Learning Sustainability with EPS@ISEP – Development of an Insectarium

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Abstract

Sustainability plays a key role in EPS@ISEP programme - the European Project Semester programme at the School of Engineering of the Polytechnics of Porto. Not just the environmental, but also economical (marketing) and social (ethics) perspectives are explored by multicultural teams during this one semester capstone/internship programme. In 2015, a team of EPS@ISEP students choose to design and develop an insectarium to grow insects for reptile feeding. The team, after exploiting the topic, contemplated growing insects not only for animal feed, but also for human food. Their motivation resulted from the fact that insects, when compared with traditional sources of protein, are more sustainable, i.e., require considerably less resources per kg of protein. This approach, in the current Earth's population growth scenario, contributes to minimise the resources required for meeting food needs. The main goal of the proposal was to raise the awareness of the participants regarding sustainable development while creating a functional, cost-effective, eco-friendly and attractive prototype. The team, driven by this multidisciplinary problem, performed: (*i*) a survey of competing products; (*ii*) a selection of the insect species to grow based on the study and comparison of the life cycle and habitat requirements of different species of insects; (*iii*) a marketing plan; (*iv*) a sustainability and an ethic and deontological analysis of the proposed solution; and (*v*) the design, assembling and testing of the prototype. Furthermore, the students also developed cross-cultural understanding, teamwork and communication skills. The project provided an excellent opportunity to foster the concept of sustainable development amongst the students.

Keywords: Engineering Education; Sustainable Development; European Project Semester; Insectarium.

1 Introduction

The European Project Semester (EPS) is a one-semester programme offered to engineering, product design and business undergraduates by 18 European engineering schools. EPS aims to prepare at the capstone project/internship level future engineers. EPS aims to prepare future engineers to think and act globally, by adopting project-based learning and teamwork methodologies (Andersen, 2004), fostering the development of complementary skills and addressing sustainability and multiculturalism.

EPS@ISEP – the EPS programme implemented since 2011 at ISEP – the School of Engineering of the Polytechnics of Porto – welcomes 3rd and 4th year mobility students during the spring semester. The structure of the EPS semester at ISEP includes one Project (20 ECTU) and five project supportive seminars modules oriented towards the specificities of each team project – Project Management and Team Work (2 ECTU), Marketing and Communication (2 ECTU), Foreign Language (2 ECTU), Energy and Sustainable Development (2 ECTU) and Ethics and Deontology (2 ECTU) (Malheiro et al., 2015). In particular, Energy and Sustainable Development and Ethics and Deontology, ensures every project has a strong focus in sustainability, as a way to raise the student's awareness to this problem. In terms of pedagogy, EPS@ISEP implements project based learning with a strong focus on multicultural and multidisciplinary teamwork. The project module is assured by a team of supervisors, from distinct scientific areas and with different backgrounds, and adopts a coaching approach, leaving teams in charge of their projects. Assessment occurs twice during the semester and has two components: self and peer (S&P) and supervisor/teacher assessment.

The S&P assessment takes into account the quality and quantity of the technical contribution, openness to others ideas, teamwork performance, leadership, attitude and initiative shown.

One of the project proposals offered in the spring of 2015 was the development of an insectarium, encompassing two goals: (*i*) to raise student awareness to the problem of sustainable food production; and (*ii*) to design and develop an insectarium. As all EPS projects (each one with a specific client, responsible for defining the project requirements and checking its compliance), the objectives of the insectarium proposal were broad: "*This project addresses the problem of how to produce food to feed the world's population. Since recent figures indicate that there are more than 200 million insects for each human on the planet, the challenge is to build an enclosure with the appropriate conditions to grow insects (e.g. mealworm or Tenebrio). This insectarium should be inexpensive, productive and have an elegant and functional design*." (Insectarium, 2015).

The team that choose this project was composed, according to the EPS 10 Golden Rules (Malheiro et al. 2015), of six students from different nationalities (Belgian, Polish, German, Spanish, Estonian and Scottish), and backgrounds (Digital media and graphic design, Computer science, Marketing, sales and purchases, Building engineering, Environmental engineering and Electronic engineering). The technical objective of the project was to create a functional, cost-effective, eco-friendly and attractive insectarium prototype. The team, driven by this multidisciplinary problem, performed: (*i*) a survey of competing products; (*ii*) a selection of the insect species to grow based on the study and comparison of the life cycle and habitat requirements of different species of insects; (*iii*) a marketing plan; (*iv*) a sustainability and an ethic and deontological analysis of the proposed solution; and (*v*) the design, assembling and testing of the prototype. This paper aims to provide an insight on how a project about home insect farming can simultaneously alert towards and motivate for the adoption of sustainable development practices.

One of the major issues for humanity is the lack of sustainable good quality food sources. The Food and Agriculture Organization (FAO) estimates that the world needs to increase its food production by 70 % by 2050 in order to serve a global population of 9 billion. Insects form part of the traditional diets of at least 2 billion people, mainly in the Asian and African regions. In the remaining regions of the world, the main use of insects is for animal feeding. More than 1 900 species have reportedly been used as human food (FAO, 2014). Furthermore, the standard food production model is unsustainable in terms of resources required (energy, soil, water) and by-products produced (emissions). Research is forcing people to re-think food production and recommending the adoption of specific insect species as a higher source of nutrition.

This paper presents in Section 2 insect farming, in Section 3 introduces the team's solution, in Section 4 describes the implementation and the functional tests, and, finally, in Section 5 draws the main conclusions.

2 Insect Farming

The concept of insect farming is relatively new. Insects are reared in a confined area (i.e. a farm) where the living conditions, diet and food quality are controlled. Farmed insects are kept in captivity and are thus isolated from their natural populations (FAO 2013). One of the advantages of insect farming is the relatively small ecological footprint compared to conventional livestock farming in terms of: (*i*) land use, (*ii*) the efficiency in converting feed into high value animal protein; and (*iii*) greenhouse gas and ammonia emission.

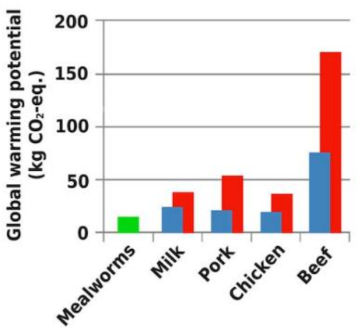


Figure 1. Greenhouse gas emissions for different protein sources production (Stromberg, 2012).

Studies conducted in the Netherlands, where mealworms are often cultivated as food for reptile and amphibian pets, concluded that insects, like mealworms, can help to solve this problem. Researchers, which analysed every input used in the process of breeding the worms, show that worms are a protein source considerably more eco-friendly than conventional protein sources. Insect farming requires less energy and produces less carbon dioxide into the atmosphere when compared with the production of milk, pork, chicken or beef (Figure 1). Pound for pound, mealworm protein (green) produces much lower amounts of greenhouse gas emissions than both the high (red) and low (blue) estimates for conventional protein sources (Stromberg, 2012).

2.1 Mealworm

Although the insectarium may be used to house different insects because of the controllable temperature and humidity, the focus is on production of mealworms since they can be eaten by animals and humans. Moreover, compared to other insects, they contain a high level of protein and are one of the easiest insect species to grow.

2.1.1 Life Cycle

Mealworms are the larval form of the mealworm beetle, *Tenebrio molitor*, a species of darkling beetle. Like all holometabolic insects, they go through four life stages: egg, larva, pupa and adult (Figure 2).

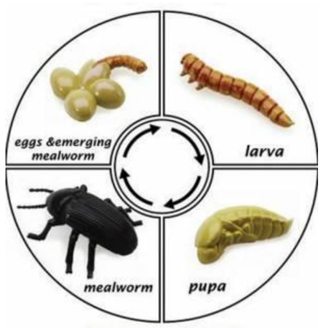


Figure 2. Four life stages of *Tenebrio molitor* (Super Teacher Tools, 2016).

The life cycle takes around a year to complete the four stages of metamorphosis. The egg is white and takes around one to four weeks to hatch and the larva to emerge. The larval stage may molt ten to twenty times before reaching the pupa stage. As a pupa, it changes colour, starting white and darkening before the beetle emerges, and grows from a length of 1.25 cm to 1.90 cm. The adult beetle is black with hardened front wings and lasts one to three months. When they reach one to two weeks of adult life, the beetles begin to mate and reproduce. A few days after mating, female beetles will burrow into soil or substrate and lay the eggs. The second stage of the insect life lasts about eight to ten weeks and is spent as a brown larva called mealworm. When first hatched, it is quite small, but will grow up to 3.8 cm long. Since it has a hard exoskeleton, the worm will need to molt and shed its hard outer shell in order to grow. Molts will occur ten to twenty times during this stage of life. A recently molted worm will be soft and white, but the exoskeleton will quickly harden. A mealworm spends its time eating and growing in order to save up energy for the next transformation.

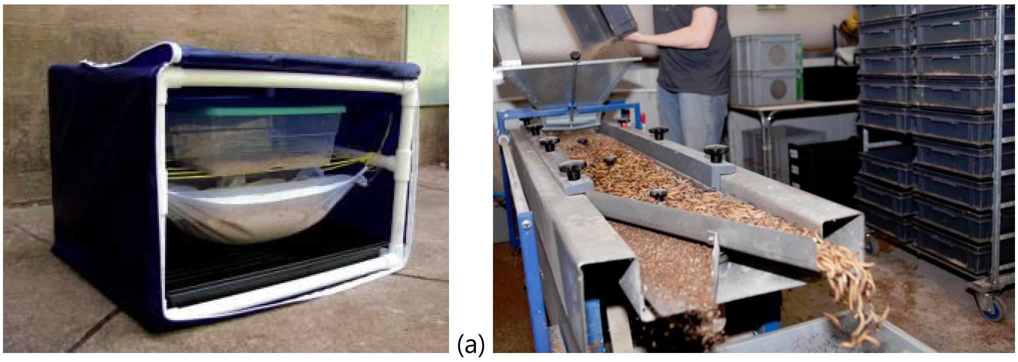
2.1.2 Habitat and Growth Conditions

Mealworms live in areas surrounded by what they eat under rocks, logs, in animal burrows and stored grains. They clean up after plants and animals and, therefore, can be found anywhere where there are such leftovers.

Raising mealworms is fairly easy since they are prolific breeders and are hardy insects. Their growth is affected by the temperature and humidity. The ideal temperature and humidity for growing a colony is around 25-27 ºC and 70 % humidity, respectively.

2.1.3 Home Farming

Domestic *Tenebrio molitor* colonies usually hatch and live in standard plastic containers. The container should be kept away from windows and direct sunlight to prevent the temperature from rising (Figure 3a). The daily light cycle is adequate, i.e. the process does not require artificial lighting. A colony of mealworms will reproduce faster with a higher humidity, but, in most cases, the natural humidity in the air will be sufficient. In a dry climate, it may be necessary to raise the humidity. The substrate of the container will be the food - wheat bran, oatmeal, cornmeal, wheat flour, ground up dry dog food or a mixture of these dry foods. Slices of potatoes, apples, carrots, lettuce, cabbage or other fruits and vegetables are used to supply water to the worms. Potatoes are often preferred since they last a while and do not mold quickly.



(a) (b)

Figure 3. Insect Farming: DIY kit sold by Tiny Farms (Tiny Farms, 2016) and Kreca insect farm in Ermelo (Kreca, 2016).

2.1.4 Industrial Farming

In Europe insect farming is at an early stage. The European Commission is currently co-financing a research project to explore the feasibility of using insect as a protein source, following a recommendation of the European Food Safety Authority (Finke, M. D. et al., 2015). The European Union prohibits the use of insects to feed livestock. Nevertheless, there are large companies investing in the sector like Proti-Farm, a producer of insect ingredients for the food and pharmaceutical industry based in The Netherlands. In 2014, it acquired Kreca, a company with in-house knowledge of breeding and rearing 13 different species of insects. Kreca's production, which includes 12 different insect species, is intended for human food (5 %) and pet food (95 %). The farm consists of eight barns where the temperature varies between 25 ºC and 30 ºC, depending on the insect species. The insects are fed on corn or groat meal obtained from local providers. Inside the barns, racks of boxes hold hundreds of kilograms of insects (Figure 3b), eating several tonnes of meal and producing a few tonnes of insects per week. Proti-Farm sells whole insects, protein powders (isolated, concentrated, hydrolysed) and (refined) lipids.

3 System Architecture

Before defining the system architecture, EPS students have to study and define the environment in which their product will fit and the restrictions that apply.

3.1 Marketing Plan

During the elaboration of the marketing plan, the team identified the strengths, weaknesses, opportunities and threats regarding the potential market – market SWOT analysis, performed market segmentation and defined the marketing programme for the product. During this study, the team concluded that the market offers many different types of bug-specific farming structures. However, it is lacking a general solution for household users, i.e. a solution for farming different species of insects. As a result, the team decided to create a home insectarium to house different species. For example, Space for Life (2016) suggests and provides instructions for raising ants, house crickets, mealworms, praying mantids and monarch butterflies at home. Since the light, temperature and humidity requirements differ from species to species (Space for Life, 2016), such a product must be reconfigurable. Ideally, the insectarium should include a control system to operate the heating, cooling and lighting subsystems in accordance with the readings from the installed temperature, humidity and light sensors. In addition, since it is intended for the domestic market, it should be attractive and easy to maintain. Figure 4 shows the initial structure drawings and the brand logo INSECTO, which were defined together with the marketing plan (Bentin et al., 2014).

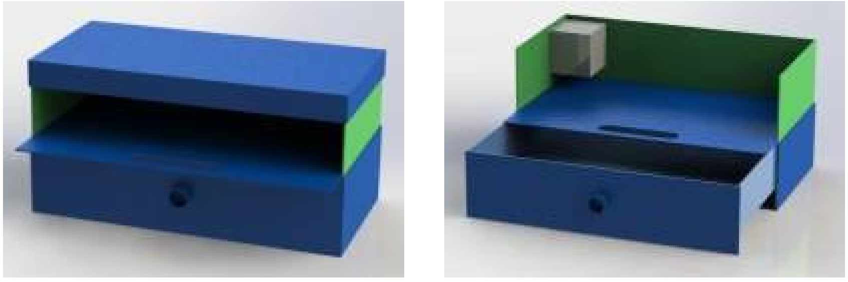


Figure 4. First sketches and INSECTO brand logo.

3.2 Sustainability Issues

There is no universal definition of sustainability. For the team, sustainability is "*a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations.*"

In terms of the structure, the team chose to keep the manufacturing, assembling and maintenance simple and easy. The result was INSECTO – a boxy, modular insectarium composed of a reduced number of parts – which allows stacking for larger production schemes. The team selected acrylic glass – polymethyl methacrylate (PMMA) – to build the structure of the insectarium since it is a durable material with a long life cycle and a good temperature and sound isolation. The PMMA temperature insulation maintains the insects at a comfortable temperature with low power consumption. The electronic components were chosen according to their energy consumption (sustainability) and the selected software was open source (cost).

3.3 Proposed Architecture

The air conditioning of the insectarium (temperature and humidity) is the main technical aspect of the project. Air conditioning can be divided into heating, cooling, humidification and dehumidification processes with specific energy demands. Since the simultaneous control of temperature and humidity is rather complex and exceeds the pre-defined budget (100 €), the team decided to incorporate in the insectarium two additional elements: an air heating resistor and air renewing fan. This approach uses the resistor to raise the internal temperature and the fan to reduce both the internal temperature and humidity.

To control automatically the temperature and humidity inside the insectarium, the team selected an Arduino microcontroller, a humidity sensor, a temperature sensor, a resistor, a fan and, for the user interface, a Liquid Crystal Display with a keyboard (Figure 5). The microcontroller is connected to the humidity sensor (input), temperature sensor (input), the keyboard (inputs), the LCD (output), the resistor (output) and to the fan (output). The microcontroller controls the fan speed and the resistor power through pulse width modulation (PWM), i.e. the fan and resistor are connected to the microcontroller via PWM outputs.

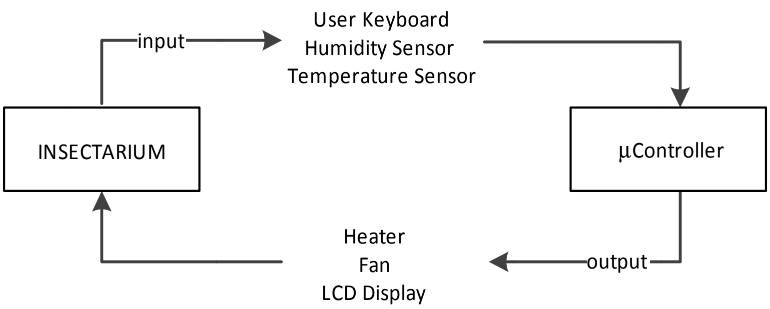


Figure 5. Control system diagram.

The proposed system differs from the Dot It Yourself (DIY) home solutions because it is modular, reconfigurable (via the user interface) and automatically controls (via the control system) the most relevant environmental parameters (temperature and humidity) for breeding different species of insects at home. This approach meets the client requirements and extends further the spectrum of possible clients.

4 Implementation and Functional Tests

4.1 Main Components

The team performed the selection of materials and solutions, analysing the quality, economy and sustainability aspects. For the structure, the team opted for PMMA plastic due to its durability and resistance. The structure was built with existing PMMA leftovers (reuse). The team, for the control system and according to the comparative study undertaken, chose: (*i*) an Arduino Uno microcontroller; (*ii*) a DHT22 humidity and temperature sensor with an accuracy of ±2 % for the humidity and ±.5 ºC for the temperature; (*iii*) a 28 Ω resistor (reused from a toaster); (*iv*) a 12 V 0.13 A fan (reused from a Personal Computer); (*v*) a ULN2003A high-current Darlington transistor array to boost the current for the fan and resistor; (*vi*) an Itead 1602 LCD shield with keyboard; and (*vii*) a power supply AC/DC 230 V AC/12 V 2 A (Bentin et al., 2105). The cost of these components was 60 €. Figure 6 presents the electrical circuit of the control system (left) and the flow chart of the controller software (right).

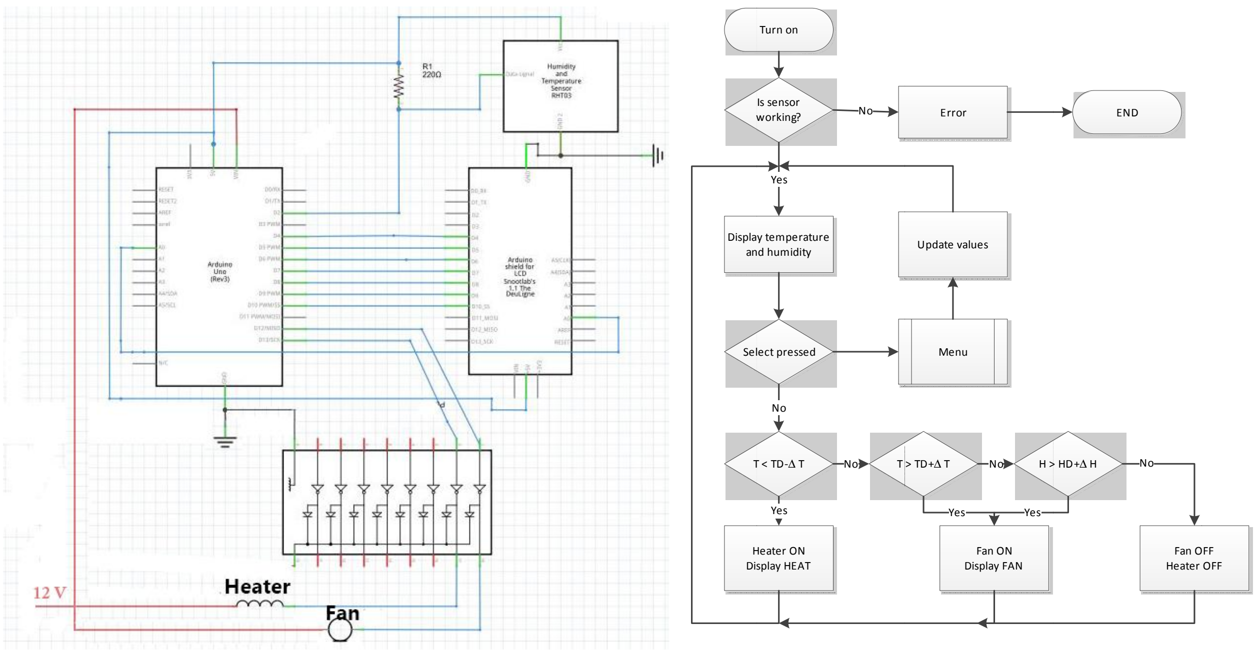


Figure 6. Electric schematic (left) and software flow chart (right).

4.2 User Interface

The main function of the insectarium is to provide different species of insects with an appropriate environment to grow and reproduce. This was achieved by creating a configurable automatic humidity and temperature control system. Figure 7 (left) presents the structure of configuration menu implemented in the user interface (right). The user can specify the desired temperature (ºC) and humidity (%), the maximum temperature (ºC) and humidity (%) variation, the percentage of heat power and the fan speed.

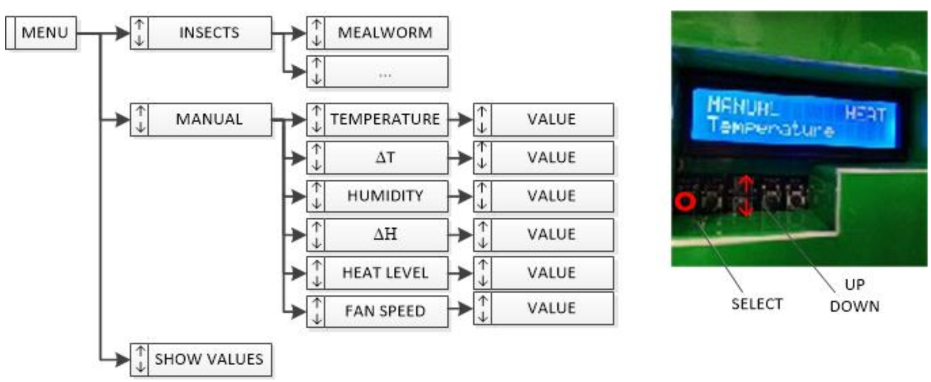


Figure 7. Menu system (left) and user interface (right).

4.3 Power Consumption

The power consumption estimation (in the most demanding scenario) of any electric appliance is a sustainability indicator. In a continuous operation scenario, the Arduino, LCD shield and the double sensor are always on. In addition, in the worst case scenario, the heater or the fan will be on, but not simultaneously.

Table 1 presents the estimated power consumption of the main system components. In the best case, when only the Arduino, LCD shield and sensor are on, the estimated annual power consumption is 7.6 kWh. In the worst case, when the heater is also on, the estimated annual power consumption reaches 49.6 kWh. This results in an estimated annual average power consumption of 26.5 kWh (equivalent to a 3 W lamp).

Table 1. Estimated power consumption.

Equipment	Voltage (V)	Current (A)	Power (W)
Heater	12	0.400	4.800
Fan	12	0.140	1.680
Arduino Uno	12	0.050	0.600
LCD shield	5	0.050	0.250
Sensor	5	0.025	0.013

4.4 Tests and Results

Initially, the team undertook basic tests regarding: (*i*) the heating and cooling functions (to determine the maximum attained temperature and the fan ability to renew the air) without control; and (*ii*) the debugging and validation of the control code. With the resistor connected to 12 V, it took in average 227 min to raise the internal temperature from 24 ºC to 31 ºC and, once it reached this maximum value, it stabilized. With the fan connected to 12 V, the temperature inside diminishes until it reaches the external room temperature. For example, lowering the internal temperature from 31 ºC to 27 ºC (room temperature) took 50 min.

Finally, with the insectarium assembled, the team conducted the functional tests and measured the actual power consumption. Figure 8 depicts the assembled prototype. The functional tests were defined together with the requirements and use cases during the design phase, a mandatory step of any EPS project.

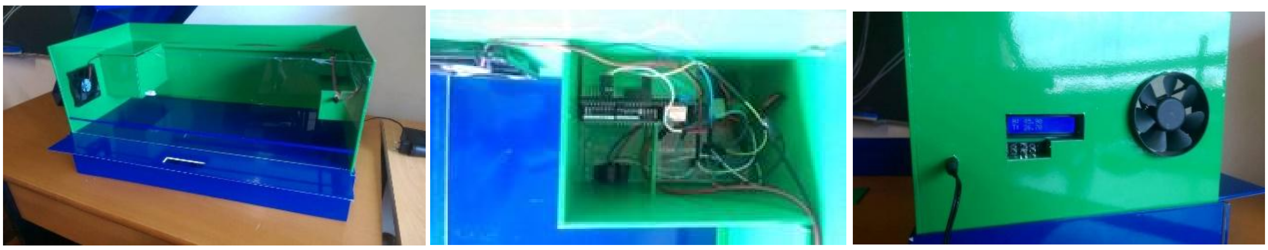


Figure 8. Photograph of the assembled insectarium.

These tests contemplated the normal operation of the insectarium, i.e. the maintenance of the temperature and humidity parameters within the user specified values. The user interface menu was fully functional, allowing the user to specify the desired input parameters. The control system was able to maintain the internal temperature and humidity within the user specified values. Table 2 presents the power consumption measured in the three operation modes (idle, air heating and air renewal), resulting in an average annual power consumption of 24.1 kWh (< than the estimated 26.5 kWh).

Table 2. Measured power consumption.

Operation mode	Current (A)	Power (W)
Arduino, LCD shield and sensor	0.093	1.116
Arduino, LCD shield, sensor and fan on	0.170	2.040
Arduino, LCD shield, sensor and heater on	0.425	5.100

5 Conclusion

This paper reports the development of INSECTO – an attractive, configurable, modular domestic insectarium for growing different insect species – by a multinational and multidisciplinary team of students within EPS@ISEP. The team perceived the project development process as *"a fun and exhilarating challenge from which we benefited greatly as an experience for our careers by living in a different country and working with people from all over Europe*.", and the INSECTO prototype as "*a product that provides sustainable food for now, but, more important, for the future*", while aiming "*to be as sustainable as possible (...) and innovative compared to other insectarium products."* These views illustrate the relevance the team attributed to this project in terms of multicultural teamwork and sustainable development practices. The functional tests showed the effectiveness of the configurable temperature and humidity control system. Further studies should be done to compare the performance of the system with traditional uncontrolled DIY systems, e.g. using mealworms, as well improve the validation of INSECTO with different room conditions.

EPS@ISEP acted as the framework to promote cross-cultural communication, multidisciplinary teamwork, ethical and deontological concerns, sustainable development practices as well technical and scientific competences within this team composed of design and engineering students.

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