A desired greenhouse climate using minimal energy*

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1 Introduction

The most important climate variables in greenhouse horticulture are temperature, humidity, and CO_2 concentration. In this work, the desired greenhouse climate is specified by grower defined lower and upper bounds on the climate variables as this would give the potential to save energy, compared to more rigid set-point control regimes. Lower and upper bounds were introduced in order to stay as close as possible to grower's daily practice. Rather than finding optimal trajectories, the grower is given the lead in defining bounds. Using optimal control techniques, the total amount of energy going to the greenhouse was minimized, instead of maximizing total profit, as the latter would require reliable crop models that are not available.

2 Optimization procedure

To use optimal control techniques a dynamic model describing greenhouse air temperature, humidity, and CO_2 concentration was needed. This model was developed and validated with data from a commercial rose greenhouse. The greenhouse was equipped with a shadow screen, a black-out screen, artificial lighting, natural ventilation, pipe rail heating, and heat exchangers (for cooling and heating).

As the goal was to save energy, the goal function was

$$\min_{Q_E, g_V, \Phi_{inj}} J(Q_E, g_V, \Phi_{c,inj}) = \int_{t_0}^{t_f} Q_E^2 \, dt. \qquad (1)$$

Next to lower and upper bounds for temperature, humidity, and CO_2 concentration, three control inputs were defined: 1) the external energy input to the greenhouse Q_E ($\mathrm{W\,m^{-2}}$), which can be either heating or cooling; 2) the specific ventilation g_V ($\mathrm{m\,s^{-1}}$); 3) injection of industrial CO_2 $\Phi_{c,inj}$ ($\mathrm{g\,m^{-2}\,s^{-1}}$). The maximum amount of ventilation, cooling and heating capacities, and $\Phi_{c,inj}$ were limited to the installed capacities. The total amount of industrial CO_2 that can be supplied to the greenhouse per day was limited by

$$\int_{t_0}^{t_f} \Phi_{c,inj} dt \le \Phi_{c,inj}^{max,day}. \qquad (2)$$

The optimal control problem was solved with PROPT - Matlab Optimal Control Software.

3 Results

The dynamic model showed good agreement with the measured climate variables.

Figure 1 shows two optimal energy trajectories for different values of the amount of available CO_2 , $\Phi_{c,inj}^{max,day}$.

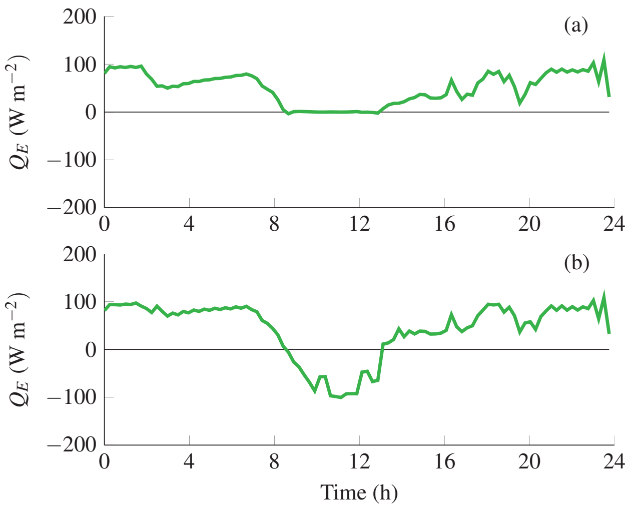

Figure 1: Optimal energy input Q_E^* for (a) $\Phi_{c,inj}^{max,day} = 1000\,\mathrm{g\,m^{-2}}$, and (b) $\Phi_{c,inj}^{max,day} = 150\,\mathrm{g\,m^{-2}}$ for April 25, 2012.

In the upper graph (a), CO_2 was not limiting, and only heating was needed to keep greenhouse air temperature in between the bounds. The upper humidity bound was maintained by natural ventilation. In the lower graph (b), CO_2 was limiting, and as a result of this, active cooling (negative Q_E) was applied in order to keep the ventilation windows closed as much as possible. Some extra heating was applied in (b), in order to not violate the humidity constraint. Active cooling also contributed to vapour removal because of condensation in the heat exchanger due to cooling.

The optimization procedure including CO_2 confirms and explains the current practice that active cooling is used to maintain a higher indoor CO_2 concentration.

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