Optimal control of greenhouse climate with grower defined bounds

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1. Objective

Greenhouse horticulture is a large consumer of natural gas. An optimization framework to minimize the total energy input to a greenhouse was developed and analyzed for a modern greenhouse with active cooling and industrial CO_2 injection.

2. Optimization procedure

- A dynamic model was developed for greenhouse air temperature, humidity (Van Beveren et al. 2015) and was extended with a model for CO_2 concentration of greenhouse air.
- Given the model, initial conditions $T_{air}(0)$, $\chi_{air}(0)$, and $CO_{2,air}(0)$, external inputs, and constraints on the climate variables and control inputs, the optimal control trajectory that minimizes total energy input over time can be found by minimizing the following functional J:

$$\min_{Q_{E,h},Q_{E,c},g_V,\phi_{c,inj}} J(Q_{E,h}, Q_{E,c}, g_V, \phi_{c,inj}) = \int_{t_0}^{t_f} \left(Q_{E,h}^2 + Q_{E,c}^2\right) dt$$

  where $Q_{E,h}$ is heating, $Q_{E,c}$ cooling, g_V the specific ventilation, and $\phi_{c,inj}$ the injection of CO_2. Also the total amount of CO_2 that could be injected per day is a constraint.
- One full year was optimized and compared with data from a 4 ha commercial rose greenhouse (Fig. 1).
- Standard optimization settings, based on grower's operation of the greenhouse were formulated to compare the optimal situation with the grower.
- The so called 'minimum pipe temperature', as used in practice, can be easily incorporated in the optimal control formulation.

3. Results

The daily optimization results with standard settings for the whole year 2012 are shown in Fig. 2 and Table 1. Optimization for the whole year resulted in a reduction of 47 % in heating, 15 % in cooling, and 10 % in CO_2 injection for the year 2012. When the minimum pipe temperature of the grower was implemented, still, a reduction of 28 % in heating, 14 % in cooling, and 10 % in CO_2 injection use was found. The effect of different bounds on the optimal energy input was analyzed.

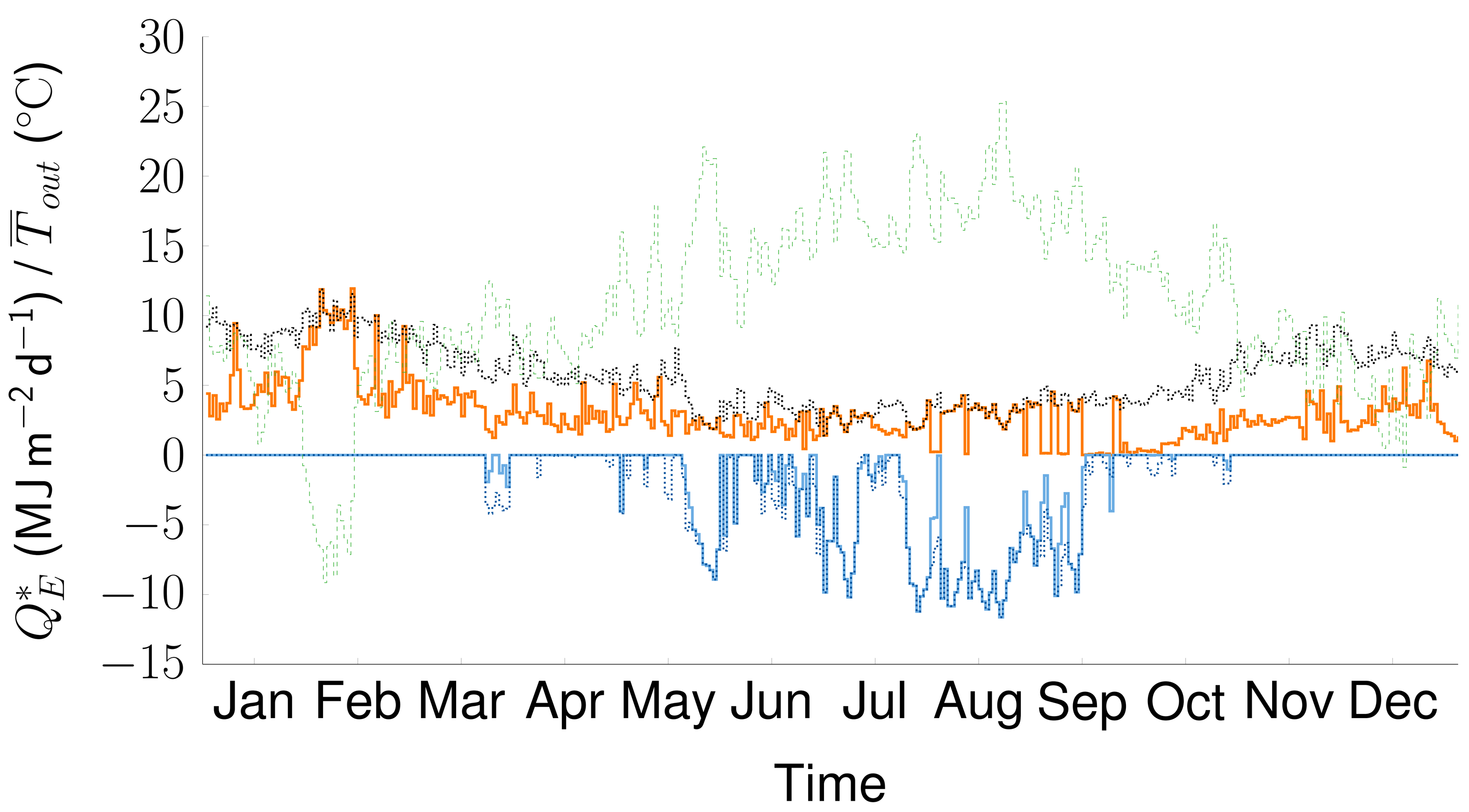

Figure 2. Results of daily optimization with standard settings for 2012. Optimal heating (—), optimal cooling (—), heating grower (⋯), cooling grower (—), and mean outside temperature (⋯).

Figure 1. 4 ha commercial greenhouse production facility.

Fig. 3 shows the effect of changing the boundaries for CO_2 on 16 June, 2012. A lower lower bound for the CO_2 concentration leads to lower energy input by heating and cooling, because the windows can be opened more during day time instead of using active cooling. If more CO_2 is available per day, the same effect occurs.

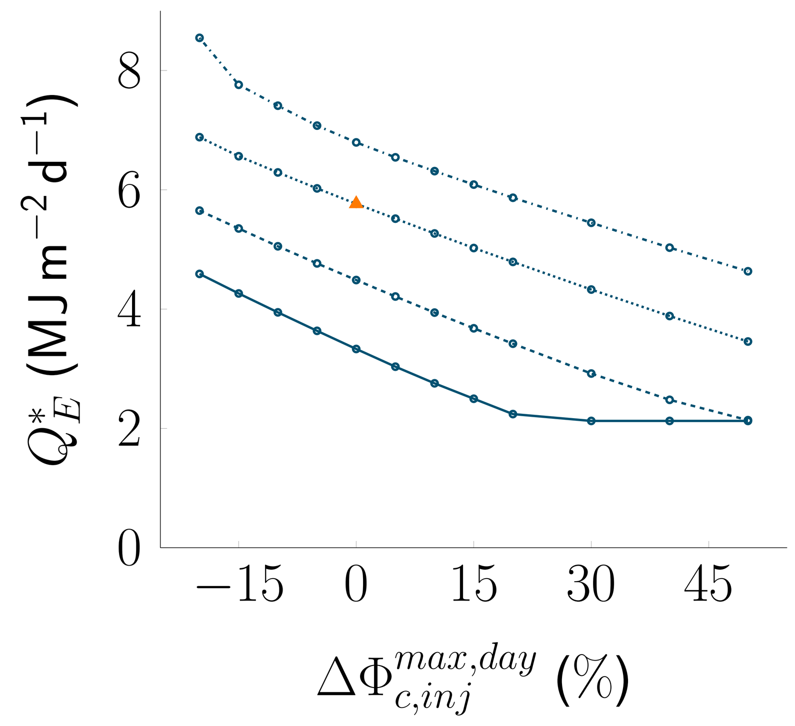

Figure 3. Effect of changing CO_2 bounds for 16 June, 2012. Values for $CO_{2,air}^{min}$ were the standard settings −20 % (·), −13 % (·), −3 % (·), and 7 % (·). Other settings were standard optimization settings. · is optimization with standard settings.

Table 1. Total heating, cooling, and CO_2 injection of the grower, the optimal situation with standard settings, and the optimal situation with minimum pipe temperature as used by the grower for 2012.

	Heating GJ m^{-2} y^{-1}	Cooling GJ m^{-2} y^{-1}	CO_2 injection kg m^{-2} y^{-1}
Grower	2.08	0.71	95.4
Opt standard settings	1.10	0.60	85.7
Opt minimum pipe	1.49	0.71	85.9

4. References

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