A Methodology for Controlling Smart HVAC Systems in Planetary Environments

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VIRGINIA SPACE GRANT CONSORTIUM

Building lunar habitats

To explore space, astronauts need smart habitats that support life in harsh environments.

The moon's lack of an atmosphere causes extreme temperature fluctuations with temperatures dropping to -246°C and rising as high as 121°C.

HVAC systems are instrumental in these habitats because they maintain thermal comfort.

Can an HVAC driven by data collected on Earth operate in a lunar environment?

What is Model Predictive Control (MPC)?

A **cost function** is minimized through **control actions** for a **constrained system**.

This MPC

- minimizes energy use and maximizes thermal comfort
- simulates a building powered by the grid and solar energy

$$J = \min \sum_{t=0}^{N} |\gamma \times \text{HVAC Power}_t| + (\text{room temp}_t - \text{room temp}_{\text{desired}})^2$$

subject to

$$\begin{bmatrix} \text{room temp}_{t+1} \\ \text{battery E}_{t+1} \end{bmatrix} = A \begin{bmatrix} \text{room temp}_t \\ \text{battery E}_t \end{bmatrix} + B \begin{bmatrix} \text{HVAC power}_t \\ \text{PV power}_t \\ \text{grid power}_t \end{bmatrix} + E \begin{bmatrix} \text{outside temp}_t \\ \text{irradiance}_t \\ \text{internal gain}_t \end{bmatrix}$$

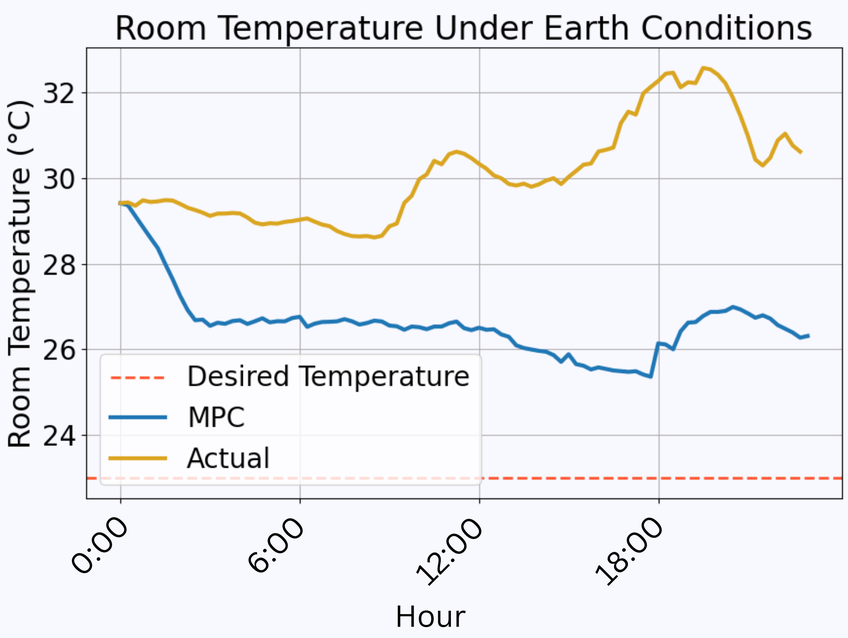
$$\begin{aligned} \text{battery E}_t &= 0 \\ -10 \leq \text{HVAC power}_t, \text{grid power}_t &\leq 20 \\ \text{HVAC power}_t &= \text{grid power}_t \\ 0 \leq \text{PV power} &\leq 0.2 \times \text{irradiance}_t \end{aligned}$$

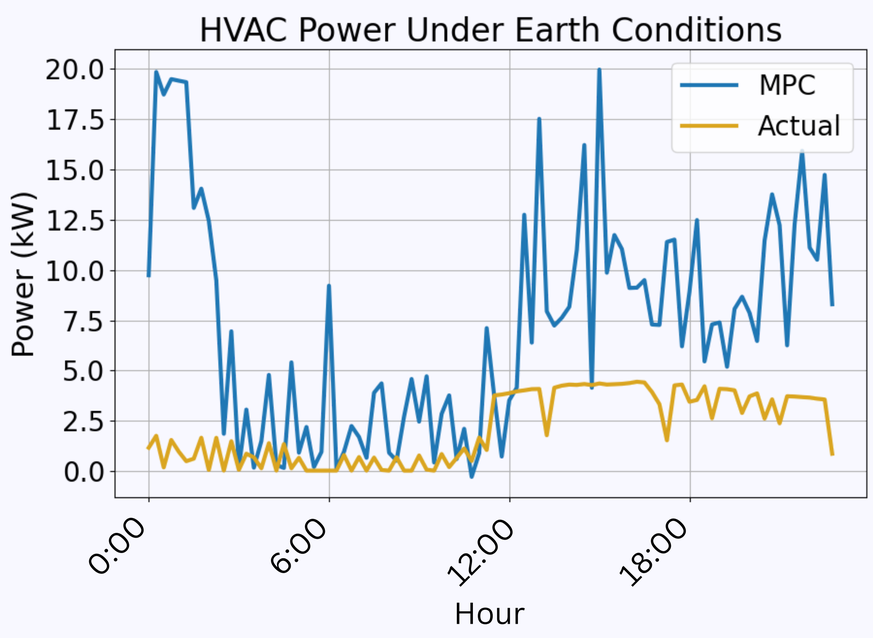
Simulating an HVAC on Earth

Data collected from Austin, Texas finetuned an MPC. The weights listed had low error rates.

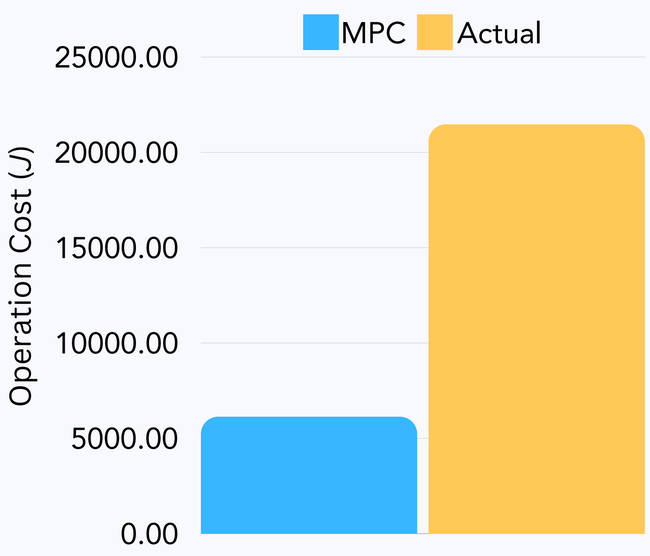
$$A = \begin{bmatrix} 1.00259 & 0 \\ 0 & 0 \end{bmatrix} \quad B = \begin{bmatrix} -0.01628 & 0.03451 & -0.01628 \\ 0 & 0 & 0 \end{bmatrix} \quad E = \begin{bmatrix} -0.00037 & 4.69157 \times 10^{-5} & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

While the MPC approaches the desired temperature, it requires more power than the system already in place.





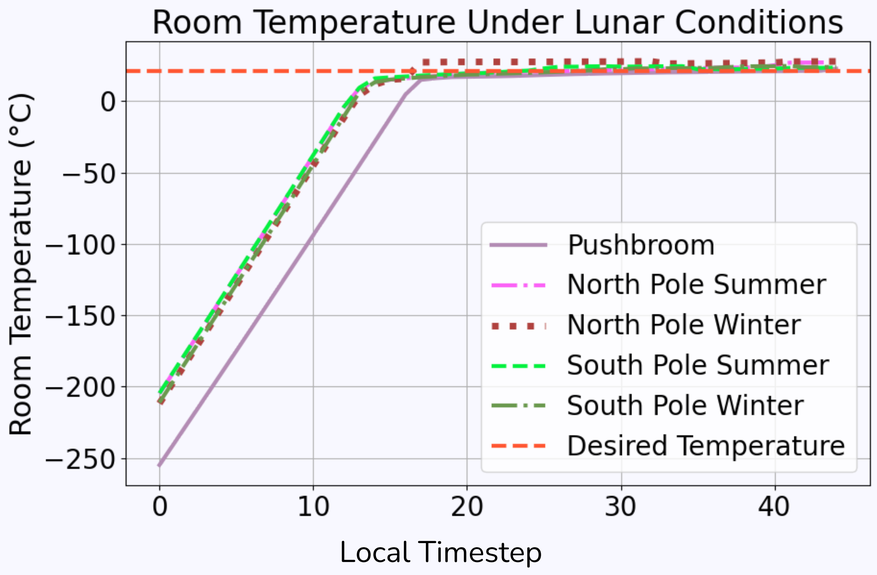
Despite this, the MPC outperforms the system already in place.

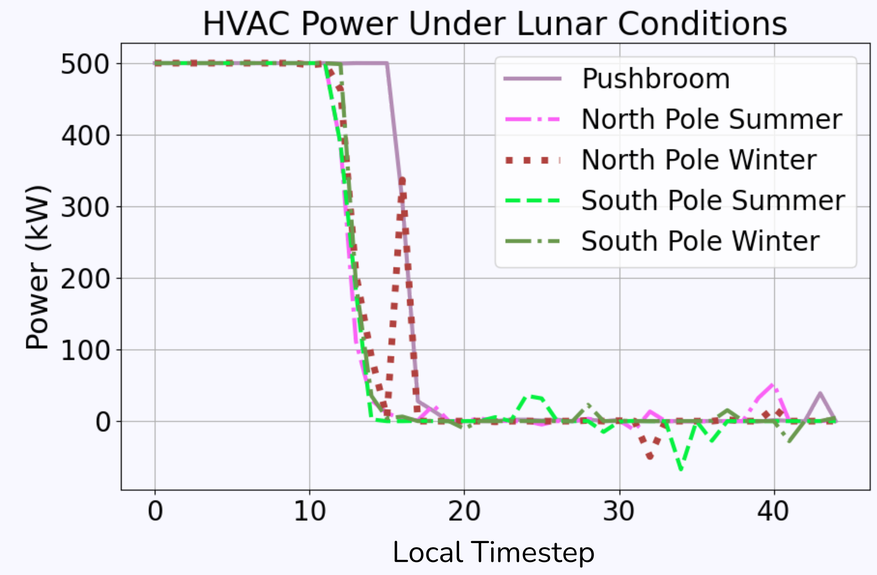


Simulating an HVAC on the Moon

Weights derived from Earth data had to be modified for the MPC to operate under lunar conditions

$$A = \begin{bmatrix} 1.00259 & 0 \\ 0 & 0 \end{bmatrix} \quad B = \begin{bmatrix} 0.01628 & 0.03451 & 0.01628 \\ 0 & 0 & 0 \end{bmatrix} \quad E = \begin{bmatrix} 0.00037 & 4.69157 \times 10^{-5} & 0 \\ 0 & 0 & 0 \end{bmatrix}$$





- While the MPC can heat a space to the desired temperature, the cost increases to over 1 million due to increased energy usage.
- If fed in correct data, this methodology could modulate heating and cooling power in a lunar habitat.
- The lunar south pole had the lowest operational cost *J*.

Limitations and Future Work

Technological Transferance

- HVACs calibrated to Earth cannot be used under lunar conditions and vice versa.
- The vast differences between the Earth and lunar environment could cause this failure of transferance.

Predicting radiance

- NASA does not collect data at the lunar poles. Pushbroom mapper data was used as a substitute.
- A supervised machine learning model could estimate these values

Reinforcement Learning

- Once deployed, the MPC weights do not adjust to accommodate changing conditions.
- Reinforcement learning eliminates this static design and could improve performance

EnergyPlus Models

- Factors such as HVAC efficiency, and home size influence heat transfer but are not represented in the MPC.
- EnergyPlus models account for these factors and offer a method of optimization.

Full Paper