Energy-efficiency gains by an innovative cover of greenhouses

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INTRODUCTION

The question that was addressed some decades ago by the Dutch government to the Wageningen University is: "how can the energy use of Dutch greenhouses be improved?" Since 1990 the LEI Wageningen UR institute researches the energy topic of greenhouses in the Netherlands. A monitoring of the sector's energy use and energy-efficiency is since then annually published [1].

The monitors by LEI primarily indicate the progress that is made in the energy reduction of the sector in the Netherlands. A large reduction can be seen over the period 1990 – 2010. In 1990 the sector used 40,9 m^3 natural gas equivalent/m^2, and it used 29,6 m^3 gas equivalent/m^2 in 2010. This realization was due to some explicit policies, of which the cogeneration policy, an implementation of combined heat & power systems in greenhouses, has been most effective. This strategy enables the sector to produce power commercially from natural gas, and use the cogenerated heat for its own heating purpose.

However we will formulate here also criticism on the realizations that are carried out. 1) Due to the CHP-concept and its amounts of 'free' heat, the energy-efficiency of greenhouses in the Netherlands is improved, but one can also see that these policies mean a barrier for real (vital) progress. The proportion of sustainable energy as used in Dutch greenhouse is low: only 1.8% of the used fossil energy (fig. 2). Applied high tech innovations of greenhouse design, like aquifers and heat pumps, could not boost the proportion of sustainable energy use of Dutch greenhouses in recent years. 2) As disappointing is the absolute figure of energy consumption which LEI reveals, being still over 8% of the national gas consumption [1]. 3) Thirdly, it is reported in the monitor 2011 that a drawback in energy reduction has occurred in 2011. This means that the fossil energy consumption is raising again, due to two factors as represented in figure. 3.

PROBLEM ANALYSIS

The sustainability problem described here represents an economic problem for the Netherlands. Dutch greenhouses deliver horticultural products for inland use as well as for export, and this industry is acting in an open, merely global market. The sector employs 60.000 people today, but may lose its economic position by upcoming, warmer countries due to their less energy consuming cultivation methods, As energy will be an important parameter for the future (given the tendency of energy prices to rise), the acceptation of most unsustainable energy levels will gradually enforce that Dutch greenhouses will be losing their markets.

Therefore it was resolved in the Dutch Agro covenant 2020 that a 20% proportion of sustainable energy should be used in Dutch greenhouses by 2020 [2]. However, the sector makes very little progress on this goal; the progress of the last years was 0,2 % per year, an amount which is being due to power trading mainly. The remaining progress until 2020 must now be an improvement of 18,2 %; a perspective which is completely out of reality.

Figure 1 Greenhouse

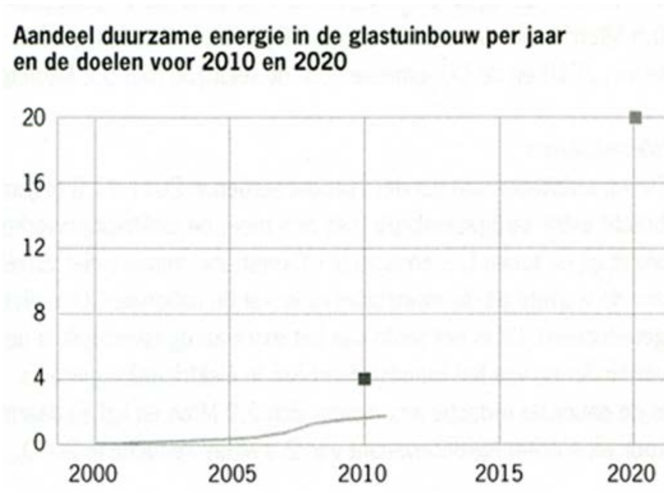

Figure 2 Sustainable energy used in Dutch greenhouses, the actual proportion (line) and targets (dots)

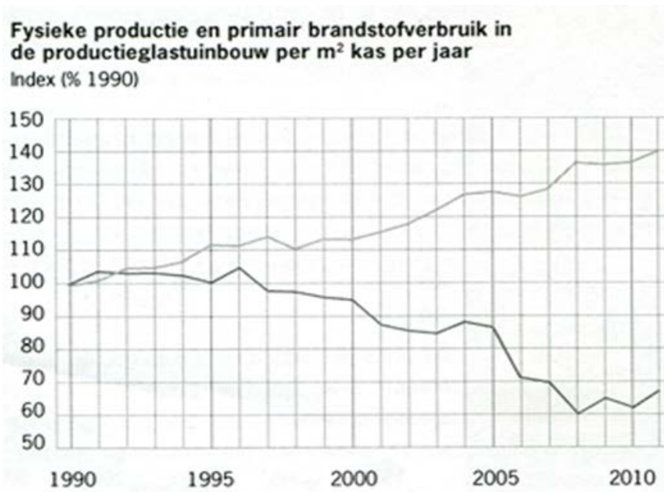

Figure 3 Actual tendency in primary energy use in Dutch greenhouses, indicated by the black line

However, the former strategies are still followed: product economization and process economization. The first strategy means cultivation of new varieties and qualities of the crops; the second is a reduction of the energy costs. The first strategy is also called 'intensification', having the goal of producing more with less. Actually, the 2011 monitor shows that the intended product intensification in terms of less energy use is not possible: gradually more energy is needed if the indoor climate of the greenhouses is 'tailored' by using artificial lighting, crop cooling, etc. This extra energy consumption is not going to be compensated by the second strategy (including the policy of CHP). As an extra inland complication the acreage of the industry should be mentioned; this is already 10.500 hectares now, being 105 km^2 and 0,37 % of the Dutch soil.

A logical thesis for solving the problem of the greenhouse energy consumption is to reduce the heat conduction through the cover. This is illustrated by some calculations. In a greenhouse the conductive heat transfer is the linear result of the U-value of the applied cover and of the operational temperature gradient. There are U-value's of 5.8 W/(m^2.K) for single layers of glass (4 mm), 3.3 W/(m^2.K) for double layers of glass (4–6-4 mm), and of 1.9 W/(m^2.K) for twin wall polycarbonates (16 mm). Given the mean thermal conditions, typically $T_{in,day}$ of 23.0 °C, $T_{in,night}$ of 16.0 °C and $T_{out,year}$ of 10.1 °C (mean outdoor temperature), the cover will cause thermal fluxes that vary from 27,0 – 82,3 W/(m^2) during daytime, and from 12,3 – 37,6 W/(m^2) during nighttime. This results into energy losses that vary from 0,62 GJ/(m^2.year) to 1,89 GJ/(m^2.year) for U-values from 1,9 - 5,8 W/(m^2.K) respectively. An application of reflective coatings in order to reduce this value has serious drawbacks on the so called PAR-performance that is essential for the admission of photosynthesis active radiation for crops. Hence an applied coating on a cover will diminish the growing of the crops and consequently frustrate the intended intensification.

Convective heat losses are being less important than conductive losses in greenhouses for some reasons. The use of ventilation is based on controlling the RH of indoor air below a critical moisture level of 80% (such that crops are prevented from fungicide attacks). For ventilation an air change factor of 2,5/h is needed. The convective losses are equal to the energy needed for preheating fresh outdoor air. They have become less important firstly because the convective losses are compensated by the application of climatic devices like heat exchangers. Without the use of heat exchange devices the convective energy consumption should be estimated 270,9 KJ/(m^2.h), an amount of 1,73 GJ/(m^2.year). Applying a heat exchanger and/or a solar heating collector can be effective up to 75 %. However the use of aquifers in Dutch greenhouses increases, the effects are not reducing the fossil energy consumption, which is due to the fossil energy needed for the operation of the heat pump.

From these calculated amounts we see a difference with the monitored energy use, as the calculated heat losses are 1,2 GJ/(m^2.year) + 0,25 x 1,73 GJ/(m^2.year) = 1,63 GJ/(m^2.year) in 2011. The monitored energy use in 2011 is 0,95 GJ/(m^2.year), indicated by LEI. (0,95 GJ/m^2 means 30,2 m^3 natural gas equivalents.) This 0,68 GJ/(m^2.year) gap is very significant and can just mean that the conductive heat losses are dominant for the entire energy use. Most of the convective losses are actually compensated by accounted effects of energy policies that are implemented. As an implication of this insight it now seems cautious that the rising energy consumption of 2011 could not be adapted; it shows that the actual trends of rising energy use may continue in the future since the average conductive heat losses cannot be reduced anyhow.

AN OPPORTUNITY FOR SOLVING THE ENERGY CONSUMPTION PROBLEM OF GREENHOUSES

In the way we have approached the Dutch greenhouse energy problem, we have found that it cannot be solved by the applications of convection reducing services only. Hence there is a quite other way of questioning required, as is put in this question: - "can we solve the energy-efficiency problem of greenhouses by applying a new cover?"

Ideally, aimed performances of an innovative cover would comprise: a) transmittance of light (as high as possible), b) thermal insulation (as high as possible, meaning a low U-value), c) air change capacity (enough for keeping indoor air RH below 80%). This typical choice is motivated by the problem approach that the energy-efficiency is equivalent to the 'making the best out of available natural resources'. In order to accomplish this goal we wish performances that help each other performing their functions. Performances should get positive correlation, which is why we couple them in new properties of the cover. Hence in order to fundamentally solve the problem we need to get a physical relatedness of important climatic factors. From this view we propose a new material in which transparency, ventilation and thermal insulating are one, instead of being mono-functional

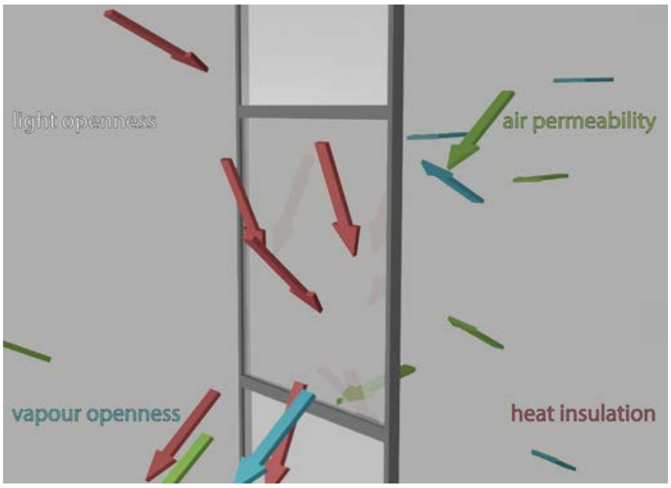

Figure 4 Conceptual representation of a greenhouse cover, based on the co-regulation of climatic factors

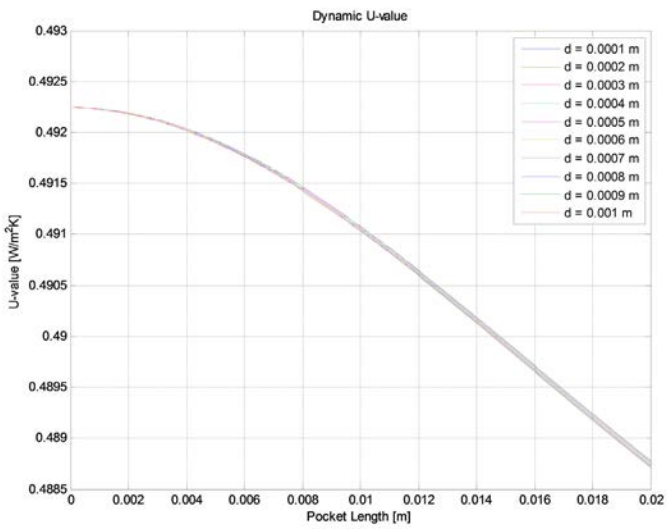

Figure 5 Calculated dynamic U-value

performances. As a result the new concept uses combined fluxes, and filters them. A flow of air and a flux of heat will co-regulate the performances. The essence is how to optimize these flows, and how to optimize the co-regulation.

PRELIMINARY CALCULATION OF PHYSICAL PROPERTIES

In order to study the expected thermal performances of the concept, some numerical simulations have been made based on the interactions of the air flow and the thermal flux inside the material. Figure 5 shows the calculated dynamic U-value. A typical value is about 0.5 W/(m^2.K), which is 4 x lower than the U-value of a two walled polycarbonate cover, and more than 6 x better than the U-value of a cover made of double glazing. It is about 12 x better than a cover made of a single glazing. The graph in figure 6 shows the calculated energy efficiency of the cover. This efficiency has a typical value of about 70%, which means that a proportion of 70 % of the static conductive heat loss will be recovered.

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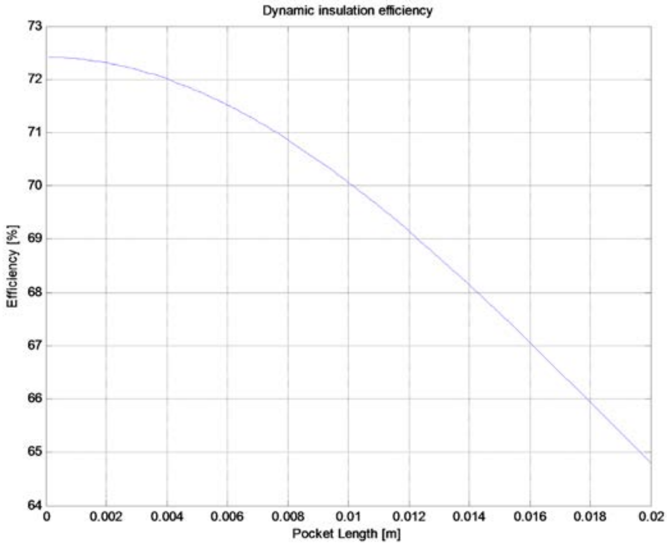

Figure 6 Calculated energy efficiency of the cover

L.A. (Bert) van Schaijk

Eindhoven University of Technology
Department of the Built Environment
Unit Building Physics and Services