EBVC: Electronic Bee-Veterinarian – Beyond Monitoring and Onto Control


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Sponsor: USDA NIFA

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Outline

- Introduction & Background
- Dataset & Experimental Setup
- Proposed Framework: EBVC
- Experiments
- Conclusion

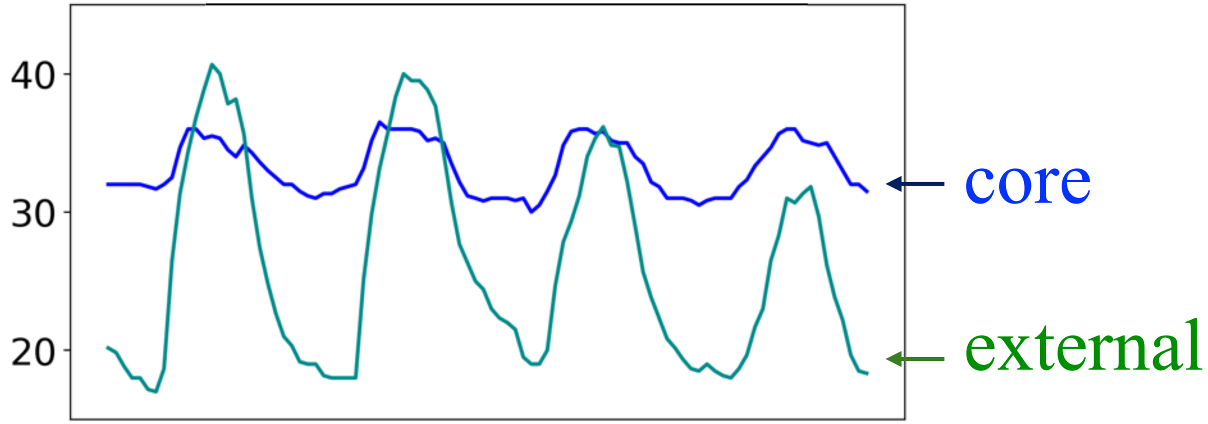
Honeybees are Vital Pollinators

- > 80 crops
- ~ $550 billion globally
- ~ $29 billion for the US
- if bees die, agriculture will suffer.
- 2025: ~ 62% of US bees lost

Background (1/2) - thermoregulation

Core Area
(Near brood nest area)

Temperature (^{0}C)



Timeticks (t)

$33^0C \leq$ Core Temp, $\Theta(t) \leq 36^0C =$ 

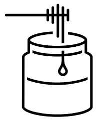
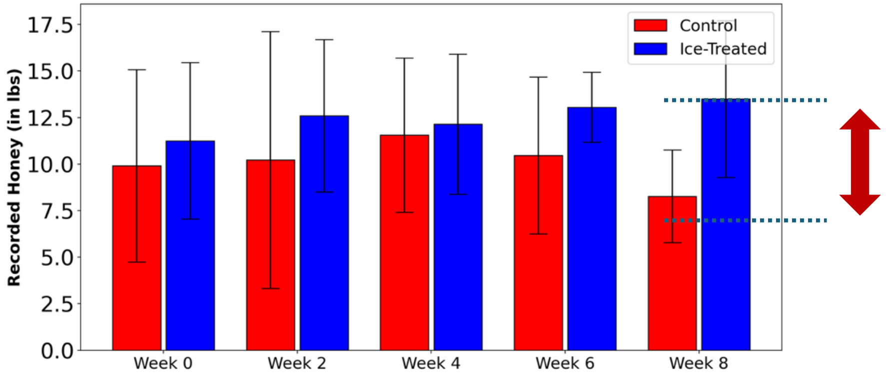
Temperature deviation -> bee thermoregulation
-> lost honey production.

Background (2/2) - treatment


Control Hive
(5 in total)

Currently: Beekeepers add ice-packs


Treated Hive
(5 in total)

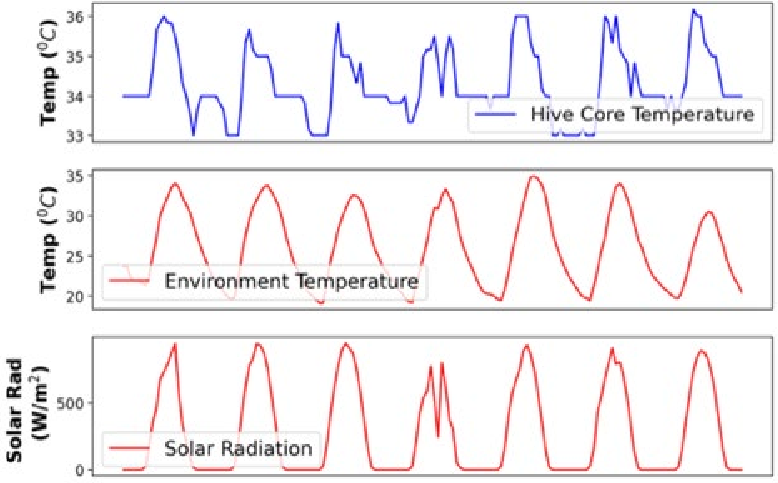



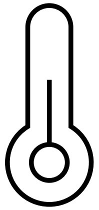
More honey, if ice-treated

Our goal: How to automate ‘ice-packs’/treatment?

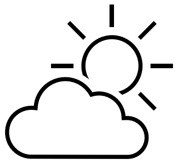
Problem Statement: automate treatment

GIVEN:

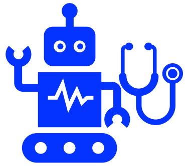




Sensor Data



Weather Station Data



EBVC

FIND:

Activate Heating

Activate Cooling

G1: Controller Schedule

– 

Installation Cost

+ 

Additional Honey Production

G2: Estimate Revenue

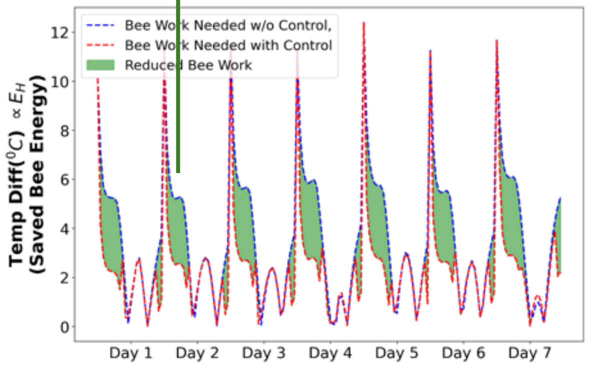
Contributions : EBVC

- C1: $EBVC_{model}$ Thermal Model

$$\boxed{\nabla^2\theta \propto \frac{\partial\theta}{\partial t} = \sum_j k_j(\theta - \theta_j) + \ \dots}$$

- C2: $EBVC_{honey}$ Honey Production

Reduced Bee Work ∝ Saved Honey



- C3: $EBVC_{opt}$ Temperature Control

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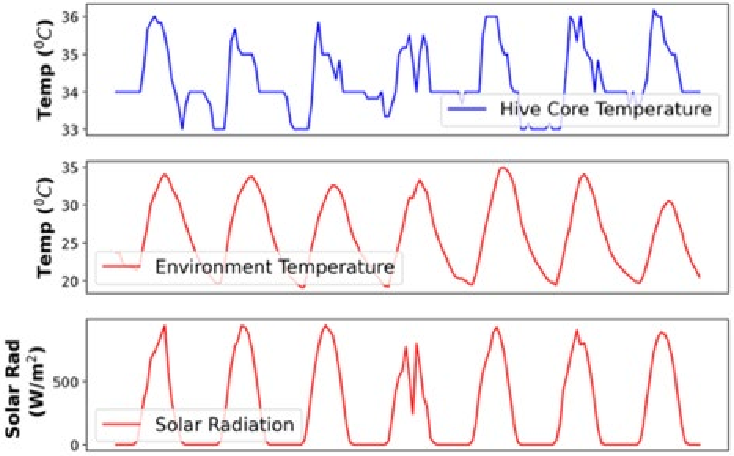
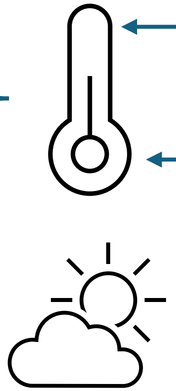
Dataset & Experimental Setup

Hive Data:

Environment Data:





Core Area
(Near brood nest area)

Sensors

Peripheral Area
(external temperature)

California Irrigation Management Information System (CIMIS)

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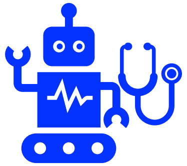
Overview (1/2): EBVC Hardware



EBVC

Empty Hive

Amortized cost:
~ $62/year

Temp. Sensor

Raspberry Pi

Bluetooth

Sensing & computing

Peltier Cell (Cooler)

(BeeHive Box)

Heating Pad

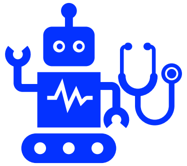
Actuator

Solar Panel

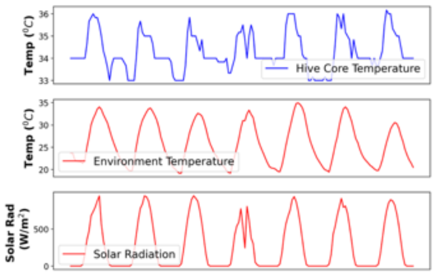
Battery Bank

Power

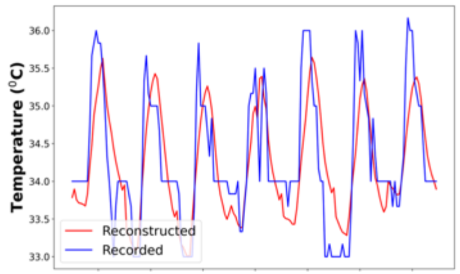
Overview (2/2): EBVC Software

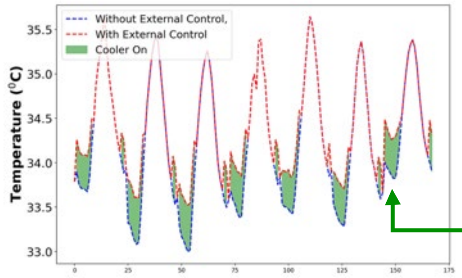


EBVC

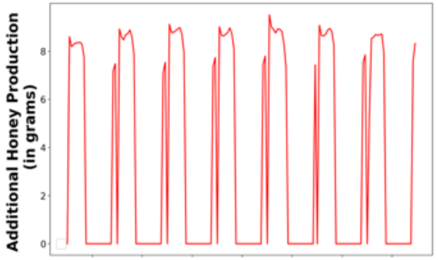


1) *EBVC*$_{model}$: Estimation





Saved effort



3) *EBVC*$_{honey}$: Honey Production

***G2:* Estimate Additional Revenue**

2) *EBVC*$_{opt}$: Optimal Control

***G1:* Controller Operation Schedule**

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  - $EBVC_{honey}$
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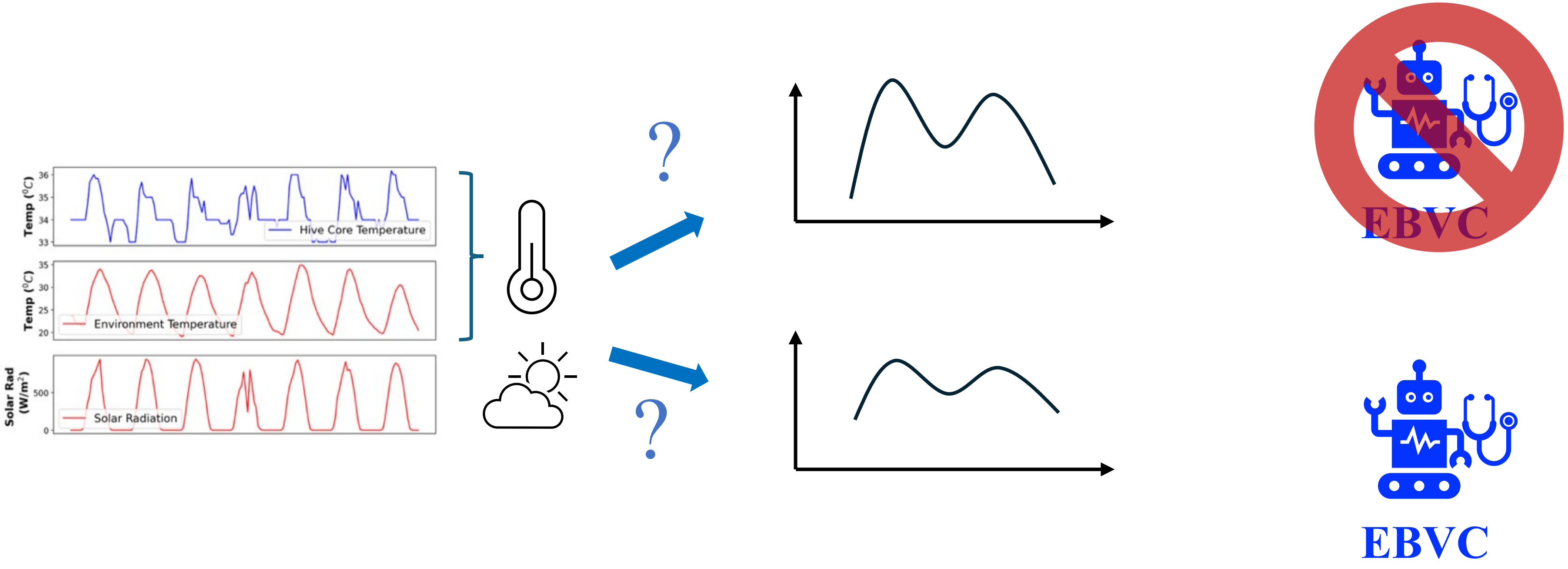
EBVC$_{model}$ for Thermal Modeling

Q: What will the temperature be, with/without EBVC?



EBVC$_{\text{model}}$ for Thermal Modeling

Q: What will the temperature be, with/without EBVC?

A:

$$\frac{\partial \theta(t)}{\partial t} = 6[(k_w + k' + k_a)(\theta_e(t) - \theta(t)) + \alpha_w S(t)] - h\frac{r_c r_h\left(1 - e^{-\theta(t)}\right)}{r_h + r_c e^{-\theta(t)}} - P(t)$$

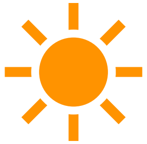
DETAILS

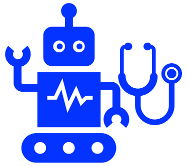
EBVC$_{\text{model}}$ for Thermal Modeling

Q: What will the temperature be, with/without EBVC?

A:



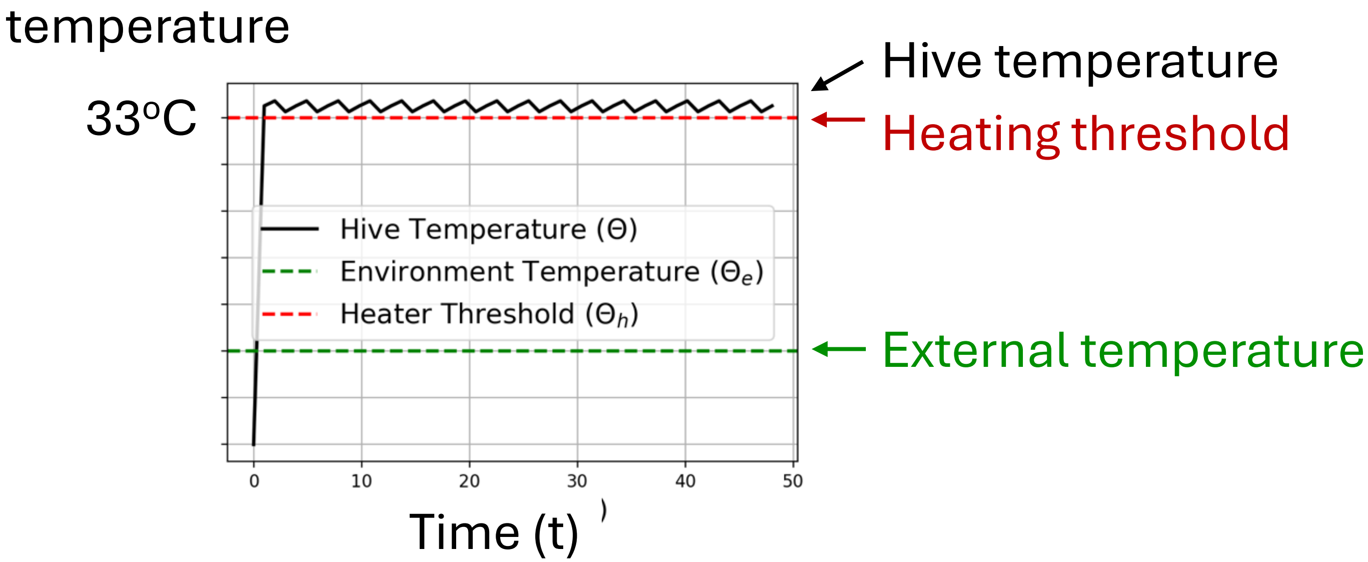




$$\frac{\partial\theta(t)}{\partial t} = 6[\underbrace{(k_w + k' + k_a)}_{\text{Newton's law of cooling}}\underbrace{(\theta_e(t) - \theta(t))}_{\text{Thermal diffusion}} + \underbrace{\alpha_w S(t)}_{\text{Solar radiation}}] - h\underbrace{\frac{r_c r_h\left(1 - e^{-\theta(t)}\right)}{r_h + r_c e^{-\theta(t)}}}_{\text{Honeybee thermoregulation}} - \underbrace{P(t)}_{\text{EBVC}}$$

EBVC$_{model}$ for Improved Thermal Modelling

$$\frac{\partial \theta(t)}{\partial t} = 6[(k_w + k' + k_a)(\theta_e(t) - \theta(t)) + \alpha_w S(t)] - h\frac{r_c r_h(1 - e^{-\theta(t)})}{r_h + r_c e^{-\theta(t)}} - \underbrace{P(t)}_{\text{EBVC}}$$



Control Theory: P-Controller

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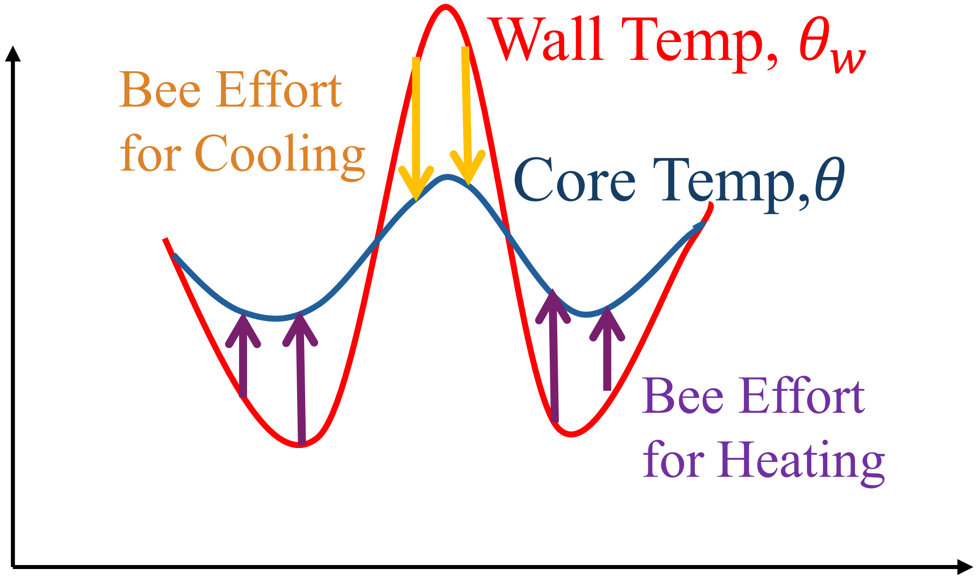
EBVC$_{honey}$ for Honey Production Modelling

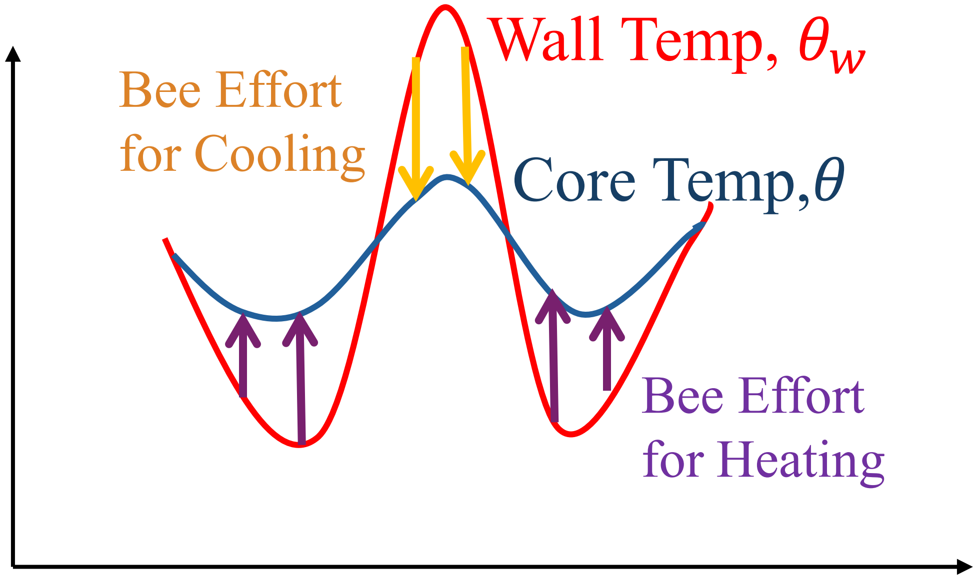


1^{o}C cooling ∝ 12g honey

1^{o}C heating ∝ 3g honey

DETAILS

$\text{EBVC}_{\text{honey}}$ for Honey Production Modelling



1°C cooling ∝ 12g honey

1°C heating ∝ 3g honey

For Heating, $$H_H(t) = 3|(\theta_w - \theta) - (\frac{1}{6}\left(\sum_{n=1}^{5}\theta_w + \theta_{w_{b,adj}}\right) - \theta_{adj})|$$

For Cooling, $$H_C(t) = 12|(\theta_w - \theta) - (\frac{1}{6}\left(\sum_{n=1}^{5}\theta_w + \theta_{w_{t,adj}}\right) - \theta_{adj})|$$

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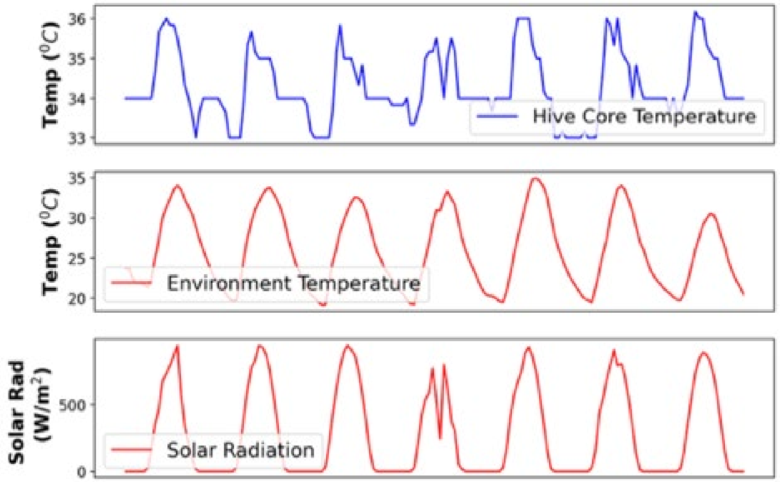
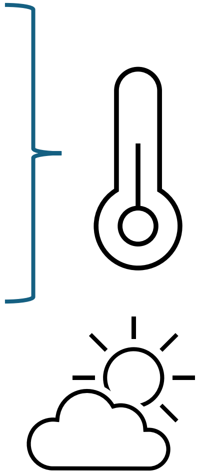
EBVC$_{opt}$ for Control Optimization





Activate Heating

Activate Cooling

(Fixed thresholds: we can do better than that.)

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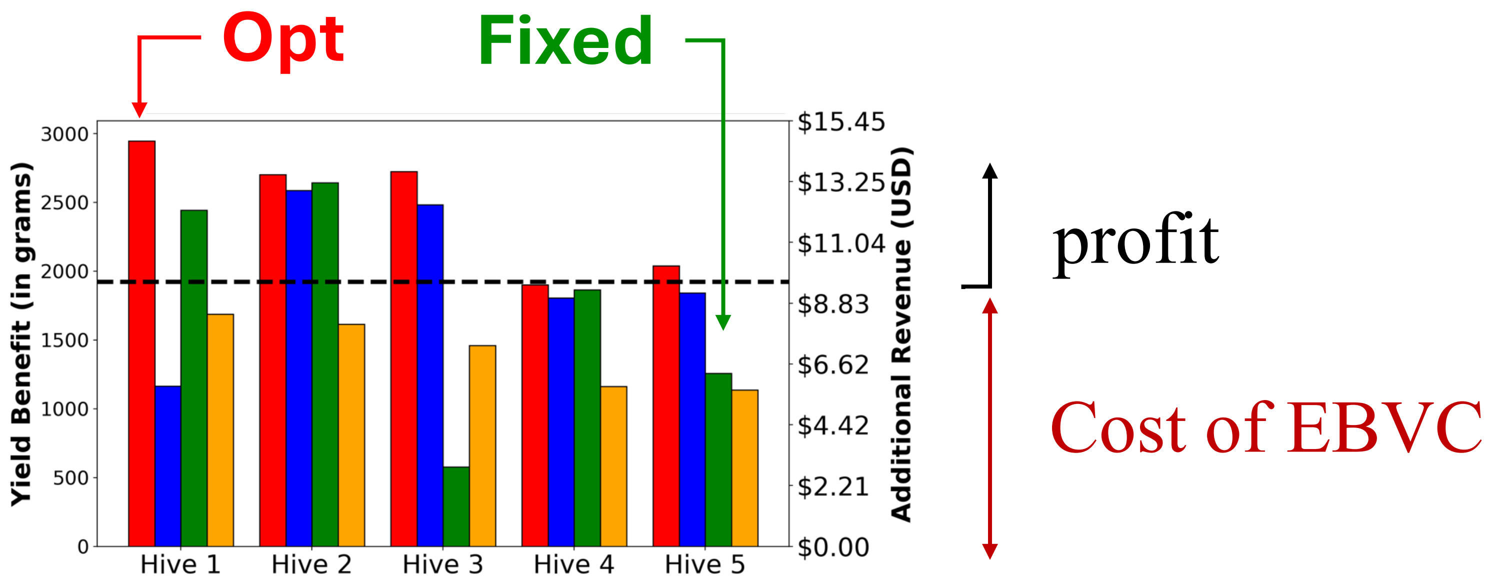
Q: Yield?

Baselines:
1. FCFS: First-Come First-Serve
2. Fixed threshold $\theta_{L_T} = 33^0C$, $\theta_{H_T} = 36^0C$
3. Fixed operation time



Estimated gain: ~ $71 / year

+ Even more: pollination benefits

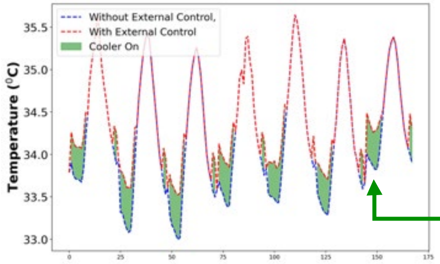
CONCLUSIONS

EBVC

- C1: $EBVC_{model}$ Thermal Model

$$\nabla^2\theta \propto \frac{\partial \theta}{\partial t} = \sum_j k_j(\theta - \theta_j) + \ \ldots$$

- C2: $EBVC_{honey}$ Honey Production



Saved effort

- C3: $EBVC_{opt}$ Temperature Control

Activate Heating

Activate Cooling

GitHub github.com/rtenlab/EBVC

Sponsor: USDA NIFA