2.3 Electrical power consumption

As expected, the main consumer is the VLT/VLTI telescope complex on the Paranal mountain top platform. It contributes to 2/3 of the power consumption. This includes the four unit telescopes, the VLT survey telescope (VST), the VLTI complex, the four auxiliary telescopes (AT1 to 4) and the control building (CB) where also the cooling plant for the supply of the cooled media is located.

Figure 3 shows that the remaining 33% of the 1130 kW are almost evenly distributed between the VISTA telescope (102 kW, including 35 kW for the Chiller), the base camp, where the workshops and technical services are located and the "Residencia" (staff accommodation, visiting astronomers and logistics offices).

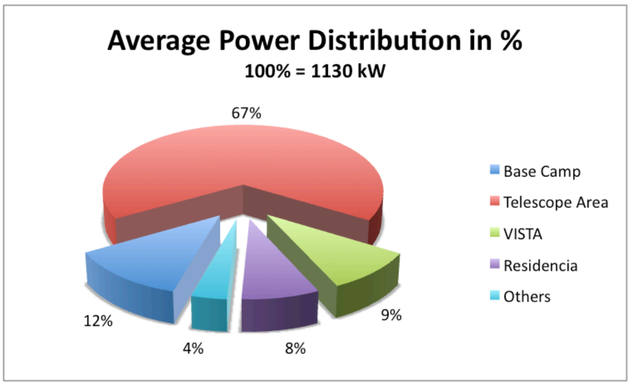
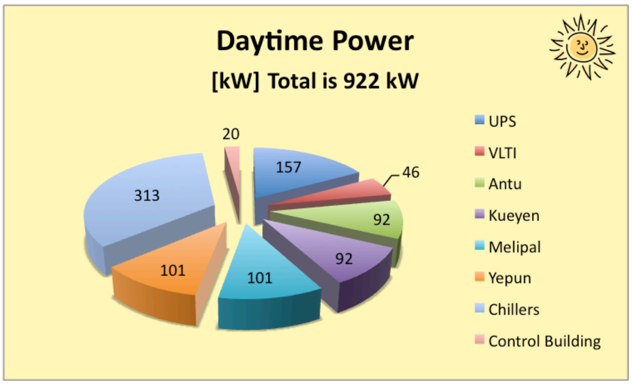


Figure 3. Electricity load distribution

The main power demand (Figure 4) in the telescope area is for the chillers (including pumps etc.), which supply cooled media to the telescopes. The local air-handling units in the unit telescopes consume also of the order of 50 – 60 kW and as they are switched off during the night, the power of the individual telescopes is reduced correspondingly. These are the two main reasons for the day/night difference.



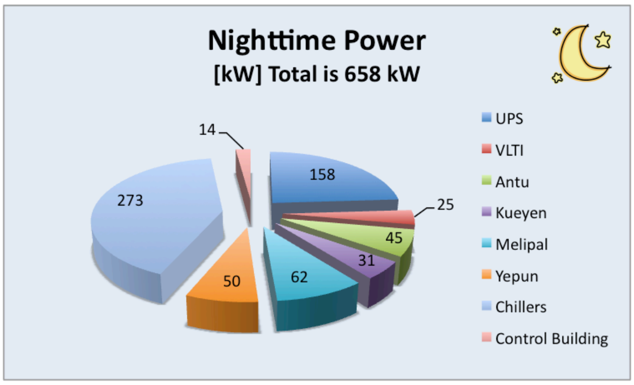


Figure 4. Typical daytime and nighttime power distribution in the telescope area (not including VISTA) on April 4, 2010

Yet another interesting data is the amount of UPS power that is being supplied to the telescope control system, the instruments and the computers: It is of the order of 160 kW. This value is also determining the size of the UPS system. In order to guarantee an independent power back up during a power cut for at least 30 minutes, it should have a capacity of not less than 80 kWh.

When looking at the day/night and summer/winter consumption pattern in Figure 5, one can see that night time consumption of the telescopes is lower because the air conditioning system is idle, and summer day consumption is higher when the day time temperature demands higher air conditioning. However, nights are similar in summer and winter, which can be explained by the constant demand of cooling for the electronic equipment and operational power for the telescopes and auxiliary equipment like pumps, hydraulic bearing system and the control system. Winter consumption at the Residencia is caused by the electrical heating system in the rooms and offices. The VISTA winter nighttime values are not yet representative, as VISTA went only recently into regular operation.

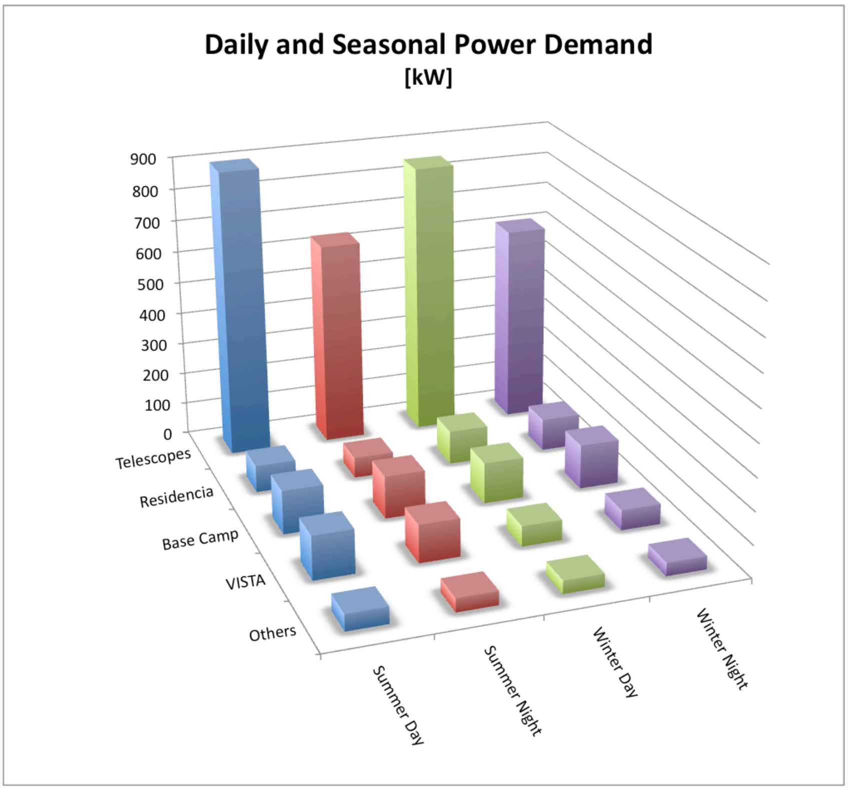


Figure 5. Seasonal and daily fluctuations of power

2.4 CO_2 footprint

For the calculation of the carbon footprint (CFP) of the Paranal observatory, several assumptions have been made. Firstly, the calculation includes all the transports of the ESO personnel, contractors, visiting astronomers and technical staff on missions, both for domestic transportation in Chile as well as the international flights from Europe. Secondly, it includes the transport of fuel, water, groceries and waste. Thirdly, it includes the emission caused by board and lodging of the staff at the observatory. And it also includes a 10% surcharge on the fuels to account for the secondary emission, produced during fuel extraction.

The total carbon dioxide equivalent emission is 22’000 tons per year and if the observatory would have to offset the carbon emission, the yearly costs would amount to US$ 440’000, assuming a cost of 20 US$ per ton of CO_2 equivalent.

The VLT/VLTI observatory produced in 2008 and 2009 approximately 960 peer-reviewed papers. Hence, each of this paper produces a CFP of 45.8 tons of CO_2 equivalent and would cost roughly 1000 US$ to offset. In comparison, this corresponds to 10 times the yearly CFP of a person at world average.

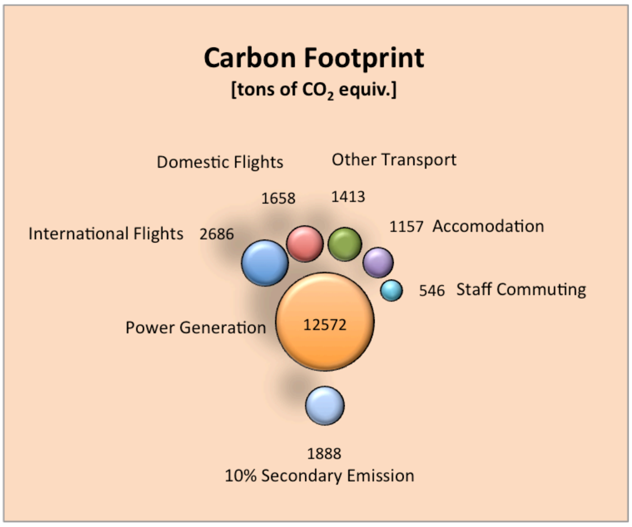


Figure 6. CFP of the Paranal observatory: A total of roughly 22’000 t CO_2 equivalent is released per year.

How can the CFP be reduced? The heat recovery for the hot water heating in the Residencia contributes to a saving of 140'000 l of LPG, corresponding to 240 t CO_2 equiv. This is a very small reduction and it would require a considerable effort to reduce it further. Only the use of renewable energy can make a difference here and therefore it is also important from this point of view to make a change.

3. ALTERNATIVES

3.1 A look at renewable energies

For our preliminary study, all alternative energy sources that are not CO_2 emission free are being left out. Energy produced from biogas from waste processing, geothermal and hydroelectricity either from tidal energy or dams are not considered here because of their unsuitability: The peculiarity of the site where the observatory is located limits the choice of feasible alternative energy sources. Table 1 summarises three potential energy sources that have a real chance to be successful in terms of economical and technical aspects and considering the characteristics of Paranal.

Table 1. Comparison of alternative energy sources for Paranal.

	Photovoltaic (PV)	**Solar thermal**	**Wind**
Advantages	Direct conversion into electricity	Simple technology	Proven technology, economic
Disadvantages	High tech, expensive	Moderately expensive	Intermittent availability of power
Suitability for use in island mode	Day-night cycle requires some sort of storage	Hot or cold water storage required	Difficult to deal with intermittence of power
Energy Payback Time	1-3 years, depending on semiconductor technology	0.5 – 1 year	0.5 years
Lifetime	20 – 25 years	25 years	25 years
Sustainability	PV cell production and elimination of old cells produce hazardous waste	Excellent - none of the materials is scarce	Regular Lubrication oil waste

For both sources, solar radiation and wind, the observatory site is in a quite favourable location: The average ground solar energy is of the order of 6-7 $kWh/m^2/day$, which is among the highest values worldwide. The median wind speed at Paranal is 6.6 m/s and the power input is around 350 W/m^2. Therefore, wind power could also be exploited very well, but maybe not very close to the observatory, as there is some concern with respect to the turbulences that are produced by a wind turbine. A location would have to be carefully selected and more data needs to be collected in order to optimize the size of a wind farm.

According to a model calculation and considering the wind statistics of the site (see Figure 7), a yearly energy of 4.5 GWh could theoretically be harvested with a modest 1.5 MW - 72 m rotor diameter wind turbine, or 3.5 GWh with two smaller 755 kW - 42 m rotor diameter wind turbines. This corresponds roughly to between 35 and 45% of the yearly energy demand at Paranal. Cumulating wind farm and solar chillers, 40 to 52 % could be saved.

One big problem is of course the fact that Paranal is not connected to any electrical grid and therefore all power that would be generated on-site would have to be consumed, as there are no feasible storage concepts available yet. Hydrogen, hydraulics or compressed air are not suitable as a storage media at the Paranal site and electricity storage is also not yet feasible. Therefore, wind energy and also PV generation from the sun, despite being technically feasible, are not contemplated to be a real possibility to cover Paranal's energy needs in the short term.

Remains the solar thermal energy: This is low-tech and simple. Thermal collector fields supply hot water or vapour directly to either a Stirling machine to produce electricity or the heat is being used in an adsorption or absorption cooler to generate cooled media. The latter principle shall be analysed in chapter 4. Heat recovery from the turbine generator would only be an option if the observatory would remain forever unconnected from the Chilean grid. Then, an upgrade to a combined cycle system, where also the waste heat from the multi-fuel turbine is going to be used for electricity generation, would be highly recommended. As this is unsure for the moment, only a stepwise approach is indicated in order to avoid investments that would be futile before they paid back.

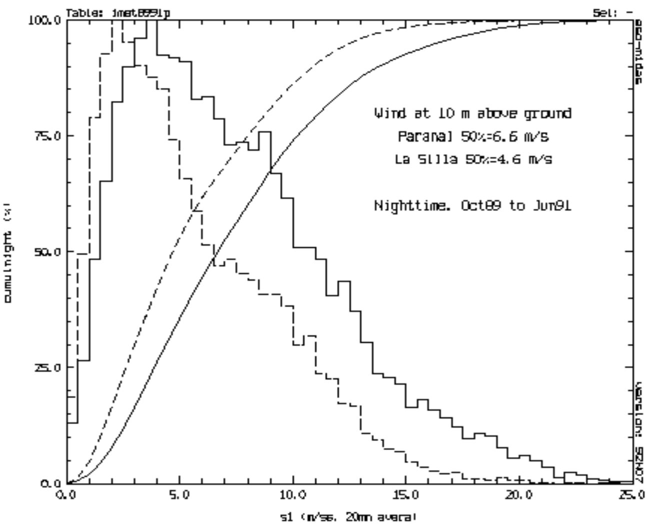


Figure 7. Histogram of wind speed at 10 m above ground: 50% of the time the wind is above 6.6 m/s

3.2 Energy savings

Every effort to save energy has a direct impact on the CO_2 emissions. There are lots of strategies for savings and many of them can be applied in a straightforward manner to the operation of the observatory. Awareness is also of importance and the observatory management has taken the initiative to foster several initiatives for energy saving.

Here is a list of things that can contribute to immediate energy savings:

- Switching off of unused equipment like lights, computers and monitors.
- Force the replacement of obsolete equipment by new and energy efficient equipment.
- Equipment that idles on stand-by power needs to be energy efficient (i.e. printers, monitors, displays).
- Sleep mode and stand-by initiated as soon as possible and operationally safe.
- IR motion detectors that switch off lights in rarely frequented areas.
- Adding capacitor banks to compensate the reactive power in the observatory power grid.

3.3 Other “green” aspects

Overcoming the temptation to “green-wash” the observatory’s energy policy, it is worthwhile to mention here also other measures that can contribute to the reduction of energy consumption and greenhouse gases at the observatory. Among them is the waste management that includes recycling of all materials that are reasonable, like paper, PET bottles, glass and waste from the mechanical workshop and discarded chemicals and oils.

Then, transport and specially the intercontinental flights and domestic commuting are very high contributors to the contamination caused by the operation of the observatory: Locating the staff as close to the observatory as possible would be an option but is difficult to enforce as this interferes with the personal preferences of the staff. Intercontinental flights contribute 12% to the CFP and domestic transport to 17%. Remote observing and longer working shifts could reduce this numbers, but would put considerable restraints on the operational model of the observatory.

Local commuting on the observatory site could be done in the future with electrical vehicles that are charged during daytime from a photovoltaic field. Cars for commuting accrue 1 million km and consume 61’000 l of gasoline per year. A photovoltaic collector field of approximately 4000 m^2 would be required to supply this power.

The biggest contributor, both to the CFP as also to the operational costs, is the power generation. Attacking this contributor is by far the best way to go greener!

4. SOLAR COOLING

4.1 The VLT/VLTI cooling system

The enclosures of the four VLT unit telescopes have to be air conditioned, in order to avoid that the 20 ton 8.2 m primary mirror changes its temperature during daytime. A sophisticated control system predicts the outside temperature at the time of opening of the enclosures in the evening and maintains the inside temperature during daytime at this temperature value. A considerable amount of energy is used to feed the three chillers, which supply the air-handling units in the telescopes with cold water. Figure 8 shows the cooling circuit in the telescope area.

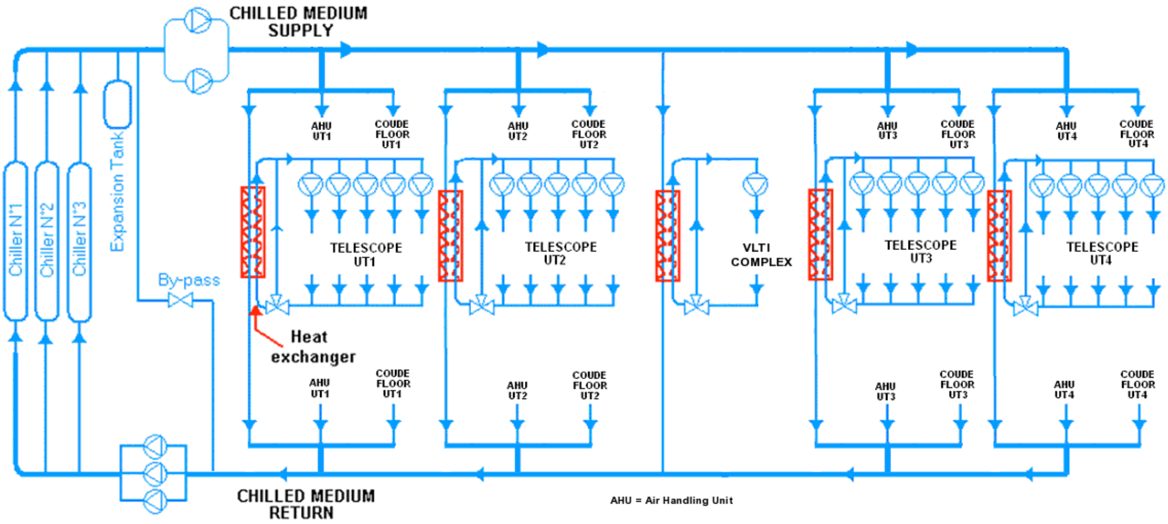


Figure 8. Cooling circuit of the telescopes and the VLTI installation

To meet the summer cooling demand of 200 – 250 $kW_{thermal}$ per unit telescope, at least two chillers and four dry coolers are running continuously during daytime. The electrical power consumption of each chiller is 142 kW and 7 kW for each dry cooler. The power for the circulation pumps and associated control systems is not included in these values.

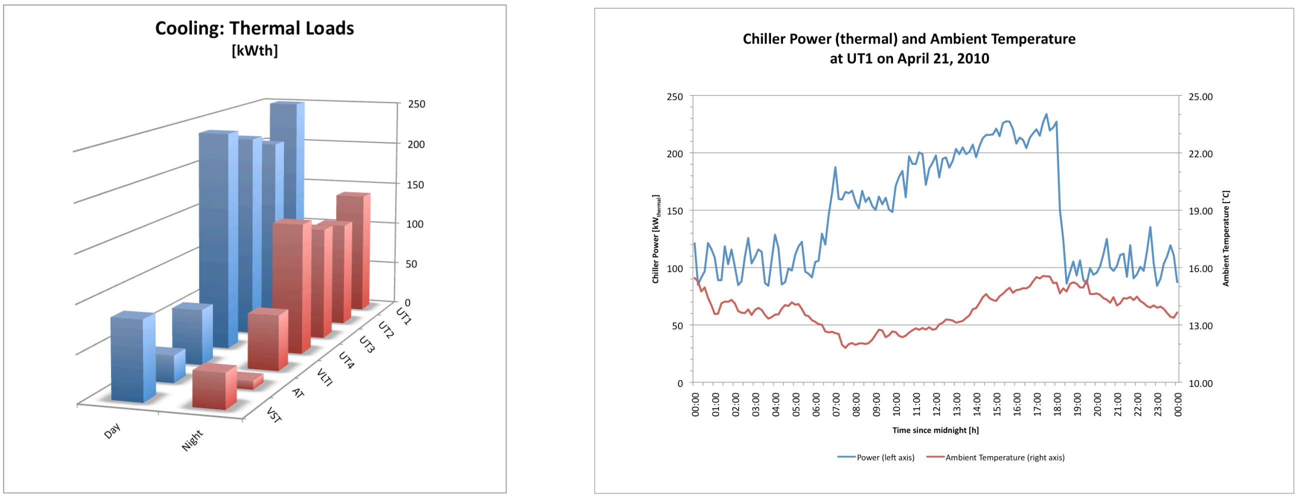


Figure 9. Average thermal loads (left) of the telescope cooling system during a summer week and daily plot of one telescope (right) on April 21,2010.

The plot in Figure 9 shows that the chiller power increases with increasing ambient temperature and closing/opening of the telescope enclosure is also clearly visible. The thermal power consumption of 100 kW during the night increases to 200 kW on that given day. On average, the night cooling power is 47% of the day power. An analysis of the present system shows that there is a saving potential of 285 kW during daytime, corresponding to the electrical power for the two chillers. This energy could be saved if one would apply a different system for the cold medium supply, which would use solar energy.

4.2 The new concept

All three renewable energy sources listed in Table 3 would potentially be suited for the substitution of the chillers. However, wind energy is not a good choice because of its irregular and intermittent supply of power. To decide between PV and solar thermal is easier when one considers the simplicity of the technology and the sustainability as explained above in chapter 3.1. It is therefore proposed to use a solar collector field and feed the hot medium to adsorption / absorption coolers via a hot water storage tank. The choice of whether an adsorption or absorption chiller shall be used remains to be decided, but adsorption chillers have their advantages. While the newer adsorption chillers use Silica-Gel as adsorbent, are easier to maintain and need only very few power, absorption chillers use the corrosive Lithium Bromide as absorbent, require a daily dilution cycle and are more complicated to maintain and have a lower life time. The number of chillers is depending on technical and commercial aspects and is therefore not yet decided.

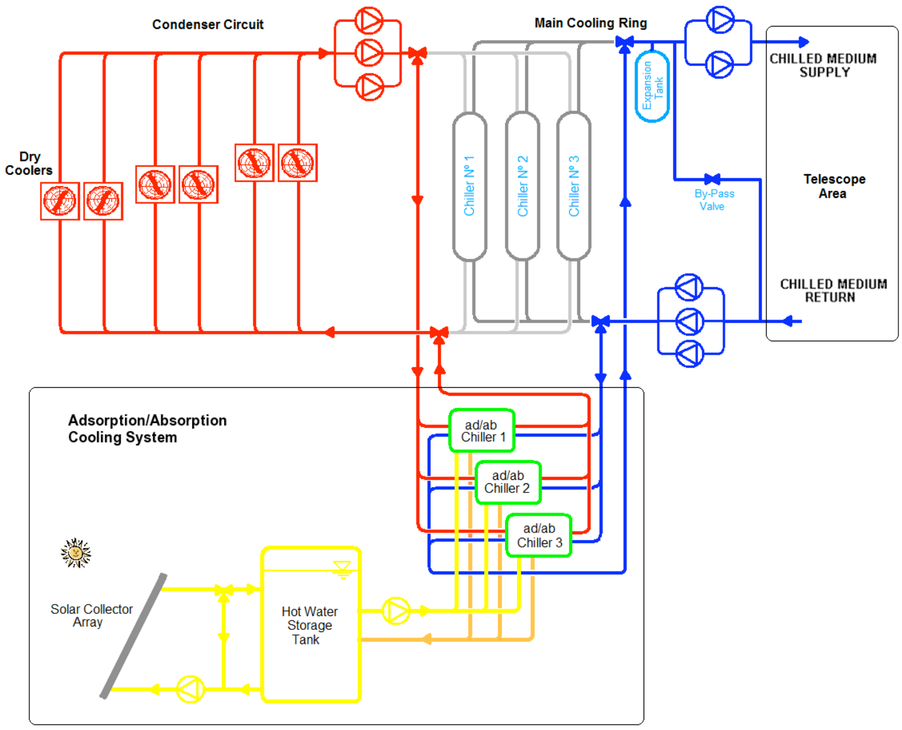


Figure 10. Arrangement of the solar cooler with the existing cooling system

The three conventional compressor chillers will only be used for back up and possibly during nighttime if the stored hot water is not sufficient to provide for night coverage.

For an effective load of 1100 kW_{th} and a 33% load margin a design load of 1463 kW_{th} is required. Assuming a chiller efficiency of 50%, the heat input to the system has to be 2926 kW_{th} or 1 MW_{th} per chiller. The total solar collector area is calculated at 7315 m2 with a conservative 50% collector efficiency and an average insolation of 800 W/m2.

It's also possible to configure the system such that it could cover both, the day and night demand. To satisfy a maximum thermal demand of 1463 kW during 12 hours for the day and 731 kW during 12 hours for the night, during the day additional energy has to be stored for the night in the hot water tank. This would require to add 3658 m2 to the area of solar panels, resulting in a total area of ~11'000 m^2.

4.3 Costs

For the cost estimation an assumption has to be made in terms of the possible energy savings. In the best case one assumes two chillers running for 12 h per day in summer and one chiller for 10 h per day in winter. One chiller is running during the night the whole year. This results in a yearly energy consumption of 1.6 GWh or 14.5% of the total yearly electrical energy demand.

Payback on investment is estimated to occur in 6 years, at April 2010 LPG prices. But it is pretty sure to assume that this will occur earlier in view of the increasing fuel prices. A more exhaustive calculation is of course required and only a detailed study that is planned for later this year will give a clear picture.

5. OUTLOOK

As already mentioned, the original concept for the power generation and supply of the observatory, as conceived 20 years ago, has not considered any future move from fossil fuels to renewables. In terms of prime energy consumption, the efficiency of the gas turbine power generation is very low and therefore not economic in the long term. The geographical separation between the power station and the telescope area is approximately 3 km and makes the application of a district-heating concept theoretically possible, despite of the high investment costs. But only a part of this waste heat could be used to substitute the 15% electricity share used for cooling. In view of a possible future connection to the Chilean grid, the observatory would on the one side terminate its direct dependency on fossil fuels, but on the other hand depend then suddenly on the energy mix of the Chilean power generation, which is also mainly based on fossil fuel. Therefore, a combination of solar thermal energy for the cooling of the telescope enclosures together with wind power and PV for a variable but perhaps full substitution of grid power in the future, would in fact transform Paranal into a green observatory.

6. CONCLUSION

This study has shown that it is not easy to satisfy the (mostly electrical) power demand of the observatory only with renewable energy sources like sun and wind power, as long as there is no connected to a grid. Operating a multi-fuel turbine in island mode without heat recovery is not ideal, and the operational costs of the observatory will heavily depend on fuel prices. For some areas however, the application of solar thermal energy is adequate and economically feasible, as proposed in this paper for the case of the enclosure cooling of the telescopes.

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