Integrated Facility HVAC Energy Consumption Model

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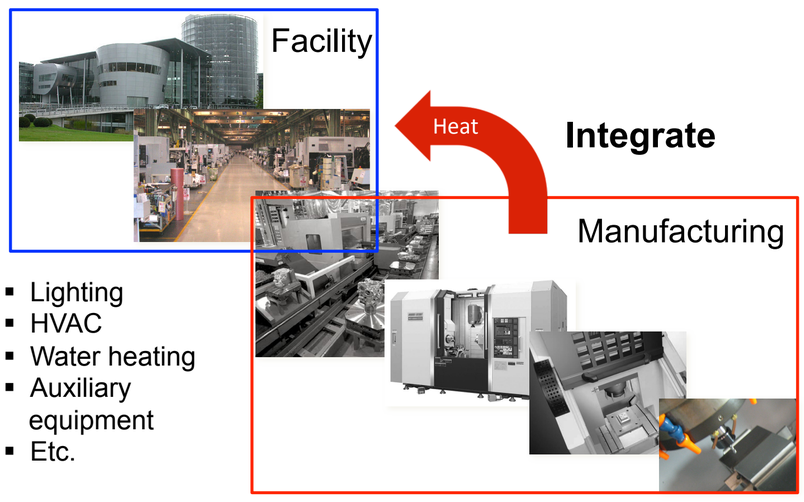
Objectives

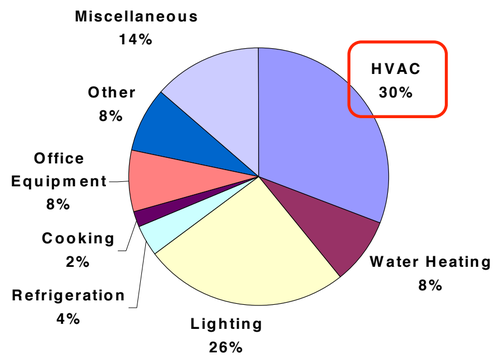
- Create a simply yet comprehensive facility (HVAC) energy consumption model
- Integrate activity (i.e. heat dissipation) during manufacturing via parameterization of a thermodynamic model



Introduction

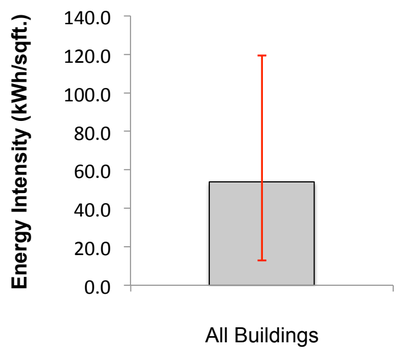
- Facility level energy consumption is non-negligible
- Numerous factors involved: location, building type, temperature and humidity, process equipment, etc.
- Existing professional software: overly complex; lack parametric ability for manufacturing, difficult to integrate with other models

Commercial Building Primary Energy Consumption Breakdown



Source: Roth, K.W. et al. (2002)

HVAC Electricity Consumption Intensity



Source: 2003 CBECS Survey Data (2008)

Model Overview

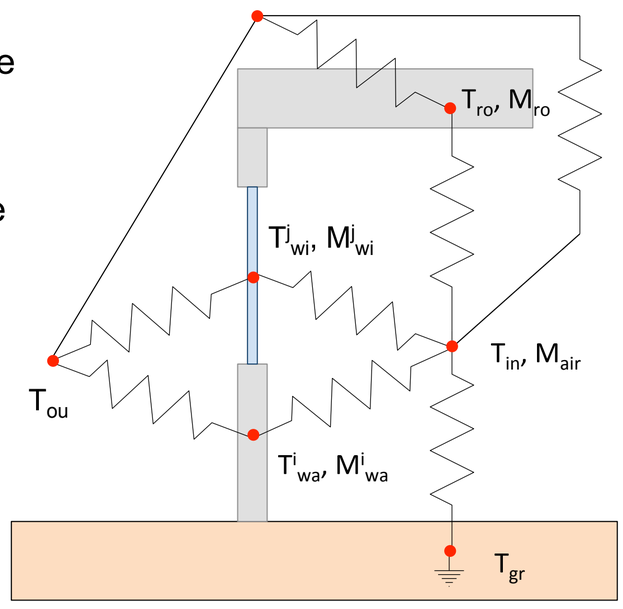
- Hybrid model utilizing:
  - Bin Method: piecewise (hour-by-hour) modeling based on temperature differences
  - Forward modeling: based on thermodynamics and actual engineering principles (e.g. building design, location, etc.)
- Determine change in internal stored heat energy
  - $\Delta E(t)_{stored} = E(t)_{in} - E(t)_{out} + E(t)_{generated}$
  - Calculate if heating or cooling is necessary based on the facility temperature setpoints and the generated heat due to manufacturing
  - Temperature setpoints vary depending on time of day (work vs. non-work hours) and day of year (winter or summer)
- Input empirical data for outdoor temperature, solar irradiance (direct and diffuse), and outdoor wind velocity

Model Formulation

- Resistive network (1-D):
  - T_{ou} : outdoor temperature
  - T_{in} : indoor temperature
  - T_{ro} : roof/ceiling temperature
  - T_{gr} : ground temperature
  - T^{i}_{wa} : i^{th} wall temperature
  - T^{j}_{wi} : j^{th} window temperature
- Thermo-energy balance

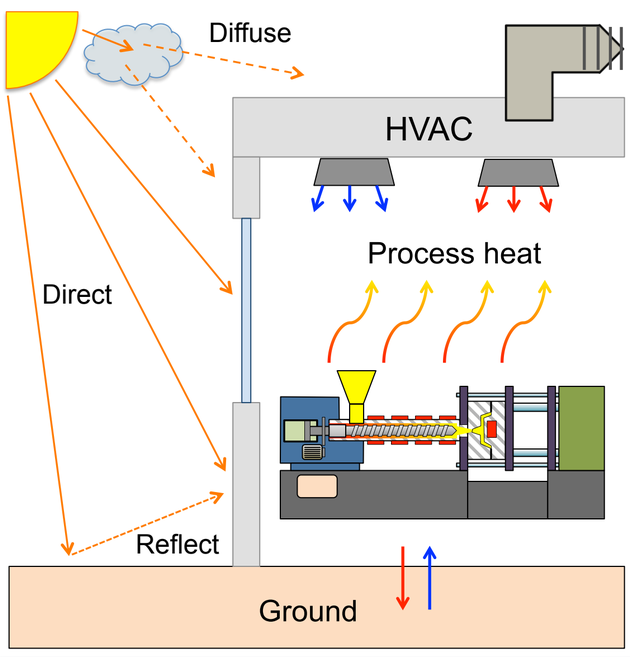
$$Q_S(t) - \sum_i UAdT_i(t) = MC_P\, dT/dt$$

  - $Q_s(t)$: process heat dissipation



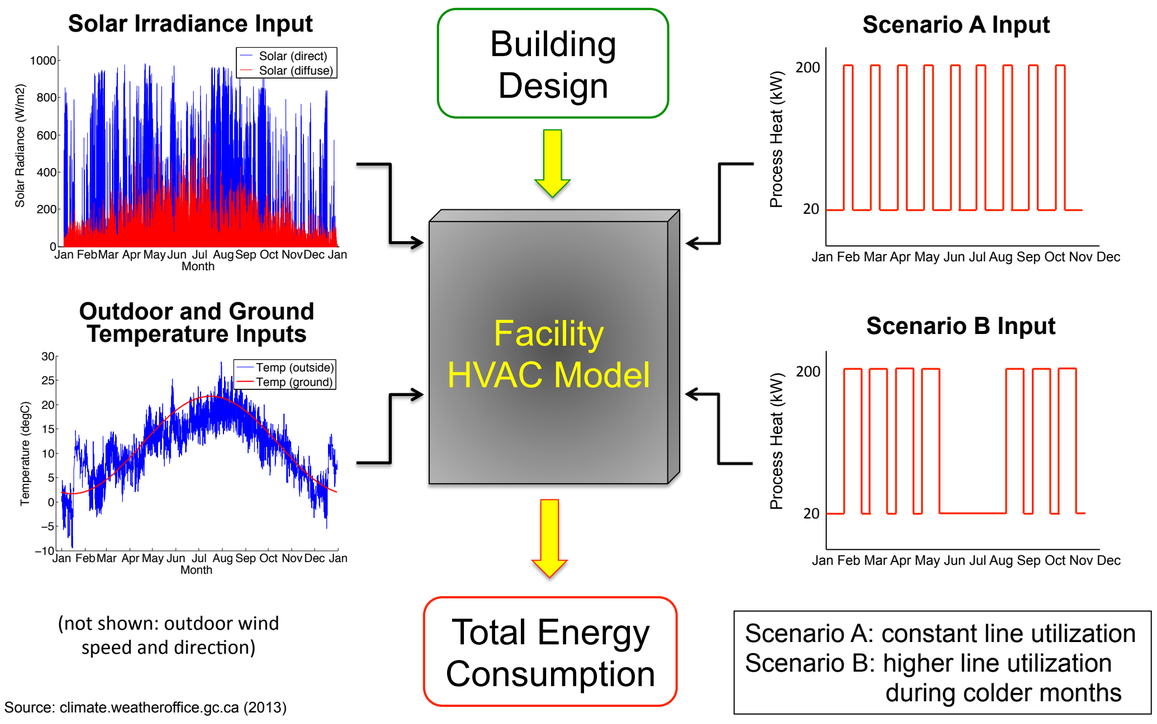
Sources of Heat

- Solar irradiation and process heat

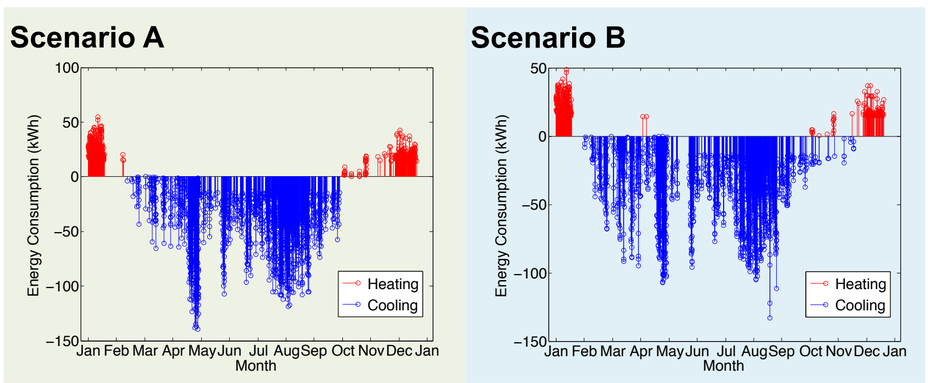


- HVAC cooling and heating required to balance internal heat gain
- Outdoor air intake can be adjusted depending on temperature difference (current model assumes fixed air intake)
- Outdoor wind changes the building's heat transfer properties

Case Study: Vancouver



Results



Annual Energy Consumption	64.6 MWh	54.5 MWh

- HVAC energy dominated by cooling load
- Shifting manufacturing to higher utilization in the colder months reduced annual energy consumption by 15% (with same total heat dissipation)
- Can perform process/scheduling optimization to reduce HVAC heat load and optimize the outdoor air-intake to reduce cooling load

Summary

- HVAC energy consumption is a complex balance between solar irradiation, outdoor temperature and wind speed, process heat, outdoor air intake, and indoor temperature setpoints
- Process heat dissipation can play a significant role on the HVAC energy consumption
- Reduction in the HVAC energy consumption:
  - Optimizing the production scheduling for a given heat profile
  - Incorporating a dynamic air intake controller to balance the internal heat with with the outdoor air temperature
  - Relaxing the temperature setpoints
- Model accuracy can be improved:
  - More precise building and HVAC design data
  - Better understanding of ventilation and airflow requirements, which influences material heat transfer properties

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