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SOLAR COOLING AT THE OENOLOGY AND VITICULTURE RESEARCH CENTRE, BUSKETT, RABAT

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ABSTRACT: This paper describes the design, installation and testing of two solar cooling systems at the Oenology and Viticulture Research Centre, Buskett, Rabat, Malta. One system consisted of a bank of photovoltaic panels converting solar energy into electricity which was fed into the national grid and a conventional vapour compression chiller powered by electricity from the grid. The second system was based on an ammonia-water vapour absorption chiller which was driven by hot water from a bank of vacuum-tube solar collectors. Dry re-cooling was chosen as the method of heat rejection.

Keywords: Solar cooling, solar refrigeration, vapour absorption chiller.

1 INTRODUCTION

ViEnergy was a joint project between Maltese and Sicilian partners, co-funded by the EU Italia-Malta programme, that looked at how the wine industry can contribute towards energy sustainability and combating greenhouse gas emissions [1]. Its overall objective was to analyse the use of energy in the wine industry, including the cultivation of grapes, in order to find ways to reduce its energy consumption and its carbon footprint. It included work packages on the characterisation and potential use of biomass from the wine industry, fixation of carbon dioxide and the use of ethanol in diesel to reduce emissions.

Another work package involved the setting up of two solar cooling systems at the Oenology and Viticulture Research Centre (OVRC), Buskett, Rabat. One system consisted of a conventional vapour compression chiller driven by photovoltaic panels (PVs) and the other, a vapour absorption system based on water-ammonia driven by hot water from a series of vacuum tube solar collectors.

The objective of this project was to study the feasibility of using solar energy to provide the cooling required during the fermentation of the grape juice in the production of wine, a process that is basically exothermic. This heat, unless removed, can lead to the death of the micro-organisms that are responsible for the fermentation process. A secondary objective of this work package was to establish the relative merits of the two systems in terms of energy consumption, cost and complexity.

The design of the systems and the drafting of the tender documents was undertaken by Robert Ghirlando as project leader and Redeemer Axisa, as project officer, under the auspices of the Institute for Sustainable Energy, whereas the actual issuing of the tenders and procurement process was carried out by the Directorate for Parks, Afforestation and Countryside Restoration (PARK) within the Ministry for Sustainable Development, the Environment and Climate Change (MSDEC).

2 DESIGN CONSIDERATIONS

The systems were designed to provide a cooling capacity of around 15kW. The budget for the two systems was €150,000. The systems were expected to provide cooling during the fermentation of the wine which normally occurs in Malta towards the end of August and early September. The design of the systems was based on computer models developed using the software Polysun.

3 THE SYSTEM BASED ON PHOTOVOLTAIC PANELS AND A VAPOUR COMPRESSION CHILLER

This system consists of grid connected photovoltaic panels and a vapour compression chiller, as shown in the "Polysun" diagram, Fig. 1.

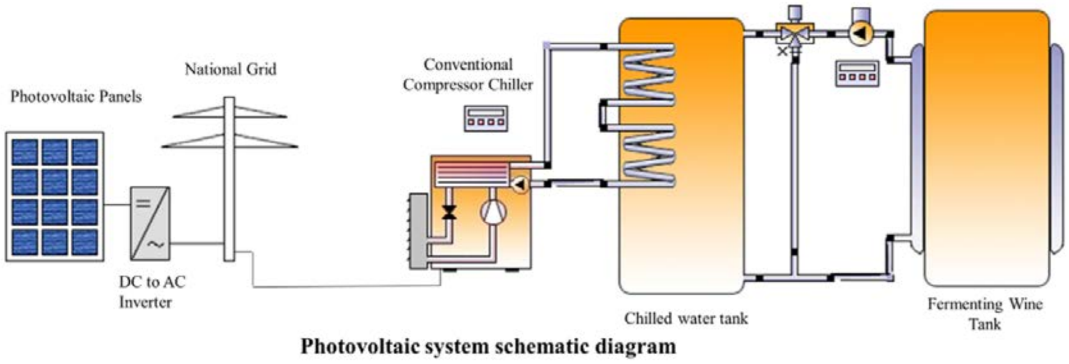

Figure 1: The PV-Vapour Compression Chiller System

3.1 Advantages of a PV-Vapour Compression Chiller System

A system based on photovoltaic panels combined with a vapour compression chiller has a number of advantages:

- Uses off-the-shelf well proven technology, with all the advantages that this entails;
- Can supply electricity to the grid when cooling is not required;
- Refrigerator units are available in all sizes, and easy to install;
- The electricity grid can be used to provide power to drive units when there is no sun, i.e. the grid acts as an energy store;
- Smaller initial system costs.

3.2 Location of panels

From some preliminary approximate calculations, it was established that there was not enough roof area to accomodate both the PV panels and the vacuum tube solar collectors. A decision was taken to install the thermal collectors on the roof of the building and most of the photovoltaic panels on a canopy structure, since the thermal collectors are more bulky and require periodic maintenance. Thus the proposed PV system consisted of three arrays located at different parts of the OVRC, as shown in Fig. 2 and Fig. 3, as follows:

i) a roof mounted PV array (Figure A) consisting of 12 panels mounted on an independent support structure resting on two load bearing walls.
ii) a canopy mounted PV array (Figure B) covering part of the drive and consisting of 40 panels.
iii) a field mounted PV area (Figure C) consisting of a single row of 21 panels mounted in a landscape orientation, due to height restrictions, on a support structure fixed on a base of precast concrete panels laid on a weed mat on top of the existing soil level.

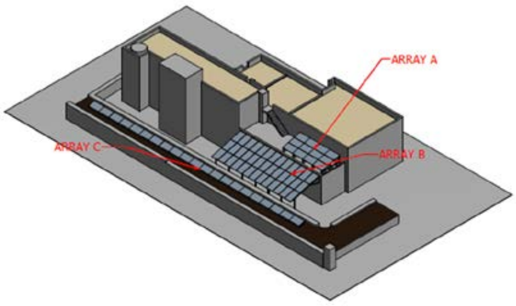

Figure 2: The location of the PV arrays

Figure 3: Photograph showing the PV arrays

3.3 The Vapour Compression Chiller

The vapour compression chiller for this project was already available at the OVRC. It has a cooling capacity of 15 kW and is specifically made for use in a winery. Design of the system was based on the principle that the energy consumed by the chiller during the harvesting period, would be produced entirely by the PV system, which was therefore specified to have at least a peak power rating of 17.5kW at standard test conditions (STC).

3.4 Angle of inclination of panels

Since the highest demand from the system occurs during harvest time of the grapes, the angle of inclination of the panels was optimized for the period which goes from the last week of July till the first week of September.

From simulations carried out on PVGIS [2] and F-Chart software [3], it was determined that the optimum energy yield during wine harvesting is achieved by using an inclination angle between 15 to 20 degrees, as seen in the Fig. 4. The panels were installed at 15 degrees.

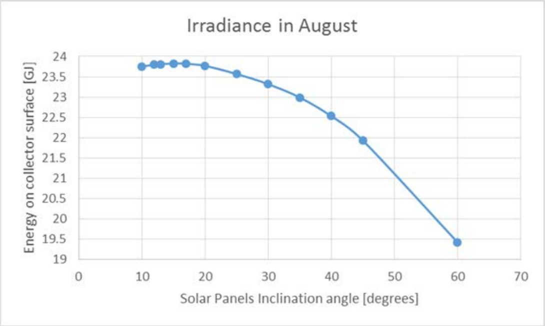

Figure 4: Plot for radiation energy incident on to the panels' surface against different inclination angles

3.5 Shadowing

For both the PV and thermal collector systems, a study was carried out on the proposed installation to check for shadowing.

Shadowing of a single PV panel has a much more adverse effect on the whole system than when considering the same effect on a solar thermal collector system. A PV panel that is connected in a string in series and is shadowed, becomes a resistance for current with the result that the silicon cells are heated. This effect is undesirable as it accelerates the degradation of the silicon cells. Shadow length calculations were done using both the points method and solar profile angle method. These calculations were based on hourly data obtained from the Institute for Sustainable Energy of the University of Malta. The period of interest for this system was from 24th July till 8th September. As expected the longest shadows occurred during September as the sun is lower in the sky.

In addition to the calculations mentioned above, another method was to use a 3D modelling software to view the shadow path. Google SketchUp 8 [4] was used to model the winery building, and then a shadow function was used to map the shadows on the building, and on the plane containing the PV panels. This was done after the building was given the correct orientation relative to the magnetic compass, and the location in terms of GPS coordinates.

Other major criteria that affected the design of the installations of both the PV panels and the solar collectors were the constraints imposed by the Malta Environment and Planning Authority. One of the constraints was a limitation on the overall height of the solar panels. Another constaint was that the canopy structure was not to be attached to the older part of the building, which is a scheduled building. Another factor was the need not to cover the windows under the canopy for sanitary reasons.

After having considered all these constraints, the final design is shown in Fig. 5. For the period during grape harvesting, there was minimal shadowing. When the whole year was analysed, there was a minor problem which occurred in April since the sun will set 'behind' the building. Thus there is a shadow from the building itself. However, it can be noted that this only occurred after 1600 hrs (i.e 1500 hrs solar time). Thus to minimise the effect on the rest of the system, the last row of panels which were susceptible to some sort of shadowing was connected to a separate string during wiring of the PV panels. Then each string was connected in parallel to the dc-ac inverter.

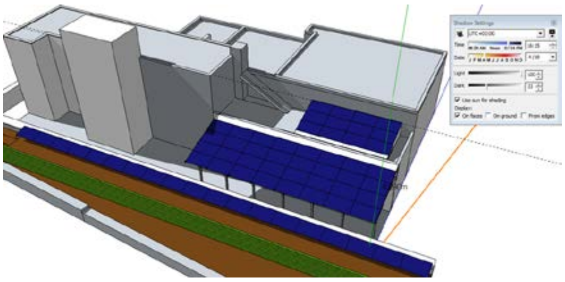

Figure 5: Screenshot from GoogleSketchUP indicating the final design

This final design also included a row of panels on the field adjacent to the OVRC building. The canopy structure which consisted of an average span of about 4.25m was the most expensive support structure as compared to the other two arrays. So having it fully utilized was a good point of this final design, while also providing shade to the underlying wine storage hall. This would eventually lead to reducing the heat load for the south facing wall under the canopy.

3.4 Installed system

The PV system was connected to the grid in the first week of November 2014. Figure 6 shows the PV arrays on the roof of the building and on the canopy. Specifications of the installed system are:

1. Photovoltaic Panels: 260W peak @STC and 15.96% efficiency
2. Inverter: 20kW, Max efficiency 98.2%
3. System Peak Power – 18.7 kW
4. Expected energy yield per year was 29,700kWh. 5. Specific cost for this system was 2400 €/kWp including costs of the supporting structures.

The electricity produced by the system from 3rd of November 2014 up to 16 September 2016 (318 days) amounted to 33615 kWh, an average of 105.7 kWh/day. The specific value works out to 105.7/18.6 = 5.68kWh/kWpeak.

Figure 6: The PV arrays on the roof of the building and on the canopy.

4 SOLAR POWERED VAPOUR ABSORPTION COOLING (VAC) SYSTEM

The second system is the vapour absorption refrigeration system, which uses thermal energy instead of mechanical energy to provide cooling.

4.1 Advantages and disadvantages of this system

Some advantages:

- Reduced electric energy per kW cooling
- Reduced electric load at peak demand
- Use of renewable energy source or waste heat

Some disadvantages:

- System design quite complex
- Performance highly dependent on air temperature for air cooled systems
- Limited suppliers for smaller systems

4.2 System design

Figure 7 shows the whole system, with all of its main components connected together, namely the (i) the solar collectors which provide the hot water to drive the generator of the chiller, (ii) a hot water tank (serves as a drainback tank), (iii) the absorption chiller, (iv) the re-cooler which rejects heat to the ambient air, (v) a cold water storage tank, and (vi) the wine tanks.

Vapour absorption chillers utilise two fluids for their operation, an absorbent and a refrigerant. The two most common fluid pairs are lithium bromide-water and water-ammonia, where the first mentioned fluid is the absorbent and the second the refrigerant. Lithium bromide-water cannot be used where cooling temperatures are expected to get close to zero degrees Celsius in order to avoid the possibility that the refrigerant (i.e. water) freezes. Thus, lithium bromide-water tends to be used for air-conditioning systems and water-ammonia for refrigeration purposes. For this project, it was decided to go for a water-ammonia chiller.

Vacuum tube solar collectors, Fig. 8, were chosen as the means of converting solar radiation into heat as they can provide the highest water temperature without the use of concentrators. It was decided not to use the latter to avoid the need of tracking systems which could cause problems due to their having moving parts exposed to the elements. It was also decided to use a drainback system, where the water drains back by gravity into a tank when the recirculating pump is switched off. This avoids the possibility of the water in the system over-heating and turning into steam when the water is not being circulated and no heat is being absorbed

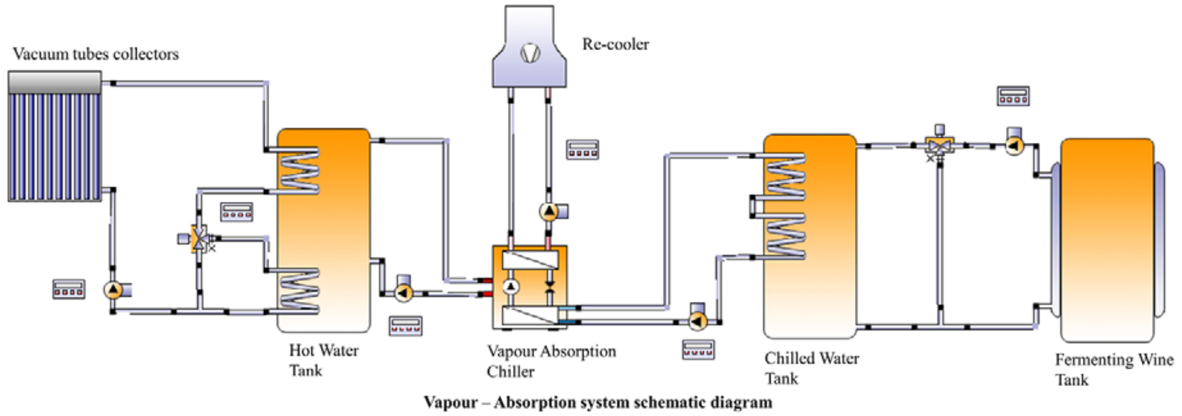

Figure 7: Schematic of the vapour absorption system

in the chiller. The drainback tank also acts as a heat storage tank. However, since it has a relative small volume, the amount of hot water stored is not significant.

Figure 8: Vacuum tube solar collectors on the left and PV panels on the right.

For the heat rejection (recooler) system, a number of options were considered. Since the site was not close to the coast, it was not possible to use sea-water as a heat sink; a system favoured by hotels by the sea. Another option was to sink a closed loop system into the water table, but this option was discarded after discussions with Malta Resources Authority. This left only a choice between a wet or dry cooling tower. Finally it was decided to choose a dry cooling tower over a wet one, to avoid the risk of legionella, to eliminate the need for water (not readily available in the required quantities at the OVRC) and to eliminate the need for water pre-treatment and the higher maintenance with water cooling. The downside of this choice is a lower efficiency of dry recooling compared to wet recooling.

4.3 The vapour absorption chiller

The vapour absorption chiller installed at the OVRC is a PinkChiller ® PC19 (19kW cooling at nominal conditions) with the following specifications:

Ammonia-water based for sub-zero temperatures
Designed to run from solar hot water
Single effect
Electric power consumption - 450W
12kW cooling power
Working temperatures:

- Hot water circuit: 95 – 87 ºC
- Chilled water: 12 – 6 ºC
- Cooling circuit: 40 – 35 ºC

The performance curves of the vapour absorption chiller can be seen in Fig. 9. Figure 10 shows the chiller on the left of the picture, the drainback tank at the top on the right and a vapour compression chiller at the bottom on the right.

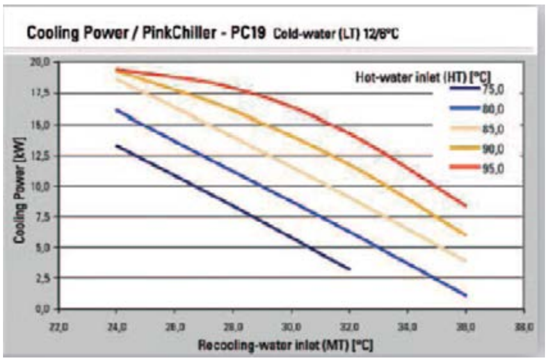

Figure 9: The peformance curves of the chiller.

Figure 10: The vapour absoption chiller (left), the drainback tank (top, right) and a vapour compression chiller (bottom, right).

Basically, the chiller is connected to three water circuits: (i) the hot water circuit, (ii) the chilled water circuit and (iii) the recooling water circuit. These will be described next.

4.4 The hot water circuit

Figure 11 is a diagram showing details of the hot water circuit design. This circuit consists of two sub-circuits. One circulates hot water from the solar collectors to the drainback tank and back. When the pump is off, water drains back to the tank by gravity, leaving the collectors without water. The other sub-circuit circulates water between the drainback tank and the chiller. In this case, the sub-circuit is always full of water, but the circulating pump only comes on when the chiller is on and the temperature of the water in the drainback tank has reached the minimum temperature for the chiller to operate, i.e. 65°C.

4.5 The chilled water circuit

In the initial stages of the project, a hot water storage tank of 2300 litres became redunant in the Faculty of Engineering of the University of Malta. It was therefore decided to utilise this tank at the OVRC, where it was installed on the ground floor of the building, see Fig. 12.

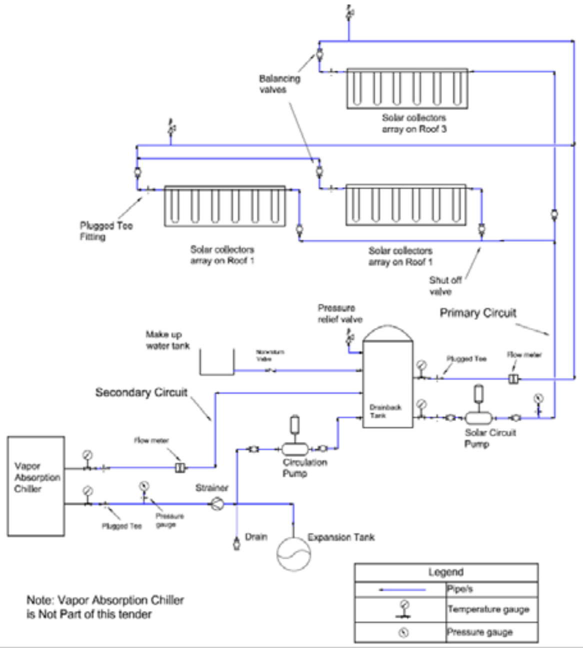

Figure 11: The "design" schematic of the hot water circuit.

A heat exchanger, consisting of a length of corrugated stainless steel piping was coiled inside the tank, Fig. 13, and formed part of the closed loop chilled water circuit together with a pump. Thus, the chilled water from the chiller would circulate through this heat exchanger and cool the water stored in this tank; this cold water would then be made to circulate through the wine vats.

Figure 12: The cold water storage tank, with the DAQ box on the left, a power meter on the right.

Figure 13: The heat exchanger coil inside the tank.

4.6 Recooler circuit

Figure 14 shows the "design" recooler circuit, whilst Fig. 15 shows the recooler.

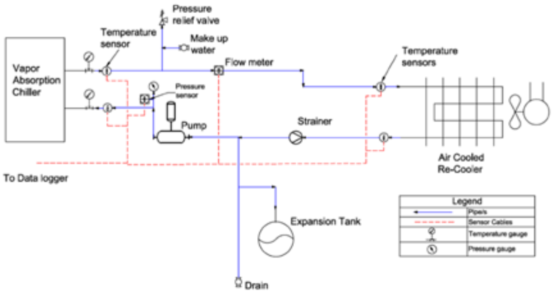

Figure 14: The schematic for the "design" recooler circuit.

Figure 15: The recooler

5 CONTROL AND MONITORING SYSTEM

A temperature control and data monitoring system was designed, installed and tested in 2015 in time for the vendemia (grape harvest) of that year. Indeed, both solar cooling systems, complete with the control and monitoring system were tested in September 2015.

The control system was based on Model Predictive Control and was the subject of an MSc in Engineering (by research) carried out by Joseph Agius supervised by Simon G. Fabri [5]. A paper on this control and monitoring system was presented at an international conference [6].

The instrumentation consisted of:

1. Temperature measurement at various points by means of wire wound Resistance Temperature Detectors (RTDs) with a PT100 Class A accuracy measuring element and Type T Thermocouples.
2. Pressure Transducers at various points
3. Each hydraulic circuit was provided with a Turbine flow meter, with an external (not wetted) magnetic pickup.
4. Three electric power meters to measure the power consumption of the two chillers and the recooler.
5. A silicon cell type pyranometer to measure the insolation for assessing the performance of the PV panels. This has very similar characteristics as the PV panels and was aligned for the same tilt of 15 degrees.
6. A thermopile pyranometer for assessing the performance of the vacuum tube collectors.

6 RESULTS

The graphs below show some of the results obtained by Joseph Agius [5] between the 18th and 22nd September 2015.

Figure 16 shows the measured solar radiation resulting in the hot water temperatures shown in Fig. 17. PT_005 measured the temperature of the hot water at the outlet of the solar collectors, whereas PT_004 measured the temperature of the hot water at the inlet to the chiller. The difference between the two temperatures is due to the fact that PT_004 is located between the drainback tank and the chiller, and therefore does not sense any change in temperature when the circulating pump between the drainback tank and the chiller is off.

Figure 18(a) shows the temperatures of the water in the chilled water circuit and the cold water storage temperature. These graphs show the cooling power of the chiller. PT_009 measured the chiller's inlet temperature and PT_008 the outlet temperature. It is interesting to note that the chiller is able to cool the water down to around 5°C from around 25°C. The increase in temperature of the water in the cold water storage tank, Figure 18(b), is due to the fact that the cold water is being used to cool the wine that is fermenting in the vats.

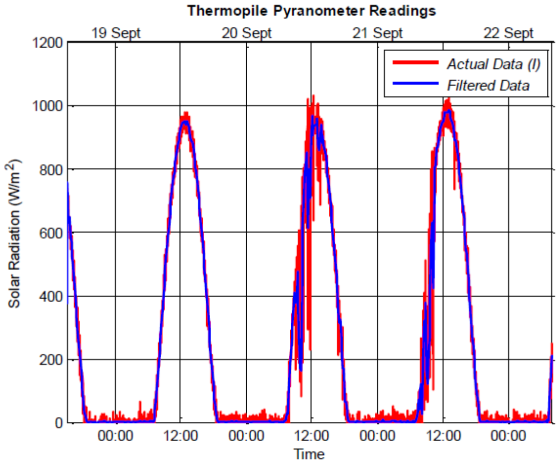

Figure 16: Insolation as measured by the Thermopile Pyranometer [5].

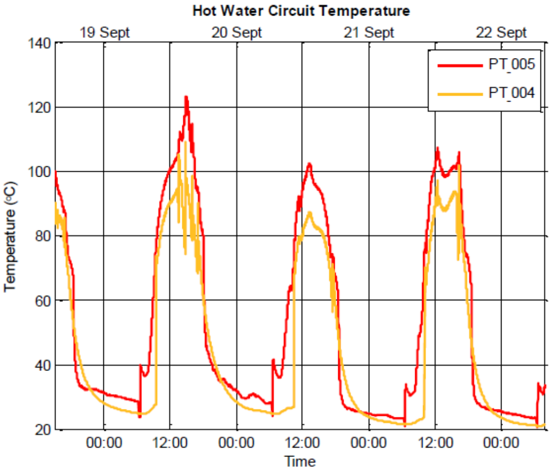

Figure 17: The temperatures measured in the hot water circuit [5].

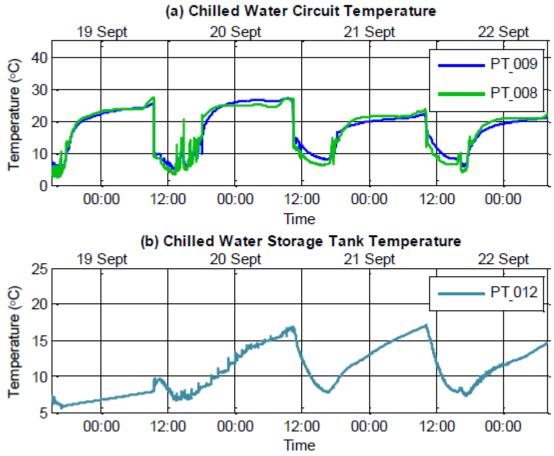

Figure 18: (a) the temperatures of the water in the chilled water circuit; (b) the temperature of the water in the chilled water storage tank [5].

Figure 19 shows the temperatures at the recooler. PT_011 measured the water temperaature at inlet to the cooler and PT_007 at the outlet, whereas TC001 measured the roof ambient temperature. This latter temperature limits the efficiency of the recooler, since the recooler cannot reject heat below this temperature.

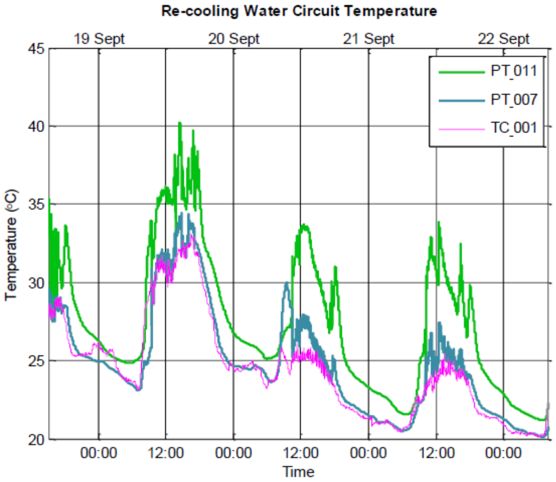

Figure 19: Temperatures at the recooler [5].

7 CONCLUSIONS

The results clearly show that the vapour absorption system works and can produce the chilled water required. Due to the intermittency of the sun, however. some form of storage is required. Results showed that the cold water storage tank only loses a couple of degrees in 24 hours, thus proving to be an effective cold store.

On the other hand, the solar collectors were sized to produce enough hot water to drive the chiller even when the sun is not at its highest, such as early morning. This means that they produce more heat than can be absorbed by the chiller at other times of the day. This is dangerous as it can lead to overheating of the hot water circuit resulting in high system pressures. In fact, during testing, it was often necessary to resort to covering some of the solar collectors.

The system is however complex to install and operate when compared to a conventional vapour compression chiller driven by electricity from PV panels. Moreover, the latter have the advantage that use can be made of the grid as a means of energy storage for when there is no sun. The grid can also usefully absorb any unutilised renewable electricity generated. This of course presumes that a grid is available.

8 CURRENT WORK

The next step in the development of the vapour absorption system is the optimisation of its performance; this is currently the subject of another MSc dissertation by Roberta Vella. There is little scope in trying to optimise the other system since it is based on conventional PV and vapour compression technology which is well developed and tested.

One of the issues being tackled is the overheating of the hot water circuit. One solution being studied is the diversion of some of the hot water to one of the wine vats, which could then be used as hot water storage. This hot water could also act as a load for testing of the cooling system when there is no wine fermenting.

9 ACKNOWLEDGEMENTS

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