Optimal Control of Greenhouse Climate using Genetic Algorithms

Hartmut Pohlheim

Technical University Ilmenau, Faculty of Informatics and Automation, Germany

Adolf Heißner

Institut für Gemüse- und Zierpflanzenbau Großbeeren/Erfurt, Germany

Overview

- Introduction / Motivation
- Integrated Greenhouse climate model
- Optimization using Genetic Algorithms
- Experiments and Results
- Summary and Outlook

Motivation

understand and control processes in greenhouses

- development and use of complex models
  - → inside climate model
  - → plant model (crop growth and yield)

previously published solutions:

- modeling of single components
  - → temperature, CO_2 concentration or air humidity
  - → plant models
- modeling of long term processes (whole growth period)
- restriction of application
  - → control of components can not be done independently
  - → not applicable for online control
  - → not usable for short time tasks

Problem definition

Formulation of an integrated short time model

- including:
  - → greenhouse climate
  - → crop growth (plant model)
  - → outside weather conditions
  - → control equipment
- providing
  - → prediction of all inside climate conditions in a 15-60 minutes time interval
  - → use for short time control tasks
    - ⇨ optimization of crop growth / yield
    - ⇨ prevention of stress

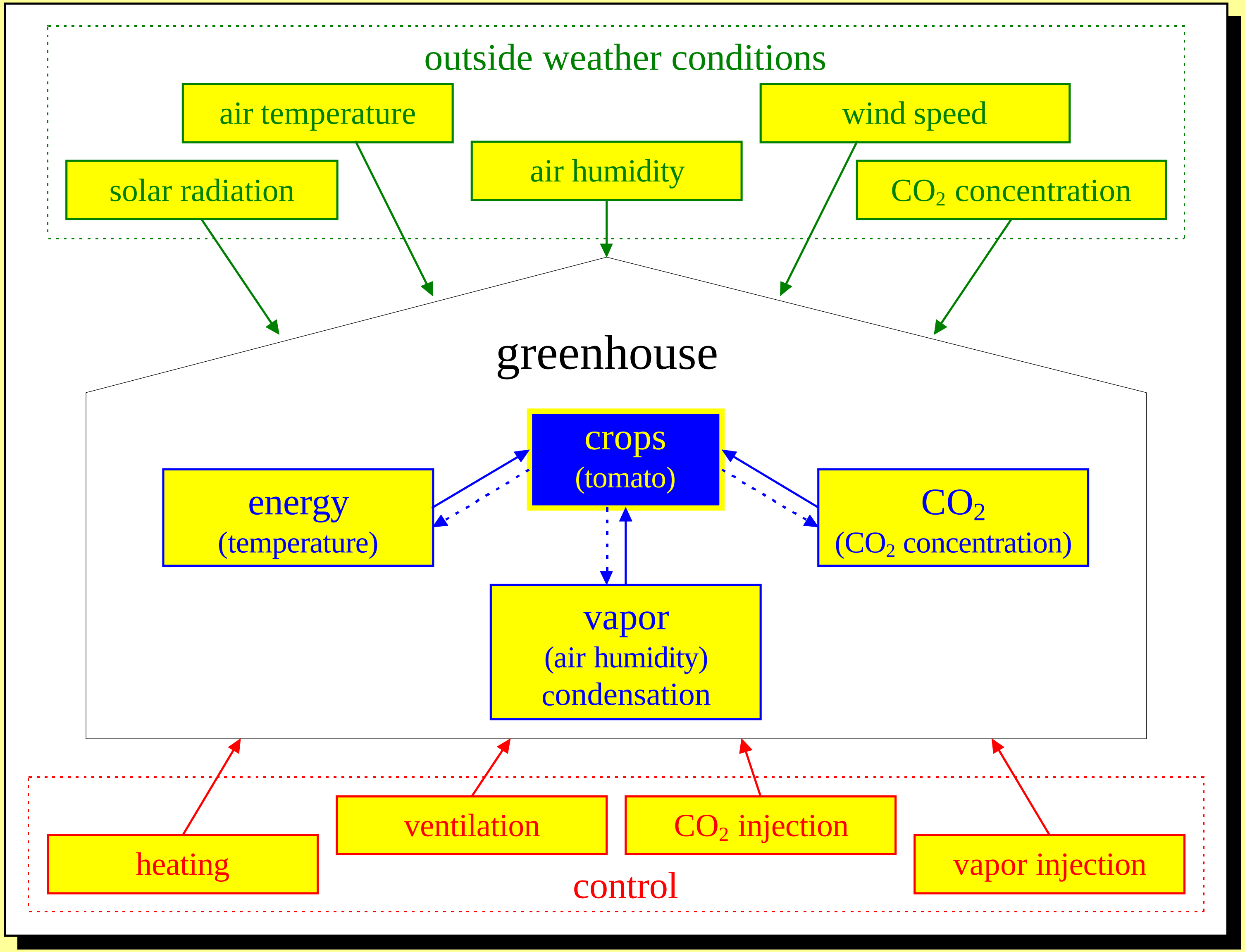
Greenhouse model

Structure

TU ILMENAU

Informatics and Automation

Structure of integrated greenhouse model



Greenhouse model

Balance equations

Simulation of the integrated model

- 4 greenhouse balance equations
  - → energy balance
  - → vapor balance
  - → CO_2 balance
  - → condensation / evaporation
- 2 plant balance equations
  - → CO_2 exchange
  - → transpiration
- yield / biomass (derived from CO_2 exchange)
- profit (yield minus control costs)

- system of first-order differential equations
- simulated using Runge-Kutta methods of 4th order

TU ILMENAU

Informatics and Automation

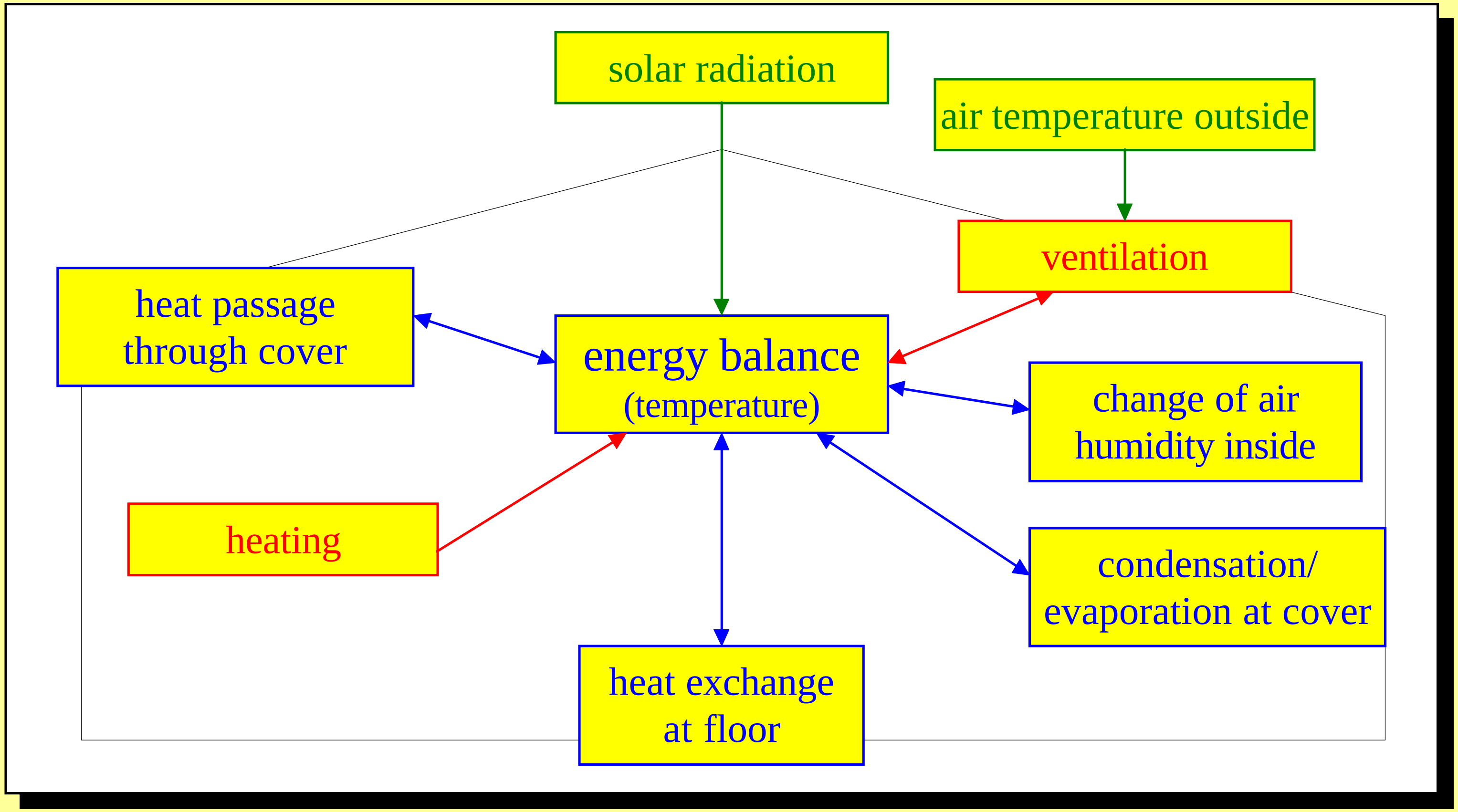
Greenhouse model

Energy balance

TU ILMENAU

Informatics and Automation

Components of energy balance

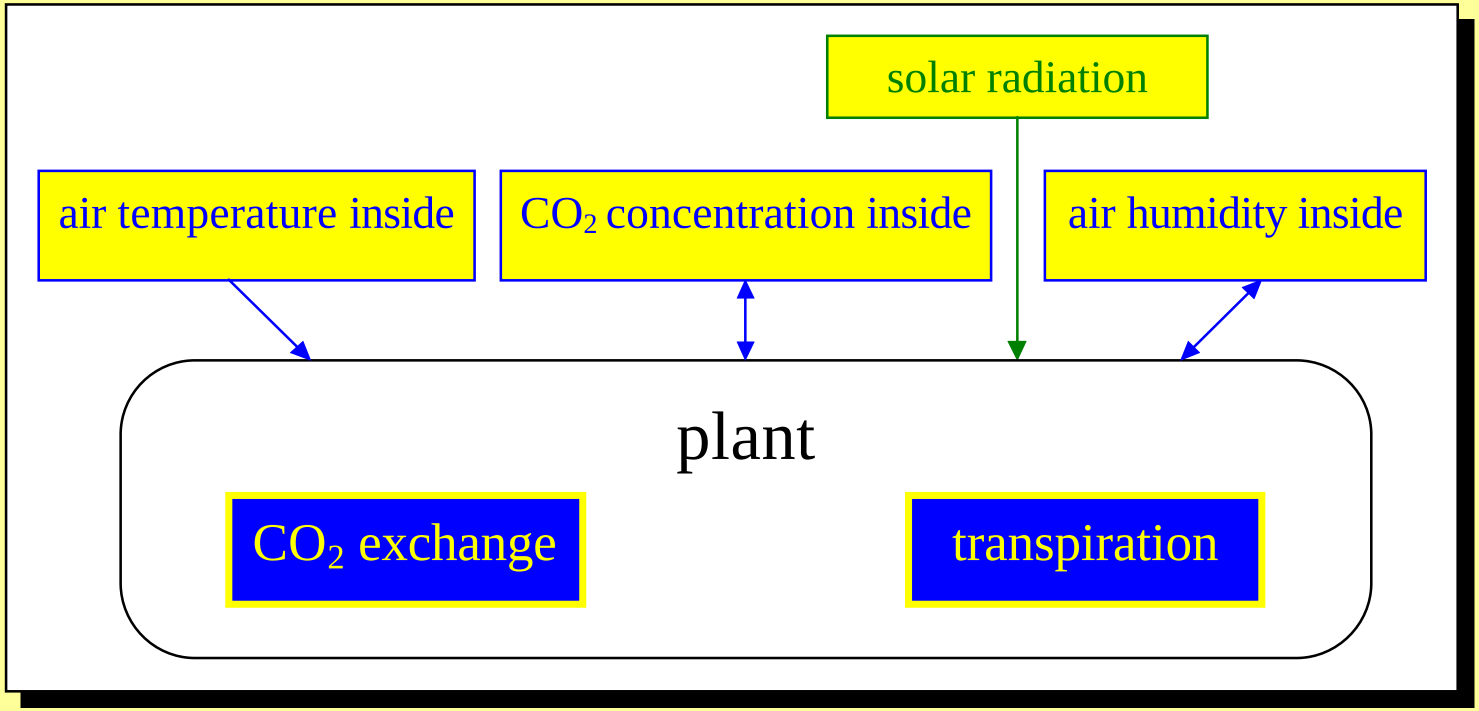


$$DTEMI = (1/(CG+GH \cdot CPD \cdot DDI)) \cdot (Q+qglob-qluwe-qduga-qboden-qkonden-GH \cdot (VDW0+CPD \cdot TEMI) \cdot DDDI)$$

Greenhouse model

Plant model

Components of plant model

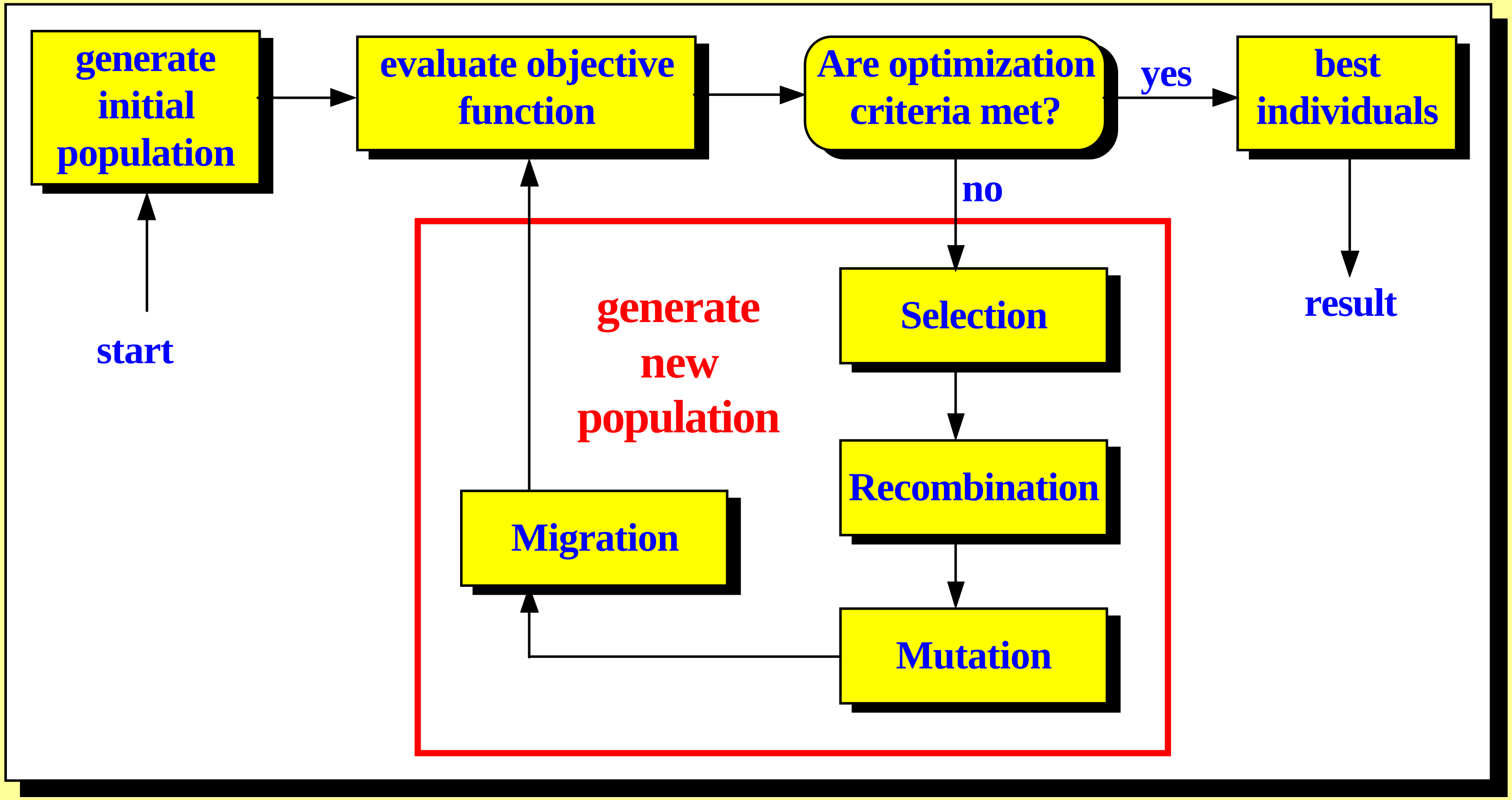


- CO_2 exchange and transpiration are computed relative to standard conditions
- use of parametric equations

Motivation

- calculation of a control
  - → value of every control component over control time
  - → methods of optimization of dynamic systems
- use of Genetic Algorithms
  - → straightforward application (compared to gradient methods)
  - → incorporation of problem specific knowledge
  - → incorporation of constraints
- What do we need?
  - → objective function (cost function)
  - → representation of solutions / individuals
  - → problem specific knowledge

Structure of the genetic algorithm



- Evolutionary (Genetic) Algorithm Toolbox for use with MATLAB
- Multiple Population GA: 4 subpopulations with 50 individuals each
- linear ranking, truncation selection, generation gap 0.9, discrete recombination, real valued mutation, unrestricted migration

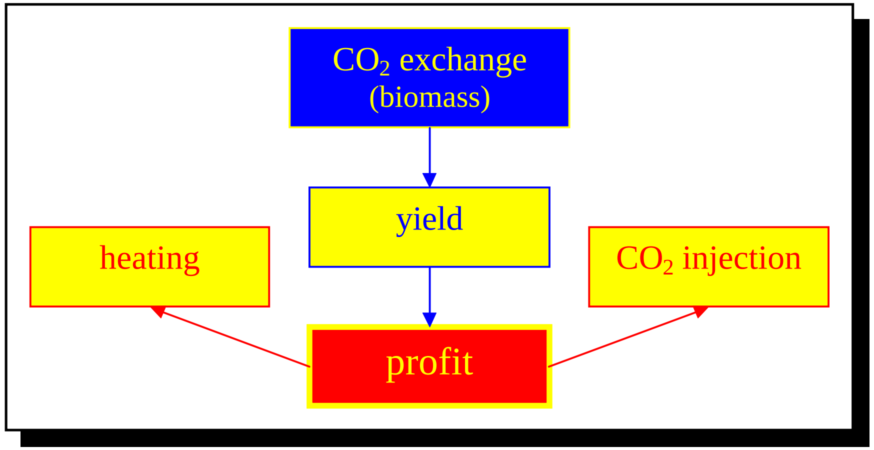
Optimization

Objective/cost function

Objective function (cost function)

- maximization of profit

$$Cost = \int_{T_S}^{T_E} GEWI \, dt + Penalty$$



- prevention of stress
  - → minimal / maximal temperature
  - → maximal CO_2 concentration
  - → minimal / maximal air humidity

$$Penalty = \sum_{i=1}^{NumConstr} \left(W_i \cdot \int_{T_S}^{T_E} \left| \left(Val_i - Constr_i \right) > 0 \right| dt \right)$$

TU ILMENAU

Informatics and Automation

Optimization

Representation
Initialization

Representation of individuals

- individuals represent control of simulation period
  - → use of 3 controls (heating, ventilation, CO_2 enrichment)
  - → controls discretized at equidistant points (first order hold)
  - → control step every 15 minutes
  - → simulation period: 2 hours

$$NumVar = \left(\frac{SimTime}{ControlStep} + 1 \right) \cdot NumControl; \qquad ControlStep = 0.25h \qquad NumControl = 3$$

Incorporation of domain specific knowledge

- initialization of individuals
  - → restrict initialization to a small band of domain
  - → band defined by experience for standard weather conditions
- changing domain depending on time of year

Comparison

previously published solutions

- use of models and simulation to find better set points
  - → day/night temperature
  - → night CO_2 enrichment
- no immediate reaction to changing conditions (prices)

new integrated model and genetic algorithms

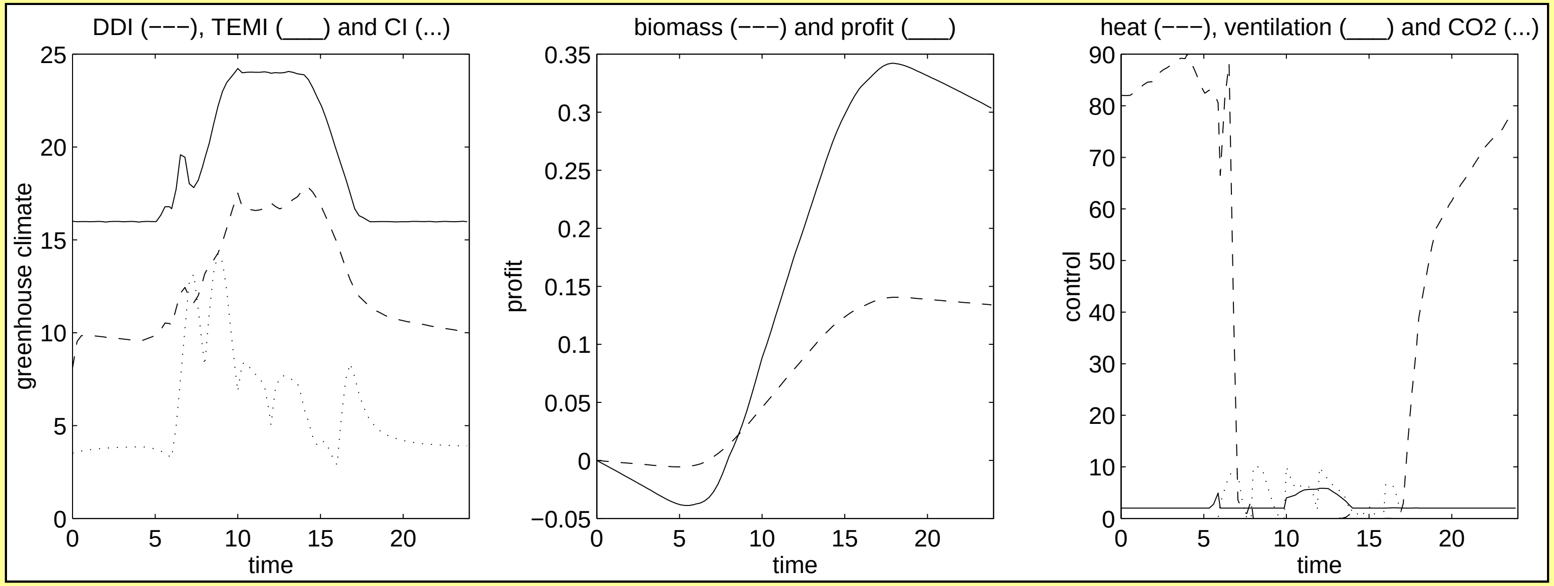
- optimal control of greenhouse climate
- applicable for different objectives
- immediate response to changing conditions
- use for online control

Experiments

Typical days

Optimal control for typical days

- optimization for April
- heating high during night (lower temperature constraint)
- ventilation on over noon (upper temperature constraint 24°C)
- CO_2 injection on during whole day (no or less ventilation)

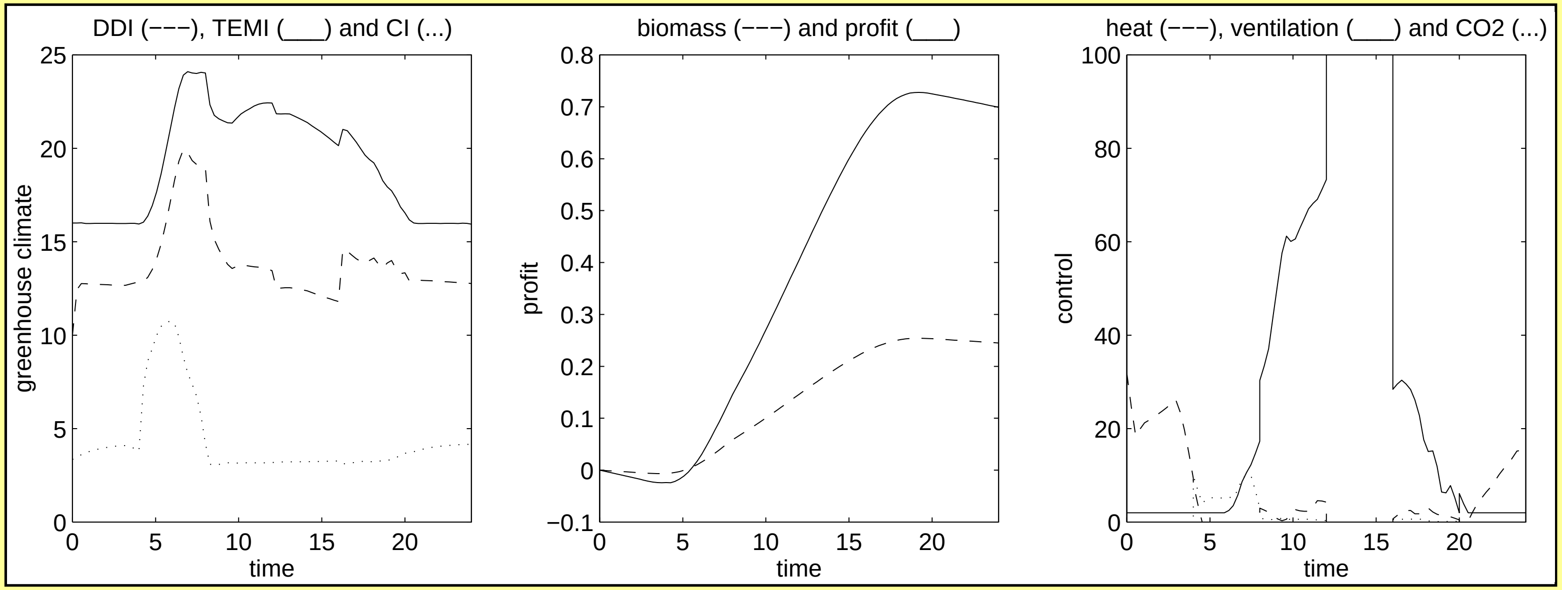


Experiments

Typical days

Optimal control for typical days

- optimization for June
- heating on during night (lower temperature constraint)
- ventilation on during day
  (upper temperature constraint, 20°C better than 24°C)
- CO_2 injection on during morning (before ventilation opens)



Experiments

Changing prices

Optimal control under changing prices

- prices of heating (energy) and CO_2 were changed
  - → 3 times as high as standard price
  - → $^1/_3$ of standard price

- optimization for February
- high prices
  - → biomass: 1.1 g/(m²·h) profit: -0.09 Pf/(m²·h)
  - → heating as low as possible (lower temperature constraint)
  - → nearly no CO_2 injection
- low prices
  - → biomass: 1.5 g/(m²·h) profit: 0.03 Pf/(m²·h)
  - → heating higher than keeping temperature above 16°C
  - → during daytime CO_2 injection

Summary

Advantages

- presentation of an integrated greenhouse model includ.
  - → greenhouse climate
  - → plant growth
  - → control equipment
  - → outside weather conditions
- use for short time prediction tasks
- optimization using Genetic Algorithms
- employment of different objectives
  - → profit maximization, prevention of stress, constraints
- ready for online control
- incorporation of problem specific knowledge

Summary

Outlook

- new and enhanced plant models
  - → paprika, cucumber, radish
- use of real world weather data
  - → currently done using measured data from 1995
- comparison with different control strategies
  - → constant set points for greenhouse climate
- definition of new objectives for optimization
- enhancements to the evolutionary/genetic algorithm
  - → multiple strategies for subpopulations
  - → competing subpopulations
  - → employment of problem specific genetic operators
- multiobjective ranking of different objectives

TU ILMENAU

Informatics and Automation