

HVAC Optimization for Greenhouses



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Problem & Motivation




Problem:

Given data of **external temperature** and **relative humidity**, configure the optimal parameters on HVAC system to **minimize cost** of operation while ensuring adequate growth conditions for the plants in a Greenhouse.



Motivation:

Sustainable methods for farming are gaining importance due to environmental issues as well rising food consumption needs, hence leads to higher costs. Finding the right parameters ensures higher yields at lower costs.



Challenges (if applicable)

- Formulating the mathematical problem was a challenge to understand and implement Thermodynamics and HVAC Systems.
- Had to approximate plant water emission (transpiration) and CO₂ absorption (photosynthesis) rate via horticulture means.
- Assumptions to simplify the system.
 - Fixed greenhouse cubical dimensions: 40 x 40 x 6
 - Uniform air distribution within the greenhouse
 - Assuming the walls and roof of the greenhouse is glass with constant conductivity.

Mathematical Formulation

- Optimization function: Minimize cost

Heating Rate * Cost of Heating +
Cooling Rate * Cost of Cooling +
Humidification Rate * Cost of Humidification +
Dehumidification Rate * Cost of Dehumidification +
CO2 Emission Rate * Cost of CO2 Emission

- Constraints: (Equality)

- Heat Energy Flow Balance
- Moisture Energy Balance
- CO2 Emissions Energy Balance

- Bounding Constrains: Plant Requirements, HVAC equipment restriction

- $\text{Rate(Heating, Cooling, Humidification, CO2 Emission)} \geq 0$
- $50\% \leq \text{Relative Humidity} \leq 100\%$
- $70\text{F} \leq T \leq 80\text{F}$
- $2.65 \leq \text{Ventilation} \leq 265$

Optimization Variables

Relative Humidity (RH)

Temperate (T)

Heating Rate

Cooling Rate

Ventilation Rate

Humidification Rate

Dehumidification Rate

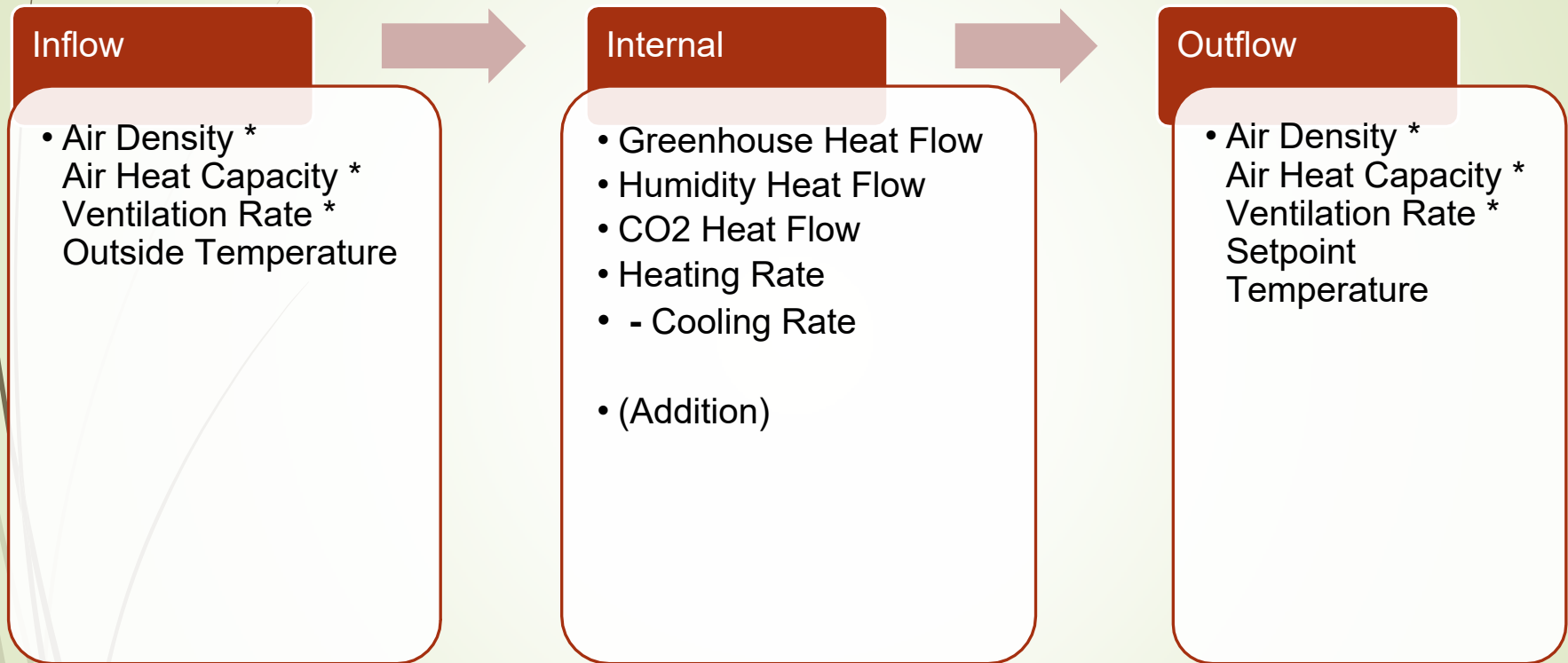
CO2 Emission Rate



LAW OF CONSERVATION OF ENERGY

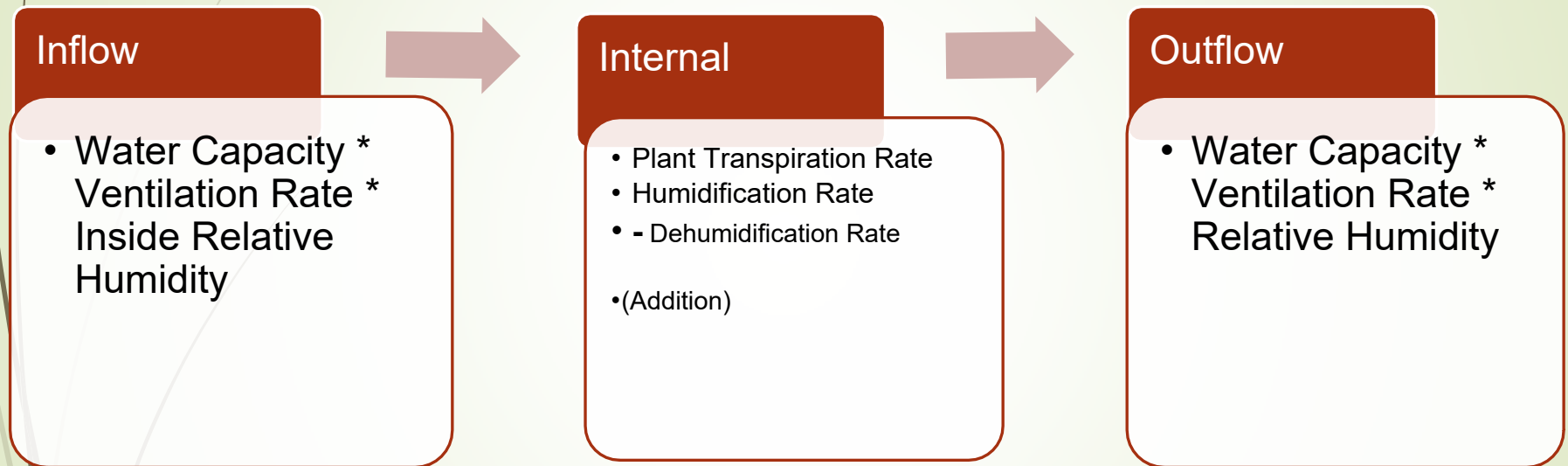
$$\text{Inflow} + \text{Internal} - \text{Outflow} = 0$$


Heat Energy Balance



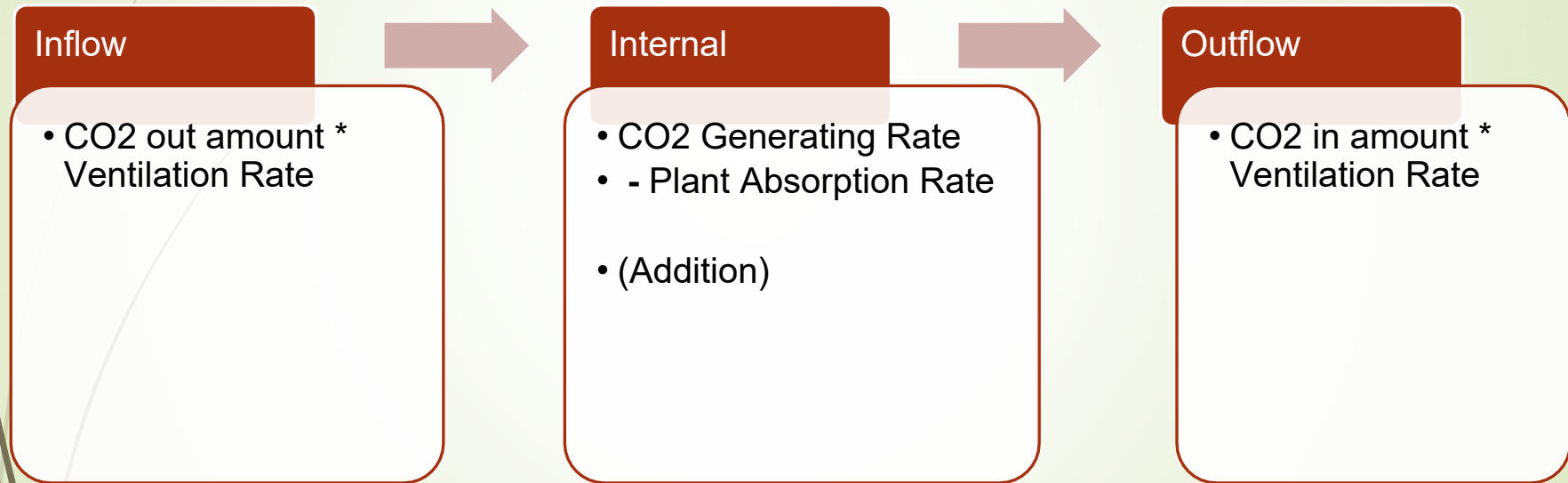
- Humidity Heat Flow = Latent Heat * Humidifier Rate
- CO2 Heat Flow = (CO2 Heat Constant/Mass of CO2) * CO2 Rate
- Greenhouse Heat Flow = Material Conductivity * Area * Difference in outside and inside temperature

Moisture Energy Balance



- Water Capacity = $0.7278 * (T * (9/5) - 459.67) - 32.189$
- Inside Relative Humidity = $5 * (T \text{ at dewpoint} - (T - 273.15)) + 100$
 - $T \text{ at dewpoint} = (T_{\text{out}} - 273.15) - ((100 - RH_{\text{out}})/5) + 273.15$
- Plant Transpiration Rate = Changes with the type of plant, ~120.7

CO2 Emission Balance



Plant Absorption rate is constant: 2.73

Numerical Studies

- Tools used to solve the problem:
 - Python: `scipy.optimize.minimize`
 - Solver:
- Numerical results:
 - Given outside Temperature, Relative Humidity: 70F ,50%
 - Optimal Cost:
 - Optimal Values:

Variable	Value
Relative Humidity (RH)	
Temperate (T)	
Heating Rate	
Cooling Rate	
Ventilation Rate	
Humidification Rate	
Dehumidification Rate	
CO2 Emission Rate	



Lessons and Discussion

- Given the outside temperature and relative humidity, we have obtained the best parameters to set in order to obtain the least cost of operation.
- Future Work:
 - Analyze the nature of the different functions used. (Convexity)
 - Analyze the dual solution and determine if strong duality holds.
 - Account for other physical constraints and parameters like Human energy, Lighting, Soil Moisture etc.
 - Constraint of CO₂, change in value of plant CO₂ absorption rate and plant water transpiration rate can be another function that can vary with the type and number of plants.