D1.2

Performance data of the partial automation trial period on demonstrator 1

THEGREEFA

Thermochemical fluids in greenhouse farming

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

Document references

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[1] PU = Public

PP = Restricted to other programme participants (including the Commission Services)

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Executive Public Summary

The original scope of this deliverable was the presentation of the performance data of the demonstrator 1 operating with a partial automation system., e.g. in the demonstrator in the Swiss greenhouse, which was and will be continuously in commercial operation. During the implementation there was some delay and it was not possible to have the intermediate phase of partial automation. As a consequence, the performance data were collected after the installation of the full automation system and are presented in this deliverable.

The system installed in the greenhouse integrates three functions in a single installation and automation system: heating, cooling, dehumidification. The control system consists in two control levels: 1) control of air temperature and humidity through the single absorbers, 2) overarching control of the entire system, managing the emptying and fulling of the absorber, regeneration and storage systems.

A first demonstration was run in October 2022 with 6 absorbers in operation, there was a forced interruption after 3 days. A second long continuous operation under mixed condition (cooling and heating) was performed at the beginning of November 2022: all the absorbers went in operation, the humidity and temperature inside the greenhouse was controlled automatically by the TheGreefa’s system. The demonstration period is considered started. The system was stopped after approximately 8 days to allow maintenance works planned in the greenhouse.

The deliverable presents the measurement data collected during the tests to prove the functionality of a single operation and the main data of the system during these two long continuous operations.

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1. Introduction

The air conditioning system TheGreefa is installed in a Swiss greenhouse of Meyer Orchideen AG to control the air temperature and humidity through absorption process.

This is the first time that a TCF circuit has been installed in such a complex system with multiple absorbers interconnected to a single regeneration system; in addition to that, continuous commercial operation must be guaranteed. The implementation of the full automatization of the system has been more challenging than expected: some modifications were necessary in the hydraulic system, the integration of the new PLC (programmable logic control) in the existing control system was not possible due to an incompatibility at hardware and software level. Furthermore, the pandemic situation had postponed the delivery of some components. All these reasons caused a delay in the implementation of TheGreefa in the greenhouse.

In any case, the functionality of single operations was tested during the implementation of the PLC, that means there was no need anymore to have a 30-days test period separated from the demonstration period as foreseen in the Grant Agreement.

A first attempt to start the demonstration period has been done in October, even if two absorbers were out of operation due to problems with the heat exchanger. After less than three days the safety chain transfers the control from TheGreefa to the control system of Meyer Orchideen.

The first long continuous operation with all absorbers was performed at the beginning of November 2022: all the absorbers went in operation, the humidity and temperature inside the greenhouse was controlled automatically by the TheGreefa's system. The demonstration period started. The system was stopped after approximately 8 days to allow maintenance works planned in the greenhouse.

Please note that this document incorporates parts of the deliverable D1.3 "Concept for a fully automated control system and operating manual". They are fundamental parts as guidance in the understanding of the content of this deliverable.

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2. Meyer Orchid greenhouse

The sorptive greenhouse air-conditioning system is used to air-condition the greenhouse No. 12 of Meyer Orchideen AG in Wangen near Dübendorf (Figure 1). The greenhouse has a surface of 600m^2 and there are 28 plants tables. The main type of plants in this greenhouse are orchids in the flowering stage, which requires a constant indoor climate with a temperature of 18 to 22°C and a relative humidity between 50% and 70%. If necessary, some of the tables can be used also for other types of plants, which require the same ambient conditions.

Figure 1: Greenhouse No. 12 of Meyer Orchideen AG. One of the 9 absorbers in market in green (right). The orange pipes on the top are the air suction pipe system. The new structure of table is visible (white wall with blue edge around the crops)

The sorptive greenhouse air-conditioning system consists of eight absorbers, one desorber, four buffer storage tanks plus the balance of plant. The absorbers are installed inside the greenhouse, each one of them supplies conditioned air to a minimum of 2 up to a maximum of 4 tables. The air is conveyed to the absorbers through a bored piping system installed at a height of about 3 meters above the tables. The tables are enveloped in a wall to maintain the conditioned air directly on the crops. The desorber and the four storages are located outside the greenhouse in a wood container (Figure 2). The system is connected to water circuit of the heating and cooling system.

Figure 2: Desorber (left) and TCF storage tanks (right) in the container outside the greenhouse.

The main components of the plant and the control system are described in deliverable D1.3 "Concept for a fully automated control system and operating manual", the description of the system is reported here again to facilitate the reading of this document.

The structure of the entire system is shown in the P&I diagram (Figure 3).

Dotted lines indicate parallel pipeline with the same functions, for example 9 parallel lines of diluted TCF enter to storage S2.

The absorber LW9 is not connected anymore to the tables, which are not anymore in use.

In the eight **absorption scrubbers** (also called **absorbers)** (**LW1 – LW8**), the air, which is taken from the greenhouse ceiling via a piping system evenly distributed, is treated by a tempered TCF in order to maintain the optimum humidity and temperature for the plants in the greenhouse. **Fans** (**VE1.1- VE8.1**) then transport the conditioned air via pipes to the tables. One absorber can treat the air necessary for two up to four tables.

The temperature of the TCF is adjusted in **heat exchangers** (**W1.1 – W8.1**); the heat exchanger is a part of the absorber circuit. All the absorbers are connected to this circuit. Water flows in the absorber circuit. The water is heated via the **heat exchanger W20.2** by a heating circuit of the entire greenhouse using wood pellets and groundwater heat pump or is cooled down via the **heat exchanger W20.3** connected to the cooling water circuit of the entire greenhouse.

The relative humidity of the conditioned air, which is almost in phase of equilibrium with the TCF in the absorber head, can be directly adjusted via the concentration of the TCF in the absorbers. Since the TCF is constantly enriched with absorbed humidity, it is necessary to replace periodically the diluted TCF with a concentrated TCF. The diluted TCF is pumped by the **pumps P1.2 – P8.2** from the absorber scrubbers into the storage **tank S2** and the concentrated TCF stored in the storage **tank S1** is pumped to the absorbers by the **pumps P30.1 – P30.8.** The installed pumps are diaphragm pumps.

The regeneration (concentration) of the TCF is carried out by the **desorber LW10**, which operates in batch mode (see section 1.4 of deliverable 1.3). The diluted TCF stored in tank S2 flows to the sump of the desorber through a natural gradient and recirculated to the head of the desorber by the **pump P10.1**. When the desired TCF concentration is reached, the concentrated TCF is redirected to the storage tank S1.

The temperature in the desorber for the regeneration process (e.g. evaporation process of the water in the TCF to the air) influences the velocity needed to reach the required concentration of the TCF. The TCF is heated in the **heat exchanger W10.1** by glycol-water solution of an intermediate heating circuit (desorber circuit). The glycol-water solution (frost-proof) is necessary because the desorber is housed outside.

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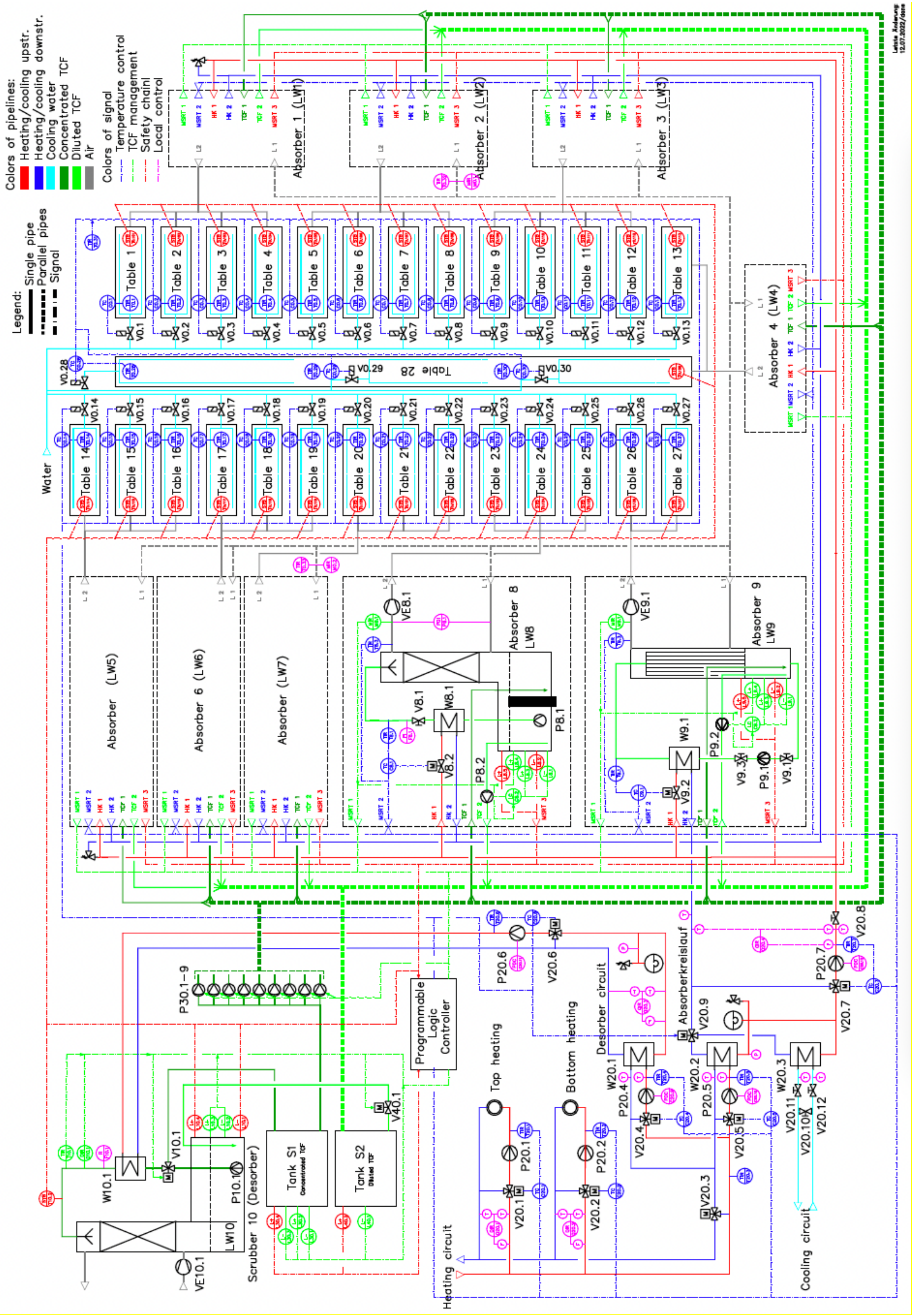

Figure 3: P&ID of the sorptive greenhouse air-conditioning in the demonstrator in Wangen bei Dübendorf.

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3. Test of single functionality/procedure

The full automated control system is designed to maintain the temperature and humidity in the greenhouse within the required range of values. As soon as the temperature and/or humidity approach the upper or lower limits of the required range, the control system brings the values again in the comfort zone and gives the signal to start the substitution of the TCF without the intervention of the operators. In a similar way, the PLC system guarantees to have always enough concentrated TCF and starts the regeneration process as soon as there is not enough reserve of concentrated TCF.

If the actual values of temperature and humidity are outside the comfort zone, the PLC system shuts down automatically and the control is taken over by the traditional control system installed many years ago in the greenhouse. In case the TheGreefa is switched-off, the intervention of the operator is then required to switch-on again the TheGreefa system.

Each single procedure has been tested step by step and optimised during the implementation of the PLC, before being, integrated in the master control. This section describes the two main and significant procedures of TheGreefa: the TCF change in the absorber and the TCF regeneration in the desorber.

TCF change in absorber

The air humidity in the greenhouse is controlled by the TCF concentration. If the concentration becomes too diluted, the air humidity starts to increase, because a too diluted TCF cannot anymore absorb further air humidity. In this case, the TCF shall be changed. The absorber is emptied till the minimum level possible, then it is filled with TCF concentrated at 32%. The resulting TCF concentration is 29.77% corresponding to a relative air humidity of 50%RH in phase equilibrium and at 20°C.

The procedure to empty and fill-up the absorber sump is described in the deliverable D1.3, section 2.3.1.

The procedure was tested for each absorber. TheFigure 4 and Figure 5 show the data of the PLC describing what the logic control concept for the TCF changes in an absorber:

- The relative humidity at absorber outlet is constantly and slightly increasing as well as the level in the absorber sump;
- the level L3 is reached at approximately 18:00 (point a in Figure 5) L3 indicated the maximum level for the concentrated TCF, e.g. it will be significant during the filling process with concentrated TCF. The level remains always below L4, threshold for safety chain: too high level, overflow;
- At 19:48 the relative humidity reaches the upper value 60% (point b Figure 4);
- The emptying process starts (point b in Figure 4 and Figure 4): the PLC sends the signal to switch-on on the emptying pump Px.2;
- the recirculation pump Px.1 is switched off as soon the TCF level decreases below L2 (point c Figure 5);
- The Px.2 continues to pump the TCF from the absorber sump to the S2, the minimum level L1 admissible for the safe operation of the Px.2 is reached 3 times, at the fourth time the Px.2 is definitely switched off (point d Figure 5);
- The filling procedure starts at approximately 20:05 (point e Figure 4 and Figure 5);
- The reaching of the level L3, maximum level for concentrated TCF, indicates that the filling procedure is completed, at appr. 20:10 (point f Figure 4 and Figure 5);
- the absorber enters again in normal operation (point g in Figure 4 and Figure 5).

The entire procedure lasts approximately 20 minutes.

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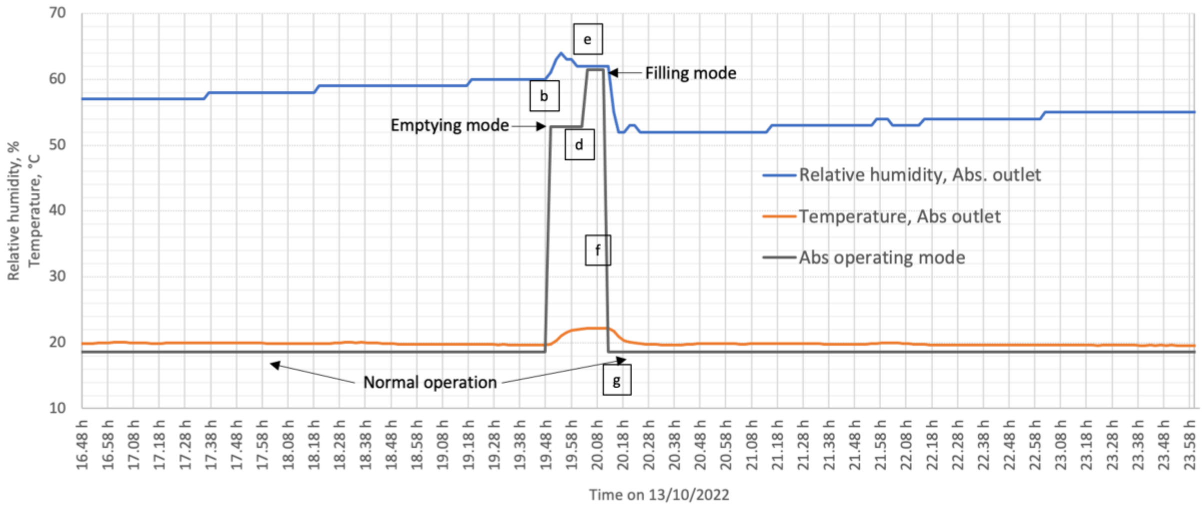

Figure 4: Humidity and temperature at absorber outlet, and operating mode of the absorber as visualized in the PLC

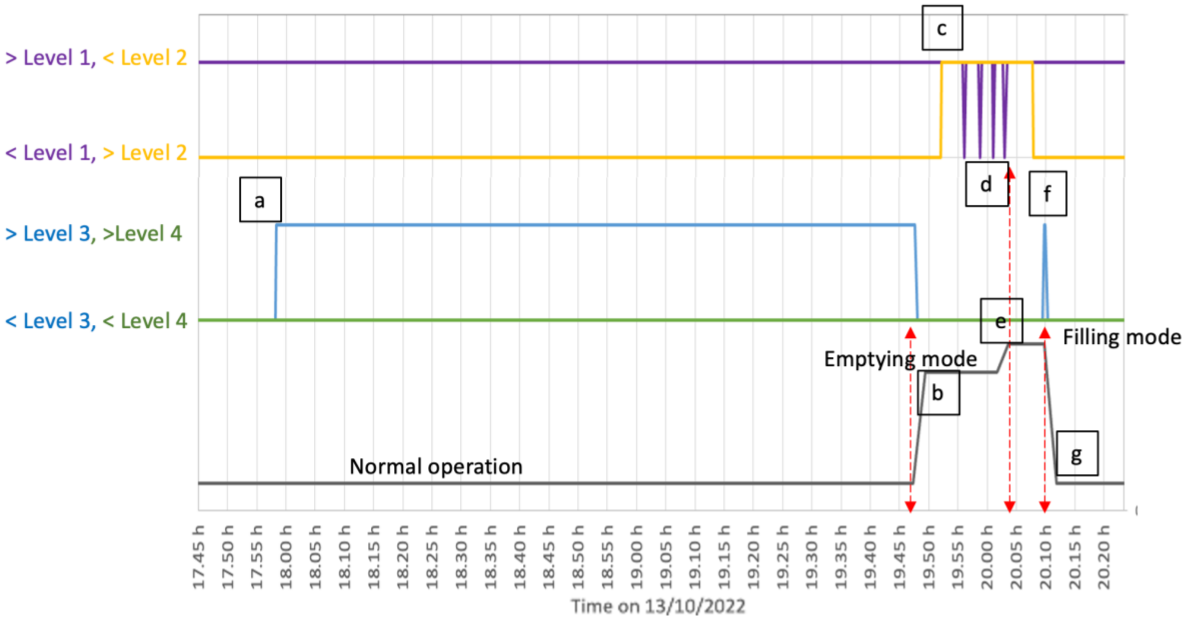

Figure 5: Liquid levels in the absorber sump and operating mode of the absorber before, during and after the procedure of TCF change as visualized in the PLC

All different procedures have been tested, as for example the waiting mode of the absorber in case other two absorbers are in emptying mode, or the safety chain in case the high level in absorber sump (L4) is reached.

First adjustment and optimisation have been implemented after the first tests: for example, the operation On / Off of the pumps and of the ventilator of the absorbers were not recorded by the PLC (they are not shown in Figure 4 or Figure 5). The lack of registration turned difficult the detection of problems during an emptying procedure due to a leakage. For this reason, the new PLC can monitor whether the pumps and fans shall be on or off.

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Operation of the desorber

The operation of the desorber shall guarantee that there is always enough concentrated TCF in the storage tank S1. The entire procedure is described in the deliverable D1.3, section 2.3.2.

The procedure was tested first with the desorber without connection to the system and then in real operation. The Figure 6 shows the data of the PLC describing what happens in the desorber system connected to the absorber system before, during and after the regeneration.

The value of the TCF temperature T10.1 and the TCF concentration D10.1 are significant only during the desorption process, when the TCF is flowing inside the pipes. Before and after the desorption, the TCF pipes are empty.

The diluted TCF is pumped from the absorber sumps in the tank S2 and per gravity flows through the open valve V40.1 in the desorber sump. The description below refers to to Figure 6.

- The high level L10.3 in the desorber sump is reached, the valve V40.1 closes at approximately 6:00. The desorption process could be start, but the tank S1 of concentrated TCF is still full (level > L30.3). The desorber waits also for the signal from the S1;
- The level in S1 decreases below L30.3 at 6:17, the desorption can start;
- The desorber, e.g. pump P10.1, the fan VE10.1 as well as the pump P20.6 of the heating system are switched-on at 6:17. As soon as the recirculation of the TCF is in stationary condition, the measurement of the TCF temperature T10.1 and concentration D10.1 becomes significant and can be monitored;
- The required TCF concentration 32% is reached at 7:48. The pump P20.6 is switched off. The desorber runs in cooling mode;
- The TCF is cooled down till 34°C, the TCF regeneration is concluded, and the emptying mode starts at 8:03: the fan V10.1 is switched off, the position of the valve V10.1 is changed from recirculation mode to storage mode, the TCF is pumped to the tank S1;
- The emptying mode ends when the minimum level L10.2 of the desorber sump is reached, at 8:07. The desorber enters in stand-by mode: the pump P10.1 is switched off, the valve V40.1 returns in open position, the valve V10.1 returns in recirculation position for the next regeneration process.

The regeneration procedure here described is an optimisation of the procedure described in the deliverable D1.3, section 2.3.2. In comparison to the deliverable D1.3, the cooling down mode has been added. This mode is specific for the demonstrator in Wangen, where there are installed just TCF buffers storage (S1 and S2) and not larger or seasonal storages. In the first trial operations with entire system (desorber and absorbers in operation), a very high air temperature was recorded at the absorber outlet immediately after the filling procedure of the absorber. The reason was that the TCF is heated up to approximately 46°C during the regeneration and then the regenerated TCF is quite immediately pumped from the tank S1 to the absorber sump. The TCF had no time to cool down. The added cooling-down procedure smooths these picks of the air temperature at the absorber outlet; they are still present, but are smoothed and not dangerous for the flowers.

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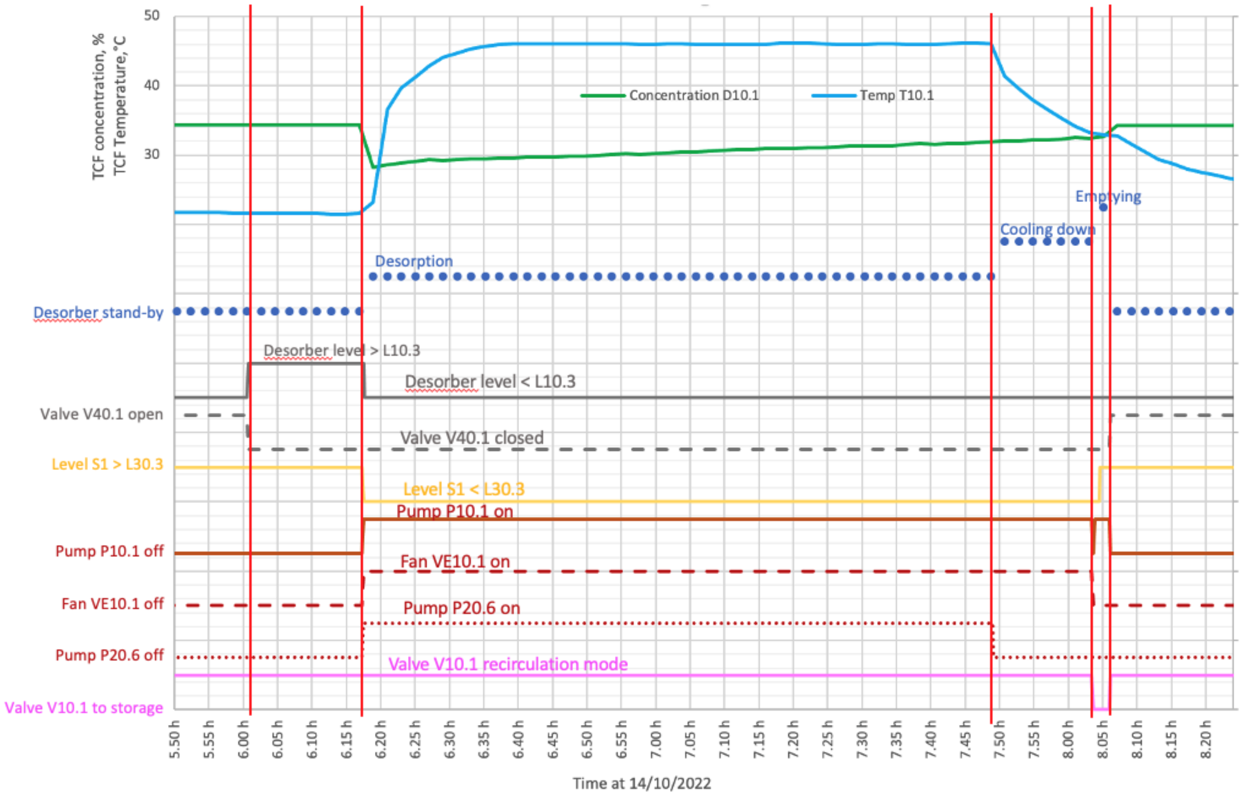

Figure 6: Desorption procedure as visualized in the PLC

4. Performance over long period operations

First demonstration

The first trial operation has started in October 2022, even if two absorbers were out of service due to problems with the heat exchanger.

TheGreefa was running for three days without disfunction or interruption.

The performance of the absorbers can be extrapolated by the measurement data of the air condition at the inlet and outlet of the absorbers (Figure 7): TheGreefa can maintain the temperature at absorber outlets constant and the relative humidity at the requested levels without any fluctuations.

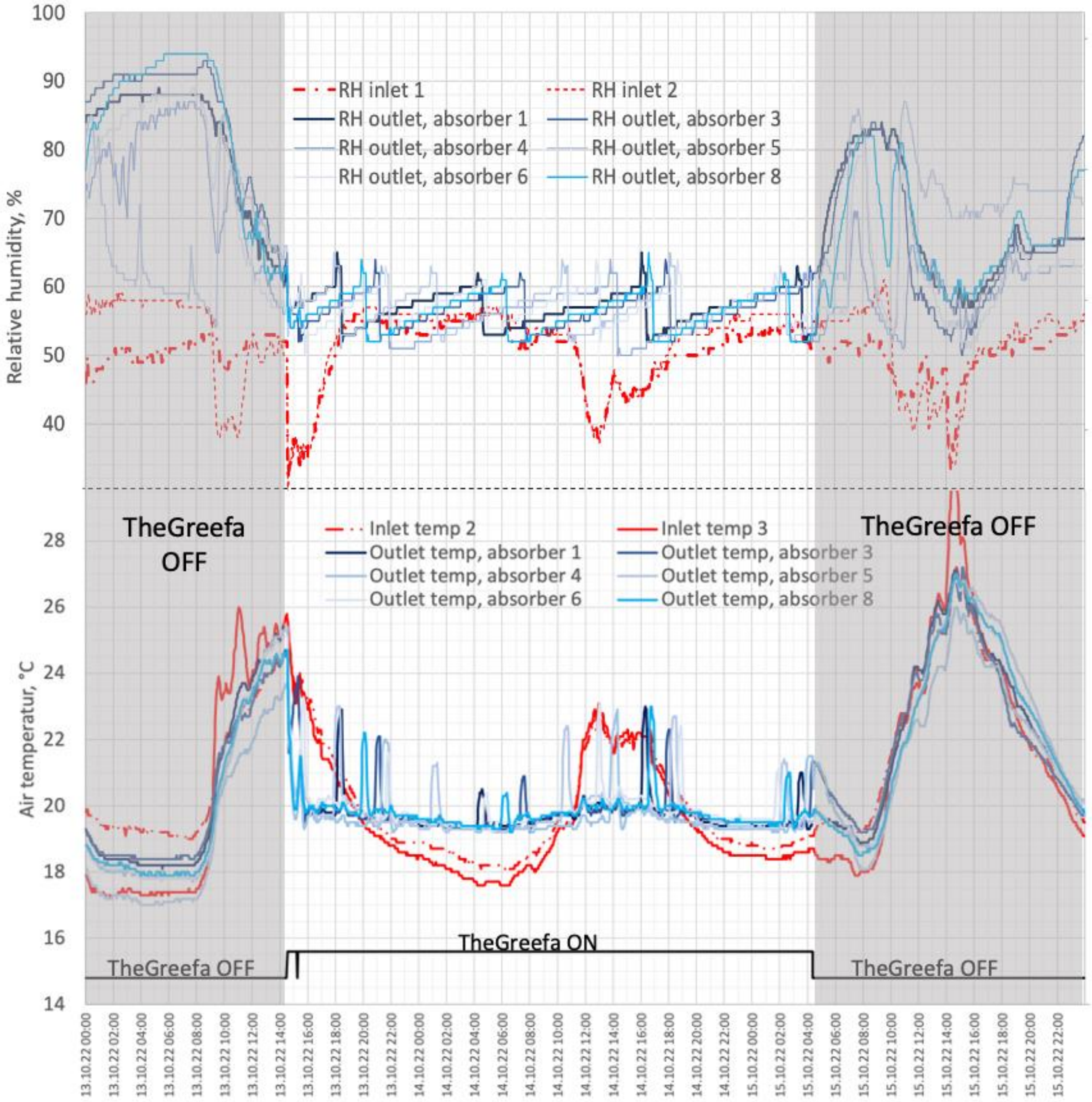

Figure 7: Relative humidity and temperature at inlet and outlet of the absorbers

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The temperature at the inlet of the absorbers, corresponding to the temperature of the greenhouse recorded and used by the conventional control system, has fluctuations (red lines in Figure 7). The absorbers maintain the temperature of the air leaving the absorber around 20°C, practically without fluctuations (blue lines in Figure 7). Picks of temperature are recorded immediately after the TCF change in the sumps, when TCF around 30°C is pumped to the absorber pump (see section "TCF change in absorber", page 9) but they do not have a negative impact on the plants.

The absorber also maintained the relative humidity at the absorber outlet inside the permissible range without any fluctuations: the relative humidity increases constantly due to the dilution of the TCF, and when it reaches the limit value of 60% rh, the procedure of TCF change starts in the corresponding absorber. The relative humidity at the absorber inlet has fluctuations similar to the air temperature, with a minimum of 30% and a maximum value of 60%. It is important to notice that the system records the relative humidity and not the absolute humidity. Water is absorbed inside the absorber, e.g. the absolute humidity at the absorber outlet is lower than at the inlet, but due to higher temperature in the greenhouse than at the absorber outlet, the relative humidity of the greenhouse is lower.

The situation above the crop tables is different. The air temperature is measured closed above all crop tables (Figure 8). In this case, the temperatures have the same fluctuations of the greenhouse temperatures. This is due to the thermal dispersion between the absorber outlets and the tables, and it is not directly correlated to the absorption process.

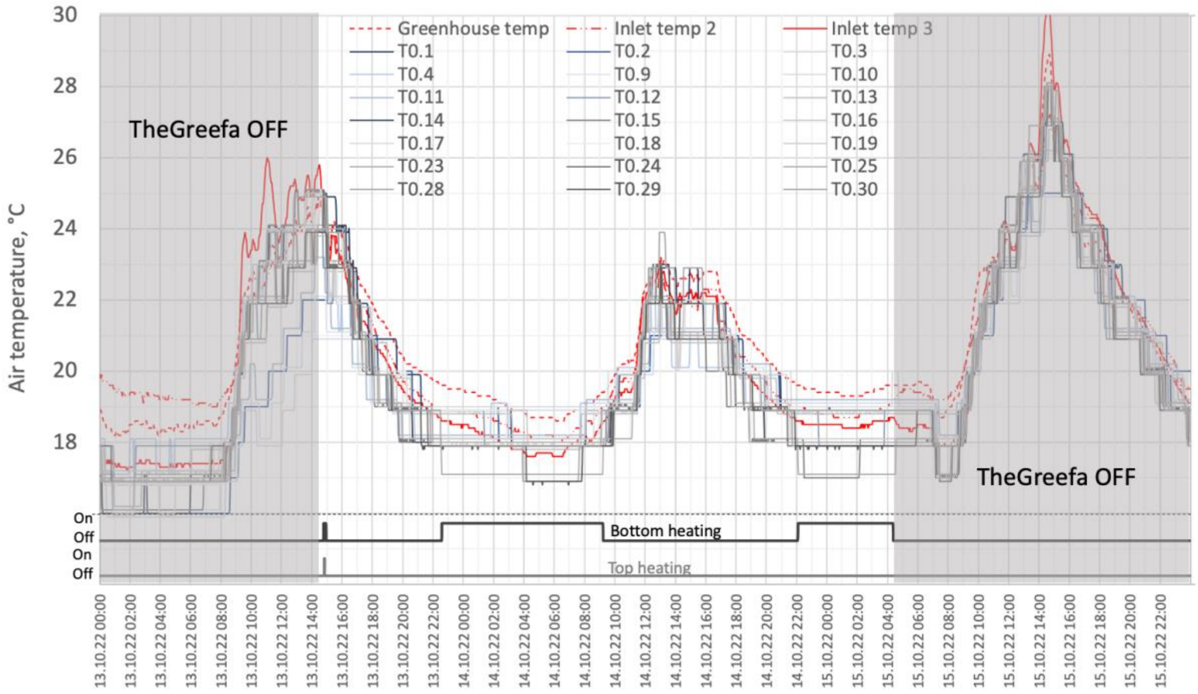

Figure 8: Temperature of the greenhouse and above the plant tables

The performances of the absorbers are good. However, the design and construction of the air distribution system could be further optimised. The fluctuations remain in any case inside the temperature comfort range.

It should be noted that the fluctuations during the operation of TheGreefa is slightly lower than without it. More data over longer periods are needed to confirm this.

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Another data for assessing the performance of the system is the thermal energy consumption.

The air temperature is regulated by controlling the temperature of the TCF in the heat exchanger Wx.1, heating or cooling it. Should the temperature of the greenhouse fall below a limit, the heating under the tables is also used. The heating above the tables is switched on to prevent condensation on the walls should the temperature drop further.

The Figure 9 shows the cumulative energy consumption for all heating systems in the greenhouse of TheGreefa. During this first demonstration, the absorbers were in cooling mode, that means that the TCF was cooled down in the heat exchanger by cooling water. The consumption was approximately 60 kWh. At the same time, the heating system below the tables provided 100 kWh of heating and heating system above the tables approximately 150 kWh.

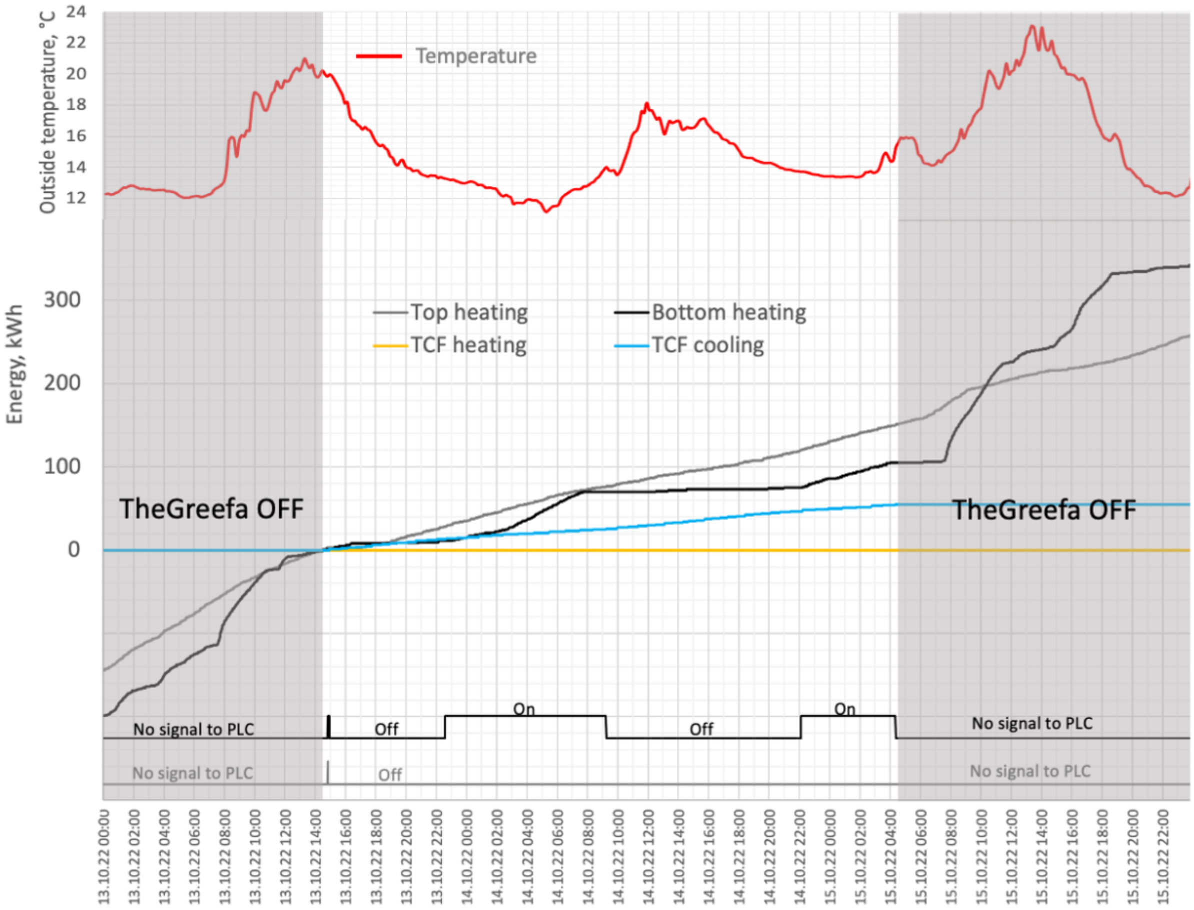

Figure 9: Heat consumption in the greenhouse and status of the bottom and top heating systems

It seems to have a contradiction: TheGreefa system cools down, while the existing control system heats up. The data from the PLC were analysed to understand the reasons.

- Bottom heating system: the activation of the bottom heating was due to a different control logic between the existing system and TheGreefa PLC. In case the temperature of a single table fails under a certain value, the bottom heating system is switched-on. On the other hand, the absorber mode changes from cooling to heating mode, if the temperature of all tables fails under a value. Due to the

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different locations of the tables (different radiation, natural ventilation, transpiration of vegetables), there are differences in the temperatures between the tables. The criteria for the activation of the bottom system and the change from cooling to heating mode in TheGreefa will be further tested

- Top heating system: the PLC did not activate the top heating system. This is reported in Figure 9, grey line on the bottom, but it is also to see that the heat consumption increases constantly. This was due probably to a leakage in a valve, so that warm water flew constantly to the system.

It is also interesting to see that the heating consumption of the bottom heating system before and after the TheGreefa's operation is higher than during the operation, even if the illuminance (radiation) was lower (Figure 10). This could be due to reduced heat losses. As reported in the Figure 10 (data recorded by the existing system of Meyer Greenhouse), the windows were opened during the operation of TheGreefa only for a very short period and with a reduced degree of opening (in average below 20%). It is also to recognise that during TheGreefa operation the relative humidity of the greenhouse remains always below 80%, what is very good for the growth of the plants, while before and after TheGreefa operation, the relative humidity always reached the limit of 80%. The window-opening algorithm needs to be analysed in detail, the windows should actually be open when the relative humidity reaches 80%, which means that the windows should not have been opened during the operation of TheGreefa.

Further data over longer periods will be needed to confirm these considerations. After less than a 3 days operation, the safety chain detected during the desorption process a too low level in the desorber sump (L10.1) and the control were transferred to the existing control system. That happened also in further short trial operations. The cause could be traced to liquid waves formed during the operation of P10.1. The problem is under investigation.

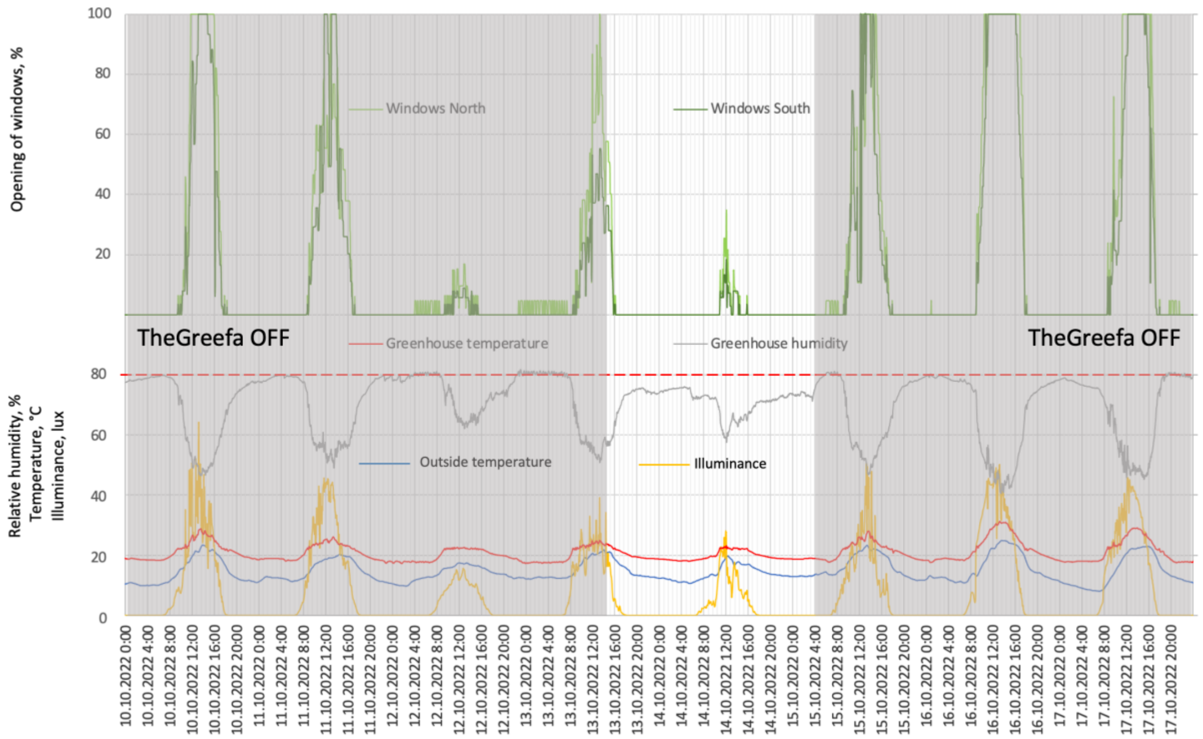

Figure 10: Data recorded by the existing control system of Meyer Orchideen.

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Long period operation

A new test was performed at the begin of November with all absorbers in operation. The absorbers were in operation without interruption for a period of 8 days; TheGreefa were then manually switched-off to allow maintenance works in the greenhouse.

The performances and the trend of the measurement data are similar to the previous test (Figure 11).

The relative humidity at the absorber outlet can be maintained inside the required range, it increases constantly due to the decreasing of the hygroscopic property of the TCF with the increasing of its dilution. The TCF is changed as soon as the humidity reaches 60% rh. The temperature at the absorber outlet also remains within a defined range: the air temperature was constant (see 2, 5 and 9 November in Figure 11) when the TCF temperature was actively controlled because the absorber was in cooling or heating mode.

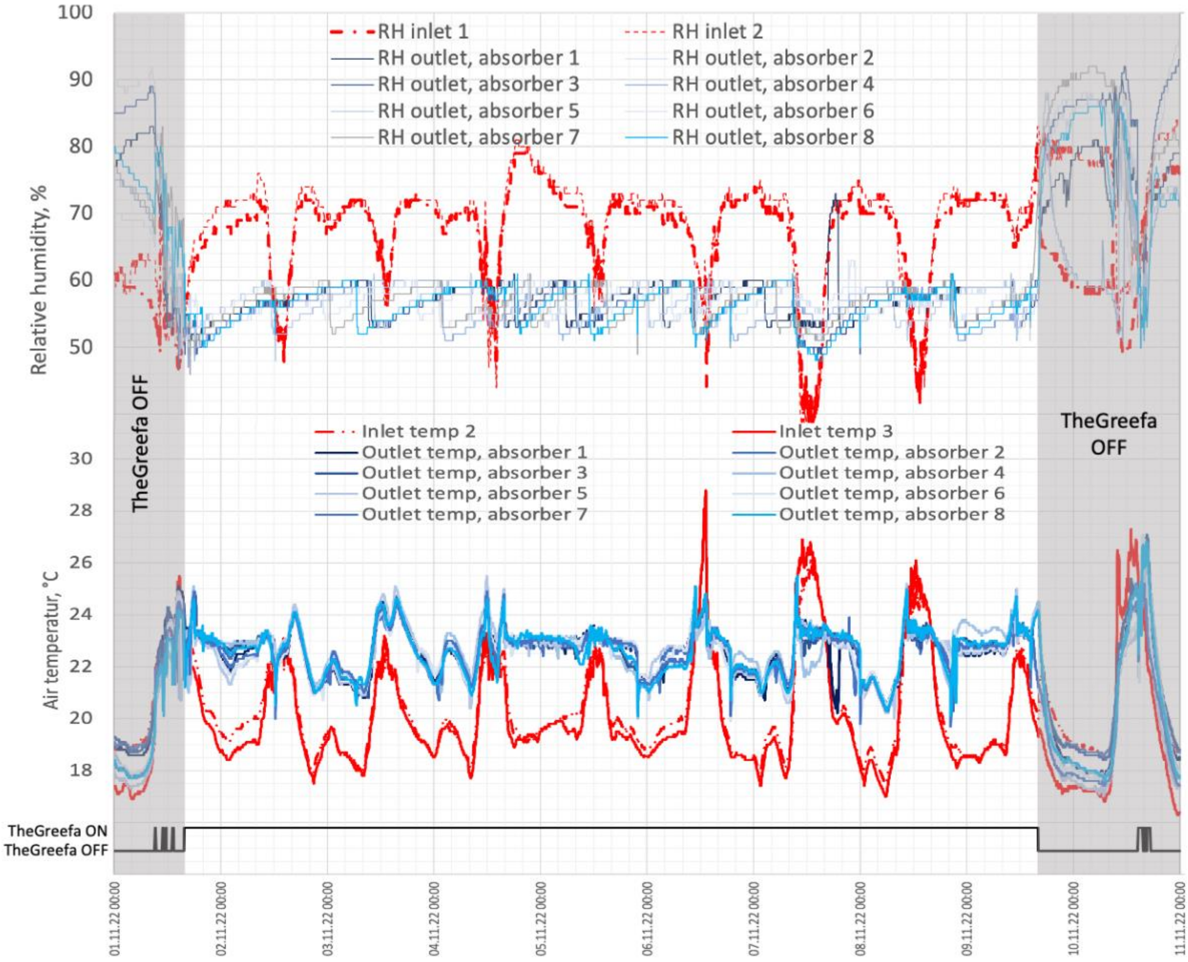

Figure 11: Relative humidity and temperature at inlet and outlet of the absorbers over a period of 8 days

Similar to the previous trial run, the temperature above the tables follows the temperature of the greenhouse (Figure 12).

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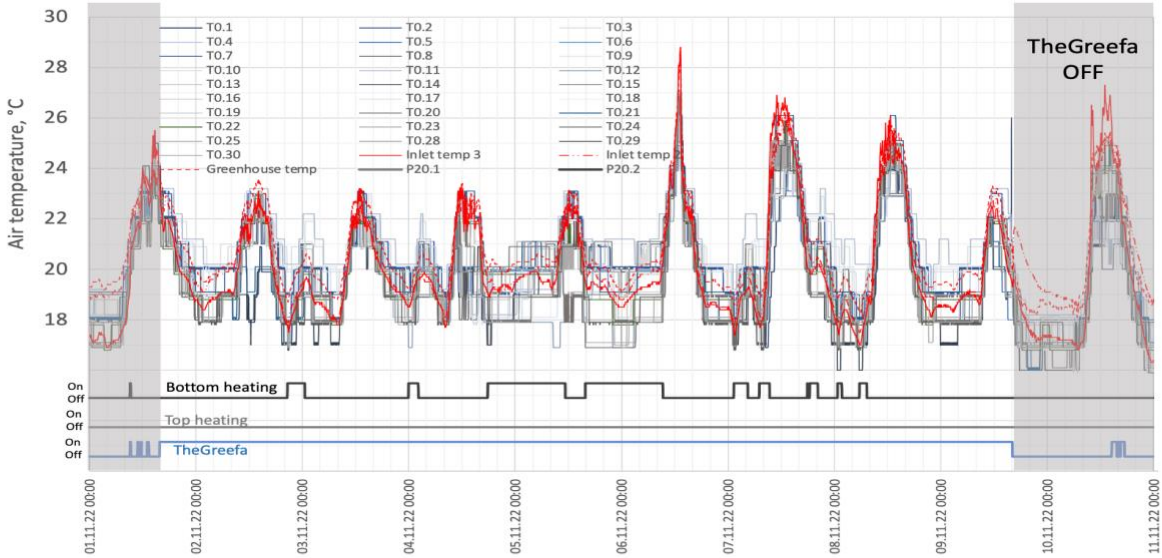

Figure 12: Temperature of the greenhouse and above the plant tables over a period of 8 days

The outside temperatures were in November lower than in October. The bottom heating supplied 2300 kWh in 8 days. The absorbers remained during this period in neutral mode (no heating or no cooling) or in cooling mode. Only on the 9th of November, the heating mode was activated (Figure 12). This “competition” between cooling mode of TheGreefa and switching-on of the bottom heating is still under investigation and the set-up parameters for the bottom heating shall be further adjusted.

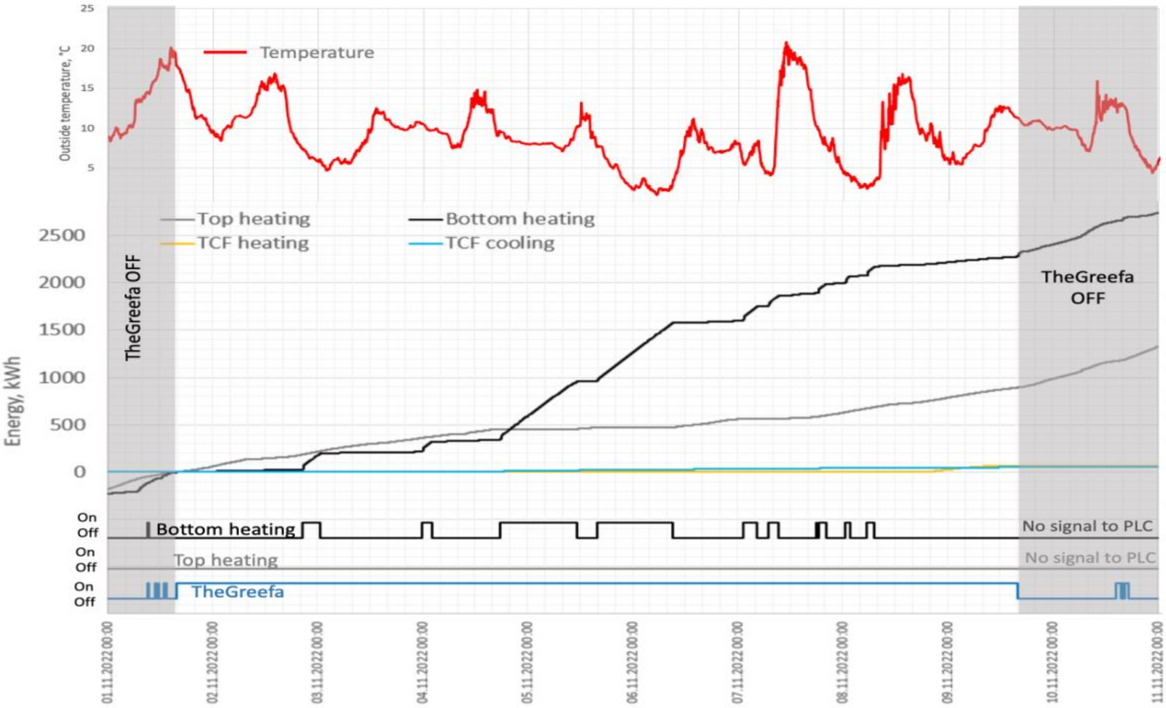

Figure 13: Heat consumption in the greenhouse and status of the bottom and top heating systems over a period of 8 days

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The relative humidity of the greenhouse did never reach the maximum value of 80% during the TheGreefa operation (Figure 14). However, the windows have slightly been opened for a short time (with a reduced degree of opening as average opening less the 20%). Excluding TheGreefa operation, the relative humidity reached daily the 80% rh and then was reduced opening the windows.

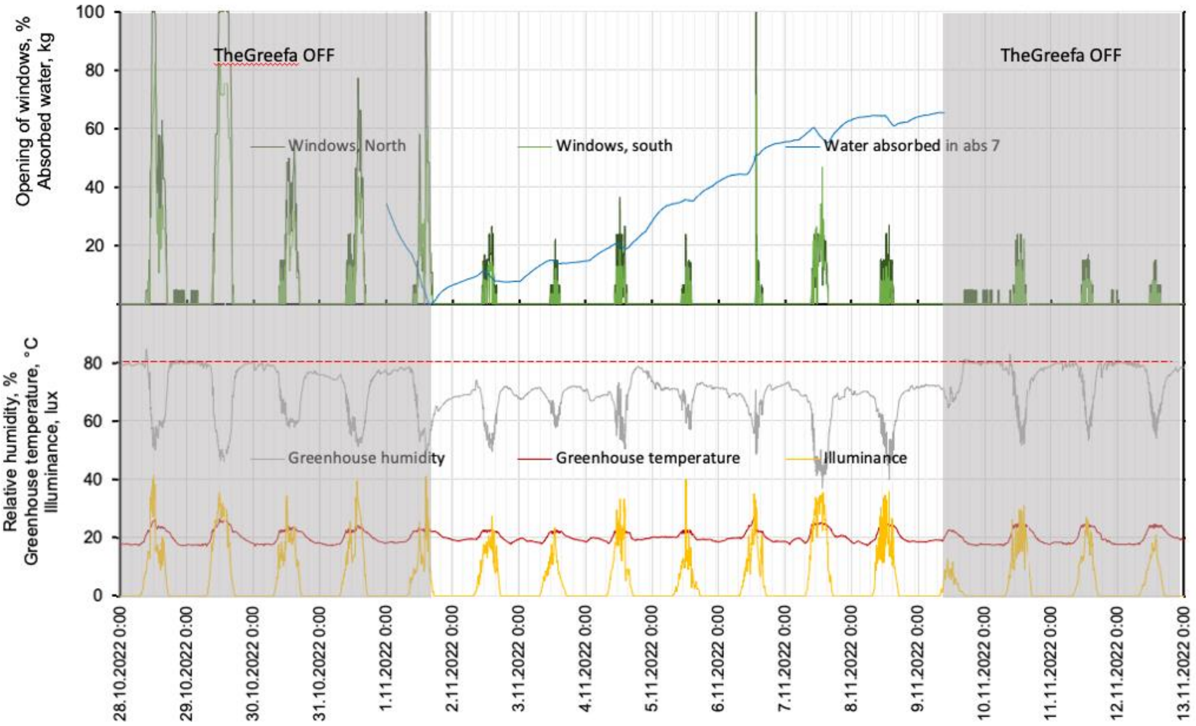

Figure 14: Data recorded by the existing control system of Meyer Orchideen during the period between 28th October and 13th of November 2022.

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5. Conclusion

These first demonstrations over several days showed that the absorbers achieved the scope of maintaining the temperature and humidity at the absorber outlets at the required level. The next efforts are to reduce the heat loss between the absorber outlets and the end points (plants on tables). Besides, the heating system configuration of the existing Meyer Orchideen control system and the absorber heating/cooling system must be optimized so that the Greefa heats as much as possible through the absorbers and uses the other heating system as a support.

After improving the main points, the heat consumption of the Meyer greenhouse will be compared to the heat consumption of a similar greenhouse in order to understand the energy savings. Simulations will support and complete this evaluation.

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