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 CO_2 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
  - Rate(Heating, Cooling, Humidification,CO2 Emission) >= 0
  - 50% <= Relative Humidity <= 100%
  - 70F <= T <= 80F
  - 2.65 <= Ventilation <= 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

Inflow + Internal - Outflow = 0

Heat Energy Balance

Inflow

- Air Density * Air Heat Capacity * Ventilation Rate * Outside Temperature

Internal

- Greenhouse Heat Flow
- Humidity Heat Flow
- CO2 Heat Flow
- Heating Rate
- \- Cooling Rate

- (Addition)

Outflow

- Air Density * Air Heat Capacity * Ventilation Rate * Setpoint Temperature

- 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

Inflow

- Water Capacity * Ventilation Rate * Inside Relative Humidity

Internal

- Plant Transpiration Rate
- Humidification Rate
- - Dehumidification Rate

•(Addition)

Outflow

- Water Capacity * Ventilation Rate * Relative Humidity

- Water Capacity = 0.7278* (T * (9/5) - 459.67) - 32.189
- Inside Relative Humidity = 5*(T at dewpoint - (T-273.15)) + 100
  - T at dewpoint = (T_out-273.15)-((100-RH_out)/5) + 273.15
- Plant Transpiration Rate = Changes with the type of plant, ~120.7

CO2 Emission Balance

Inflow

- CO_2 out amount * Ventilation Rate

Internal

- CO_2 Generating Rate
- - Plant Absorption Rate
- (Addition)

Outflow

- CO_2 in amount * Ventilation Rate

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 CO_2, change in value of plant CO_2 absorption rate and plant water transpiration rate can be another function that can vary with the type and number of plants.