A METHODOLOGY FOR CONTROLLING SMART HVAC SYSTEMS IN PLANETARY ENVIRONMENT

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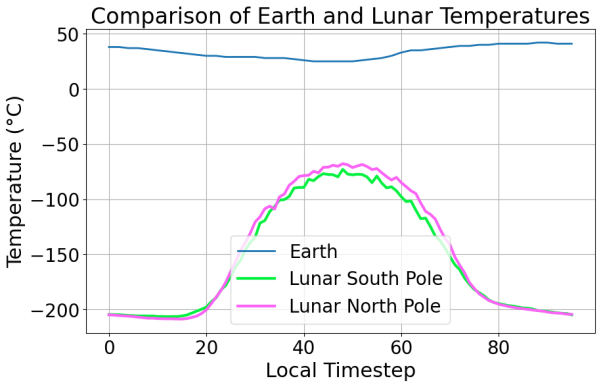

Figure 1: Summer Earth temperatures are significantly higher than that of lunar polar temperatures

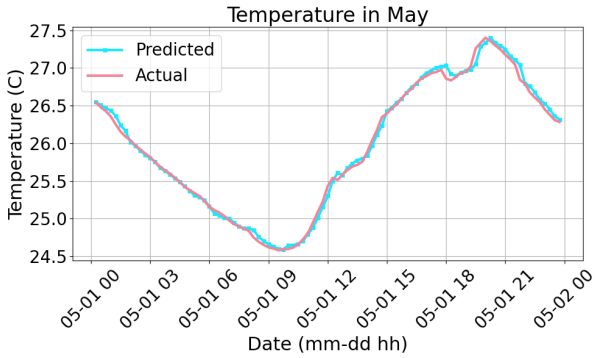

Figure 2: The predictions of the linear regression model closely follows actual values.

Abstract

Introduction

Methodology

Datasets
Pecan Street
Lunar Reconaissance Orbiter

Choosing a model

Formulating the MPC

RMSE	MAPE
0.138	0.305

Table 1: Errors for linear regression weights fitted to Pecan Street data

Results

Modeling an HVAC system on Earth

Modeling an HVAC system on the Moon
A Lunar MPC gone Wrong

MPC	Cost
Lunar-based MPC using earth weights	27,767,444.7
Earth-based MPC using lunar weights	48,504.8

Table 2: Miscalibrated HVACs

$$J = \min \sum_{t=0}^{N} |\gamma \times \text{HVAC Power}_t| + (\text{room temp}_t - \text{room temp}_{\text{desired}})^2 \tag{1}$$

subject to

$$\begin{bmatrix} \text{room temp}_{t+1} \\ \text{battery E}_{t+1} \end{bmatrix} = A \begin{bmatrix} \text{room temp}_t \\ \text{battery E}_t \end{bmatrix} + B \begin{bmatrix} \text{HVAC power}_t \\ \text{PV power}_t \\ \text{grid power}_t \end{bmatrix} + E \begin{bmatrix} \text{outside temp}_t \\ \text{irradiance}_t \\ \text{internal gain}_t \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} -1000 \\ -500 \\ -1000 \end{bmatrix} \leq D \begin{bmatrix} \text{HVAC power}_t \\ \text{PV power}_t \\ \text{grid power}_t \end{bmatrix} + G \begin{bmatrix} \text{outside temp}_t \\ \text{irradiance}_t \\ \text{internal gain}_t \end{bmatrix} \leq \begin{bmatrix} 1000 \\ 500 \\ 1000 \end{bmatrix} \tag{3}$$

$$\text{battery E}_t = 0 \tag{4}$$

$$-10 \leq \text{HVAC power}_t, \text{grid power}_t \leq 20 \tag{5}$$

$$\text{HVAC power}_t = \text{grid power}_t \tag{6}$$

$$0 \leq \text{PV power} \leq 0.2 \times \text{irradiance}_t \tag{7}$$

where:

- γ serves as the price for powering the HVAC. It is set to 4.322.
- $\text{room temp}_{\text{desired}}$ is the desired room temperature which is 21° Celsius
- A are the weights for the system: room temperature and battery energy level.
- B are the weights for the control inputs: HVAC, PV, and grid power.
- E are the weights for the external disturbances: outside temperature, irradiance, internal gain.
- D and G are weights for the mixed input constraints.

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

Figure 3: Weight matrices derived from Pecan Street data

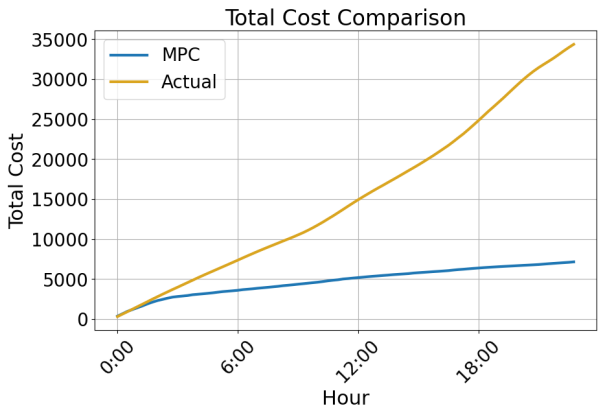

Figure 4: The MPC results in a cost of 7,160, outperforming the HVAC system in Austin, Texas that has a cost of 34,369.5.

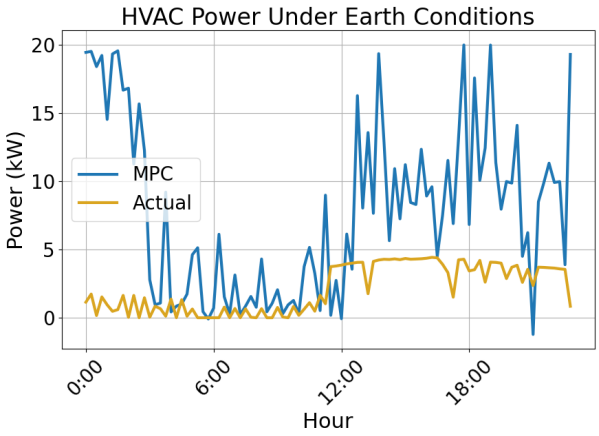

Figure 6: For the MPC to approach the desired temperature, the HVAC system must consume more power.

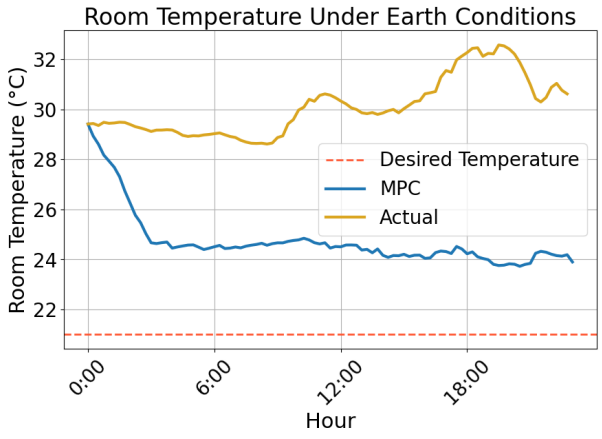

Figure 5: The MPC approaches the desired temperature whereas the HVAC system in Austin, Texas, does not.

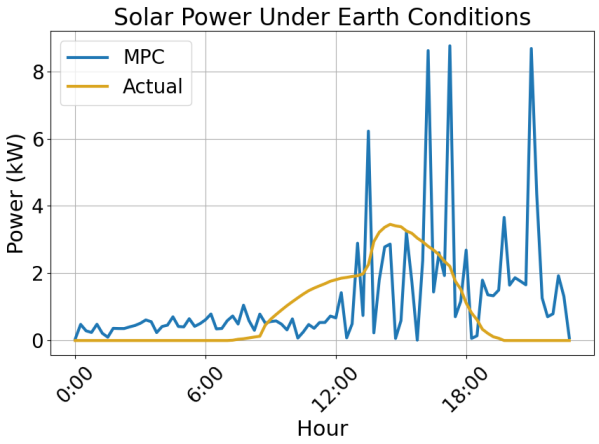

Figure 7: For the MPC to approach the desired temperature, the photovoltaic systems must produce more solar power.

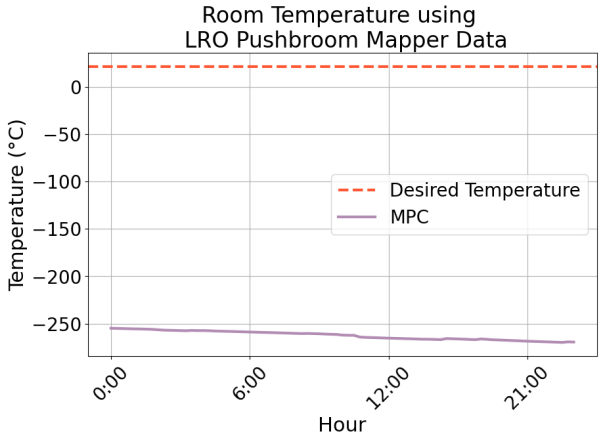

Figure 8: An MPC using weights derived from Pecan Street Austin, Texas data experiences lunar conditions. The MPC's behavior is unexpected as the temperature does not approach the desired temperature.

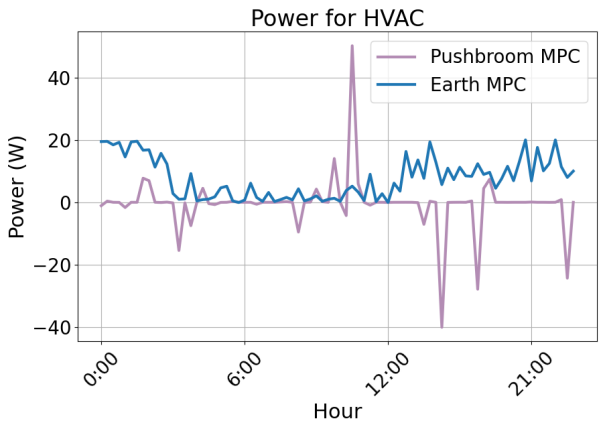

Figure 9: The HVAC power levels are nonsensical. As indicated in Figure 1, lunar temperatures are extremely low, meaning the HVAC would have to be heated and hence a positive number.

Altering the weights

Using lunar technology on Earth

Discussion

Limitations

References

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

Figure 10: Weight matrices derived from Pecan Street data

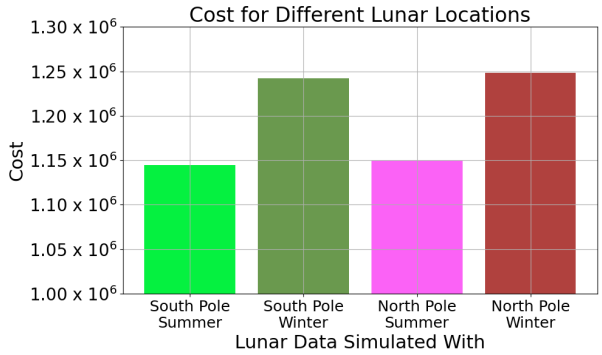

Figure 11: The cost of operating an HVAC MPC are significantly higher 7160.3, the cost of operating one on Earth. These costs are significantly lower than the cost associated with the pushbroom mapper: 2,090,326.9.

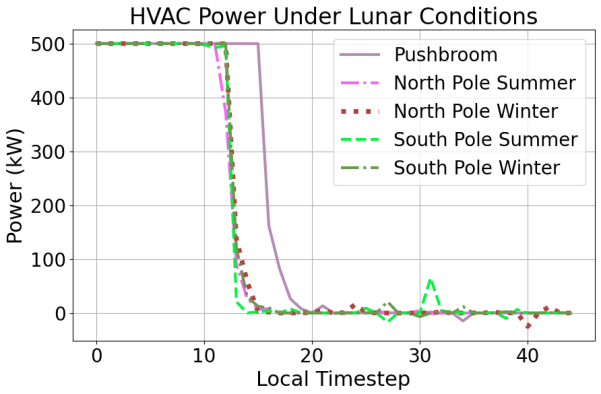

Figure 13: While all HVAC power levels eventually converged to 0, the MPC exposed to pushbroom data took longer to converge to this value as opposed to other MPCs.

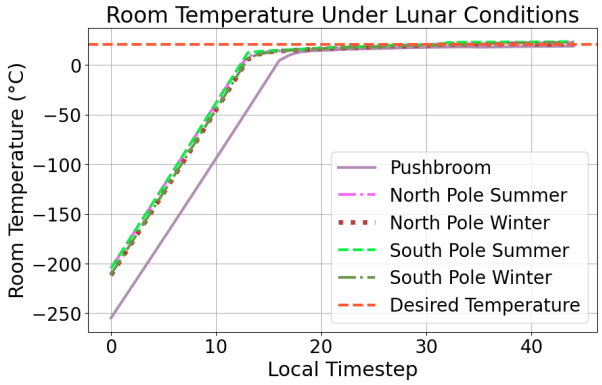

Figure 12: An MPC using lunar weights was exposed to many different polar and seasonal conditions. The MPC exhibited similar behavior across all scenarios.

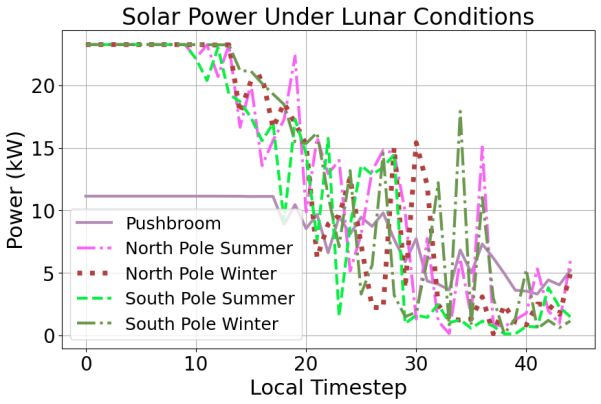

Figure 14: The photovoltaic power required by each MPC varies from lunar dataset to dataset.

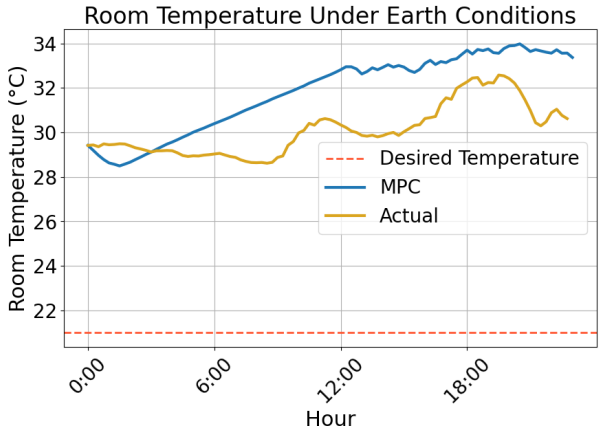

Figure 15: An MPC using lunar weights was exposed to Earth conditions. The resulting indoor temperatures did not approach the desired level.

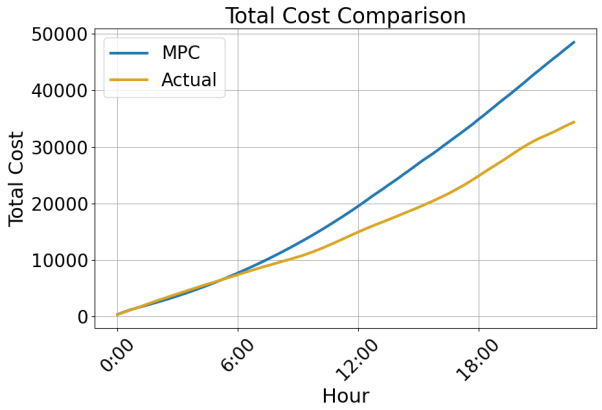

Figure 16: The same MPC mentioned in Figure 15 resulted in costs much higher than the control: the HVAC system already present in the house.