Comparison of Two Heating System for Tropical Plants Production in Mediterranean Conditions

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Abstract

Protected productions in Mediterranean climates require suitable design of greenhouses and environmental control equipment. In Italy most greenhouse structures and equipment have been designed mainly in periods with low energy prices thus they are often very traditionally manufactured and low performing from an energetic point of view. Renewing the structures and adopting sophisticated inside environment control systems is generally very expensive but, overall, these additional investments not always allows increasing the grower returns.

Moreover, in the case of very exigent tropical plants production, it is not possible to find compromises between the agronomic performance of the greenhouse production system and the corresponding cost management. The replacement of traditional diesel oil fuelled boiler with wood biomass one is, at present, a feasible and cost-effective option where the conditions are favorable.

A study case was analyzed considering a commercial installation located in Liguria Region, Italy, specialized in moth orchids (*Phalaenopsis Spp.*) production. The study case shows a comparison of the annual fuel consumption and the relevant costs and management tasks with the two heating systems.

It was conducted an economic comparison between the use of diesel and the use of biomass through a software that has interpreted the real data and simulated future consumption. It was finally verified the simulated results with data obtained from the greenhouse in the following year with the use of biomass.

It was possible to conclude that the replacement of traditional diesel oil fuelled boilers with wood biomass ones is a feasible and cost-effective solution given the present situation and considering the predictable energetic evolution.

Keywords: greenhouses, energy saving, alternative energy use, internal microclimate, heating system, logistic

Introduction

The growing importance of tropical plants production as moth orchids (*Phalaenopsis Spp.*) (Griesbach, 2002) is taking place also in Italy but requires, in despite of its Mediterranean climatic surroundings, very high input levels (both agronomic and energetic) to satisfy the high-demanding growing cycle needs (Lee, 2002). Actually, in nature moth orchids can be found throughout the entire tropical Asian region where they grow at daytime temperatures of 28-35°C and nighttime temperatures of 20-24°C (Blanchard and Runkle, 2005). Fairly high relative humidity levels have to be maintained in the range between 60 and 80% (Arditti and Pridgeon, 1997).

Moreover the plants need shaded conditions with light intensities ranging from 75 to 214 (max 300) mmol·m^{-2}·s^{-1} photons, at plant level, following the cultivation phase (Runkle, 2007). Replicate this environment in protected conditions in the Mediterranean could be very

expensive. Moreover, recent increases in fuel prices has forced producers to savings measures.
The reduction of inputs of energy is not always possible or sufficient to restore profitability. Investing in new greenhouses at low energy is not always feasible due to high initial costs. An optional strategy could concern the use of alternative and cheaper fuels (Garcia et al., 1998; Chau et al., 2009) by simply converting the central boiler.
Liguria Region, even if situated in the Northwest part of the Country, has a mild temperate, Mediterranean climate thus developing a strong position in specialized ornamental and horticultural cultivations.
In the present work, the economic performances of a greenhouse plant heated by a hot water pipes system, converted form diesel oil to biomass central heater is presented.

Methods
A greenhouse (C.&G. floricoltura) located in Liguria Region, Italy, specialized in moth orchids (Phalaenopsis Spp.) production has been considered. The greenhouse plant was located on the plain of Albenga. The greenhouse is very traditional for the Region and consists of 15 to 20 years old steel, single glass gutter-connected frame, 3 m maximum height and 4,124 m^2 total surface (9,699.9 m^3) articulated in 6 productive units (PU1 to PU6) (Fig. 1).

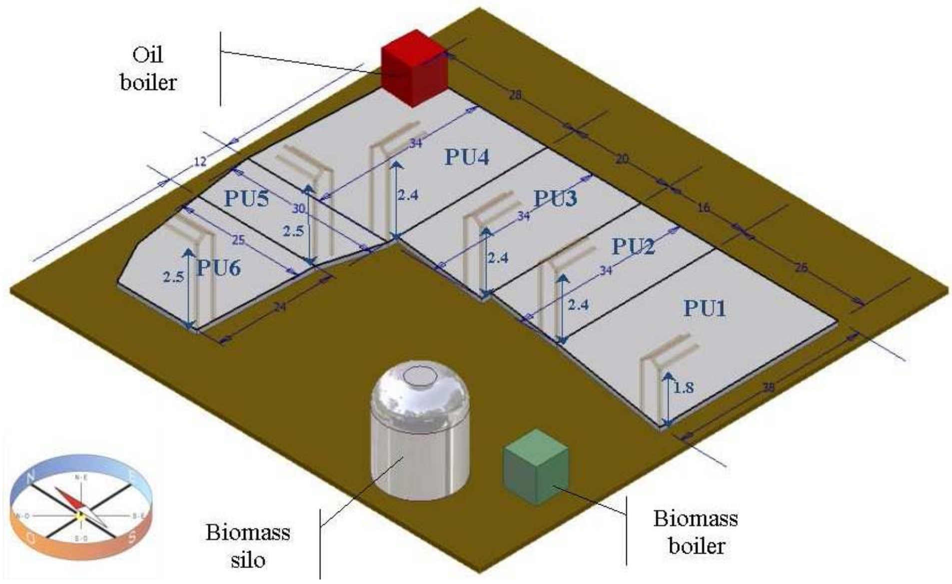

Fig. 1. Scheme of the greenhouse arrangement and location of the productive units (PU) and boilers (the dimensions are expressed in meters; greenhouses heights are not in scale).

The PU have been constructed in different periods and are slightly different in overall dimensions and microclimate management. The heating schedule, planned for 12 months·year^{-1} heating, is reported in table 1.

Table 1. The heating schedule in the different PU.

PU	Minimum temperature regimes
1	15-18°C
2	18-20°C
3	18-20°C
4	23-26°C
5	23-26°C

To improve both the thermal insulation and the light intensity control, a white, semitransparent foamed plastic coat, 3 mm thick, was fixed under the roof. The conventional heating system was based on a central diesel oil boiler 1.16 MWt power and an under-bench hot water pipe system network.
A year-round (2007) monitoring of the monthly oil consumption was performed and the number of tank replenishment was recorded. Because of the high price level oscillations of the considered period, two levels (min. and max.) of diesel oil charge were retained. Considering that any investment focused in oil saving was evaluated unfeasible in comparison with the use of a cheaper fuel, a biomass boiler was added to the conventional one without any changing in the frame structure and microclimate management.
At the end of 2007 a multi-fuel wood biomass boiler 1.39 MWt power (mod. Spitfire manufactured by Metalref, Pistoia, Italy) complete with biomass silo and control accessories, was fitted in the system without modifying any other structural element. The biomass boiler was connected to the existing hot water pipe systems by means of 125 mm diameter, high performances, pre-insulated, district heating supply type, thermal pipes (mod. Rauthermex, manufactured by Rehau, Erlangen, Germany).
Moreover, to further cut water heat dispersion, a reduced number of pipe joints was used. An experimental phase to adjust the biomass-based system was performed in December 2007. A year-round (2008) monitoring of the monthly biomass consumption was performed and the silo replenishment was recorded. No changes were adopted for the microclimate management and controls given the specific requirements of the plants and the standard equipment of the grower.
The biomass used was mainly based on wood chips and sawdust pellets. A small amount (4.6% on annual wet weight basis) of other biomasses (coconut and hazelnut shells, grape seeds, olive-stones) was used mainly for the purpose of testing the boiler.
The wood chips (provided by the Benso Group, Savona, Italy) came from FSC (Forest Stewardship Council) certified forests located in the Bormida Valley at the surrounding mountain area characterizing the Northern side of this Region, at distances <40 km.
This oil-to-biomass conversion has been the first accomplished on the plain of Albenga and, given the rich wood availability of the district, it could represent a strong reference for the growers of the area.
Estimation of the energy needs of the greenhouse given the variable year-to-year weather conditions and in order to produce comparable figures between the two considered years and to provide considered indications for the district, the free decision support system (DSS) Virtual Grower 2.0 (Frantz, 2008) was used to estimate the energy demand of the greenhouse in average steady conditions.
The mentioned real dimensions, materials and set ups of the studied greenhouses were introduced in the computer program accepting the software assumptions; only the

temperatures of the environment outside the greenhouse were adapted to the Albenga weather conditions referring to the Regional database.
Considering the medium-low airtight closure of the greenhouses, a conversion efficiency coefficient nh for the process was considered to be 0.51; the assumed number of air changes per hour ranged from 0.5 to 0.9 h-1 depending on the greenhouse PU.

Results

From values recorded in the monitored period was elaborated the montly cost required for heating by boiler with diesel (Fig. 2).

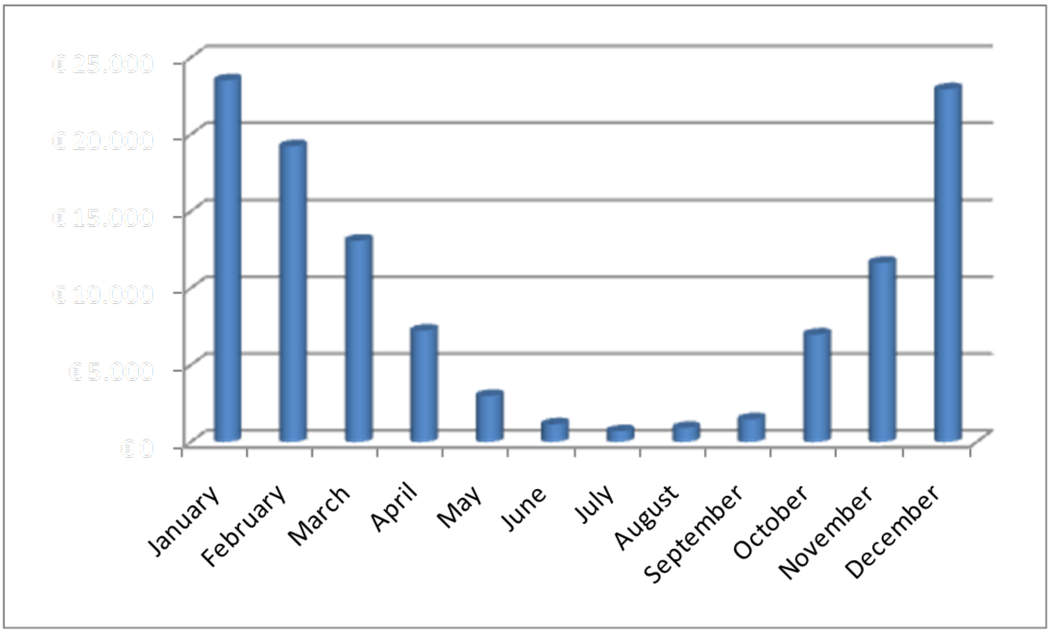

Fig. 2. Heating cost released into the greenhouse in 2007 by diesel oil.

The mean energy consumption per unit floor area was 44.6 $W \times m^{-2}$ ranging from maximum 81.0 $W \cdot m^{-2}$ (February) to minimum 7.0 $W \cdot m^{-2}$ (July). The number of tank replenishments depends upon the volume of the tank; in the considered case a 15.0 m^3 tank was used requiring 10 replenishments per year.
To provide such levels of energy, the 2007 diesel oil consumption resulted 126,000 kg ranging from 1,680 $kg \cdot month^{-1}$ in July and 18,480 $kg \times month^{-1}$ in January with a specific annual cost of 23.6 to 27.3 $€ \cdot m^{-2}$ following the price applied in the considered period (0.76 to 0.89 $€ \cdot kg^{-2}$).
This cost depends on the energy released in the greenhouse that couldn't be reduced in order to guarantee the optimal conditions for such plants as Orchids.
Based on the known results, collected in 2007, it was possible to perform simulations with a dedicated software in order to ensure consistency of values in terms of energy requirements and can make predictions for next year by proposing fuel alternatives.
The simulations were carried out with the Virtual Grower 2.0 that requires input data about the materials and layout of the greenhouse and cultural programming. In this case the structural changes were not included, nor the production cycle. Then set points remained the

same for two years to process. The only factor that was changed was the kind of fuel. In particular it was considered the pellet and chip which characteristics are given in Table 2.

Table 2. Main characteristics considered for the fuels used in the case study.

Fuel	Fuel Characteristics		
	Mass energy density ($MJ \cdot kg^{-1}$)	Unit price (€$\cdot kg^{-1}$)	Specific price (€$\cdot MJ^{-1}$)
Diesel oil	40.9	0.88	0.02
Wood chips (67% DM[1])	8.9	0.08	0.008
Sawdust pellet (90%DM[1])	18.8	0.15	0.009

[1]DM=dry matter

Calculations from Virtual Grower 2.0 simulation seem to give better results with chips and pellets (Fig. 3).

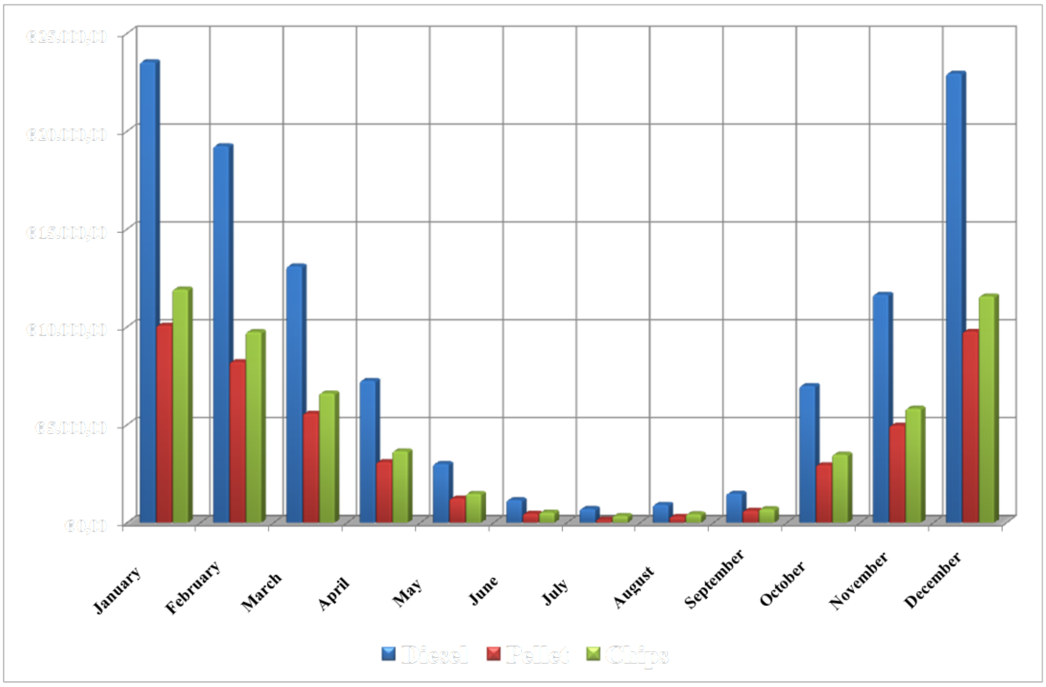

Fig. 3. Simulated pellet and chips costs and diesel costs to predict the 2008.

After the installation of the biomass boiler, the 2008 fuel consumption was recorded (Fig. 4). The biomass boiler was fed with wood chips, sawdust pellets and other biomasses depending on the market most convenient price. The annual biomass consumption resulted 481,560.00 kg lowering the yearly heating specific cost to values of 14-16 €$\cdot m^{-2}$. It was decided to consider the monthly supply of the biomasses pelleted or chipped in comparison to diesel in order to evaluate the ability of the boiler feeding system to manage fuels with different physical properties; moreover it allowed to pursue the better economic performances by choosing at the moment the most convenient product on the market.

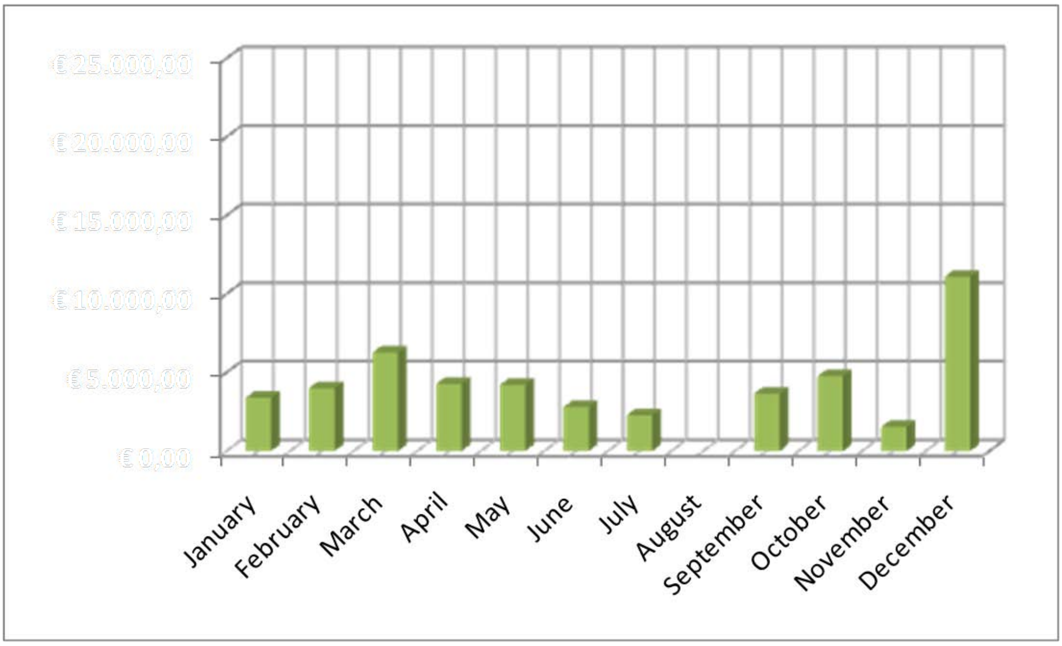

Fig. 4. Heating cost registered into the greenhouse in 2008 by biomasses.

The total fuel quantity consumed with this fuels was 3.7 times higher in weight and about 12 times in volume thus reflecting on the labour requirements and on the space needs for handling and storing the biomass.
This consequence was more evident with the wood chips gives their lower density in comparison with sawdust pellets. This was the main raison for what at the end of the considered year a gradual substitution of the chips with pellet was taken in consideration.
Other two consequences of the conversion on the general cost were an increasing of the electric power consumption due to the electric powered feeding and cleaning system of the boiler and an increasing of the labour cost for the weekly ashes removing from the boiler furnace and cyclone and the feeding auger speed adjustment following the different biomass characteristics. The most evident outcome of the conversion was a reduction of the annual cost for fuel estimated 49.9% lower in comparison with the oil standard system.
It was calculated the correlation between the values of monthly consumption of biomass and simulated values with the software Virtual Grower 2.0 and this correlation was 60%.
The differences showed between the measured and calculated data are mainly given by dissimilar weather data between the theoretical used by the software and actually recorded during the year 2008. Moreover, the differences are also attributable to the fact that actual values are related to sourcing, while the software processes the data according to the energy needs by the greenhouse depending on the weather.

Conclusions

The protected crops, cultivated in diffused Italian greenhouses, require considerable power inputs. In the case of subtropical floriculture is necessary to respect the considerable and constant needs of heat; these requirements increase and reache very high levels depending on the location of the greenhouse. In Italy, most of the greenhouses have been designed in periods during which prices for energy consumption were very low and therefore show a poor performance from an energy standpoint. Renew structures and adopt sophisticated control systems within the microenvironment is generally very expensive and also, overall, these additional investments are not always capable of increasing company revenues. Moreover, in the case of tropical and subtropical flowers, with high needs, it is not possible to find compromises between the agronomic performance of the greenhouse production system and the corresponding cost management. The replacement of the source of energy supply normally consists in diesel oil is a feasible and cost-effective solution. The decision support systems could be an useful instrument for growers to compare possible technical solutions to achieve an economic advantage and to maintain market competition.

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REFERENCES

Arditti, J. and Pridgeon, A.M. 1997. Orchid biology: reviews and perspectives. Vol. VII. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Blanchard, M.G., Runkle, E.S. 2005. Temperature effects on flower induction of two Phalaenopsis orchid hybrids. In: Proceedings of the 18th World Orchid Conference, Eds. A. Raynal-Roques, A. Roguenant, D. Prat. Dijon, France, p. 120-123.

Chau, J., Sowlati, T., Sokhansanj, S., Preto, F., Melin, S. and Bi, X. 2009. Techno-economic analysis of wood biomass boilers for the greenhouse industry. Appl. Energy 86(3), p. 364-371.

De Pascale, S. and Maggio, A. 2005. Sustainable protected cultivation at a Mediterranean climate. Perspectives and challenges. Acta Hort. (ISHS) 691, p.29-42

Frantz, J. 2008. Virtual Grower 2.0. USDA-ARS, Greenhouse Production Group, Toledo Ohio, USA.

Garcia, J.L., De la Plaza, S., Navas, L.M., Benavente, R.M. and Luna, L. 1998. Evaluation of the feasibility of alternative energy sources for greenhouse heating. J. of Agr. Eng. Res. 69, p.107-114.

Griesbach, R.J. 2002. Development of Phalenopsis Orchids for the mass-market. Trends in new crop and new uses. Eds. J. Janick and A. Whipkey. ASHA Press, Alexandria, VA, USA, p. 458-465.

Lee, C.S. 2002. An economic analysis of Orchid production under protected facilities in Taiwan: case of Phalenopsis. In: Proc. IS on Trop. Subtrop. Greenhouses. Eds. S. Chen and T.-T. Lin. Acta Hort. (ISHS) 578, p. 249-255.

Runkle, E.S. 2007. Innovative production systems for ornamental potted plants: a case study for Phalenopsis Orchids. In: Proc. IC on Qual. Manag. Supply Chains of Ornamentals, Eds.: S. Kanlayanarat et al., Acta Hort. (ISHS) 755, p. 55-60.