Applied Energy 114 (2014) 880–888

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

# Energy management strategies for commercial greenhouses

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## HIGHLIGHTS

- An energy analysis in the greenhouse has been assessed using the TRNSYS tool.
- The opportunities to improve the energy conservation in greenhouses are assessed.
- A thermo-economic assessment has been performed for selected opportunities.
- The overall energy performance in the commercial greenhouses is assessed.
- The influence on four climatic conditions is discussed.

## ARTICLE INFO

*Article history:*
Received 28 February 2013
Received in revised form 23 August 2013
Accepted 30 August 2013
Available online 9 October 2013

*Keywords:*
Energy management
Energy performance
Commercial greenhouse
Closed greenhouse

## ABSTRACT

Growth in population and the ever-increasing development of new production technology leading to rising energy use in the agricultural industry. Although the greenhouse is one of the most energy intensive sectors in the agricultural industry, it is important because of its ability to intensify production. This paper has assessed energy management strategies (including single and combined energy conservation opportunities), with special emphasis on Nordic climates, where fossil fuel-based heating is still significant, despite a recent conversion to biomass boilers.

The results show that the "Double thermal screen" and "Double glazing" with 60% reduction in energy demand are the most effective single opportunity for energy conservation. However, the highest improvement (80%) is obtainable using the closed greenhouse concept, with a potential payback of 5–6 years under favorable conditions. It can be concluded that some of the single opportunities can be more practical in terms of their PBP in comparison to a complex concept, requiring a combination of measures, such as the closed greenhouse.



## 1. Introduction

The UN predicts the world population to reach 9 billion by 2030 [1]. Therefore, innovative methods must be proposed in order to utilize the available arable lands in an effective way for providing food for this foreseen population. Here, the commercial greenhouse has been proposed as one promising solution [2]. Commercial greenhouses are used to grow plants in order to reach better quality and protect them against natural environmental effects such as wind or rain. Another benefit is giving the ability for out of season cultivation.

The operation of greenhouses makes use of the greenhouse effect. The short wavelengths of solar irradiation which are visible light can pass through a transparent medium and are absorbed by the objects on the other side. The heated objects will re-radiate longer wavelengths which are infrared and cannot pass through the transparent medium. The temperature will increase due to the accumulation of long wavelength radiation. Higher $CO_2$ concentration level can stimulate this phenomena because carbon dioxide is fairly good infrared radiation absorbent, thus retaining the heat in the greenhouse. There are many criteria in order to design a greenhouse such as [3]:

- High transmissivity.
- Heat retention in the cold period of time.
- Heat dissipation in the warm period of time.
- Having the optimal $CO_2$ level of concentration in the greenhouse.
- High level of durability.
- Cost consciousness.

Some of these criteria can be improved by using special modifications such as better type of glazing with lower reflectivity,

*Abbreviations:* EP, Energy Productivity; ER, Energy Ratio; IRAC, Infrared Anti-Condensate; SCB, statistiska centralbyrån (statistic administration office in Sweden); TES, thermal energy storage; UN, United Nation.

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0306-2619/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apenergy.2013.08.089

absorptivity and heat loss coefficient. Adequate ventilation system combined with $CO_2$ enrichment is also used [4–6]. However, with the most commonly used open ventilation system, the above criteria are never completely achieved [6]. In order to solve this problem another concept was proposed, the closed greenhouse, e.g. as presented in 1997 by a European research institute (Ecofys) [5]. A closed greenhouse does not make use of ventilation windows, so it gets very hot in the sun and climate control becomes crucial. Thus a complex climate control system is needed to control temperature, humidity and the $CO_2$ concentration [7].

Although a higher production yield can be obtained in commercial greenhouse, as compared to free land cultivation, it has to be taken into consideration that the greenhouse is one of the most energy consuming sectors in the horticultural industry [8]. This paper considers Sweden as the case study, where the total energy consumption in the agricultural sector was about 4400 GW h in 2008 [9]. Of this amount, 2300 GW h was supplied by diesel for the horticultural machineries, 890 GW h was covered by electricity and 1220 GW h was supplied mostly by fuel oil and biomass for heating purpose [10]. In the same year the total energy used to cover the heating demand in the Swedish greenhouse sector was 694 GW h which is about 15% of the total energy demand in the agricultural industry in Sweden [9]. However, for Northern climate, the heating energy demand in a commercial greenhouse represents 65–85% of total greenhouse energy demand [11]. The energy mix in the commercial greenhouses in Sweden is presented in Fig. 1. This figure shows how the total energy supply for heating has increased by 50% from 2008 to 2011. However, the heating oil consumption has recently been reduced by 18% while at the same time the biomass utilization has increased by 45% [8]. Electricity is used mainly for the artificial lighting in the greenhouse. However, electricity is also needed to operate various devices such as ventilation fans, pumps, and control system. [12]. The contribution of fossil fuel for covering the heating demand in the greenhouse in Sweden has been measured using statistical data [8]. It has been observed that until 2008 the fossil fuel was still dominating with regards to covering the heating demand while it reduced to 25% by 2011 [9]. However by considering the energy demand increment in the greenhouse sectors, (50% as it mentioned earlier), fossil fuel still makes up a significant part of the supply towards heating. Therefore, any reduction in the energy demand leads to a considerable impact towards improving sustainability in greenhouse operation. Additionally, energy is typically the largest overhead cost in the production of greenhouse crops. Therefore energy conservation in the commercial greenhouse has been emphasized in recent years in order to sustain cost efficient crop productions.

The commercial greenhouses normally have a very high output. In the modern and well controlled greenhouses, the production yield can be 10–20 times more than any outdoor horticultural section [13]. However, high input of direct and indirect energy is required in order to produce a large amount of high quality products. Fossil fuel or any kind of renewable energy sources which has been utilized for satisfying the heating and cooling demand of the greenhouse are considered as direct energy input. Direct energy inputs for the heating demand of the greenhouse have the highest impact on the overall greenhouse performance and the final market price of the product [14]. Considered as indirect energy input are: various fixed equipment and any type of materials such as fertilizer and chemical biocides as well as labor, transportation and irrigation used in production procedures [14]. Irrigation and fixed equipment have the lowest portion in indirect energy use of the commercial greenhouses, about 1–2% of total indirect energy use. However the fertilizer has the highest portion in the indirect energy use with 21% of indirect energy input. The portion of direct and indirect energy inputs to a greenhouse is illustrated in Fig. 2, and is based on data from the literature [15–17].

An energy analysis is required for further assessment on greenhouse direct energy and corresponding energy performance improvement opportunities. Therefore, a commercial greenhouse needs to be modeled and various energy conservation opportunities must be studied.

The overall objective of this paper is to explore the impact on energy efficiency improvements in the commercial greenhouse sector, comparing a number of technological pathways. The influence on climatic conditions is also discussed with a special focus given on Nordic conditions using Sweden as the case study. For

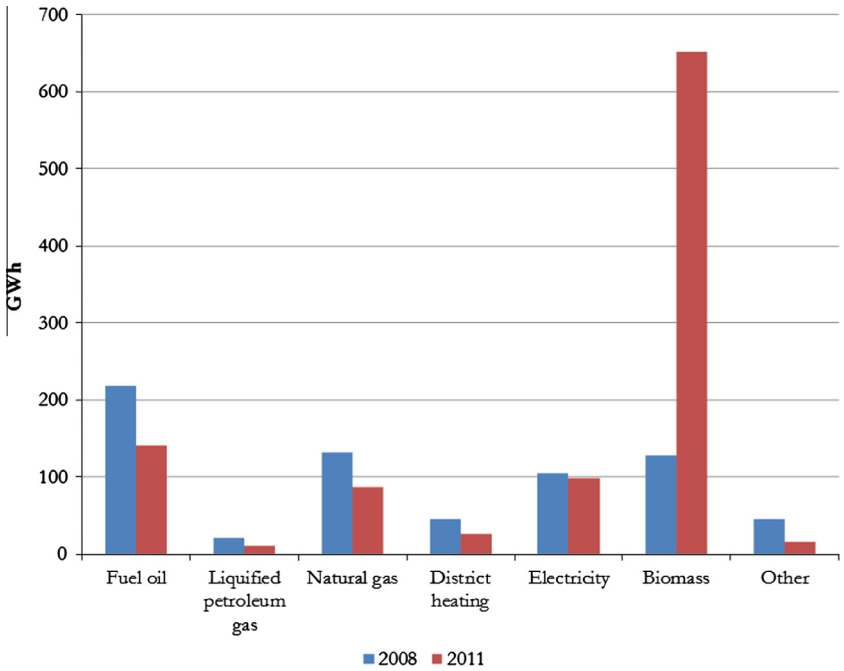


**Fig. 1.** Comparison in energy mix for the commercial greenhouse in the Sweden in 2008 and 2011 [8].