Optimal control of greenhouse climate with grower defined bounds

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1 Introduction

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 CO₂ injection.

2 Optimization procedure

A dynamic three state model was developed for greenhouse air temperature, humidity, and CO₂ concentration. Given the model, initial conditions T_{air}(0), X_{air}(0), and CO₂_{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:

\[ \min_{Q_{E,h}, Q_{E,c}, \phi, \psi_{j}} J(Q_{E,h}, Q_{E,c}, \phi, \psi_{j}) = \int_{0}^{T} (Q_{E,h}^2 + Q_{E,c}^2) \, dt \]  

(1)

where Q_{E,h} is heating, Q_{E,c} cooling, \phi_j the specific ventilation, and \phi_j^{in} the injection of CO₂. Also the control inputs had constraints. Another constraint was the total amount of CO₂ that could be injected per day. One full year was optimized and compared with data from a 4 ha commercial rose greenhouse. Standard optimization settings, based on grower’s operation of the greenhouse were formulated to compare the optimal situation with the grower. By adapting the lower bound for heating to the amount of energy coming from the pipe rail heating system in case of minimum pipe temperature, the effect of settings that growers are familiar with can be made explicit.

3 Results

The daily optimization results with standard settings for the whole year 2012 are shown in Fig. 1 and Table 1.

Table 1: Total heating, cooling, and CO₂ 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.

<table>
<thead>
<tr>
<th></th>
<th>Heating</th>
<th>Cooling</th>
<th>CO₂ injection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grower</td>
<td>2.08</td>
<td>0.71</td>
<td>95.4</td>
</tr>
<tr>
<td>Opt standard settings</td>
<td>1.10</td>
<td>0.60</td>
<td>85.7</td>
</tr>
<tr>
<td>Opt minimum pipe</td>
<td>1.49</td>
<td>0.71</td>
<td>85.9</td>
</tr>
</tbody>
</table>

Optimization for the whole year resulted in a reduction of 47 % in heating, 15 % in cooling, and 10 % in CO₂ 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 CO₂ injection use was found. The effect of different bounds on the optimal energy input was analyzed. Fig. 2 shows the effect of changing the boundaries for CO₂ on 16 June, 2012. A lower lower bound for the CO₂ 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 CO₂ is available per day, the same effect can occur.

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