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Smart Buildings

Data-Driven Optimization of Facility Operations

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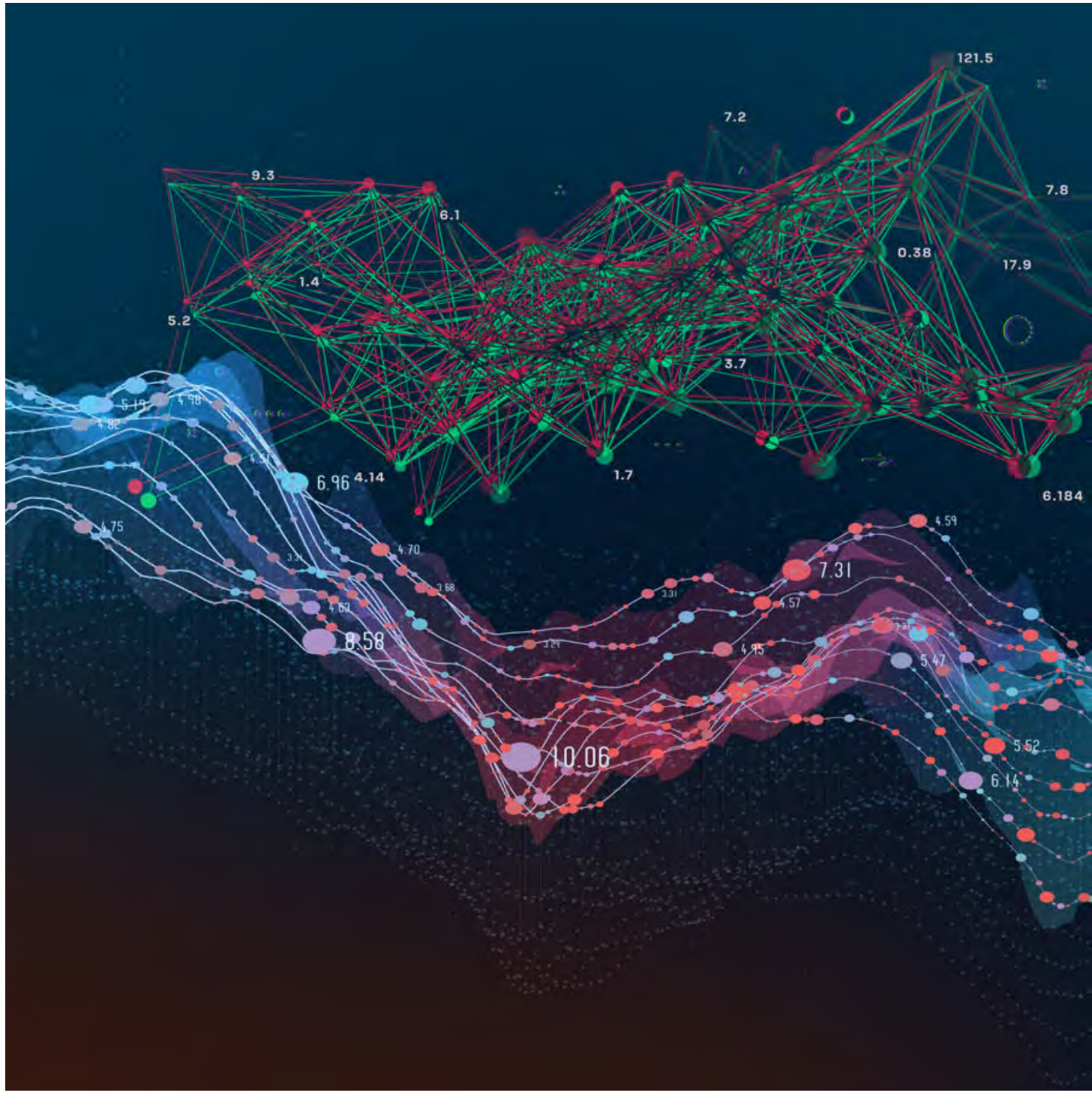

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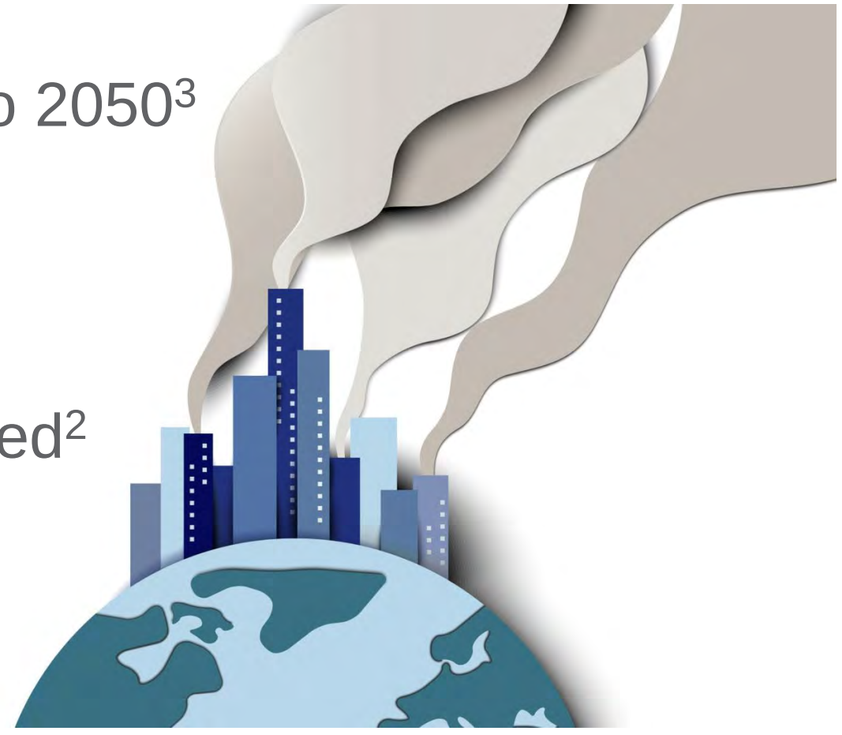
The Opportunity

- Buildings consume 39% of US energy[1]
  - 75% of all electricity
  - 35% of C02 emissions
- Consumption expected to grow by 1.3% per year to 2050[3]
- Commercial buildings play a big role
  - 35% of electricity consumed in the US[2]
  - 16% of all US CO2 emissions[2]
- ~30% energy used in commercial buildings is wasted[2]
- Essential component of decarbonized future



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1. US Energy information Administration (EIA) Monthly Energy Review, Table 2.1, April 2022, preliminary data for 2021. https://www.eia.gov/totalenergy/data/monthly/pdf/sec2.pdf
2. US Office of Energy Efficiency & Renewable Energy (EERE) “About the Building Technologies Office.” Accessed September 14, 2022. https://www.energy.gov/eere/buildings/about-commercial-buildings-integration-program
3. US Energy information Administration (EIA) Monthly Energy Review - June 2020. 2020.

The Path Forward

- Grid-interactive Efficient Buildings (GEB)
  - Department of Energy (DOE) Building Technologies Office (BTO) Initiative

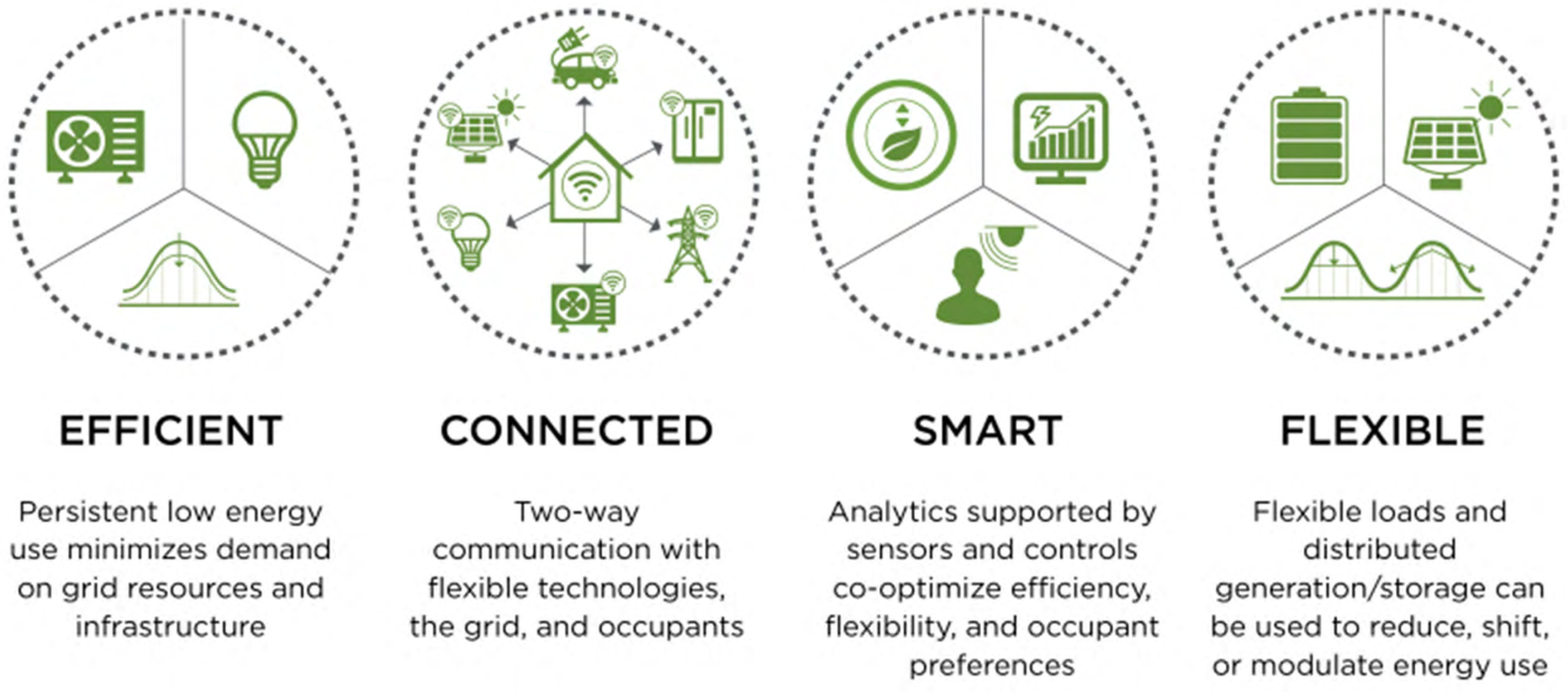
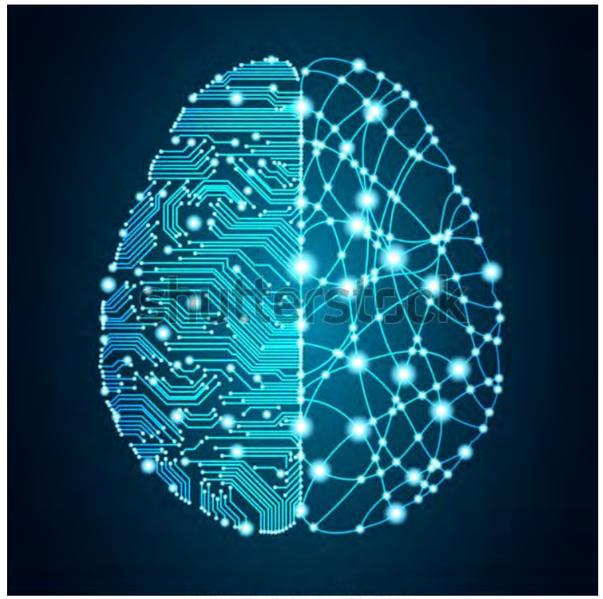


Image credit: US Office of Energy Efficiency & Renewable Energy “Grid Interactive Efficient Buildings” https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings

Smart Building Anatomy

- Modern buildings have Building Automation Systems (BAS) that control and monitor internal systems
  - Heating, ventilation, and air-conditioning (HVAC) systems
  - Lighting systems
  - Fire and life-safety systems
  - Specialized systems
- Components
  - Sensors: occupancy, temperature, humidity, flow, pressure, etc.
  - Control: actuators for air dampers, valves, motor speeds, on/off, etc.
- Control algorithms determine if a building is “smart”
  - Simple control logic in most building (not very smart)
    - ✓ Time-of-day schedules, occupancy-based, linear reset, constant value, etc.
  - Opportunity for improvement!
    - ✓ Optimized, reactive, adaptive, data-driven



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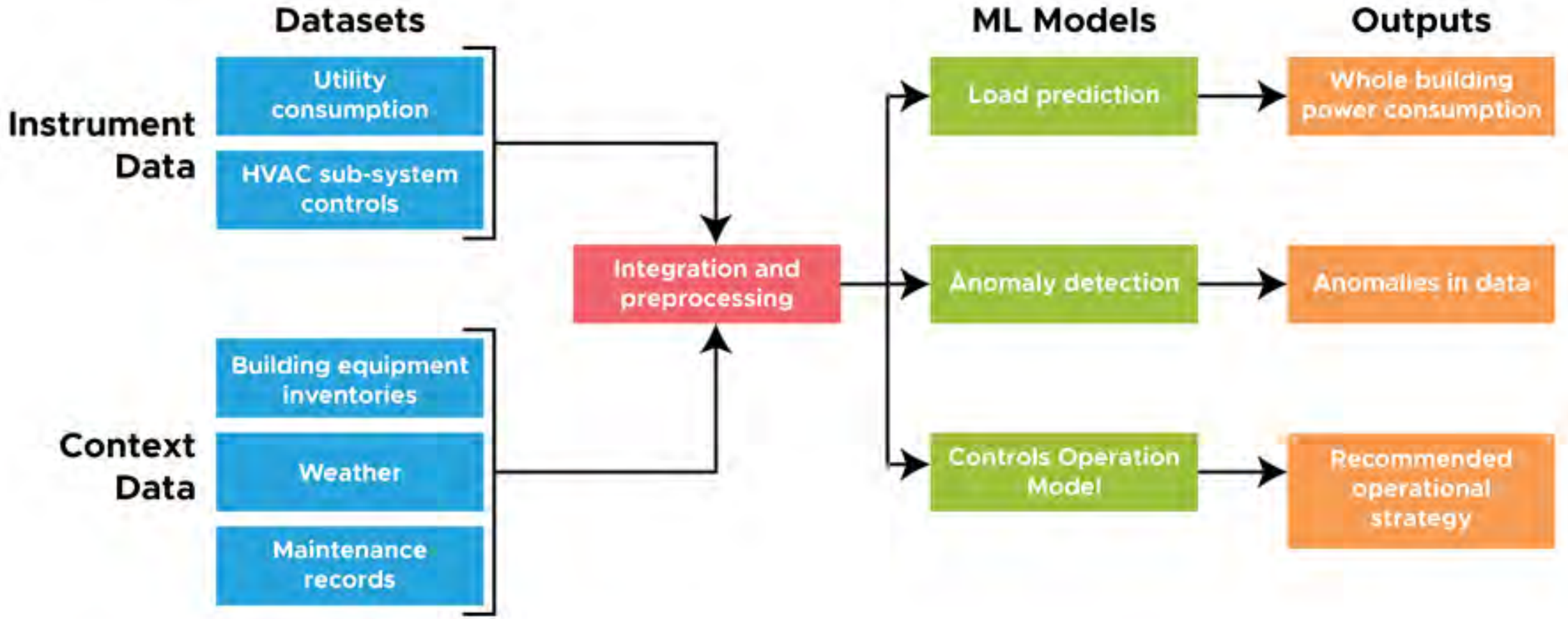
Machine Learning for Smart Buildings

- Machine Learning (ML) and other data-driven methods can be the solution!

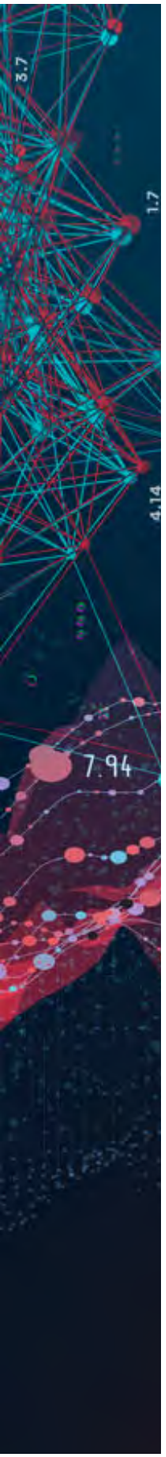
ML Workflow for Buildings with Common Use Cases



The Challenge

- ML revolution hasn't happened…yet
- Primary barriers:
  - Building industry is risk averse, slow to change, and optimizing operations is generally low priority
  - Buildings are disparate and data poor
- Real-world demonstration limited
  - Most work with advanced control and optimization strategies limited to simulation
- Some ongoing enabling projects
  - Metadata standards
    - ✓ Project Haystack, Brick, etc.
  - DOE's Benchmark Datasets
    - ✓ https://bbd.labworks.org/

Image credit: KOMO News. https://komonews.com/news/local/new-pictures-reveal-cracking-cement-forcing-closure-of-west-seattle-bridge.



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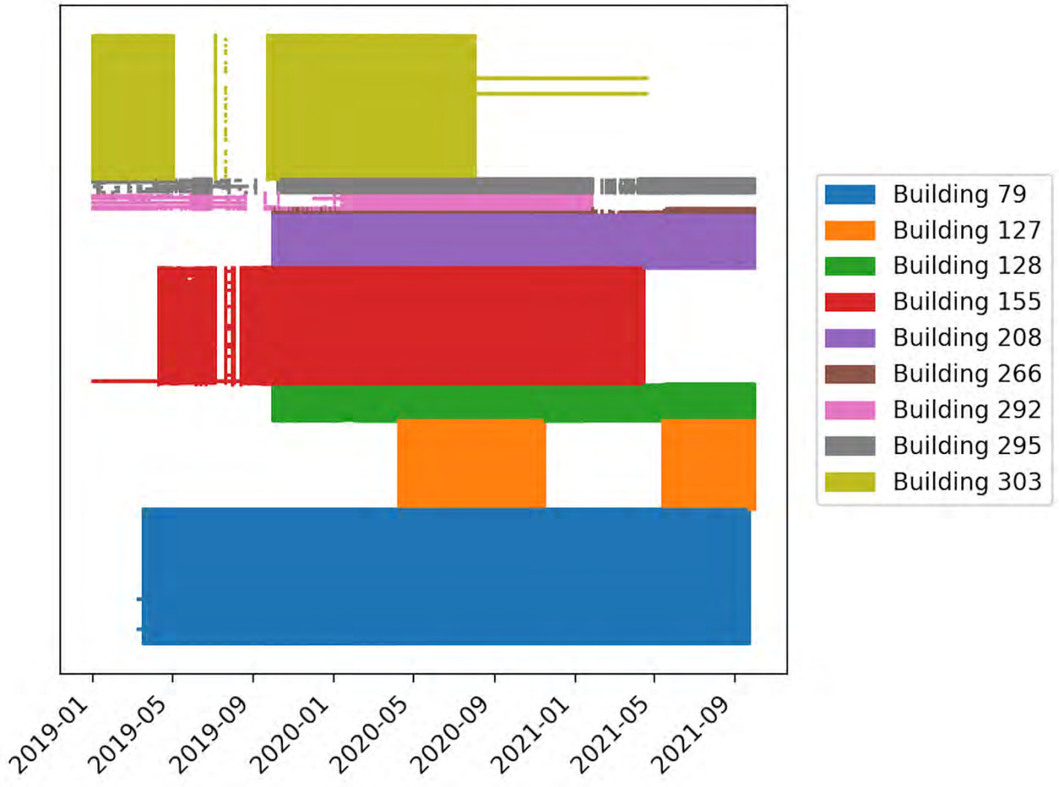
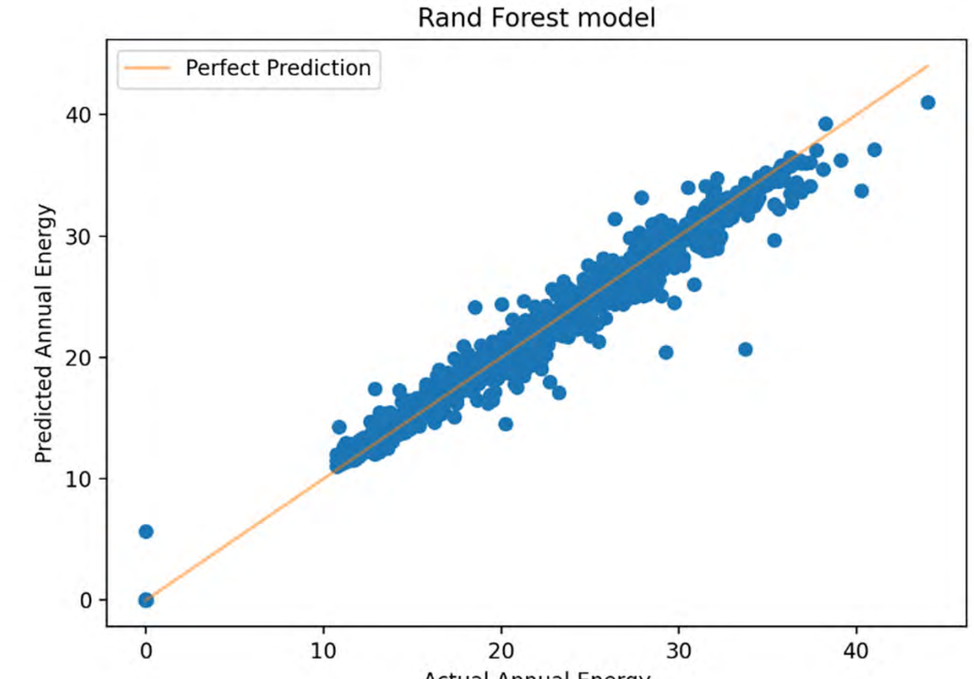
Real-World ML Demonstration

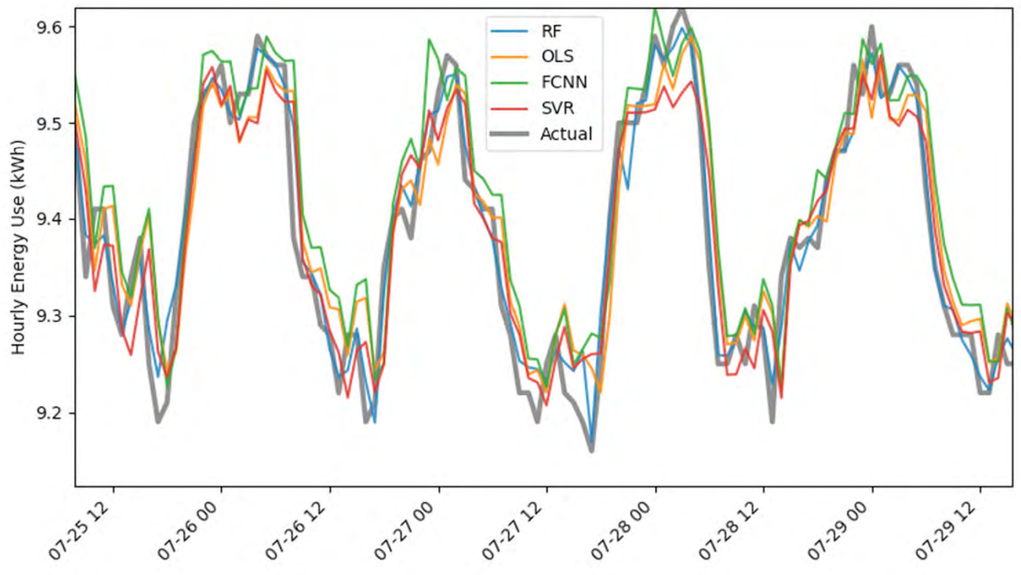
- Department of Defense (DoD) demonstration program - ESTCP
- Applied ML to an enterprise Building Control System
  - >70 buildings integrated
  - BAS and advanced utility meter data
  - Most buildings online starting ~2018
- Lofty goals, but the data limited possible use cases
  - Successfully implemented load prediction, anomaly detection, site energy prediction
  - Missing ground-truth data precluded validated fault detection

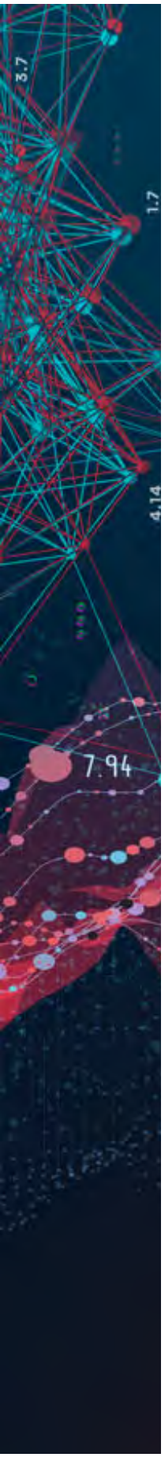


Successful Use-Case: Load Prediction

- Predicts future energy consumption
- Created baseline load prediction models for all buildings
  - High accuracy (0.98 avg r^2)
  - Robust model type and feature selection
- Deployed internal web application
- Building block for smart buildings
  - Fault detection and diagnosis (FDD)
  - Demand reduction (DR) and management
  - Distributed energy resource (DER) dispatch
  - Further improved control & optimization

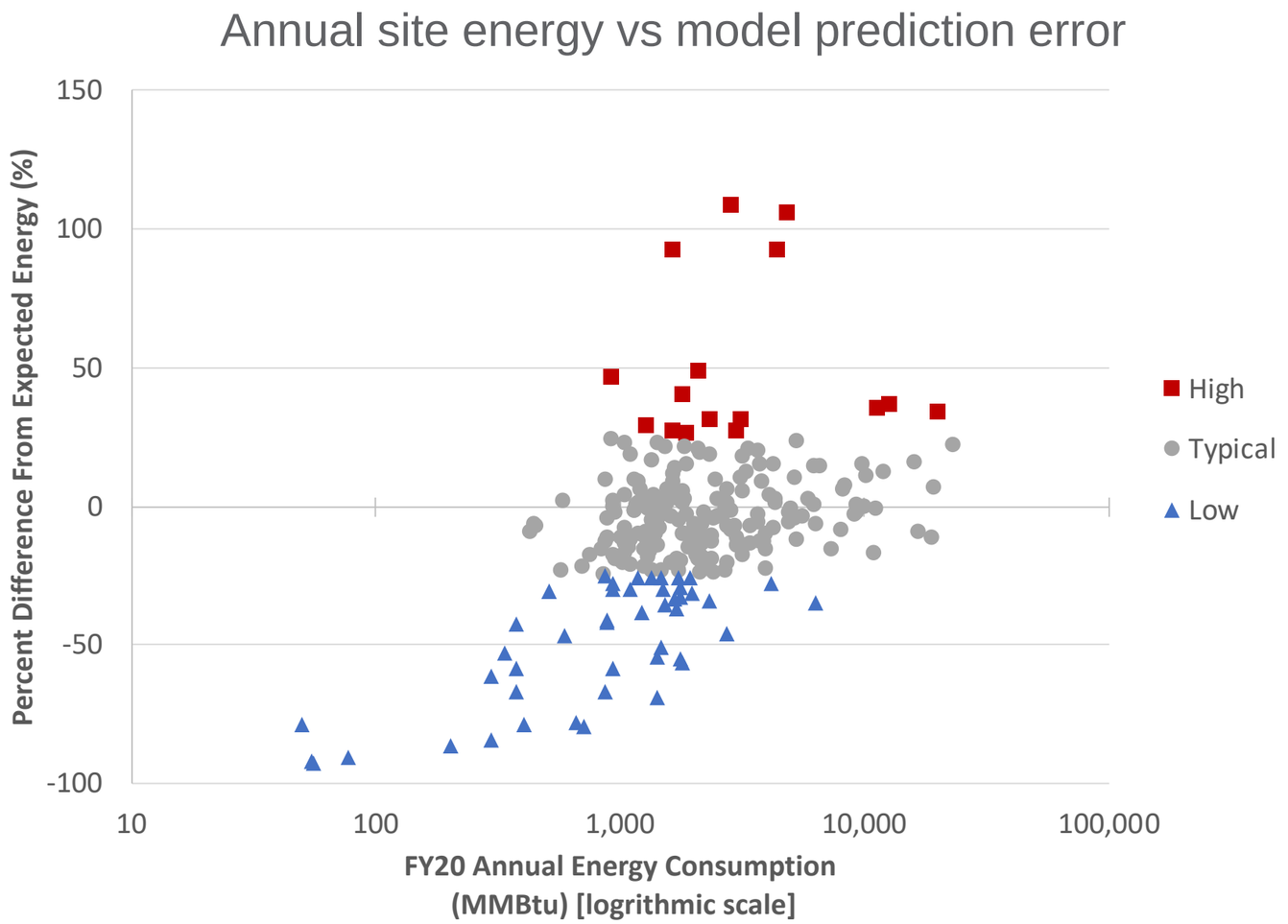






Successful Use-Case: Expected Energy Usage for Site Prioritization

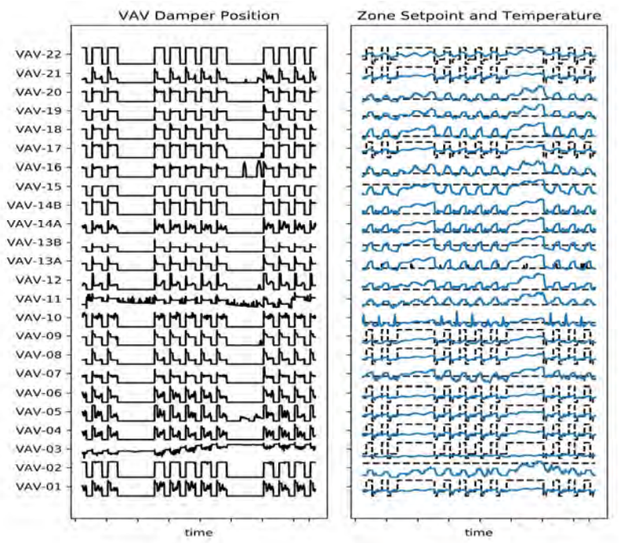
- Predicts annual energy consumption
- Simple inputs
  - Annual utility consumption
  - Weather data
  - Site metadata
- Less total data, better coverage
- Actionable results



Beyond ML:
Other Data-Driven Solutions

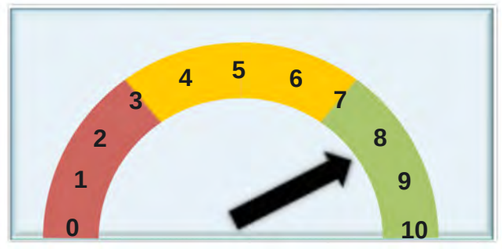
- Building Control Score
  - Provides single standardized score of controller performance
- Data-driven assessment
  - Agnostic to process variable being assessed
  - Aggregation to system, building level
- Quickly identifies performance issues

Without ControlScore

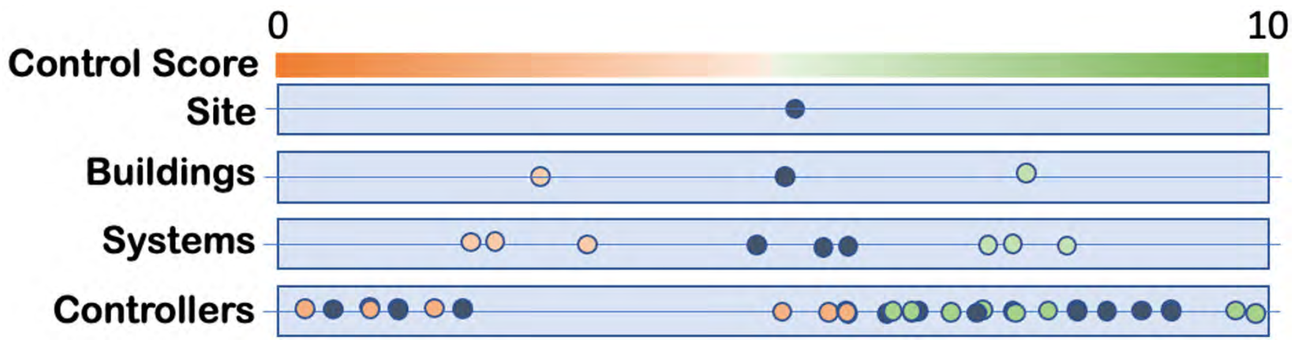


Lots of data

With ControlScore

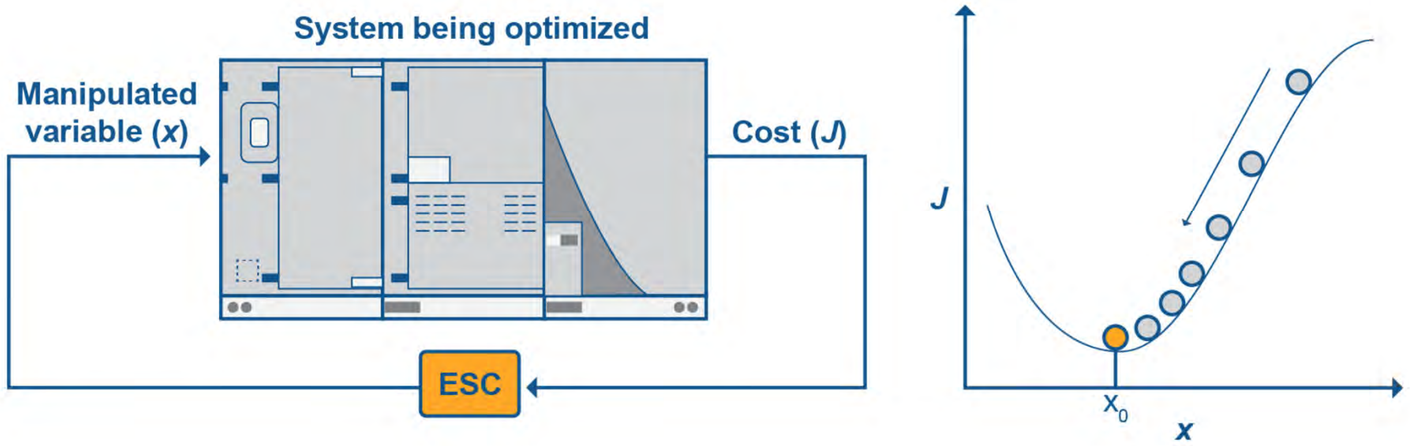


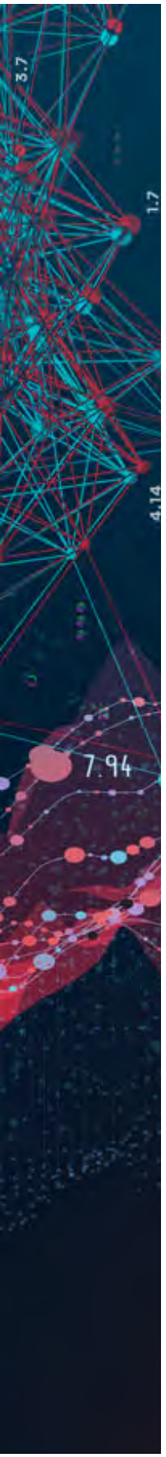
Single point of reference



Beyond ML:
Other Data-Driven Solutions

- Extremum seeking control for buildings:
  - Model-free adaptive control: perturb-and-observe
  - Real-time optimization: No need for training period
  - Robust to sensor error
- Real-world application in DoD facilities
- Optimize economizer operation and reduce simultaneous heating and cooling





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Thank you

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