NSIN Radome Heating

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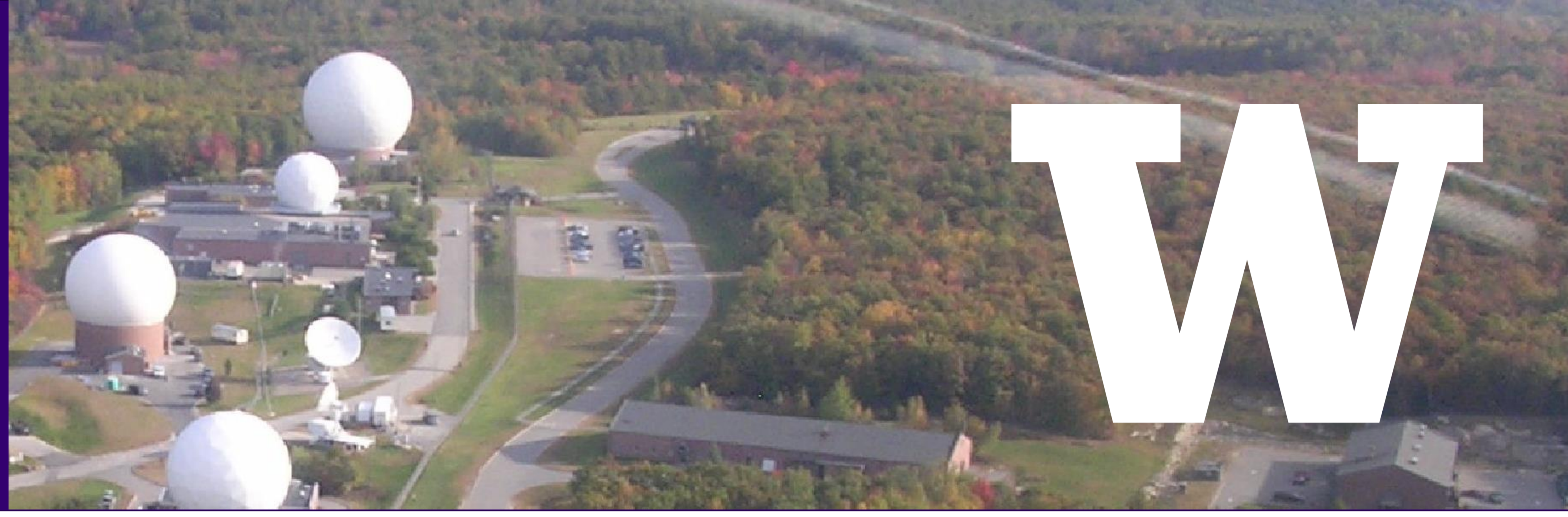

INTRODUCTION

Space Base Delta 1 is a United States Space Force garrison command that operates a network of US Space Force stations across the globe, which use ground-based radar equipment to communicate with satellites. They commissioned a case study of the 76' Radomes at New Boston Space Force Station (NBSFS) to determine ways to reduce energy used to heat the domes.

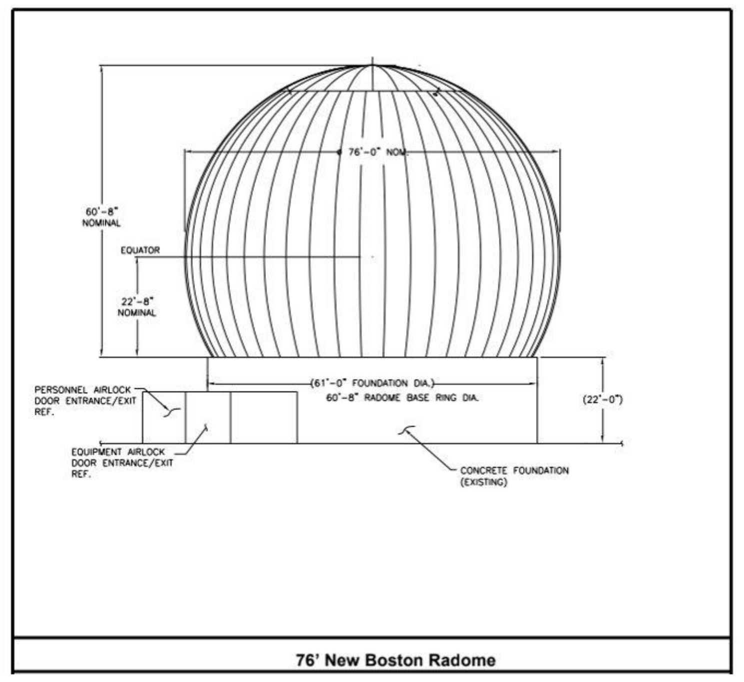

Figure 1: NBSFS 76' Radome

What is a Radome?

A Radome is a dome consisting of a thin polymer sheet (usually inflated with pressurizing blowers) that covers and protects radar antennae from the outside elements, while allowing radio waves to penetrate through.

PROBLEM STATEMENT

"We need to determine the most practical changes to be made at NBSFS to reduce the volume of fuel oil used to heat its Radomes, and to illustrate the effects and cost savings of such changes."

CORE FUNCTION

The basis of our project was to create a model for all the energy transfer processes in the Radome. We considered a numerical FEA approach, but we settled for an analytical approach using python, evaluating the heat flows through our control volume (Figure 2). Q_vent represents heat lost through air vented out, and Q_loss represents heat conductively lost through the radome skin.

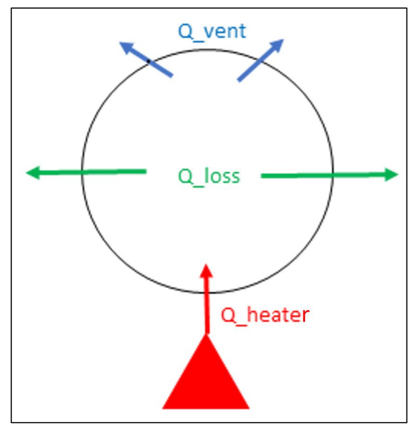

Figure 2: Radome control volume

Q_loss is calculated analytically using equation 3, which utilizes the method of equivalent thermal resistance, as shown in figure 3. The internal convective and conductive resistances are both invariant and taken from ASHRAE [1] documentation, and thermal tests* respectively. The external convective resistance is derived from a linear relationship defined in ASHRAE [1] documentation, as a function of windspeed (mph), and shown in Equation 6.

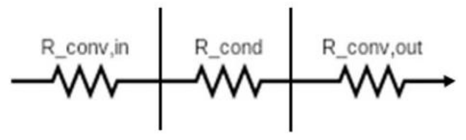

Figure 3: Thermal resistance method

DESIGN AND DEVELOPMENT

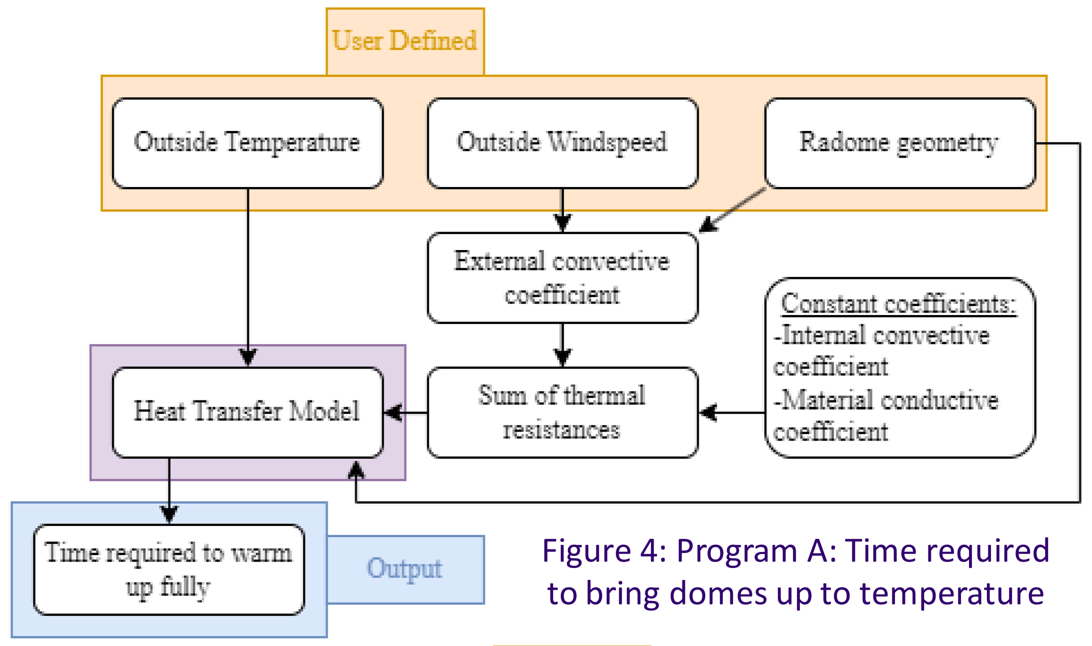

Figure 4: Program A: Time required to bring domes up to temperature

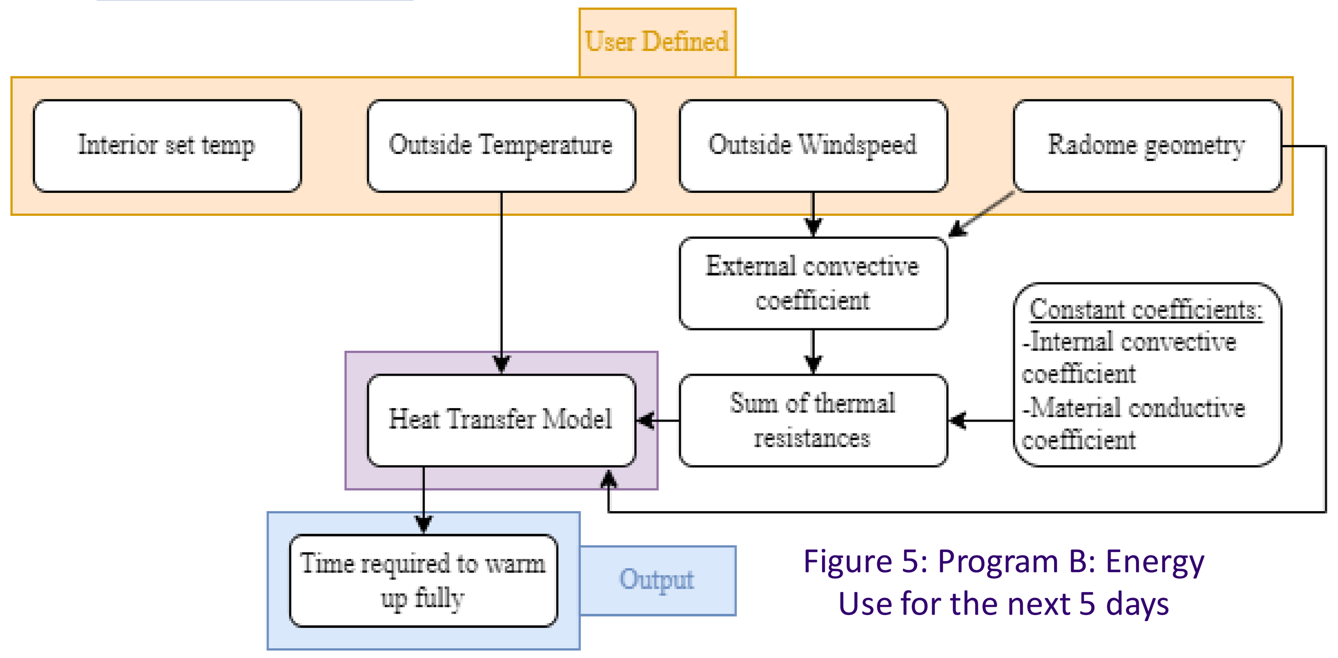

Figure 5: Program B: Energy Use for the next 5 days

$$Q = Q_{heater} - Q_{loss} - Q_{vent} \qquad \text{Equation 1}$$

$$Q_{heater} = 979,000\ \frac{BTU}{hr} = 287,097\ W \quad (if\ active) \qquad \text{Equation 2}$$

$$Q_{loss} = (T_{in} - T_{out}) \cdot A \cdot (R_{conv,in} + R_{cond} + R_{conv,out})^{-1} \qquad \text{Equation 3}$$

$$Q_{vent} = \dot{V} \cdot c_p \cdot (T_{in} - T_{out}) \qquad \text{Equation 4}$$

$$T_{in}[i] = T_{in}[i-1] + \frac{Q}{c_p V} \qquad \text{Equation 5}$$

$$R_{conv,out} = (2 + \frac{2}{7.5} * wind\_velocity)^{-1} \qquad \text{Equation 6}$$

Heat Transfer Model

The heat transfer model, shown in purple in figure 3/figure 4, and described under core functions is the basis for all preceding analysis. It utilizes equation 1 to yield an output in watts, representing total energy flowing into the dome (negative for net loss) using 3 inputs: equivalent thermal resistance, .

We determined that the two most practical ways to save energy were:

1. Turning on the heat only when necessary
2. Keeping the heat on, at a lower temperature

From here we developed 2 separate programs, A and B, shown in figures 4 and 5, to illustrate our findings. Program A estimates the time it will take to warm up the dome, and Program B estimates fuel usage for the next 5 days based on weather data, and various user inputs.

RESULTS/VALIDATION

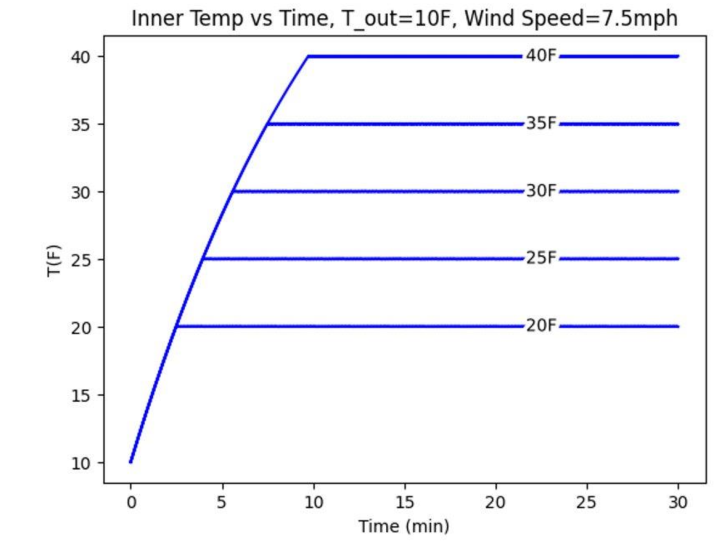

Figure 6: Times required to heat up to various temperatures, T_out=10F, Windspeed=7.5mph

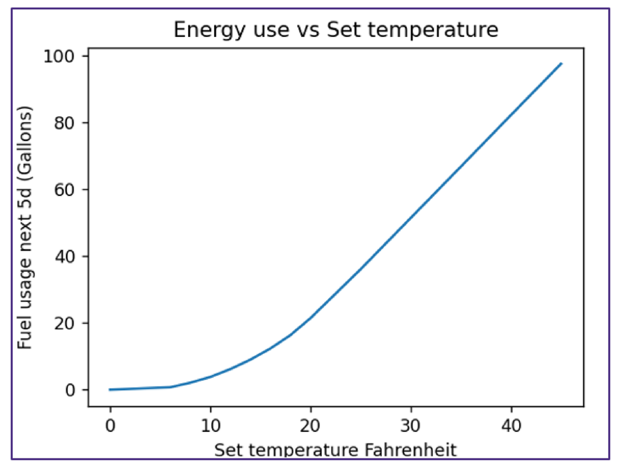

Figure 7: Energy use vs interior set temp

Taking a look at our results, there are two main points. First, from the results from program A illustrated in figure 6, the time required to heat up the dome is on the order of 10 minutes. The heaters could be left off most of the time, and the domes could be brought up to temperature on short notice even in cold/windy conditions. Secondly, small changes in interior set temperature can reduce fuel usage by a large percentage under the right conditions. Figure 7 illustrates energy savings at Pituffik SFS in Greenland, based on a 5d forecast of springtime conditions. Lowering the interior set temperature from 20 to 10 results in a tenfold reduction in energy use.

CONCLUSION & FUTURE WORK

- **While our work is specifically a case study of NBSFS, the results can be applied to the other bases in the Space Base Delta 1 network, specifically Greenland where it gets much colder.**
- **By turning off the heaters completely, the DoD could be saving up to 115,000$ at NBSFS, and 250,000$ at Pituffik SFS per Radome, per year**
- **Our programs only show our best estimation based on theory, and could be calibrated further for better accuracy of energy and fuel consumption with more real-world data**

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Mechanical Engineering Capstone Exposition
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*Thermal tests for thermal conductivity were conducted using Anter Unitherm® model 2021-SX67 Thermal Conductivity Instrument

[1] American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE Standard : Standards for Practices for Measurement. Testing, Adjusting, and Balancing of Building Heating, Ventilation, Air conditioning, and Refrigeration Systems New York: The Society, 1988.