Final report

1. Project details

Project title	EntoPower
File no.	64020-1091
Name of the funding scheme	EUDP
Project managing company / institution	Danish Technological Institute
CVR number (central business register)	DK 5697 6116
Project partners	SKOV Enorm Biofactory (included during the project) Hermetia Baruth Danish Insect Automation (DIA) Danish Technological Institute (DTI)
Submission date	13 March 2023

2. Summary

The overall purpose of EntoPower was to develop an intensive, innovative and industrial production concept for black soldier fly larvae (BSFL) production. The total energy consumption for the production of BSFL has not previously been a significant competitive parameter for BSFL producers. Previous screenings show a significant efficiency potential in heating and ventilation systems for BSFL production. In EntoPower, an innovative tunnel-based ventilation concept, strongly inspired by industrial concepts for other animal farming, has been developed and demonstrated. The newly developed ventilation system has lowered the energy consumption for ventilation to 0.7 kWh/kg larvae, saving 29 gWh/yr. for a large-scale insect production facility. The ventilation system has already been marketed and sold to existing and new insect producers. In addition, a 3D-temperature sensor has been developed and optimized during the project. The 3D temperature sensor provides detailed information on the production environment, enabling a continuous optimization of insect yield and uniformity, which indirectly decreases the energy consumption and environmental impact of insect production.

Det overordnede formål med EntoPower er at udvikle et intensivt, innovativt og industrielt produktionskoncept for sort soldaterfluelarver (SSFL) produktion. Det samlede energiforbrug til produktion af SSFL har ikke tidli-

gere været en væsentlig konkurrenceparameter for SSFL-producenter. Tidligere screeninger viser et væsentligt effektiviseringspotentiale i varme- og ventilationssystemer til SSFL-produktion. I EntoPower er der blevet udviklet et innovativt produktionskoncept stærkt inspireret af industrielle koncepter for automatiserede processer. Det nye varme- og ventilationssystem har reduceret energiforbruget til ventilation til 0,7 kWh/kg SSFL, hvilet svarer til en årlig energibesparelse på 29 gWh for en storskala SSFL-produktion. Det udviklede ventilationssystem er allerede blevet markedsført og solgt til eksisterende og nye insektproducenter. I projektet er der ligeledes udviklet og optimeret en 3D-temperatur sensor til overvågning af produktionskasser. 3D-temperatur sensoren resulterer i detaljerede information om produktionsmiljøet, hvilket giver mulighed for løbende at forbedre udbytte og øge ensartetheden, hvilket indirekte reducerer energiudgiften og miljøpåvirkningen samt øger konkurrencedygtigheden af SSFL.

3. Project objectives

At present, the insect industry is marketed as a sustainable protein source. In order to sustain this image, efforts are needed to reduce overall energy requirements, and ventilation/climate control is currently the most energy consuming part of the insect production facility. A customized ventilation and heat distribution system for insect production has not been developed, and hence current production facilities are using approx. 33% of the total energy consumption for their climate system corresponding to approx. 1.5 kWh/kg insect. The overall purpose of EntoPower was to develop an intensive, innovative and industrial production concept for black soldier fly larvae (BSFL) production. To achieve high production efficiency, it is important to reduce the manual processes as much as possible while optimizing the growth and quality of the larvae. The total energy consumption for the production of BSFL has not previously been a significant competitive parameter for BSFL producers. The mass rearing of insect is dense vertical animal farming resulting in heat and gas emission in hotspots throughout the production area, which puts immense requirements on ventilation and climate control. Previous screenings show a significant efficiency potential in heating and ventilation systems for BSFL production, and several surveys indicates that the main concern for most producers during scale up is ventilation. This main reasons for this are that the ventilation impacts the drying rate (affecting survival and feed availability), sieveable at end of production (affecting loss), climate (to avoid larval migration) and uniformity in the production stables.

In EntoPower, an innovative production concept, strongly inspired by industrial concepts for automated processes, has been developed. The new heating and ventilation system reduces the total energy consumption in production by applying energy efficient ventilators, heat exchanging, and removing water by applying high air volumes (in contrast to conditioning the air) while ensuring uniform climate and optimal growth conditions. The heating and ventilation system is based on tunnel ventilation and has been demonstrated and optimized at full-scale over a period of one year. The energy consumption was during the project lowered to approx. 0.7 kWh/kg insect with the possibility to decrease this number even further. In addition, a containerized pilot-scale facility has been developed, that allows new customers to conducted feeding trials under realistic climate conditions and from which a full-scale ventilation solution can be engineered. Lastly, a newly designed temperature sensor (3D temperature sensor) has been developed which provides detailed information on heat distribution in a production tray, providing qualified information for the climate control system.

reduktion på 85-142.000 tons CO_2 pr år i Danmark og 1,22-2,03 mio. tons CO_2 pr. år i 2030.

4. Project implementation

Prior to the project start, SKOV initiated a focus area on ventilation systems for insect production. This included hiring personnel with experience in insect production and the establishment of a collaboration with Enorm Biofactory (who was later included as a project partner). Therefore, the initial testing and optimization of the ventilation system was conducted at larger scale, conditions resembling a full-scale production and for a much longer time duration, which was not planned at the time of writing the application. The larger scale and realistic production conditions have advanced the development of the ventilation system, especially because feed, climate conditions and insect have a large interdependency. As such the ventilation system has been tested during different seasons (e.g., effect on heating requirements/humidification), different feeds (e.g., different heat/emission developments) and with natural fluctuations in the insect-physiology (e.g., viability of neonates).

Therefore, the development of the system evolved quicker than foreseen in the application, and the ventilation system was already introduced to the market in the end of the project. During the project SKOV has together with INNO⁺ and Big Dutchman, which belong to the same group, founded the group brand Better Insect Solutions, that aims to provide a turnkey solution for insect production at large scale. By providing turnkey plants to a relatively new industry, Better Insect Solutions are trying to lower the uncertainties of establishment and operations. The ventilation system plays a central role in the turnkey solutions, because the ventilation system to a large extend defines the production method (trays, production capacity) and development time. The large interdependency of feed, climate and insects has resulted in the development of a containerized pilot-scale facility, that allows new customers to conducted feeding trials under realistic conditions. This enables new customers to generate information on black soldier fly yield, emissions to the environment (e.g. CO_2, NH_3 and odour) and quality of applying different feeds, which is essential for establishing a realistic business case.

As part of the development of a ventilation system, a customized production tray was tested and optimized during numerous tests. Even though improvements were obtained, climate uniformity remained an unsolved issue. Consequently, the customized production tray was not included as part of the ventilation system. Instead, a newly designed temperature sensor (3D temperature sensor) was developed, giving detailed information on heat distribution within and between production trays.

5. Project results

The overall project objective was to develop an efficient ventilation system for black soldier fly production, which by the end of the project was introduced to the market. The overall objective and the main supporting sub-tasks and how results have been utilized are briefly described in the five sections below. As explained in section 2 below, the development of a customized production tray was not included in the developed ventilation system. Instead, a newly designed temperature sensor was developed during the project, providing detailed information on the heat distribution in production.

1. Heat development and greenhouse gas emission from Black soldier fly larvae

Greenhouse gas emission (CO_2, CH_4, N_2O and NH_3) and heat development was measured during the rearing phase of black soldier fly using four different commonly applied feeding formulation (chicken feed, former food stuffs and a feed mixture from both Hermetia and Enorm Biofactory). The feeding formulation is known to impact both heat and emission. Emission data were collected in a closed chamber with full mixing of the inside air and a controlled and measured air exchange (Figure 1). All formulations were set-up in 6 trays of 60x40 cm containing ~20.000 neonates each and was harvested after all the substrate was converted to dry frass (manual inspection). The heat development was calculated using the CO_2 production in the chamber, using the assumptions that all CO_2 production was only from biological activity.

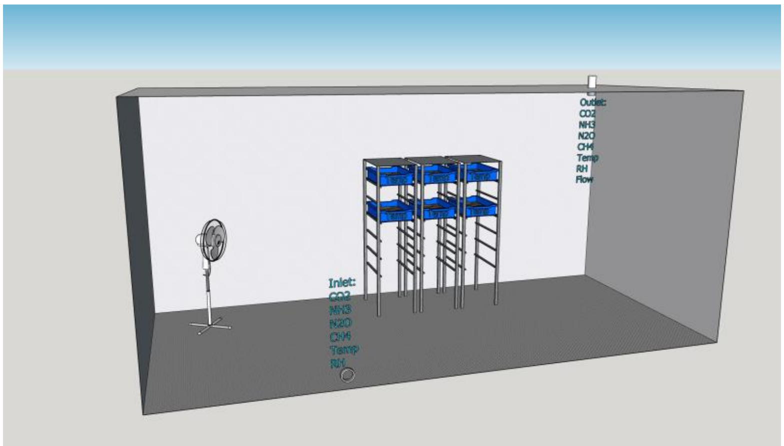

Figure 1: Schematic of the GHG test room. Sensors in the inlet was: CO_2, NH_3, N_2O, CH_4, Temperature and relative humidity (RH) sensors in the outlet was: CO_2, NH_3, N_2O, CH_4, Temperature, RH and Flow.

The results (Table 1) clearly shows that the feed formulation effects the heat and emission data significantly. As an example, the peak and average heat development varied more than 50% and ammonia emission more than 400% between the feed formulation. The results have been used as a design basis for the ventilation system.

Table 1: GHG results from four commonly applied BSF substrates

	CO2 (Kg/Kg DM)	CO2 (Kg/Kg Protein)	NH3 (Kg/Kg DM)	NH3 (Kg/Kg protein)
Chicken feed	1.878	5.365	0.033	0.093
BSF Feed1	2.617	7.477	0.082	0.233
BSF Feed2	2.330	6.657	0.070	0.201
Organic waste (pulp)	2.264	6.467	0.128	0.366

2. Development and testing of customized production tray

As part of the EntoPower project, a customized production tray was further developed and tested. The customized production tray provides a stackable, four-sided rearing tray for industrial rearing of larvae, and, when stacked with other trays, the system of trays becomes self-ventilating due to a “chimney/stacking effect”. The chimney effect could potentially reduce the ventilation need for controlling climate (e.g., humidity, temperature, and gases) and allow for a central handling of gasses occurring during production.

Several different prototypes of the customized have been tested in the project, using black soldier fly larvae and heating elements (using data from heat development measurements, see Figure 2). For both types of tests, the different prototypes have been tested using natural ventilation from the chimney and forced ventilation using a fan. In addition, a series of computational fluid dynamic (CFD) models were run to help visualize and look at internal distribution of air intake. Even though improvements were obtained, climate uniformity and a large counter-pressure remained an unsolved issue. Consequently, the customized production tray was not incorporated in the ventilation design.

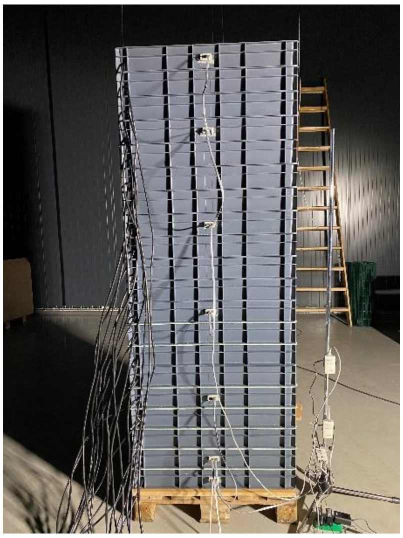

Figure 2: 20 stacked customized production trays with heating elements and temperature measurements.

3. Development and testing of ventilation system

Prior to the project start, SKOV initiated a focus area on ventilation systems for insect production. This included hiring personnel with experience in insect production and the establishment of a collaboration with Enorm Biofactory (who was later included as a project partner). Therefore, the initial testing and optimization of the ventilation system was conducted at larger scale, conditions resembling a full-scale production and for a much longer time duration. The production rooms at the pilot facility of Enorm Biofactory contains 1600 trays with a production area of approx. 0.24 m^2 per tray, which means that each test run consumes 11-13 tons wet feed and produces approx. 2-3 tons BSFL. The new heating and ventilation system reduces the total energy consumption in production by applying energy efficient ventilators and heat exchanging (see below).

The larger scale and realistic production conditions have advanced the development of the ventilation system, especially because feed, climate and insect have a large interdependency. As such the ventilation system has been tested during different seasons (e.g., effect on heating requirements/humidification), different feeds (e.g., different heat/emission developments) and with natural fluctuations in the insect physiology (e.g., viability of neonates).

The developed ventilation system, strongly inspired by ventilation for other farmed animals, is based on tunnel-ventilation (see Table 2). In contrast, to other suppliers of ventilation for insect farming, the dehumidification is conducted using high air volumes instead of dehumidification by mechanical cooling. This increases the air volumes being ventilated (≈x3) but removes the energy requirements for mechanical cooling.

During the initial part of the project much effort was put into establishing data on heat and emission development (see section 1). In addition, an upgrade to the software program Staldvent was established in the project to incorporate an insect module for simulating insect production. Using the insect module, it is possible to calculate the required dimensions of the ventilation and heating system for different production capacity based on insect heat production and weather conditions at the location of the production. In some climatic zones with very high humidity and temperature (subtropical zones), dehumidification can be troublesome during peak production with the developed ventilation system. Consequently, different dehumidification principles have been examined, both form an economical perspective (CAPEX, OPEX, ROI) and from and an environmental. The results clearly indicate that the cost of dehumidification during the short periods extreme weather conditions largely exceed the potential extra turnover/income.

Table 2: Difference between agricultural approach and industrial approach. System exampled based on 5- ton fresh larvae a day.

	Agricultural approach	Industrial approach
Recirculation (m3/h)	270.000	270.000
Ventilation in/out (m3/h)	270.000	100.000
Heating capacity (kW)	720	720
Cooling/dehumidification (m3/h)		1000

During the development of the ventilation system, an air/water heat exchanger from INNO+ was installed/adapted (component from animal houses). The heat exchangers collect heat from the exhaust air in a washer, which removes heat from the ingoing air while removing gases (emission). The recovered heat is then used to pre-heat the incoming fresh air used in the production rooms. Applying this approach, enabled the energy consumption to be lowered to approx. 0.7 kWh/kg insect biomass during the project. Additional initiatives have been identified that is expected to decrease this number even further.

Climate uniformity is crucial for a successful insect production, because:

- Yield is impacted by drying rate (survival and feed availability)
- The frass/larvae must be sieveable at end of production to limit rejected trays (loss)
- Avoid larval migration (humidity, air composition)

In order, to get a better understanding of the climate uniformity and identify areas for improvement, a large test was conducted. During the test the temperature was recorded in 30 trays and the climate (CO_2, %RH, temperature) was measured in 15 points in the production stable. Minor differences in climate and tray yield were observed throughout the production room. An example on the difference in absolute humidity in the last three days of a production is shown in Figure 3. Based on the climate uniformity test, several initiatives were implemented in production stable to lower the differences throughout the stable.

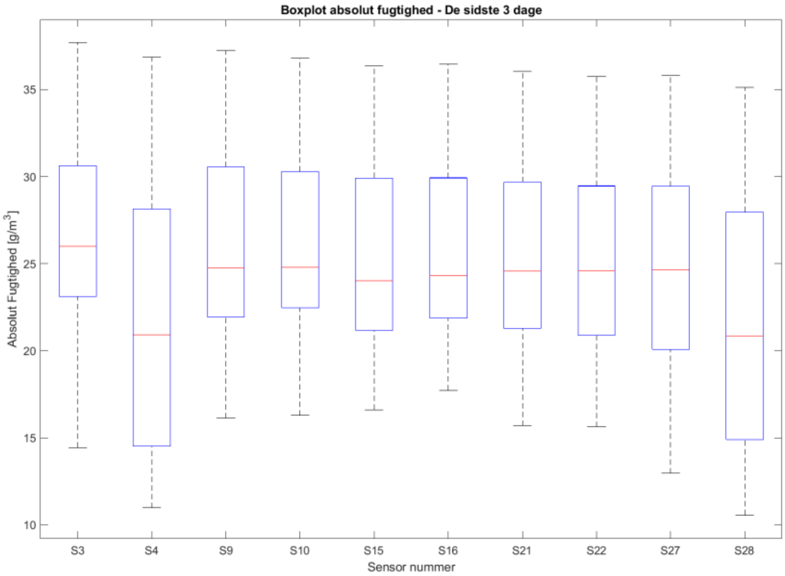

Figure 3: Box-plot of the absolute humidity in the last three days during a production (rearing)

4. Development and testing of containerized pilot-scale facility

Successful rearing of insects requires a good understanding and control of how climate, feed and insects (such as larvae density and genetics) affect each other. To assess these three parameters, SKOV has developed a containerized pilot-scale facility that allows prospective insect producers to conduct feeding trials under realistic conditions to generate information on black soldier fly production and emissions, which is essential for establishing a realistic business case. Moreover, this allows prospective insect producers to validate the ventilation solution under their unique climate conditions. The containerized solution, named a Grow-Box, is a modified 40-foot cooling container that utilizes the same ventilation concept as SKOV's large scale solution. Hence, it is a true pilot version of conditions applied at industrial level.

A prototype of the Grow-Box was placed at Enorm Biofactory, who supplied trays, feed, and juveniles. The Grow-Box was filled with nine pallets containing 40 filled trays each and the Grow-Box was set to run for seven days. A production room at Enorm, equipped with a SKOV ventilation system, was started simultaneously to provide a basis for comparison. Temperature development, along with other parameters, was measured during the trial and afterwards the final content of the trays was measured. The experiment was conducted twice, with two different feed formulations.

Both production trials went according to plan. The yield and temperature within the trays and in the air of the Grow-Box was comparable and similar to that of the full-scale system (see Table 3). The change in feed formulation between the trials had minute effects on the results, showing the adjustability and resilience of climate system. As such it is concluded that the Grow-Box works well as a demonstration of the full-scale production system.

Table 3: Production performance from a full-scale SKOV ventilation system compared to the Grow-Box.

		BSF yield (kg FM/tray)	Frass (kg FM/tray)	BSF size (Avg. g/BSF)	Max T. tray (°C)	Avg. T. tray (°C)	Max T. air (°C)	Avg. T. air (°C)	Frass DM (%)	BSF DM (%)
1. Trial	Grow-Box	1,70	1,46	0,182	43,96	35,08	36,58	33,60	80,7	33,5
	SKOV System	1,69	1,52	0,172	43,04	35,67	36,79	33,83		
2.Trial	Grow-Box	1,55	1,72	0,169	43,75	33,95	41,22	33,29	61,1	33,5
	SKOV System	1,57	1,55				37,68	32,78	63,6	31,9

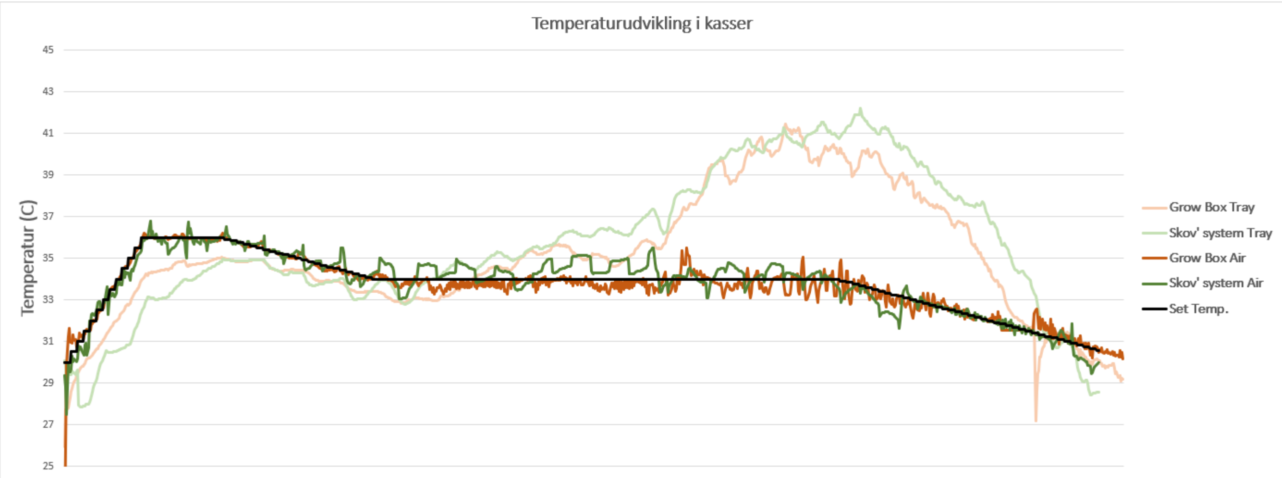

Figure 4: Temperature development during test of Grow-Box (SKOV) and within a production room at Enorm.

5. Development and testing of 3D temperature sensor

The knowledge of the temperature distribution inside a production tray as a function of time is only known to a very limited level. The method used until now is based upon a single point sensor(s) applied inside a production tray (being 600x400mm or larger). Because the colony of larvae are mowing inside the tray, a single point sensor will result in an unreliable temperature measurement. One of the positive results of a more reliable temperature measurement would be knowledge of the maximum, minimum and average temperature in the tray during production, providing valuable information on how the production conditions influence the larvae. Detailed temperature distribution information provides in-depth knowledge on how the surrounding environment affects larval behaviour and the overall survival rate and level of growth. And at the same time, the temperature distribution measurement could give a better knowledge and understanding of the ratio of heat generated by fermentation of the substrate and the heat generated by the larvae them self.

During the project, a temperature sensor providing a three-dimensional view of the temperature distribution was developed, being composed of a three-dimensional grid with small term probes (hence named 3D temperature sensor). The aggressive substrate resulted in breakdown of the first prototypes. Consequently, much effort was put into investigation coatings. Additional tests of new sensor prototypes with different coatings were conducted and finally a coating was found that was able to withstand the aggressive environment.

A large-scale temperature test in a Grow-Box (see next section) was planned by DTI, SKOV and DIA. A total of 9 trays with 3D temperature sensors were installed in the Grow-Box at Enorm Biofactory. Each tray including 48 probes, which resulted in 10 million temperature readings during the 7-day test period. The experimental layout is presented in Figure 5 and Figure 6. In Figure 7, a snapshot of the heat distribution within a single production tray is presented, indicating a temperature difference between maximum and minimum of 13.6˚C (all 48 probes read with the same timestamp max. 30 second delay). Another result was that the maximum recorded temperatures were higher using the 3D-temperature sensors compared to the point sensor (see Figure 7). As such the average maximum recorded temperature was 44.3 ˚C and 42.5 ˚C for the 3D sensors and point sensors, respectively.

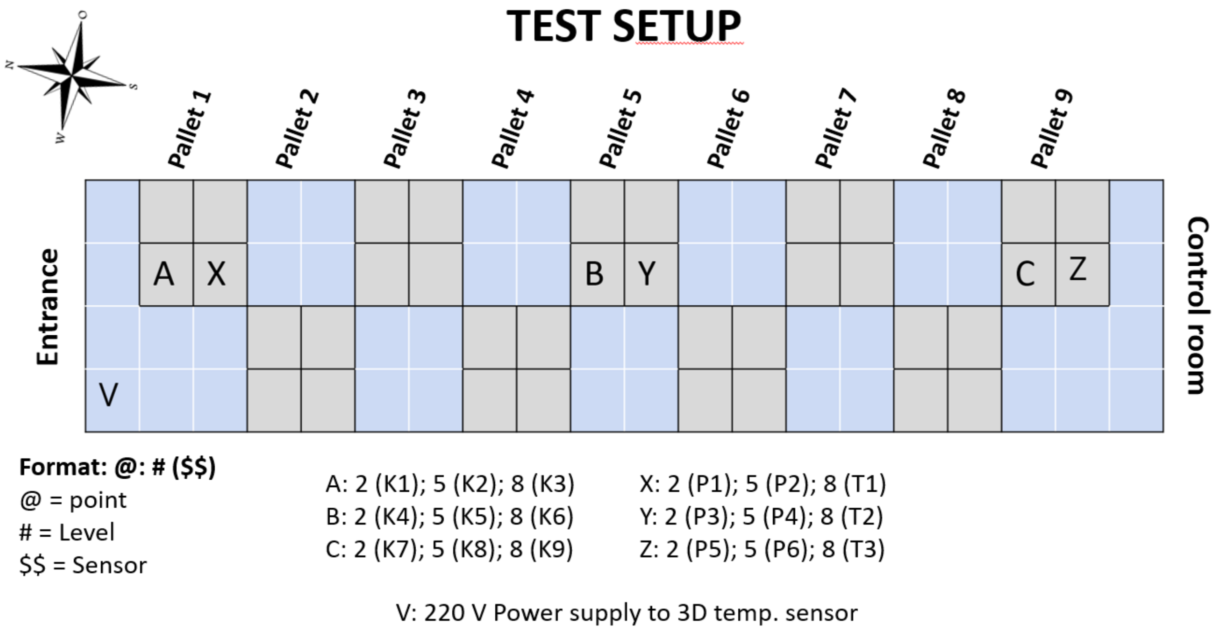

Figure 5: In location A, B, C the 3D sensors were installed and in X, Y and Z the single point temperature sensors were installed.

Figure 6: Trays on pallet inside the Grow-Box

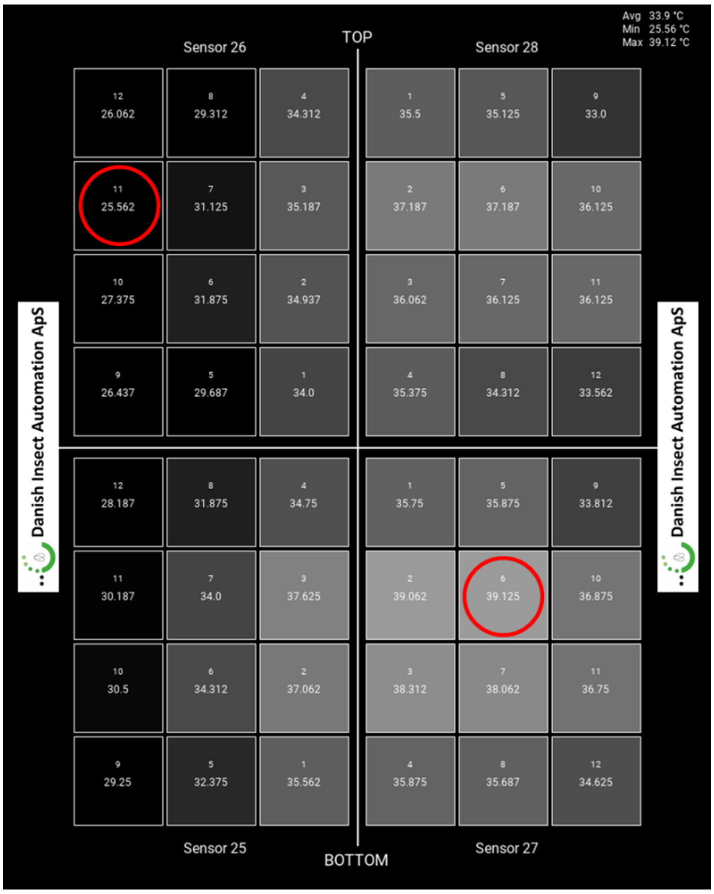

Figure 7: Snapshot of all 48 temperature probes.

The use of point sensors in a production tray, only provides very little information on the temperature development inside the tray. It is at best an indication of a temperature. The 3D temperature sensor resulted in much more detailed and precise information on heat development and movement of the colony inside the tray. More tests with the 3D-temperature sensor will help the understanding of the colony behaviour as a result of the environment (temperature and humidity) and thus provide valuable information for the further understanding of large-scale insect production.

Overall

From a commercial perspective, the EntoPower project have contributed considerably to the development and continuously improvement of the ventilation system for black soldier fly rearing. SKOV is now, together with other components and units that have been developed concurrently, marketing the ventilation system via Better Insect Solution (BIS). SKOV has during the project been actively disseminating their solutions at a number of international trade shows and conferences, including (but not limited to): VIV Utrecht 2022 (NL), Insect to Feed the World 2022 (CA), Insecta 2022 (DE), Eurotier 2022 (DE) and Green Innovation Days 2022 (DK). This has generated a large number of customer relations with existing and prospective insect producers from all over the world. Moreover, the facilities at Enorm Biofactory has been used as a show case for existing and prospective insect producers as well as authorities (e.g. Czech Agricultural Ministry and EU parlamentarians) and trade organizations from around the world.

The development of the 3D temperature sensor was finalized just before project termination. As such, the sensor has not yet been marketed. The sensor is expected to provide detailed insight to insect producers on heat development and distribution offering a thorough tool for improving yield, uniformity and decreasing energy consumption. Danish Insect Automation are already having a well-established network within the insect industry and are already in contact with a number of potential customers.

The overall project has been disseminated on several occasions, with the Insect to Feed the world in Québec City, June 22 being the most important. The conferences gather all major insect producers, prospective producers, academia and institutional investors.

6. Utilisation of project results

During the project SKOV has together with INNO⁺ and Big Dutchman founded the company Better Insect Solutions (BIS), that aims to provide a turnkey solution for insect production at large scale. By providing turnkey plants to a relatively new industry, BIS are trying to lower the uncertainties of establishment and operations. The ventilation system plays a central role in the turnkey solutions, because the ventilation system to a large extend defines the production method (trays, production capacity) and development time. During the project, and as a consequence of BIS, SKOV has invested much time and effort (far more than anticipated at the time of writing the application) in developing a HVAC solution for BSF production. This includes hiring of people with knowledge of insect production and the industry and people with experience in project management and sales. SKOV/BIS are presently in dialogue with a large number of prospective and existing insect producers and several quotations has already been submitted. One example is the new large-scale facility at Enorm Biofactory in Flemming, where the HVAC system will constitute the core of the production design.

Previous screenings show a significant efficiency potential in heating and ventilation systems for BSFL production, and at present as much as 1.5 kWh/kg insect is used for ventilation. During the project the energy consumption was lowered to 0.7 kWh/kg insect. For the new site at Enorm Biofactory this corresponds to a yearly saving of 29 gWh (100 tons BSFL/day).

In Europe (and globally) several industrial insect production facilities are constructed or are under construction. According to Rabobank, there will be an annual production of insect protein in Europe of 1-2 million t/year in 2030. Moreover, according to a recent market research report, the global BSFL market is expected to reach 2.57 billion USD by 2030. This growth is also supported by other market analyses. Thus, based on these number, 150-300 industrial facilities with a production of the Enorm Biofactory site are expected to be constructed over the next 5-10 years. Provided that the growth scenarios within the insect production are realized, SKOV/BIS expects a significant sale to the segment, having an extensive global knowledge on ventilation for other farmed animals and established sales channels. Several competing HVAC solutions are available on the market; however, many of these differ from the SKOV solution by conditioning the air and applying lower air volumes.

The 3D temperature sensor developed by DIA was finalized just before project termination. As such, the sensor has not yet been marketed. To the knowledge of the project consortium there are no competing products on the market. Danish Insect Automation is already having a well-established network within the insect industry and are already in contact with a number of potential customers. The 3D temperature is applicable for all ventilations system, and not just the SKOV/BIS solution, resulting in a relatively large number of potential customers. To ease the market penetration, the value proposition of the sensor needs to be better established.

DTI have been one of the main drivers in insect innovation at national and international level since 2014 and have fundamental insights in biological requirements and engineering solutions. Through the participation in EntoPower the knowledge on insect physiology related to production environment and ventilation has been further strengthened. This will likely increase the consulting services to the insect industry.

7. Project conclusion and perspective

From a commercial perspective, the EntoPower project have contributed considerably to the development and continuously improvement of the ventilation system for black soldier fly rearing. SKOV is now, together with other components and units that have been developed concurrently, marketing the ventilation system via Better Insect Solution (BIS). During the project the energy consumption was lowered to 0.7 kWh/kg insect, which for the new site at Enorm Biofactory corresponds to a yearly saving of 29 gWh (100 tons BSF/day). Market research reports indicates that a large number of industrial insect rearing facilities are expected to be constructed over the next 5-10 years. To allow prospective insect producers to perform realistic production test and thereby mitigate risks, a modified 40-foot container, utilizing the same ventilation concept as SKOV's large scale solution has been developed (Grow-Box). Energy consumption and production consistency are expected to be of increasing importance for existing and prospective insect producers. Hence, SKOV/BIS will over the next few years continue the work on energy optimization.

The 3D temperature sensor developed by Danish Insect Automation (DIA) in the project, clearly shows that the 3D temperature sensor provides a more detailed and precise information on heat development and movement of the colony inside the tray. More tests with the 3D-temperature sensor will help the understanding how rearing conditions and performance are affected by ventilation. DIA is already in contact with several potential customers as the 3D temperature is applicable for all ventilations system.

8. Appendices

- Add link to relevant documents, publications, home pages etc.