Greenhouse with Sustainable Energy for IoT

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Abstract. In order to support the intensive development of agricultural crops and, in particular the floricultural inside a greenhouse, with the perspective of a quick distribution in the market, increasing the economic benefits and supported on efficient and intelligent management systems energy, it is mandatory to conceive a model based on Cyber-Physical Systems (CPS) This implies, accordingly, increases in renewable primary energy sources utilization coupled with sensing technologies, include developments on Internet of Things (IoT) and Cloud Computing (CC), supported with Information and Communication Technologies (ICT) that will lead to new architectural approach applied to a proposed energy system, based on a sustainable and more engineering autonomous process. This work comes up with a new energy model that retrofits the system of a greenhouse supported with multiple sensors in one grid, to expand into CPS concept to manage sensors and controllers that will improve a profitable energy system.

Keywords: CPS, Energy Management, Efficiency, Energy Model, IoT, Computing.

1 Introduction

The Census Bureau's latest projections imply that population growth will continue into the 21st century, although more slowly [1]. To avoid starvation, the production of agriculture became massive and more productive in greenhouses [2], [3]. In 21st century, greenhouses are used for food production and, among others, floriculture.

Increase the process of plant growth was one of the goals to be achieved with this research, performing a characterization of the system, from plant conditions of growth, to environmental conditions and electrical and thermal energy deep analysis to propose an energetic and environmental sustainable model. The increasing of flower productivity should take into account no increase in the greenhouse gases (GHG) emissions and contribute to the fulfillment of international commitments set by 20/20/20 European Union Plan adopted by Portugal, based on renewable energy use as primary source, contributing to sustainable human activities and achieve eco-certification recognition [4]. The case study is a greenhouse with intensive flowers production where was performed an energy audit, comprising a survey on energy consumption by type: electrical and thermal and several simulations to improve energy efficiency. This research coupled with CPS concept could increase the energy performance to develop intense agricultural crops production and in particular the flori-cultural inside a greenhouse, with the perspective of a rapid response in placing flowers in the distribution market by increasing the economic benefits, but supported by an efficient and intelligent management energy model, in the process of plant growth [5].

The innovative proposed model consists of a mix of energy production processes based on photovoltaic panels and biomass boilers supported by CPS, where the amount of data acquired should be process with the computing power and communication interfaces between different networked systems, becoming more user friendly and less expensive. This concept rest on the interactions between multiple areas and promotes the emergence of design and process science applied to floriculture [6].

2 Benefits from Cyber-Physical Systems

CPS represents a class of control systems that consist of tightly linked computational and physical components [7]. The primary advantages of CPS when compared with others include increased autonomy, efficiency, functionality, reliability and safety level. These advantages allow CPS to be utilized in a wide range of technical fields including, power management, vehicle control and safety, advanced robotics, image analysis and IoT [8], [9]. The sensing data and accumulated information from sensors and internet knowledge is analyzed by intelligent data mining processing and the final extracted information is provided to the managers, through a diversity of interface applications, including mobile. A permanent and constant information storage in cloud computing and data mining allows real-time and newer decision-making through a human–machine interface [10]. Beyond the data collection with sensors and monitoring, the advantage is also on control the physical processes, usually with feedback loops where physical processes affect computations and vice versa. Lee mentions that CPS could significantly improve energy efficiency and demand variability, reducing our dependence on fossil fuels and our greenhouse gas emissions [7].

Energy in the real world represents the physical part of action, but on the other hand, the concept that models how systems decide on, manage, and control their actions is the information [11]. This study is mainly focused on energy audit and energy efficiency, proposing an energy model. This proposed architecture was designed to achieve, firstly energy savings in the floricultural area, increasing floricultural and agricultural in greenhouse management with major economic incomes and sustainability, as other models of energy management [12]. The objective is similarly to obtain large and quality productions due to the integrated management system, saving water resources by careful monitoring the crop vegetation needs regarding the hydric stress. Finally, was taken into account provide a low cost solution for the greenhouse owner that has limited financial possibilities, enabling its' implementation.

Rad emphasizes CPS playing an important role in the field of precision agriculture and proposed a model of agricultural management integrated system architecture based on CPS design technology [5].

The floriculture greenhouse case study presented in this paper, beyond the proposal of a new energy model that retrofits the system supported with multiple sensors in one grid, is expected to expand into CPS concept, including IoT and cloud computing to improve, even more, a profitable energy system, based on sustainable and autonomous process. The application of CPS complements the existing sensors installed to monitor the conditions inside and outside the greenhouse, which already exist. Cyberization would allow integrating the data and saving in cloud data warehouses. The data collected associated with weather forecast freely available on the internet, would improve the capacity of prediction to act in order to save energy and benefit productivity. For energy saving, the work performed included the utilization of a different biomass fuel and produce electricity, but this savings could be even more raised if coupled with controlling systems to avoid waste. So, CPS concept undertake could get information from the data collected, trough computing, to ground the management of energy spent in lightning, heating and boiler supply. All this permit to fundament decision making, that can be performed automatically through local or cloud controlling systems or by workers by remote web based or mobile devices (Fig. 1).

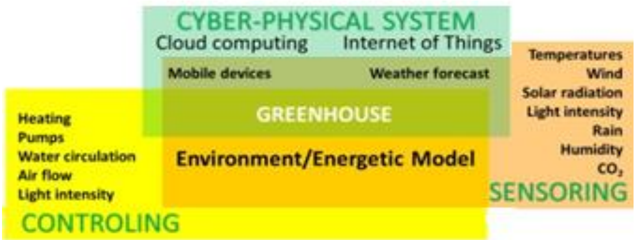

Fig. 1. CPS applied to energy efficiency and environment sustainability model.

The physical system and the energetic and environmental model already performed, improves efficiency and sustainability, and has advantages and synergies if included in such wider inclusive CPS model.

3 Greenhouse Case Study

This study is based on an energy and environmental audit and identifies critical areas of a physical complex system, in order to propose a new energy model, which intends to contribute to energy and environmental sustainability of the case study, a greenhouse. Its realization required technical knowledge in terms of electricity, thermal and mechanical energy, environment, as well as the processes associated with the species to produce and also construction parameters, materials, processes, environmental conditions, finally the local climate. The information referred to study "the agro-system" is related with the energy consumption disaggregation, to determine and assess the energy and environmental efficiency of each of the available energy sources, whether fossil or renewable sources.

The greenhouses where the study was done are located in the Alpiarça municipality at an altitude of 56m. The greenhouses are the curved roof multi-tunnel, with a total 27 tunnels, with varying lengths (75-145m) and width (8-9.6m). The height is on average 5.6m ridge and 4m in height (growth zone) with infrastructures total area of 24,104m^2 (Fig. 2a). The local minimum temperature in the winter months is about 2°C and the maximum temperature in summer averages about 30°C. The structure is made of galvanized steel, the cover material (ceiling and side walls) is composed of a three layer plastic film with a thickness of 200µm, anti-UV treatment, and light transmission of 92%, light diffusion of 14% and thermicity of 86% [13]. All tunnels have zenith windows for circulation / air renovation, with opening ½ arch, located in the ridge for a more effective output of hot air. There are no side windows, nor any forced ventilation system, but there are zenith windows. For control of brightness and temperature, the greenhouses are equipped with thermal curtains, opaque, XLS obscure placed horizontally and laterally.

Chrysanthemum plant is the produced species being used as cut flower, through a variety of species and sizes. It's kind of the family *Asteraceae* sp., *Dendranthema* genus [13]. Production of the chrysanthemum is made in beds, with an approximate width of 1.35m and 0.30m spaced for workers passage. The optimal ambient temperature for a good air conditioning plant in the winter period should be between 12ºC-18ºC nighttime, 19ºC-24ºC daytime and soil temperature with identical values. The greenhouse for plant production involves a building with the boiler, the fuel, water accumulation tanks, pumps for water circulation and biomass storage tanks. The heating indoor the greenhouse is performed using four hot water circuits, divided by tunnels. The distribution of heated water is made at a temperature of about 40°C in round ≈ 30ºC in return. A similar system of hot water circulation of used to maintain the soil temperature. The heating fluid used is obtained from the power station, using a boiler with a rated output of 2.000kWthermal, whose primary energy is the solid biomass. The system is complemented by two accumulation buffer tanks with a unit capacity of 30.000litres to address the point of consumption. To perform water circulation there are several electrical pumps to pump the hot water along the circuit that crosses all the greenhouses rooms and soil.

4 Data Collection and Results Analysis

In order to perform a deep characterization of energy consumption and environmental impact it was collected data on the energy sources used, namely electrical and thermal, using portable analyzers. The environment inside the greenhouse was quantified according to CO_2, humidity, air and soil temperature, using portable analyzers, although there is a system to measure these parameters, still without recording or storing the data, Fig. 2b. Also the combustion and gaseous emissions due to boiler operation, its performance and power calorific value were determined (Methods ASTM D240) and analyzed, based on the biomass used, namely pine wood, olive wood and olive-pomace pellets. In the study, it was also considered the calorific value analysis of each of the used biomass fuels and its moisture, as well as analysis of the ash from the burn. It was calculated the energy requirements for heating and associated costs, as well as determined the footprint carbon resulting from this activity. To fulfill the electricity needs was proposed a viable photovoltaic (PV) system. As mentioned the audit included an analysis of the environmental data, once it is fundamental to the development of crops as intense as these. This analysis was performed using several scattered multifunction equipment as indicated in the areas: indoor greenhouse and thermal power plant.

The results obtained for most parameters were within the reference values for the species production, above mentioned, except for air temperature that, for some night-time, went down to levels below the minimum set for this species. Likewise, it was detected low values for CO_2 in some periods of the day and the maximum does not exceed 626ppm. These values out of the optimal conditions for growth should be minimized or eliminated by systems that allow the monitoring and control of each parameter. The thermal energy comes from renewable sources (solid biomass) mainly to heat water to maintain the greenhouse internal temperature, through pipe hot water circulation.

The thermal energy losses should be avoided to ensure the temperature conditions for plants growth, and achieve best energy efficiency performance Fig. 2c. There were significant losses detected in several infrastructure components. The red color represents the highest temperature (higher losses) and blue color at lower temperature (lower losses). These heat losses reach resulting mainly from the bad/poor insulation of the components of hot water circulation.

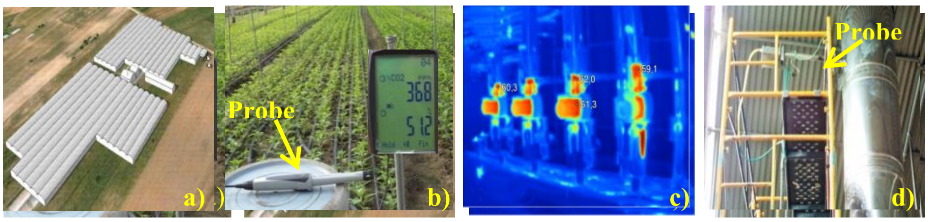

Fig. 2. Data collection in greenhouse: a) Greenhouses overview; b) Temperature, humidity, CO2; c) Thermographic images of hot water pumps; d) Gaseous emission probe.

Evaluations to combustion and exhaust emissions were held on different days because of equipment unavailability. The results for the combustion boiler as well as the exhaust emissions are interrelated, since a boiler malfunction involves exposure limit value in misfit emissions. The evaluation of higher calorific value and lower calorific value for biomass used pine wood (17.17MJ/Kg, 16.33MJ/KG), olive wood (16.75MJ/KG, 16.33MJ/KG) and olive-pomace pellets (18MJ/Kg, 18MJ/Kg) identified the olive-pomace pellets as best biomass, allowing the system automation. Thermal energy is so improved, increasing the calorific energy yield, but also reducing losses, once the loss at 105°C determined was 29% for pine wood, 18% for olive wood and 10% for olive-pomace pellets and reducing toxic emissions, Fig.2d.

The electricity used in greenhouses is only from the public power grid (normal low voltage tri-hourly tariff of 41.40kVA) and the significant energy consumptions were in the engine room (50%), cold chambers (31%) and in lighting, sockets and engines for opening the zenith windows (19%). To analyze the electricity consumption was used a portable analyzer during one week, in January, as shown in Fig. 3a, and the analysis was performed according to consumption of a whole year through itemized billing values.

During the period analyzed the peak power was 33.35kWelectrical corresponding to the largest energy needs recorded at night due to space heating requirements with the operation of circulator pumps and boiler . The results obtained show a wide range of power requirements over 24 hours, from 0.49kWelectrical up to 33.35kWelectrical, mentioned, Fig. 3b. The average power in a full day in the analyzed period corresponds to 13.81kWelectrical.

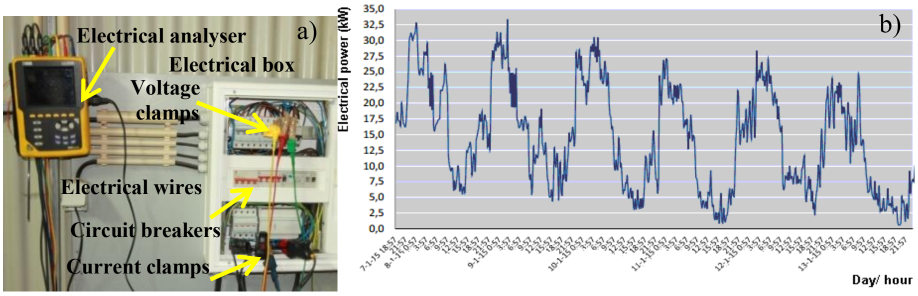

Fig. 3. Collection of electrical consumption: a) Data analyzer collecting data in electrical box; b) Electrical power recorded in the sampling week.

After determining the average hourly power consumption of monthly cycles and daily schedules, using the PVsyst software [14], introduced the monitoring data of the installation in order to scale the PV system, which is justified by the existence of abundant solar radiation in the area. The PV system to install should have 90 modules with a total power of 23.4 kWp photovoltaic field, with groups of five panels strings connected in parallel, and 18 panels connected in series. Economic analysis support the system viability because net present value is 110,725.30€ and internal rate return is 18% and 5.4years of break even, for an initial investment of 38,672.00€ in 20 years. Also, it contributes by 668.7MWh of self-consumption, 54.9MWh sold to the grid and only with 340.09KgCO_2e.

The carbon footprint of 88,381.12KgCO_2e per year along the greenhouse life cycle, using the PAS 2050, which is a cross tool of environmental sustainability providing analysis, information on the performance of the most important environmental indicators of GHG emissions (KgCO_2e) on energy consumption, namely Biomass (zero), fuel (34,300.17), electricity (45,973.52), and on fungicide (135.52), insecticide (135.70), herbicides (135,74), fertilizers (941.59) and other [15].

5 Proposal of a New Energy and Environment Model with CPS

Energy audit found weaknesses in the use of energy, both electricity and thermal, namely in boiler supply and biomass storage. These deficiencies stem largely behavioral actions by lack or absence of proactive in real time decisions. In the structure there are many employees with different and varied functions, whose responsibility for ensuring a good energy and environmental performance will be difficult to achieve, so, the installation of automatic controllers, commanded by applications that control the pumps, zenith windows and curtains.

The proposal for a new energy model, aims to contribute to infrastructure automation, based on data that permits to mitigate the influence of human behavior, increasing the efficiency triangle with areas of production electricity (photovoltaic panels), biomass fuel, heating water, air and soil,

The model objectively contributed to a significant reduction of costs either by increasing efficiency and giving the staff tools to improve the yield during work performed. It is intended to contribute to reduce GHG emissions with significant influence to environmental sustainability, namely using controlled source of biomass fuel and especially in terms of implementation of the photovoltaic (PV) self-consumption system. Also, related to thermal energy, several advices on storage and use of biomass and in hot water storage, circulation and thermal insulation.

In this regard, among the various components that make up the new model, the implementation of CPS technologies, including progress towards the IoT, CC, Infrastructure-as-a-Service and Platform-as-a-Service that largely determine the extent of the success of this energy and environmental model (Fig. 4).

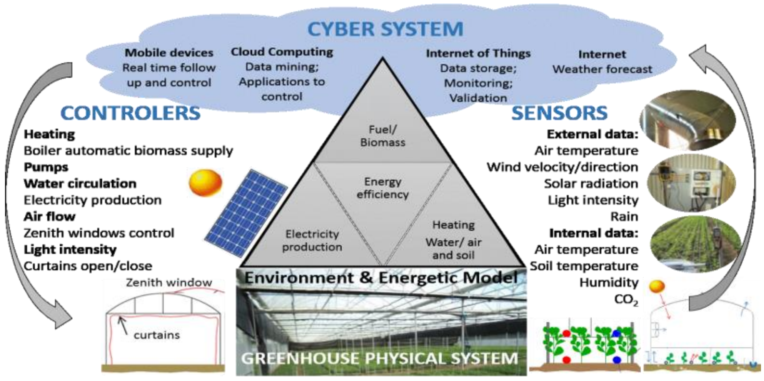

Fig. 4. Proposal of a new energy and environment model with CPS.

The greenhouse system in study has already installed an AGRITEC C800 system with sensors to climate conditions (wind direction and velocity, rain, temperature, humidity), and internal greenhouse conditions sensoring of temperature, humidity and CO_2, with the possibility to record this data. Although the software was not installed yet to transfer and save data. The actual systems of internet communication and cloud computing storage, monitoring and validating data, would be useful to install a computing system connected to the actual AGRITEC C800. Also, this system could allow to control the hot water tanks and circulation, as also the zenith windows and curtains, if a mechatronics system is installed, these could be controlled and monitored by software, acting automatic and/or validated by the owner in real time through mobile devices or web based applications

6 Conclusions

This research was performed to improve energy efficiency and environmental sustainability based on a floriculture greenhouse study. Beyond the proposal of a new energy model that retrofits the system of a greenhouse supported with multiple sensors in one grid, this work intends to expand into CPS concept, including IoT and CC to improve, even more, a profitable energy system, based on sustainable and autonomous process. The energetic and environmental model of this physical system was characterized in order to improve efficiency and sustainability, having advantages and synergies if included in a wider inclusive CPS model (Fig. 4).

As future perspective, it is intended to promote the cyberization of the greenhouse, this is a challenge of integrating computing using already existing sensoring equipment and implementing mechatronics, which has been recognized as beneficial in precision agriculture.

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