Midterm Presentation: Impact of Thermostat Accuracy

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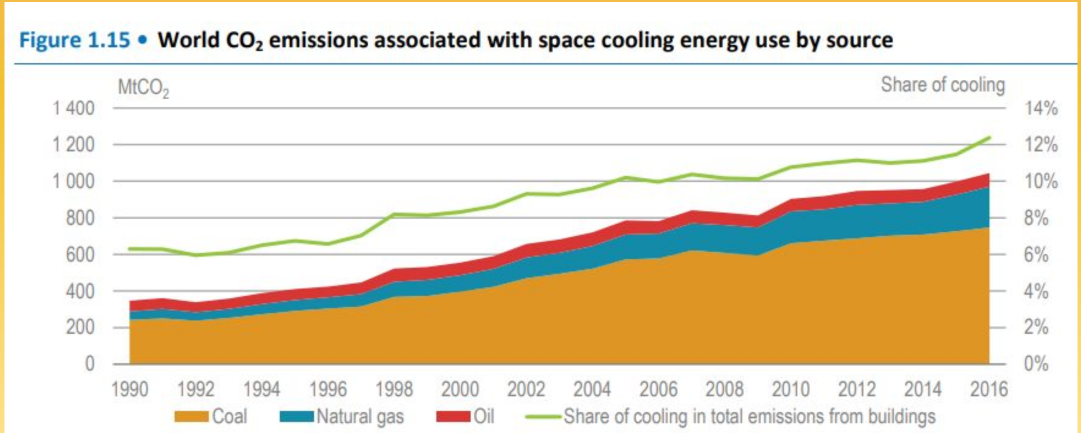
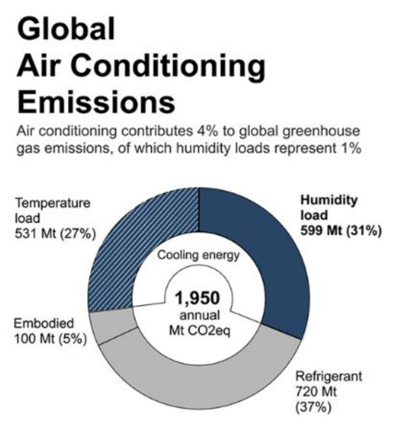
Introduction

- Woods et al. highlighted that 3.9% of global greenhouse gas emissions and 20% of building electricity use stem from air conditioning systems
- This emphasizes the importance of managing both temperature and humidity for energy efficiency since appropriate control of both is necessary to minimize excess use of energy and refrigerant materials for air conditioning and reduce costs of HVAC systems.





Research Question + Hypothesis

- Our research aims to answer the question "What are excess energy and financial costs resulting from inaccurate thermostats installed in a room?".
- By understanding thermostat control and improving HVAC system efficiency, we hypothesize that such a simulation will state that we can reduce energy consumption, minimize emissions, and minimize long-term costs through retrofitting HVAC infrastructure.
- Figure to the right is from the EIA's AEO report from 2017, representing all the sectors of energy consumption nationally for office buildings in quadrillions of BTU (Quads in the chart).

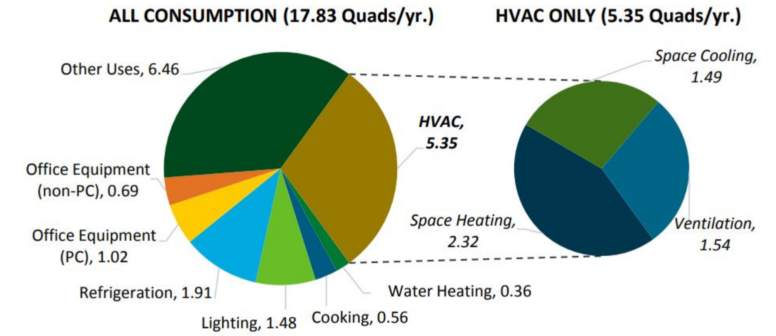


Figure 1: Commercial primary energy consumption by end use, Quads/yr. (2017)

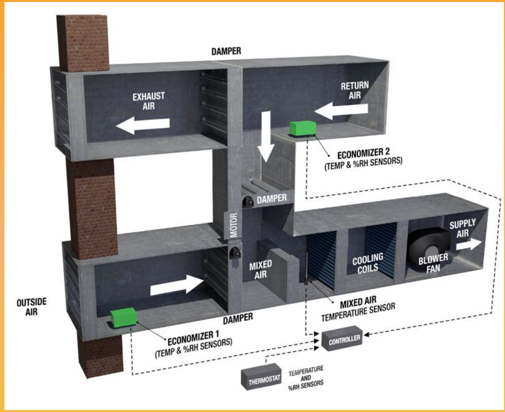
Source: EIA AEO (2017)[2]

Brief Overview: HVAC Units and (Inaccurate) Thermostats

- 3 Major Steps for effective simulation:
  - Measures for Designing HVAC Systems
  - Sources for Inefficiency in HVAC Systems
  - Models for simulating thermostat control
- Each step correlates with increasing temperature reading accuracy in the sensors, thus leading to accurate shut off corresponding to actual temps.

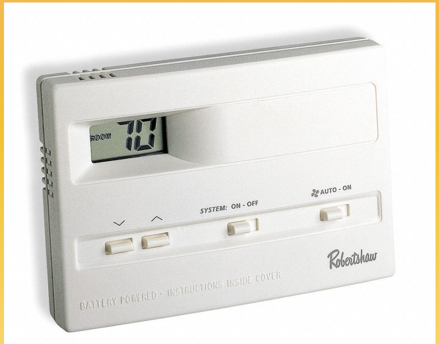
HVAC Units: Measurement

- Need an in-depth analysis on the data that HVAC Thermostats take, and their workings.
- Philip Luu, Texas Instruments;
    - General Structure of a HVAC System
        - Thermostat with sensors + User Control
            - Sensors: Humidity + Room Temperature
        - Central Controller for controlling the behaviour of air in the room
    - Modern systems may include two enthalpy economizer sensors, with one located in the return air path and other in the outdoor air path.
    - Older ones consist of NTCs and resistive temperature detectors.
    - Newer ones are more efficient in situations consisting of higher humidity levels, as the amount of cooling needed to dehumidify air is much lower than that to lower the temperature in mechanical systems.



Sources for Inefficiency in Thermostats

- Inaccurate Thermostats can account for up to about 5-20% extra energy use.
- Readings off by +/- 1C, or by 5% humidity often end up using significantly more energy
- Exemplified in older kinds of thermostats:
  - Due to usage of Bimetallic Strips which lose accuracy over time
  - Need to be extensively calibrated every 2 years or so by a professional
  - Sensor drift over time: inaccuracy increases due to wear and tear
  - Majority of campus relies on these thermostats, found various off readings
- Newer “smart” thermostats are less prone to Sensor Drift, and stay accurate for longer
  - Limitation: Physical Factors



Sources for Inefficiency in Thermostats

- Placement of the thermostats in the context of the surrounding environment
    - Windows, edges of room, and sheltered areas of room often lead to inaccuracy
    - Occupancy may also affect temperature readings, but considered negligible for our purposes
    - Too close/too far from HVAC units; proximity from direct sunlight
    - Untrackable factors: room materials, insulation, height of the sensor, enclosures, HVAC system maintenance

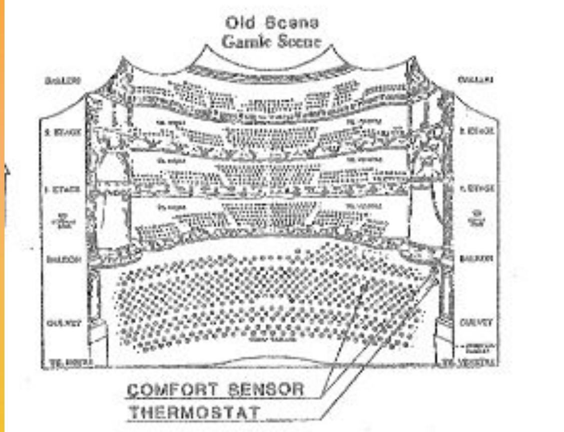


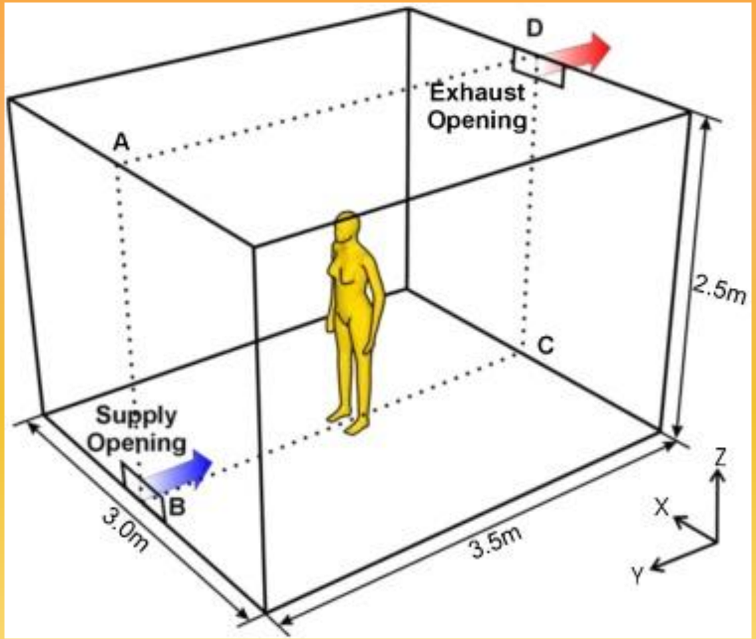
Figure 6. Thermostat position and measuring points in the Royal Theater, Old Scene.

Sources for Inefficiency in Thermostats, Contd.

- Madsen T.L., *et. al*; Denmark Technical University:
    - Thermostats placed in more central locations often lead to better accuracy for overall room temperature.
    - This includes corners, edges, near windows, and everything in-between.
        - Tested in various conditions:
            - Living Room
            - The Royal Theater at Denmark
            - Danish Parliament
    - Better accuracy of overall room temperature = more efficient HVAC energy consumption
    - Personal university experience: most thermostats are...
        - located on the walls
        - right next to a window
        - at a height or in an enclosure in some cases
        - are using the old unreliable standard
    - Obviously there are going to be temperature discrepancies in the thermostats
        - but by how much?
        - and how much extra are we paying in the context of energy used + finances?

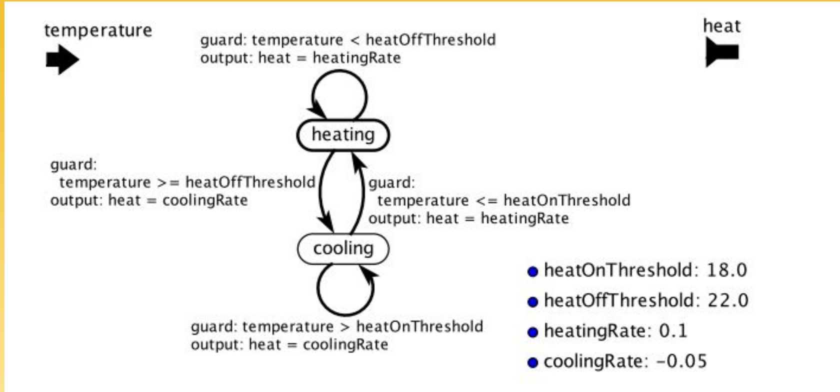
Thermodynamic Assumptions

- Room is a rectangular prism
- Desired room temperature is around 70℉ when occupied
  - In colder temperatures, thermostat can be lowered no lower than 50 ℉ when unoccupied
  - In warmer temperatures, thermostat should only be raised 5 ℉ above desired temperature when unoccupied
- Occupants are sleeping/outside for 8 hours/day
- Outdoor temperature is constant



Models for Simulating Thermostat Control

- We will model both physical phenomena [i.e. the flow of air through the ducts and their effect on room temperature] as well as controls for such phenomena to occur [thermostats and the control system for the HVAC]
- Our simulation will consist of a hybrid of Finite State Machine (FSM) models for thermostats and a PID controller model for the controls that determine airflow through the ducts to maintain a certain temperature.



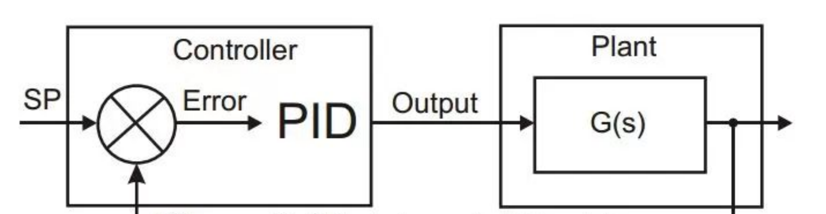


Fig 3: Block diagram for PID control

Example GUI for Our Simulation

Outdoor temp: avg/variance

Indoor temp: desired avg/actual avg

Room [give dimensions]

Location/ accuracy table of the thermostats

Drag/drop windows and doors menu:

Drag/drop thermostats menu:

Key desired temperature points drag/drop

AIRFLOW CONTROL Y/N

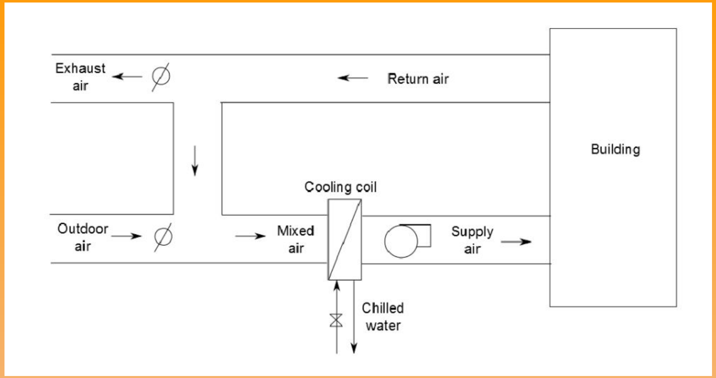
SET AS BASELINE

Excess energy used per year [kWh]:

Excess cost [USD]: $

Methods and Evaluation

- This would help us in creating a simulation to determine the excess energy and financial expenditure generated by these inaccurate thermostats.
- We would use existing experimental data to compare the results of our simulations with, to ensure accuracy and validity.
- *Low-Frequency Power-Grid Ancillary Services From Commercial Building HVAC Systems*, from Lin et. al has field data from Pugh Hall at University of Florida that they use to evaluate a similar simulation, and we will use parallel methods.



Thank you!

Questions?