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Acronyms

Acronym	Explanation	Acronym	Explanation
AMS	Atmosphere Management System	TCS	Thermal Control System
FEG	Future Exploration Greenhouse		
MTF	Mobile Test Facility		

1 Atmosphere Management System

A detailed system description can be found in the EC Design Document (D3.7).

1.1 System Performance

1.1.1 Overall performance

The atmosphere management system (AMS) regulates the ventilation rate, the temperature, the relative humidity and the CO₂ level inside the FEG.

The set points for the AMS were:

- Temperature: 21°C during the photoperiod, 19 °C during the dark period,
- Relative humidity: 65%,
- CO₂ level: 1000 ppm.

Figure 1-1 to Figure 1-3 show graphs for the three parameters of the whole nominal operation phase from February 7th to November 20th 2018. Three times the control system was shut down due to various issues. All three graphs show that by having three vertical lines going down to zero, one in April, one in May and one in August.

The temperature fluctuates between the photoperiod and the dark period set points. On some occasions the temperature during the photoperiod was well above the set point (e.g. in February, April, June and July). These temperature increases were caused by malfunctions of the thermal control system, see Chapter 2. Another issue was the drop in the temperature during the dark period below the set point. This means, that the AMS and the stand-alone heater inside the FEG were not able to keep the temperature at the set point. During all of these occasions the temperature of the external environment was very low.

On the relative humidity graph one can see two different periods of behaviour. The first one starts in March and ends end of June. In this period the relative humidity fluctuates a lot and exceeds the set point by more than 10 %. With the beginning of July the behaviour gets more stable. This was the result of difficulties with the TCS and the control and data handling system (CDH). It took several weeks of adjusting the TCS control parameters and also the TCS flow rates in order to stabilize the behaviour of the relative humidity control.

The CO₂ graph shows that the CO₂ level inside the FEG was always above the set point. Due to the influence of the activities of the on-site operator inside the FEG, the CO₂ level was much higher than initially planned.

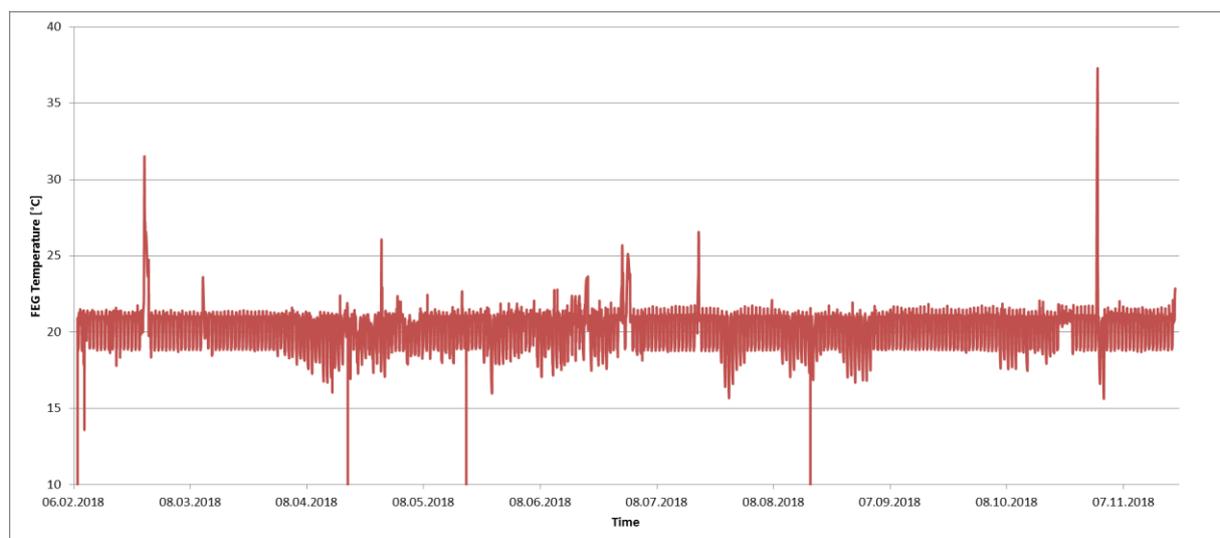


Figure 1-1: FEG temperature during the nominal operation phase in 2018.

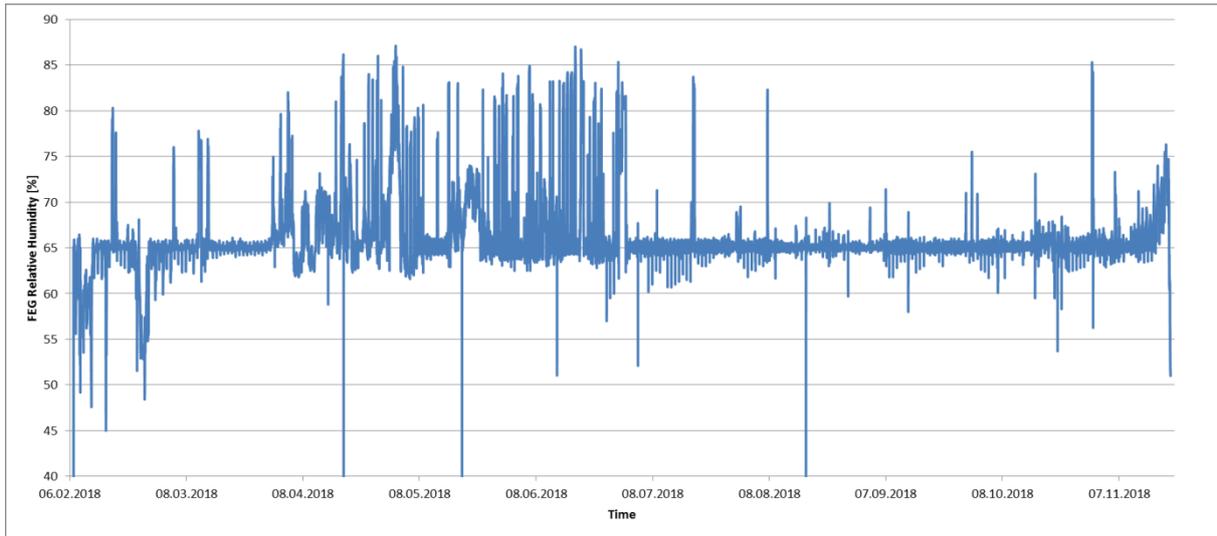


Figure 1-2: FEG relative humidity during the nominal operation phase in 2018.

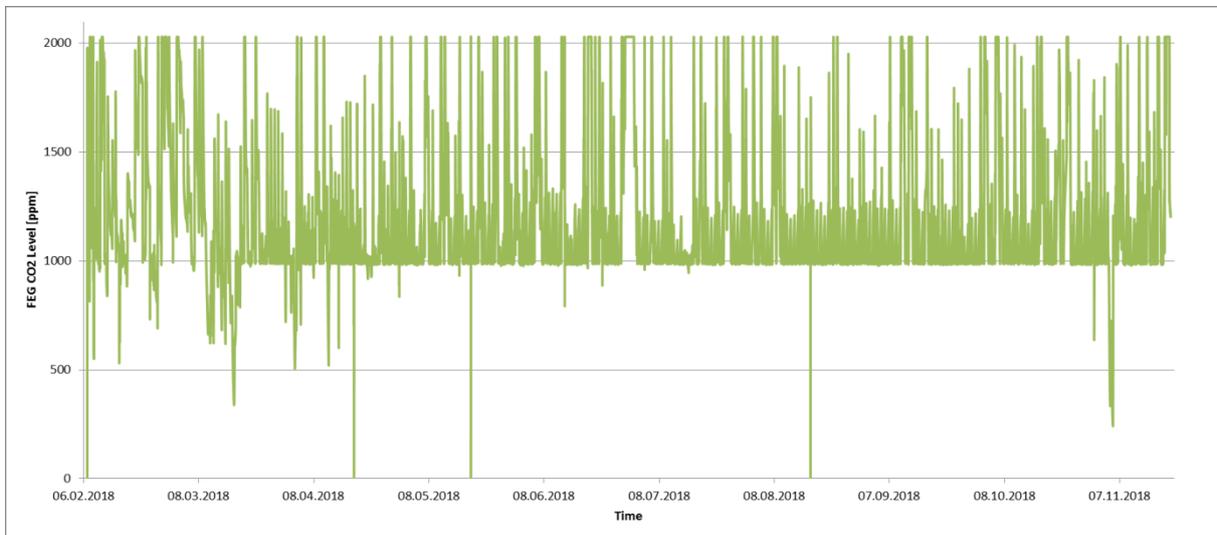


Figure 1-3: FEG CO₂ level during the nominal operation phase in 2018. (Note: CO₂ sensor range was 0-2000 ppm. Values above 2000 ppm were not measured.)

1.1.2 Examples of daily performance

The previous chapter showed graphs for the whole operational period. This chapter takes a closer look on the daily behaviour of the AMS. Therefore three exemplary days were chosen to show the system’s behaviour.

- 08.09.2018: A day without interference by the on-site operator. No human was inside the MTF during that day.
- 10.09.2018: Strong interference by the on-site operator, because of long working times inside the MTF.
- 27.07.2018: Very low temperatures of the external environment. No interference by the on-site operator.

The temperature graphs in Figure 1-4 show that on the two days in September the AMS had no problem in keeping the temperature in the dark period at the set point. On July 27th on the other hand the very low external temperatures led to a fast decline of the FEG temperature during the dark period. Even with the lamps going on and all heaters at full capacity the AMS was not able to heat up the FEG to the set point of the photoperiod in a reasonable time.

One can also see the interference of the on-site operator when comparing the graphs of September 8th and 10th. The presence of a human inside the system itself and its activities (e.g. opening/closing door to the service section) interfere with the AMS and temperature fluctuates a bit more than with-

out the human inside the MTF. However, the fluctuations are small, which shows that the AMS could cope very well temperature wise with a human being inside the MTF.

The relative humidity graphs in Figure 1-5 look very similar. The relative humidity increases slightly on the July 27th graph during the dark period because of the drop in temperature. When the FEG atmosphere heats up at the beginning of the photoperiod the relative humidity drops for a short period of time. This behaviour was expected, because the relative humidity is a function of the atmosphere temperature.

Figure 1-6 shows the CO₂ graphs for the three exemplary days. The CO₂ level rises during the dark period because CO₂ that was not bound during the photoperiod is released by the plants inside the FEG. When there is no human interference (September 8th and July 27th), the CO₂ level drops until it reaches the set point. Then the AMS pumps some CO₂ into the air streams from the bottles stored on the outside of the MTF. This can be seen in the small fluctuations of the two graphs around the set point. The situation is completely different when there is a human being inside the FEG, which is an additional CO₂ source. In the September 10th graph one can see an increase in CO₂ starting at around 10:30 and ending at 12:15. During that time the on-site operator performed some tasks inside the MTF. The operator left the MTF at 12:15 for lunch and came back around 13:40 to continue his tasks. This is the second step increase in CO₂. The operator remained inside the FEG for a while which increased the CO₂ level well beyond the sensor maximum limit of 2000 ppm. Only at the very end of the day the CO₂ starts to decline below the 2000 ppm mark.

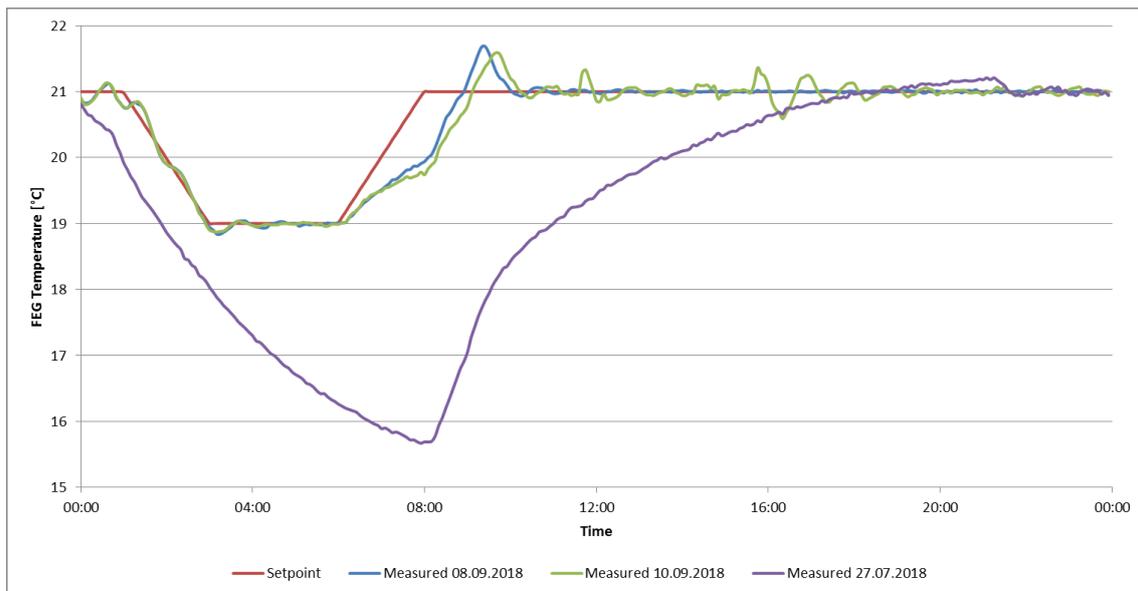


Figure 1-4: FEG temperature three daily graphs during the nominal operation phase in 2018.

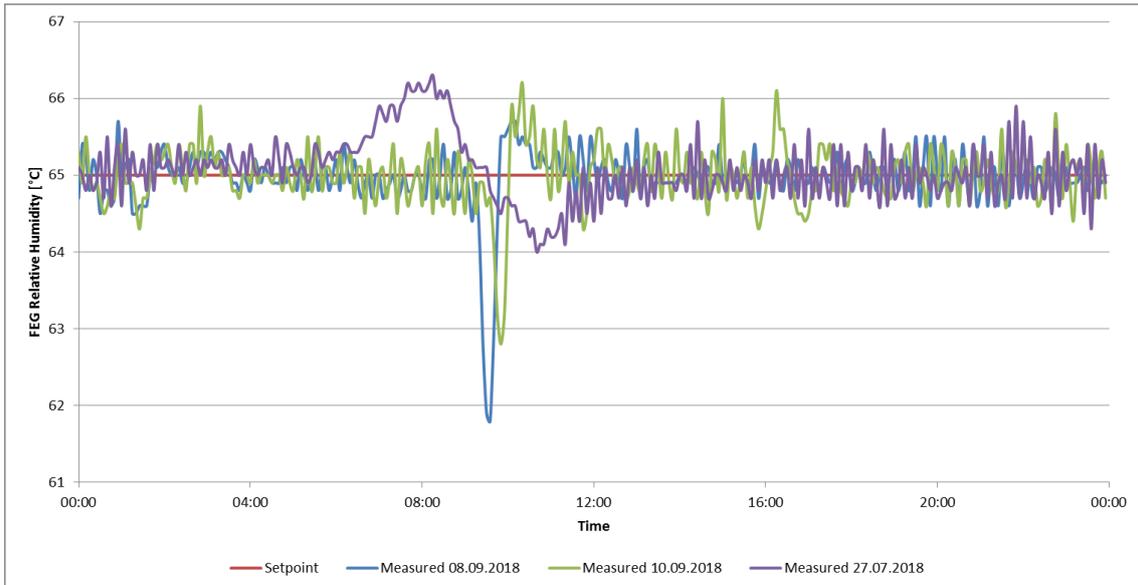


Figure 1-5: FEG relative humidity level three daily graphs during the nominal operation phase in 2018.

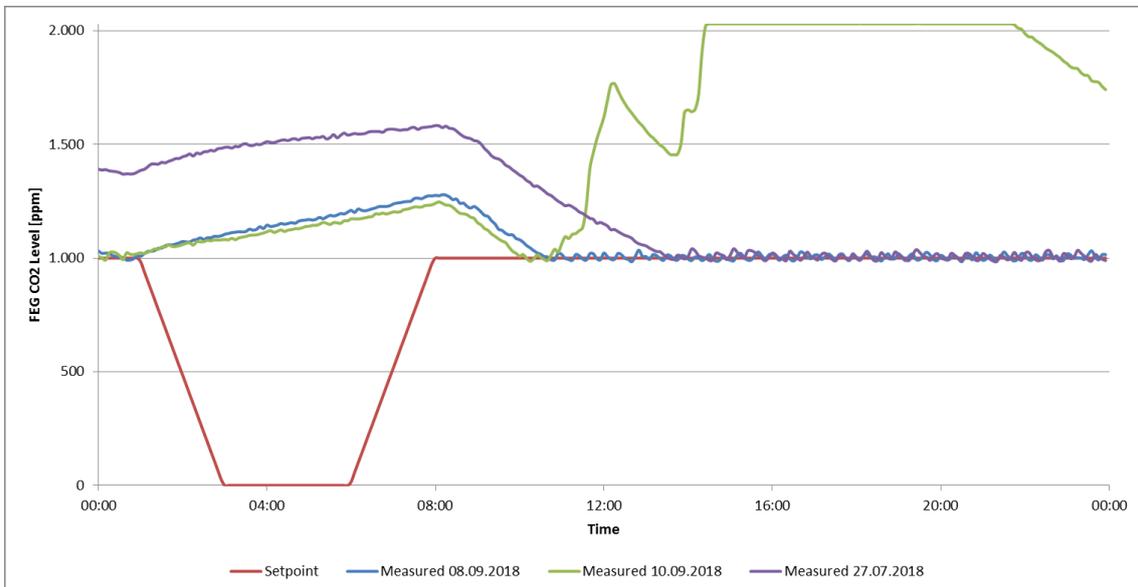


Figure 1-6: FEG CO₂ level three daily graphs during the nominal operation phase in 2018.

1.2 System Maintenance and Observed Issues

Only two issues were observed during the wintering season.

The first one being the heating elements on the CO₂ pressure regulation valve on the outside of the MTF. Initially the heating elements were turned on and off in a regular interval. However, this was insufficient from preventing the pressure regulation valve getting frozen shut. After switching the heating elements to permanently on, the valve was working as intended.

The second one is the sizing of the cooling coil. The dimensions of the cooling coil are too small for the amount of water that needs to be recovered from the MTF atmosphere. Only by increasing the cooling fluid flow rate through the cooling coil and by reducing the cooling fluid temperature could the water recovery rate be kept at a level high enough to cope with the water transpiration rate of the plants and humans. However, both cooling fluid flow rate and temperature are now at the maximum respectively minimum possible value. Consequently, the cooling coil needs to have an increased surface area to allow more condensation of humidity with higher fluid temperatures. The lower fluid temperature resulted in a too strong reduction of the air stream temperature. This in turn required the installed heating elements to run almost always at maximum capacity. But even then the capacity was not enough during very low external temperatures to keep the FEG at the defined

setting. This problem occurred only during the dark phase, when all LED lamps were switched off and consequently did not contribute to heating the FEG.

An additional issue was discovered only after the experiment phase in the summer season 2018/19. While opening the air channel of the AMS to replace the heating elements, the team on-site discovered an extensive biofilm on the surfaces of the cooling coil, see Figure 1-7.



Figure 1-7: Photo of the biofilm on the cooling coil during the inspection in January 2019.

1.3 Maintenance during the summer season 2018/19

The AMS did not receive major improvements in the summer season 2018/19. The filters and the UV lamps in the airstream have been exchanged with spare parts in order to guarantee proper functionality. The heating elements in the air stream (~3000 W) were exchanged by a stronger version (~5400 W) to help in stabilizing the FEG temperature at the set point even during very low external temperatures.

1.4 Proposed Future System Improvements

There are two main issues of the AMS that need to be addressed in the future:

- 1) Biofilm growth on cooling coil: As mentioned before extensive biofilm growth was discovered on the AMS cooling coil during the inspection in the summer season 2018/19. An antimicrobial coating could be one solution.
- 2) Cooling coil sizing: The cooling coil should be exchanged with one of a larger cooling surface area. This action is not trivial, because of the volume assigned to the AMS in general and the cooling coil in particular. Probably the exchange of the cooling coil to a larger one requires extensive reconfiguration of the AMS and TCS rack. A detailed investigation on this option is planned for summer 2019 to see whether this system improvement can be performed in the summer season 2019/20.

2 Thermal Control System

A detailed system description can be found in the EC Design Document (D3.7).

2.1 System Performance

It can be seen in the graphs over one week of Figure 2-1 that the thermal system was capable of controlling the temperatures and relative humidity within the desired range for the climate in the FEG, barring any off-nominal events. In case the outside temperature was really low during the night period (no LEDs turned on) the system needed more time to heat the FEG up again to the desired 21°C day time temperature, but most of the time the behavior was not an issue.

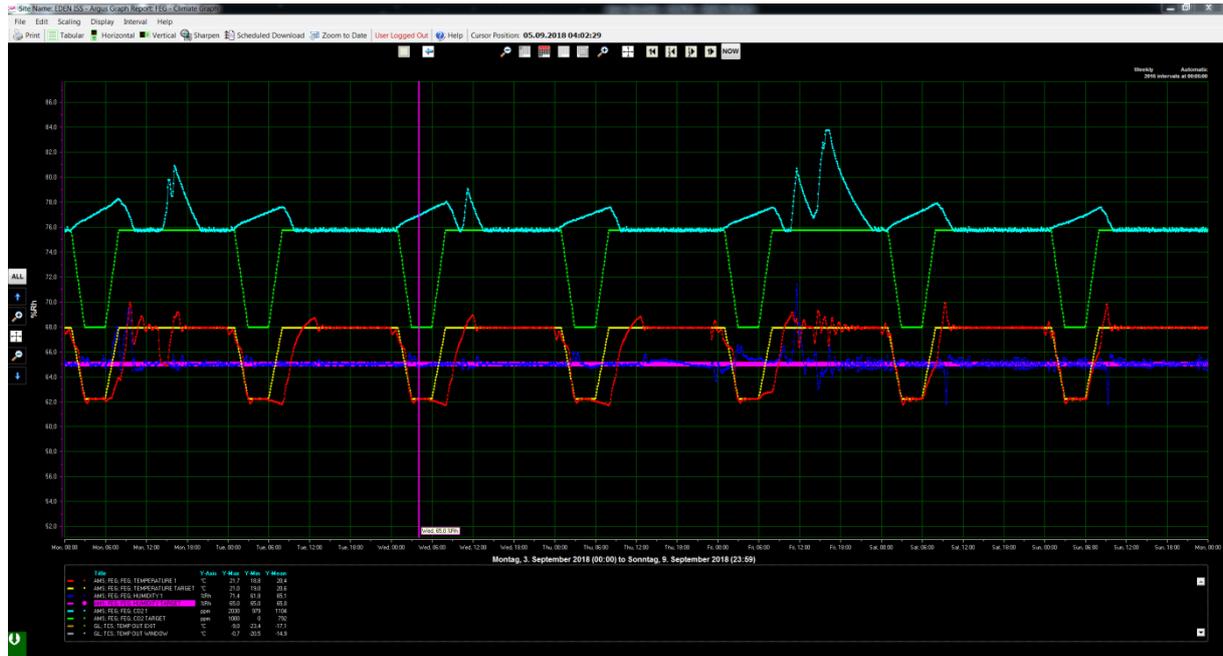


Figure 2-1: FEG Climate Graph (Argus) – showing current temperature (red line), temperature target (yellow line), relative humidity (blue line), relative humidity target (purple line), CO₂ level (light blue line) and CO₂ level target values (green line) for one week of nominal operations.

Figure 2-2 shows the day and night cycles over one week of nominal operations for the LED panel temperatures in the FEG. Also here the Thermal Control System was always capable to keep the temperatures at the desired levels and prevent the panel from overheating.

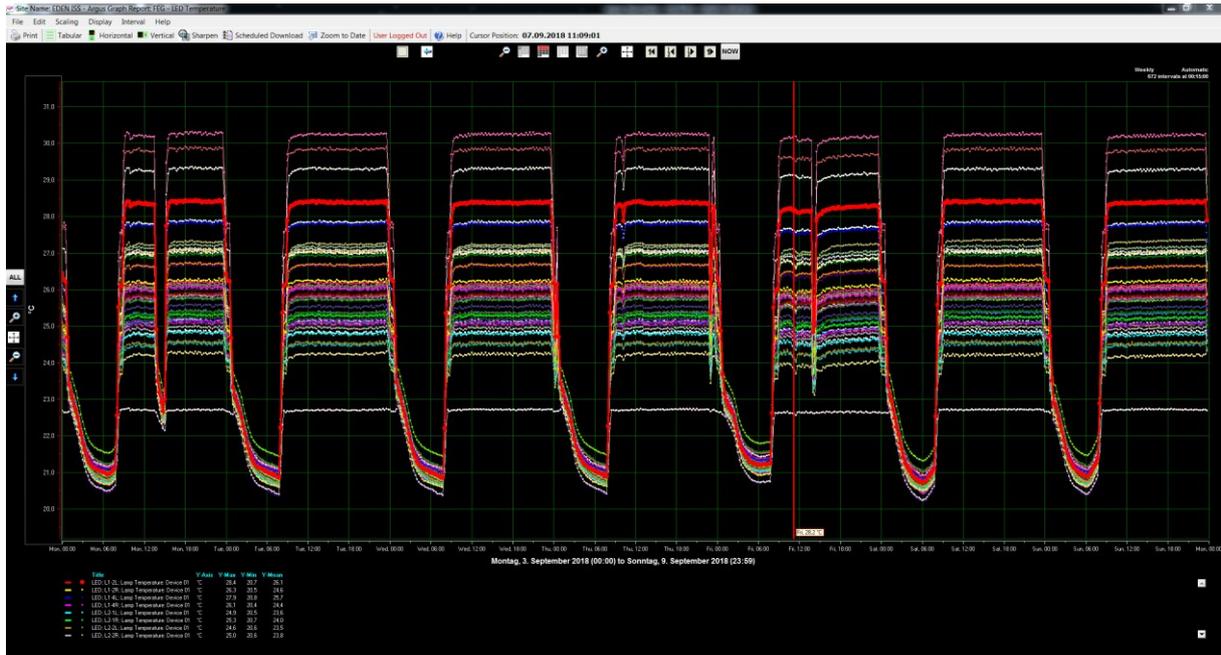


Figure 2-2: LED Panel Temperature Graph (Argus) – showing current temperature values for each LED panel for one week of nominal operations.

The following figure shows the corresponding thermal cooling line temperatures for the same week of nominal operations already shown in Figure 2-1 and Figure 2-2.



Figure 2-3: Thermal Coolant Temperature Graph (Argus) – showing current temperature values for various cooling line temperatures for one week of nominal operations.

2.2 System Maintenance and Observed Issues

During the EDEN ISS test phase in Antarctica 65 off-nominal events occurred in the period from 07.02.2018 to 02.11.2018. 20 of those events were related to the Thermal Control System of the MTF. In

Table 2-1 all TCS off-nominal events are listed with the corresponding data like off-nominal event ID, date, description of event, actions taken and cause of event.

Table 2-1: Off-nominal events regarding the TCS of the MTF.

ID	Date	Description	Actions taken	Cause/Lessons learnt
52	07.08.2018	Leak in external cooling loop Screw connection on WT1 pump outflow got loose.	Insulation removed from cooling pipes to search for leak spot. Screw connection loosened, dried and tightened again. External cooling loop pressurized to 1.5 bar.	Attempt to increase pressure in external cooling loop to 1.5 bar. Screw connection got loose and several liters of cooling fluid was spilled.
47	19.07.2018	Freezing of freecooler 3-way valve actuator again	See ID 42 and 39.	See ID 42 and 39.
46	08.07.2018	Failure of TCS temperature sensor 4 AMS IN	Broken sensor removed.	
43	29.06.2018	Plate heat exchanger in LED/ISPR and AMS cooling loop frozen	Cooling fluid of AMS and LED/ISPR cooling loop exchanged with fluid with lower freezing temperature.	Due to very low temperatures of -20 °C in the external cooling loop, the cooling fluid on the secondary side of the plate exchangers froze and blocked circulation in the cooling loops.
42	29.06.2018	Freezing of freecooler 3-way valve actuator again	Actuator removed for inspection and drying. ILS turned off for the night.	See ID 39.
41	21.06.2018	Pressure drop in external cooling loop 0.6 bar	None.	Unknown.
39	19.06.2018	Freezing of freecooler 3-way valve actuator Overheating of cooling loops, due to freecooler 3-way valve being stuck in close position.	Actuator removed for inspection and drying. ILS turned off for the night.	Freecooler fan turned on manually. This caused a temperature drop in the external cooling loop to -15 °C. This in turn caused the freezing of the actuator of the freecooler 3-way valve. Probably condensating humidity inside the actuator.
38	19.06.2018	Low pressure in LED/ISPR cooling loop again Related to ID 36.	Leak in L1-4. Lamps in L1 shut down. ILS/ISPR cooling loop pressurized to 1.2 bar. Leak glued.	Leak found in L1-4.
36	07.06.2018	Low pressure in LED/ISPR cooling loop Pressure only at 0.7 bar.	Probably leak.	No leak could be found. 19.
30	18.05.2018	Low pressure in external cooling loop	External cooling loop repressurized to 1.2 bar.	
29	18.05.2018	One freecooler fan broken	Broken fan disconnected from freecooler control box so that the remaining fan can work.	
28	16.05.2018	Pressure drop in external	None.	Probably shrinking of cooling fluid, due to very low external

ID	Date	Description	Actions taken	Cause/Lessons learnt
		cooling loop		temperatures.
26	09.05.2018	Freecooler fuse went off	Fuse needs to be replaced with stronger one.	Unknown.
25	07.05.2018	Pressure deviation in external cooling loop 0.8-1.1 bar depending on vlave position	None.	Unknown.
24	07.05.2018	Freecooler fuse went off	Fuse needs to be replaced with stronger one.	Unknown.
19	26.04.2018	Actuator of freecooler 3-way valve failure Fuse of all TCS valves in the power box went off. All valves were stuck in their last position. Freecooler valve stuck in 'closed' position. Consequently no cold cooling fluid was available. Temperature of all cooling loops and consequently temperature and humidity in the FEG went up.	Actuator of ISPR valve mounted to freecooler valve. Two bags of silicate were put into the actuator to bind humidity. Actuator was taped shut to reduce humidity getting inside. Actuator was mounted 90° turned to avoid potential condensate water dripping on the circuit boards. Condensate water would now drip into the gear. Broken actuator was repaired. One circuit line needed to be soldered to the board. Fuse on the circuit board blew off and damaged other parts. Board needed to be cleaned as remains of the fuse were causing short circuits. Two resistors of the noise filter needed to be replaced. Inductivity of the noise filter is also broken and was by-passed because no proper replacement could be found.	Failure caused by a short circuit on one of the two circuit boards of the actuator. Short circuit caused by condensate water. Water was condensing on the metal part of the actuator that is pushing the 3-way valve. The metal part was slightly corroding. Water dripped on the circuit board with the 230 VAC supply. Circuit board was damaged.
14	08.04.2018	Pressure in external cooling loop dropped to 0.9 bar. Periodically dropped to 0.8 bar causing audible alarm.	Cooling fluid added and repressurized to 1.3 bar.	Very cold temperatures (< -35°C). Probably cooling fluid shrank due to the very low temperatures. No leak could be detected.
08	14.03.2018	Ice formation in thermal subsystem rack	None.	
05	12.03.2018 17:20	Leak in WT2 cooling loop See ID 02. Failure was discovered relatively early, around one hour later. Less cooling fluid leaked than before.	See ID 02. Additionally, O-rings were replaced by new rubber O-rings. Large cable ties have been added to relief some of the tension on the connection.	Cause unknown. Probably screw connection was tightened too much and O-ring shifted its position. Low temperatures of the cooling fluid might lead to shrinking of the metal tube and screw connection causing

ID	Date	Description	Actions taken	Cause/Lessons learnt
				a leak. Humidifier needs to be turned off, as long as TCS is offline for repair.
02	24.02.2018	Leak in WT2 cooling loop Cooling fluid was leaking from the screw connection at the outlet of pump WT2. Almost all fluid of the external cooling loop emptied into the service section basin. Pressure in the line went to 0 bar. Temperatures in the other cooling loops were rising. Alarms were going on, but the failure happened during the night.	Screw connection as opened and the seals and flow-back valve inspected. No visible signs of damage of the seals. Sealing O-rings were cleaned, Vaseline was put on and the O-rings were put back into the screw connection. Fluid was pumped back into the cooling loop and the leak appeared to be sealed. Spill was cleaned up over the following week.	Cause unknown. Screw connection might have gotten lose during the transport of the MTF. O-ring seals might have moved during transport of the MTF.

In the following a selection of the above mentioned off-nominal events are explained in detail:

ID 02 and ID 05: Thermal System Rack – Piping connection issue

Description

The alignment of some of the pipes is incorrect. As a result, some force is required to fix the screw connection(s). The resulting tension on the pipes and the screw connection resulted in leakage in the WT2 (Heat exchanger 2) cooling loop on the 24th of February and the 12th of March (see Figure 2-4).

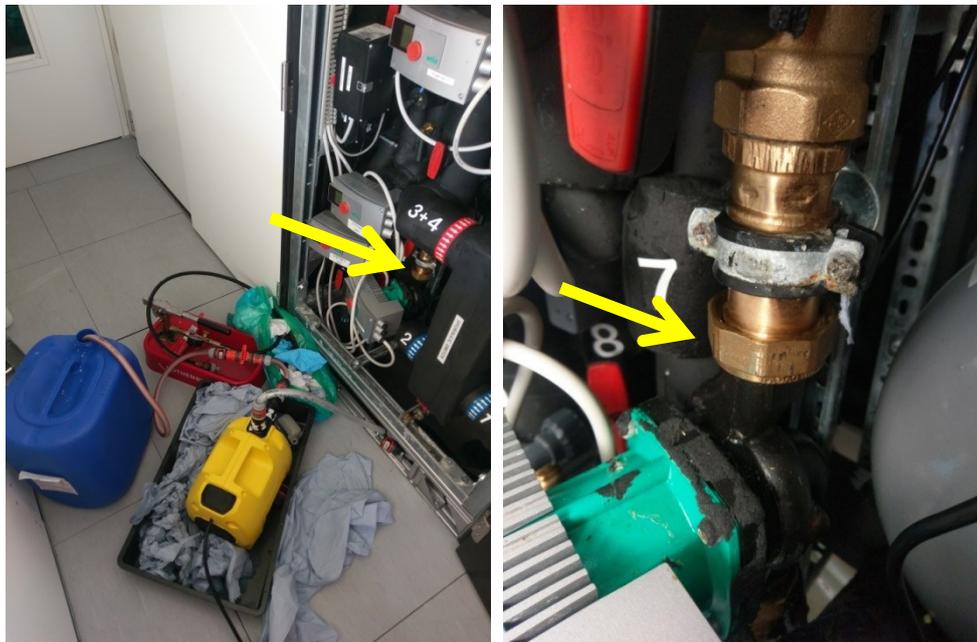


Figure 2-4: Overview of thermal subsystem rack. Arrow pointing at leak spot.

Actions taken

After the first leak, the screw connection was opened and the seals and flow-back valve inspected. No visible signs of damage of the seals (see Figure 2-5). Sealing O-rings were cleaned, Vaseline was

put on and the O-rings were put back into the screw connection. Fluid was pumped back into the cooling loop and the leak appeared to be sealed. Spill was cleaned up over the following week.



Figure 2-5: Sealing O-rings of the flow-back valve after screw connection was opened.

After the second leak, the same procedure was used. Additionally, O-rings were replaced by new rubber O-rings (see Figure 2-6 left). Large cable ties have been added to relieve some of the tension on the connection (see Figure 2-6 right).



Figure 2-6: Left: New rubber O-rings; Right: Cable ties below pump WT2. Pipe fixated to metal strut behind insulation.

ID 08: Ice formation in thermal subsystem rack**Description**

At the 14th of March ice formation in the thermal subsystem rack could be observed (see Figure 2-11), probably caused by frozen condensing water from the air in the SES. No actions were taken.



Figure 2-7: Thermal system condensation.

ID 29: Thermal System Rack – Free cooler fan failure**Description**

One free cooler fan broke on the 18th of May (see Figure 2-8). Likely cause is suspected to be the high temperature differential between the outside and inside of the fan motor.

Actions taken

Broken fan disconnected from free cooler control box so that the remaining fan can work. Free cooler is manually switched off, only on during warm periods / periods without wind, when the free cooler temperature rises too high.



Figure 2-8: Damaged free cooler fan motor

ID 39, ID 42 and ID 47: Thermal System Rack – Large increase in AMS loop coolant temperatures

Description

During the nights from the 15th until 18th of June temperature increases in the FEG (no cooling), accompanied by a simultaneous increase in the AMS cooling loop coolant temperature to 20+ degrees (see Figure 2-9 and Figure 2-10).

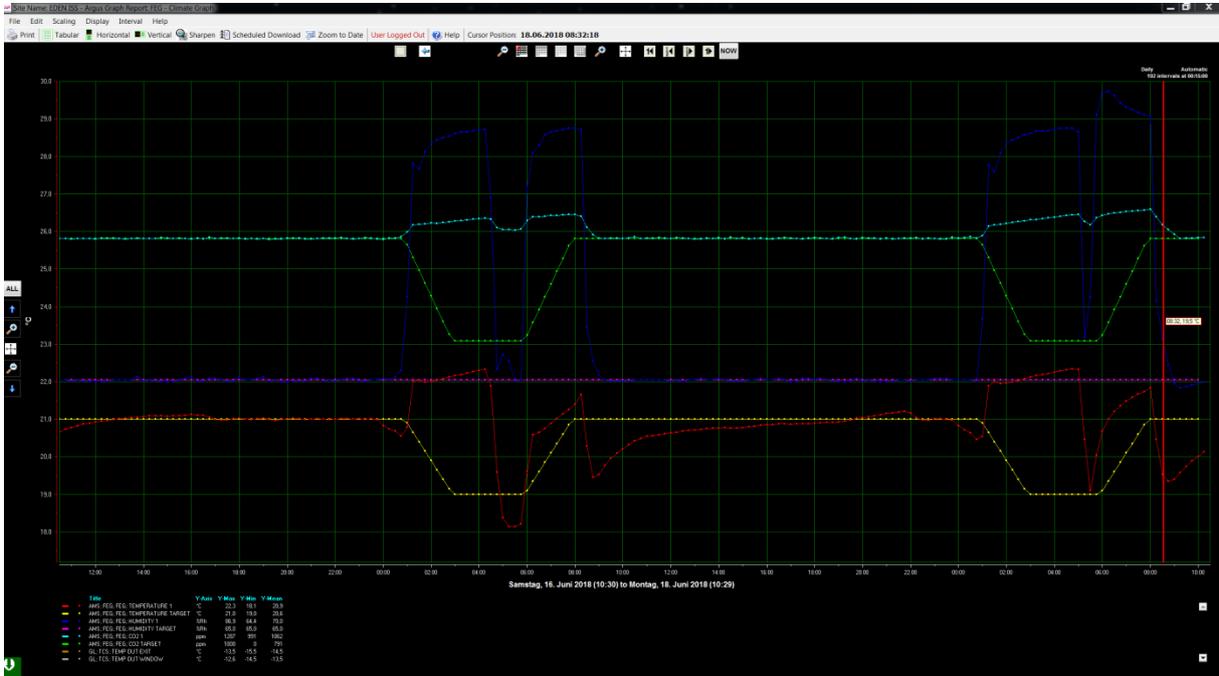


Figure 2-9: FEG Climate.



Figure 2-10: Coolant temperatures.

This behavior of the system was caused by the free cooler 3-way valve getting stuck in close position due to ice fragments between the valve and the actuator (see Figure 2-11). This prevented the system from removing heat out of the system, resulting in the increase in AMS loop coolant temperature, which subsequently prevented cooling of the FEG.

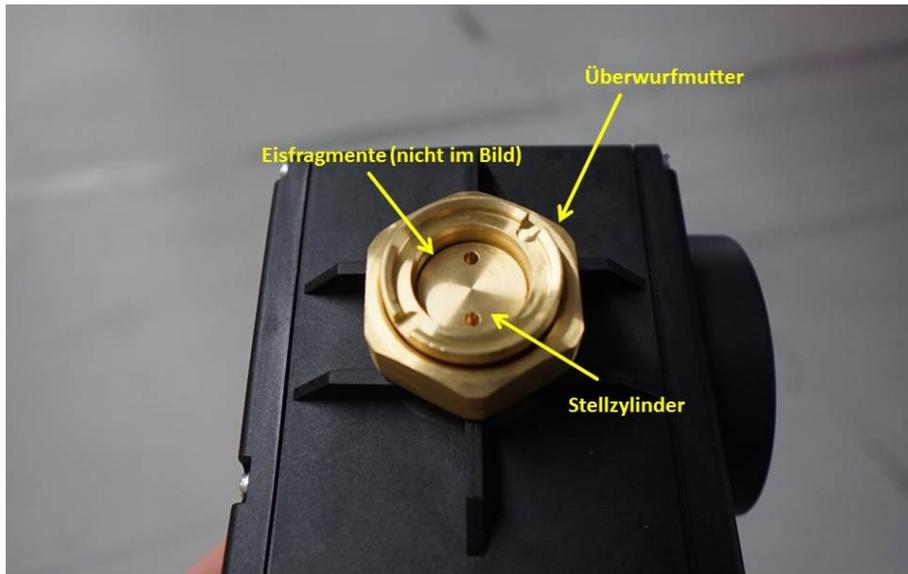


Figure 2-11: Free Cooler valve actuator.

Free cooler fan was turned on manually. This caused a temperature drop in the external cooling loop to $-15\text{ }^{\circ}\text{C}$. This in turn caused the freezing of the actuator of the free cooler 3-way valve (probably condensing humidity inside the actuator).

Actions taken

Actuator was removed for inspection and drying. ILS turned off for the night.

2.3 On-Site System Improvements

Work listed under this chapter done on-site by the maintenance/repair work team 2018/19 is pure maintenance work rather than improvements of the system. Nevertheless all the work is listed here to separate it from the maintenance work done during the overwintering period.

- Broken Free Cooler fan was replaced with new one (see ID 29).
- Broken TCS temperature sensor 4 AMS IN was replaced with new one (see ID 46)
- Installation of bucket below the TCS rack, which collects the cooling fluid in case of overpressure in the cooling loops.
- Replacement of valve actuators of the Free Cooler loop and the ISPR loop (see Figure 2-12). Grease was put on the pistons of the actuators to prevent that the 3-way valve getting stuck due to ice fragments between the valve and the actuator (see IDs 39, 42, 47).



Figure 2-12: Left: Old valve actuator with condense water on piston; Right: New valve actuator with grease on piston.

- Remove rust from the metal structure of the TCS rack, caused by condensation and cooling fluid leakage events during the overwintering season (see **Figure 2-13**).



Figure 2-13: Rust at the metal structure of the TCS rack.

- Insulation of the TCS system at the positions where condensation was detected during the overwintering season and where insulation was removed to exchange the system parts under it (see **Figure 2-14**).



Figure 2-14: Insulated Thermal Control System.

2.4 Proposed Future System Improvements

For this subsystem only small improvements are planned for the next summer season at Neumayer Station III. All major improvements of the Thermal Control System would require a full rebuild, to allow for better access and maintainability. This is currently not planned.

2.4.1 Basin below TCS

If the pressure in the thermal cooling loops gets too high, the system releases the cooling fluid in the metal basin in the subfloor of the container through a valve until the pressure is below the maximum threshold. Due to the fact that a lot of tubing of the NDS or AMS is in the basin as well as some pow-

er cables, it is really difficult to remove the cooling fluid from the basin, since some locations in the basin are hard to reach for cleaning.

An easy way to solve this issue would be to put a separate basin below the TCS rack, which collects the cooling fluid in case of overpressure in the cooling loops (replacement for bucket mentioned in chapter 3.3). This basin could be cleaned using a dedicated pump.

2.4.2 Connect Free Cooler to Argus

Right now it is only possible to start or shut-off the free cooler via the Argus software. If the operator switches the Free Cooler off using Argus, the Free Cooler stops immediately. Similar thing happens in case the Free Cooler is switched on. In that case the fans of the Free Cooler would start in full speed. This could cause damage of the Free Cooler fans.

It is planned to add the capability to the system to control and monitor the speed of the Free Cooler fans via Argus. For that purpose the Argus box has to be connected via additional cables to the Free Cooler control board and a control sequence has to be added to the software.

2.4.3 Antirust agent

As mentioned under chapter 3.3 the summer season maintenance team had to remove rust from the metal structure of the TCS rack.

Unfortunately there was no antirust agent on site to protect the TCS rack from further corrosion. For this reason it would be useful to take antirust agent to Neumayer Station III in the next summer season and cover the metal structure with it.