2022 SUMMER: CORE RESEARCH INTERNSHIP CHALLENGE

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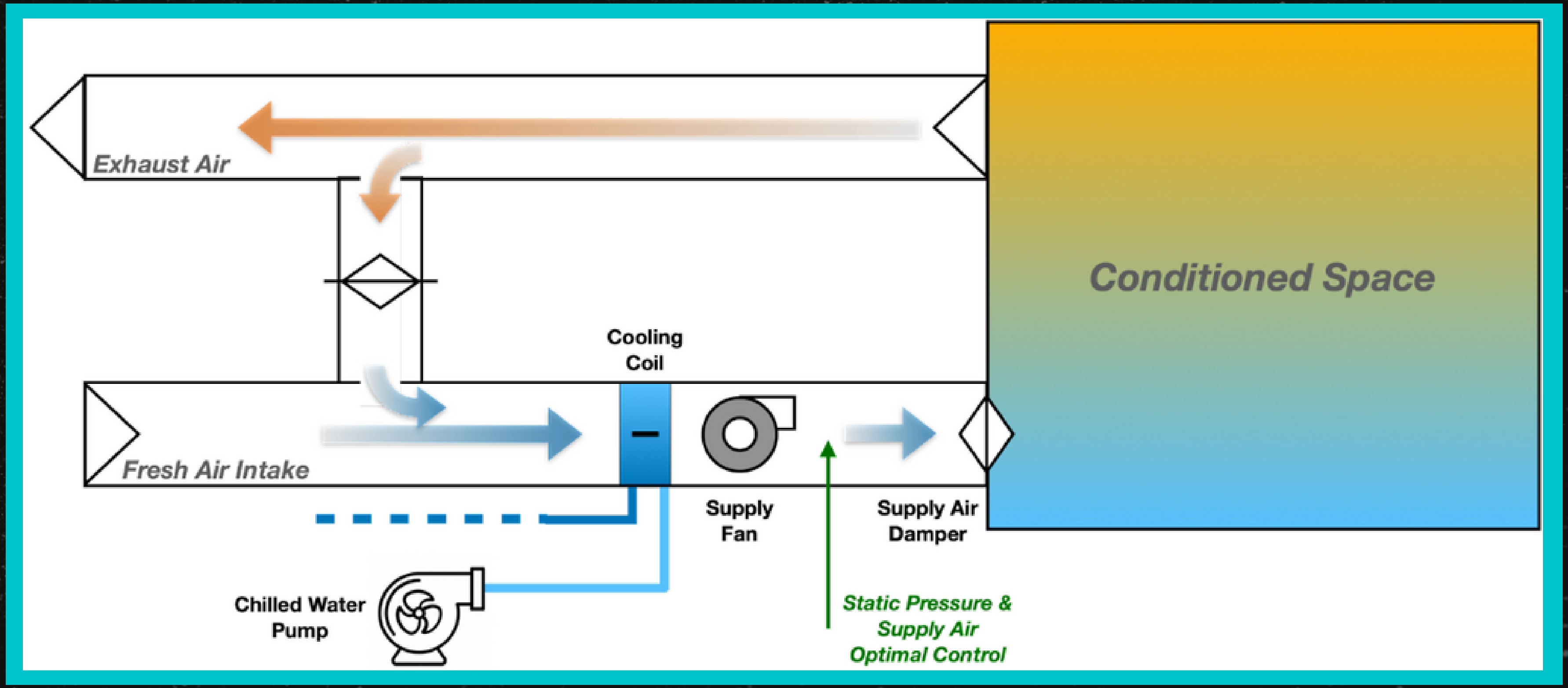
C1: RESEARCH & INVESTIGATION

What is an AHU with VAV?

An AHU with VAV is an Air Handling Unit that uses Variable Air Volume to vary airflow at a constant temperature to regulate building temperature.



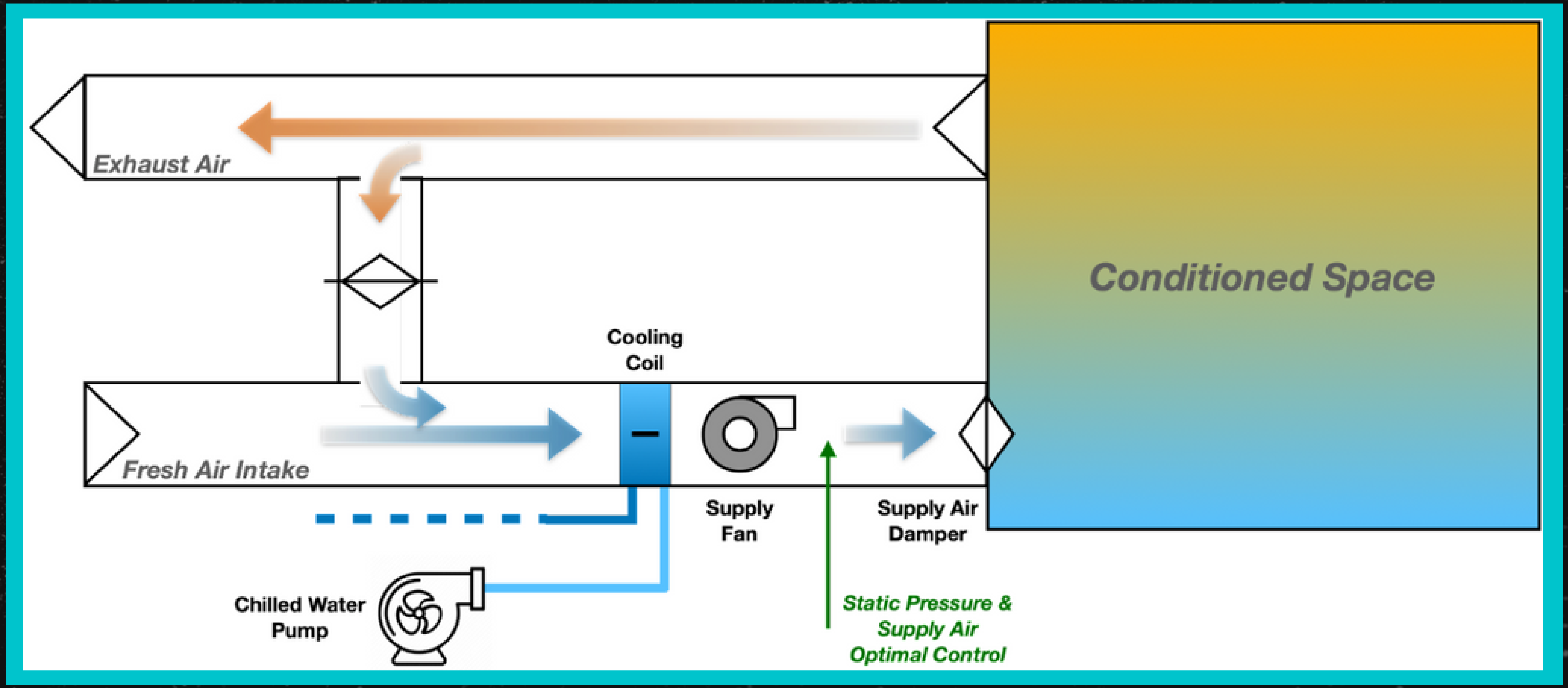
The Main Components

- Chilled Water (CHW) Pump: pumps chilled water from the chiller to the CHW coils and returns back to the chiller, absorbing heat In the air through the coils
- CHW Valve: Modulates the amount of CHW through the coil.
- CHW Coil: Exchanges heat between air and CHW to cool down air.
- Supply Fan: Circulates air to bring In cool, fresh air and extract old hot air.
- Supply Air Damper: Controls the amount air flow Into the space.

C1: RESEARCH & INVESTIGATION

How Does It Work?

The AHU takes takes fresh air and runs them through the building ducts to heat and cool different rooms in the building and takes the old air and runs it back to the AHU to be exhausted from the building. The AHU with VAV uses a supply fan to push fresh air through the ducts of the building to condition rooms (generally at 55 Fahrenheit). The VAV located for each room controls the flow of air into a room given the current temperature in the room. If a room needs more cool air, the damper position opens more. Rather than varying the temperature, the AHU with VAV, varies airflow at a constant temperature to modulate room temperatures. This results In more precise temperature control and less energy consumption.



C2: A DATA DRIVEN MODEL

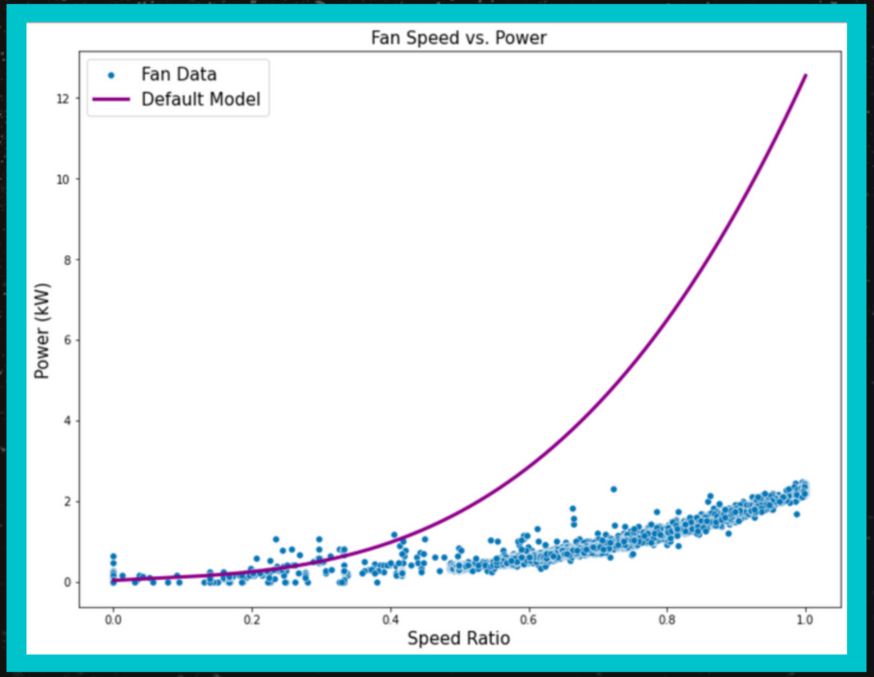
$FanPower \sim f(FanSpeed)$

The Data

- 35040 training examples. Fan Speed (Hz) and Fan Power (kW).

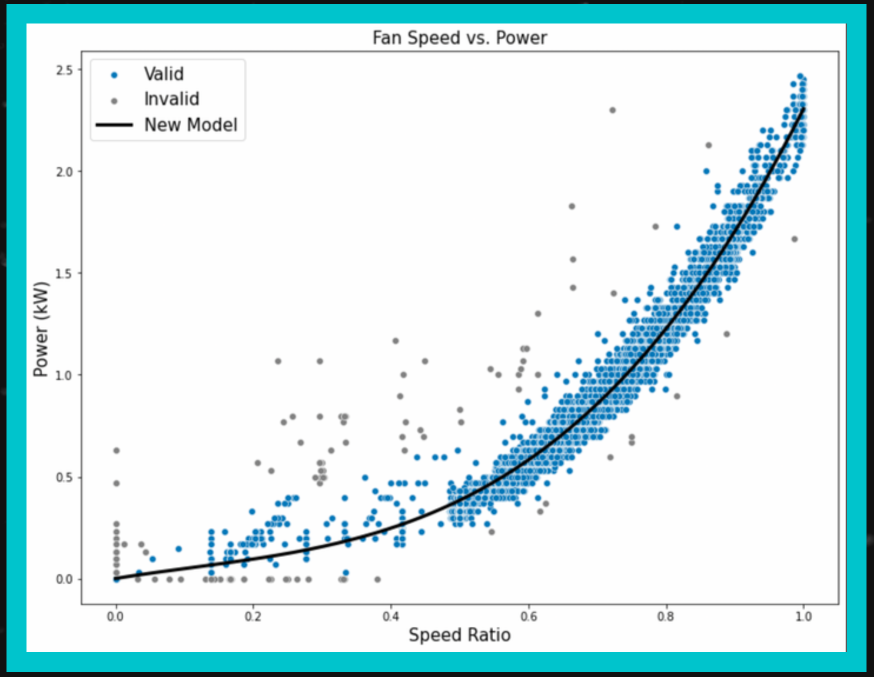
The Default Model

- Horsepower (hp) = 15, Efficiency (eff) = 0.9, Speed Ratio (freq), FanPower (kW)
- $FanPower = (1.0608*freq^3 - 0.1222*freq^2 + 0.0684*freq + 0.0022)*hp*0.7457/eff$
- Coefficient of determination (R^2) = -20.10609



A New Model

1. Normalize the Speed (Hz) to a Speed Ratio (Range 0-1) using a max Speed of 60Hz.
2. Clean and filter data based on impossible and unlikely results
   a. Assume a non-zero fan speed requires a non-zero fan power and vice versa
      i. Label any data that goes against this as invalid
   b. Use the third fan law: $HP_2 = HP_1 * (\frac{RPM_2}{RPM_1})^3$ to require a cubic relationship between speed and power
      i. Fit a cubic model, with a constraint of the the intercept being at 0 with the valid data.
      ii. Create bounds on either side of the fit using the average spread at each Speed Ratio to determine outliers.
      iii. Label any data outside these bounds as invalid
3. Refit a model based on the valid data.
   - $FanPower = 2.63482freq^3 + -0.87385freq^2 + 0.54521freq$
   - Coefficient of determination (R^2) on valid data = 0.99423



C3: POWER OPTIMIZATION

Choosing an Optimization Method

Problem Definition

Two pieces of equipment, the AHU fan and the CHW pump are consuming electric power. Find the values for the static pressure set point and supply air temperature set point that will minimize the total power consumption given the constraints.

The Setup

We are given a Nonlinear Programming (NLP) problem with a smooth, linear cost function and a set bounds and nonlinear constraints. More details on the next slide.

Chosen Approach

- Deterministic/Algebraic Optimization using an NLP solver
    - Sequential Quadratic Programming (SQP), and more specifically **Sequential Least Squares Programming** (SLSQP)
        - An iterative method for **Constrained Nonlinear Optimization.** Requires that the objective function and the constraints are twice differentiable, which Is the case.
        - Easy to implement In Python with SciPy

C3: POWER OPTIMIZATION

Formulation of Optimization

As a Mathematical Optimization:

(1) **Objective Function and Control Variables**

$$\min_{P_{Static},T_{SA}} \quad P_{fan} + P_{pump}$$

(2) **Bounds and Inequality Constraints**

$$\begin{aligned}
\text{s.t.} \quad & Pos_{damper} < 1 \\
& 0.15 < S_{fan} < 1 \\
& 0.3 < S_{pump} < 1 \\
& 0.3 < P_{static} \leq 2.5 \\
& 55 < T_{SA} < 70
\end{aligned}$$

(3) **Equality Constraints**

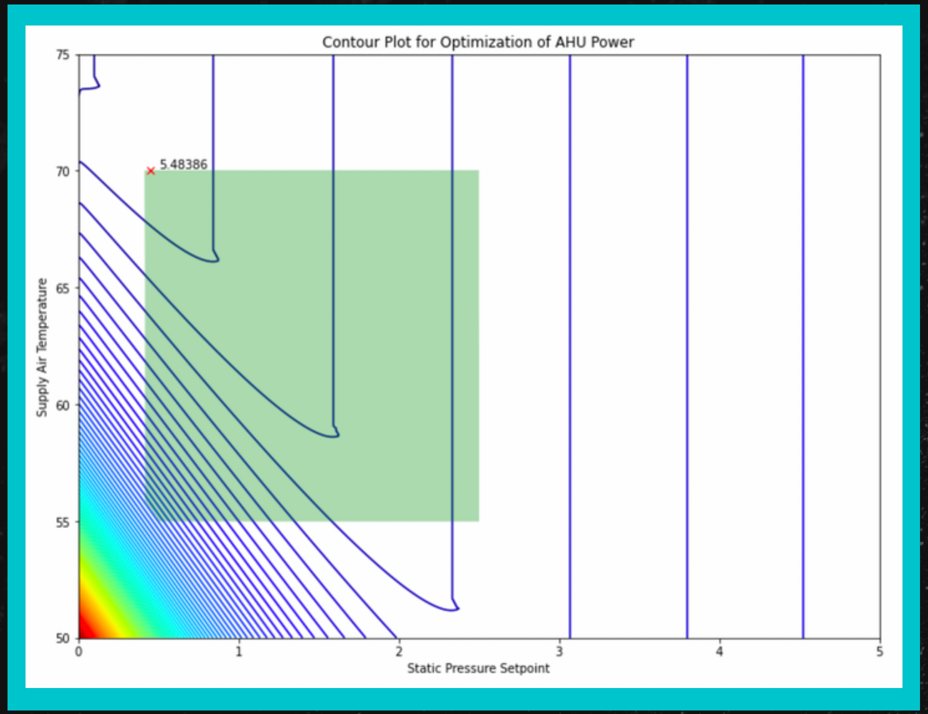
$$\begin{aligned}
\text{where} \quad & S_{fan} = (28.345(P_{static})^{0.3412} * Load_{fan})/60 \\
& \qquad \text{given } Load_{fan} = 1 \\
& S_{pump} = \begin{cases} 0.6 & T_{SA} \geq (60 - (P_{static} - 1.5) * 10) \\ 0.0015(AdjT_{SA})^2 - 0.1845 AdjT_{SA} + 6.2675 & otherwise \end{cases} \\
& \qquad \text{given } AdjT_{SA} = T_{SA} + (P_{static} - 1.5) * 10 \\
& P_{pump} = (1.0608 S_{pump}^3 - 0.1222 S_{pump}^2 + 0.0684 S_{pump} + 0.0022) * HP_{pump}(0.7457/Eff_{pump}) \\
& \qquad \text{given } HP_{pump} = 25 \;\&\; Eff_{pump} = 0.9 \\
& P_{fan} = (1.0608 S_{fan}^3 - 0.1222 S_{fan}^2 + 0.0684 S_{fan} + 0.0022) * HP_{fan}(0.7457/Eff_{fan}) \\
& \qquad \text{given } HP_{fan} = 15 \;\&\; Eff_{fan} = 0.9 \\
& Pos_{damper} = -0.221(P_{static})^3 + 1.1788(P_{static})^2 - 2.1134 P_{static} + 1.6964 + Load_{damper} \\
& \qquad \text{given } Load_{Damper} = 0
\end{aligned}$$

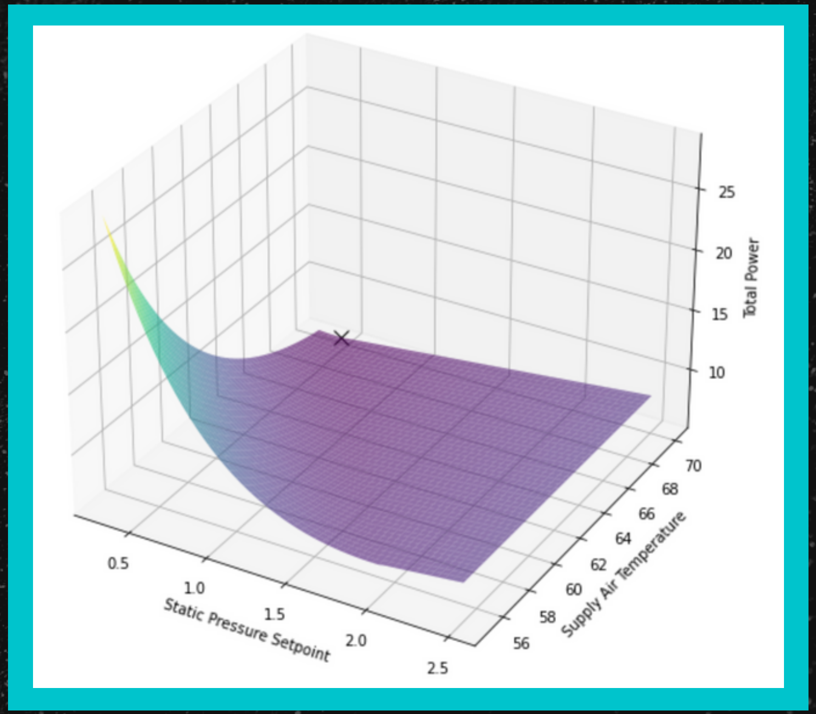
C3: POWER OPTIMIZATION

Results of Optimization

The Design Space

The design space is shown as a contour plot with constraints on the left and as a surface plot on the right. The 'X' marks the minimization of the objective function given the constraints. You can see how the combination of a low static pressure and low temperature leads to higher power consumption.





The Solution

The total power Is minimized when the static pressure = 0.44958 and the supply air temperature = 70. This results in a power consumption of 5.48386 kW.

C4: CLOSING THOUGHTS

An Imperfect Problem

Given the nature of the problem, some assumptions must be made. Some assumptions that might be too ideal would be the efficiency of the fan and the pump. Currently they both default to 90% efficiency, however this may not always be the case

When implementing this solution In a real environment there will be many other variables to consider. It may not always be the case that we want the power to be minimized. Likely there will be another set of constraints on the temperature of the conditioned space that we will need to adhere to In order to make sure we are minimizing the power while keeping the space well conditioned.

In order to fully optimize the AHU, a lot of other information would be useful. This includes but is not limited to, the size of the room, the temperature that we want the room to be, the size of the blades on the fan, the temperature of the fresh air intake, and the dimensions of the ventilation system.