AI for Buildings and Cities

Marcus Voss

Climate Change AI Summer School

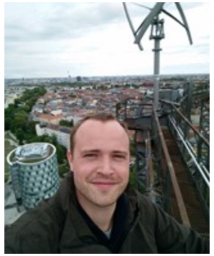
July 3rd, 2023

About the lecturer

AI Engineer &
Intelligence Architect
Birds on Mars

Member of the Board of Directors
and Community Lead for Buildings
and Transport
Climate Change AI

Before



Research Assistant and Head of Working Group
Smart Energy Systems at
DAI-Labor at TU Berlin

AI in digital vegetation management to support glyphosate phase-out

DataNet
Data · Analytics · Intelligence
DB Netz

birds on mars

See: https://www.linkedin.com/feed/update/urn:li:activity:7011359355526651904/

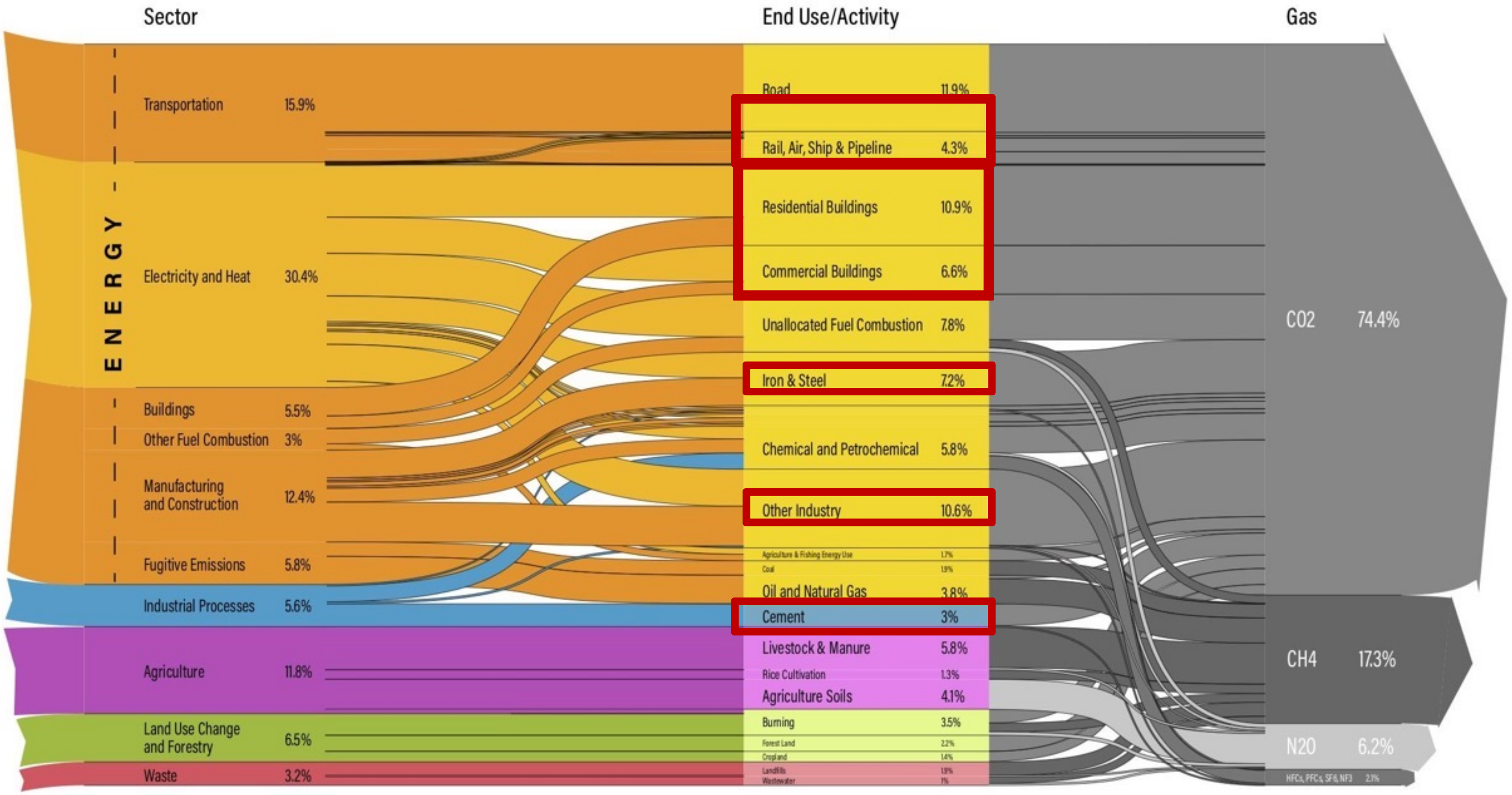
Why are we talking about **buildings** today?

Answer in the Google Form

Your initial thoughts: how do buildings affect climate change?

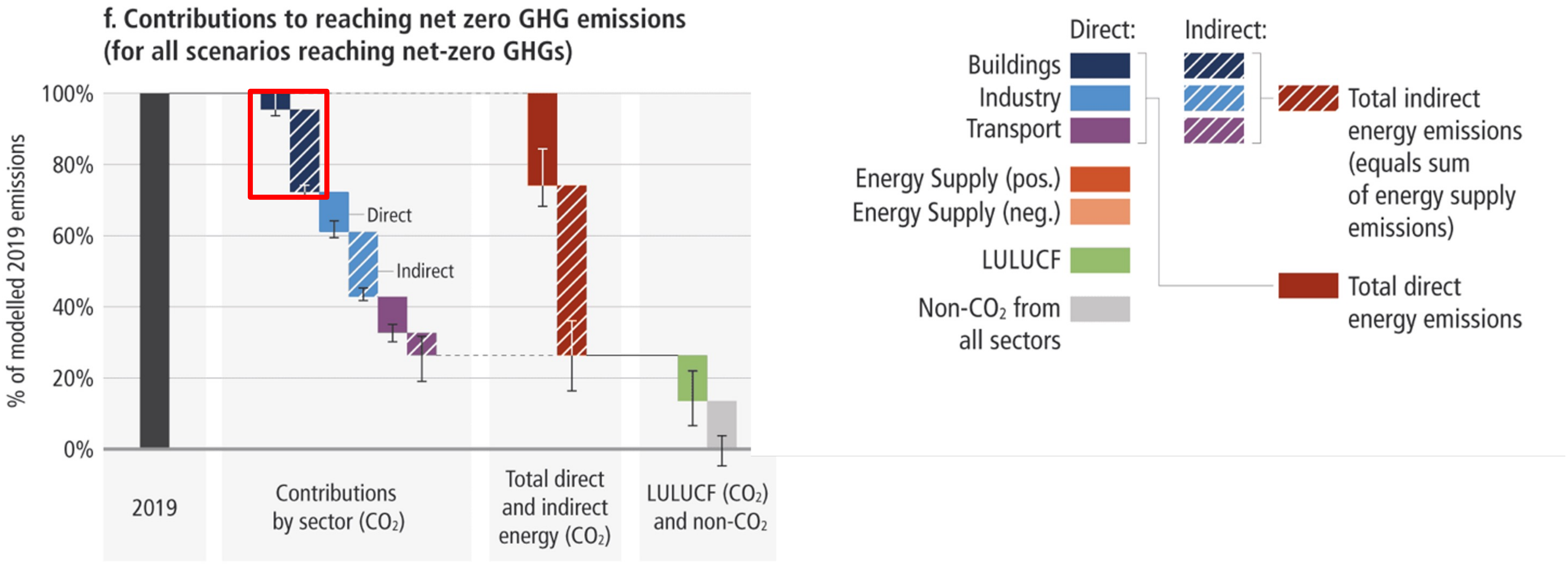
World Greenhouse Gas Emissions in 2016

Total: 49.4 $GtCO_2e$



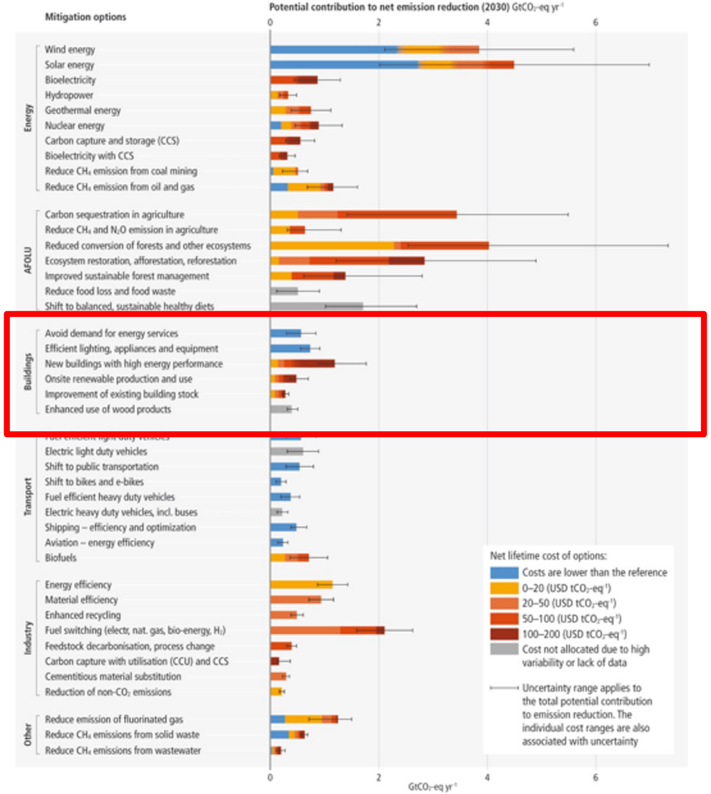
Source: https://www.wri.org/resources/data-visualizations/world-greenhouse-gas-emissions-2016

Where do buildings play a role in climate change?



Source: IPCC WGIII (2022) AR6 Climate Change 2022: Mitigation of Climate Change. Summary for Policymakers.

IPPC comparison of mitigations impacts of different options



Source: IPCC WGIII (2022) AR6 Climate Change 2022: Mitigation of Climate Change. Summary for Policymakers.

IPPC comparison ns

Source: IPCC WGIII (2022) AR6 C

Outline of this lecture

1. Introduction and Motivation
2. Building Control and Grid Interactive Buildings
3. Applications of AI and Machine Learning
4. Current Research Directions
5. Concluding Remarks and Discussion

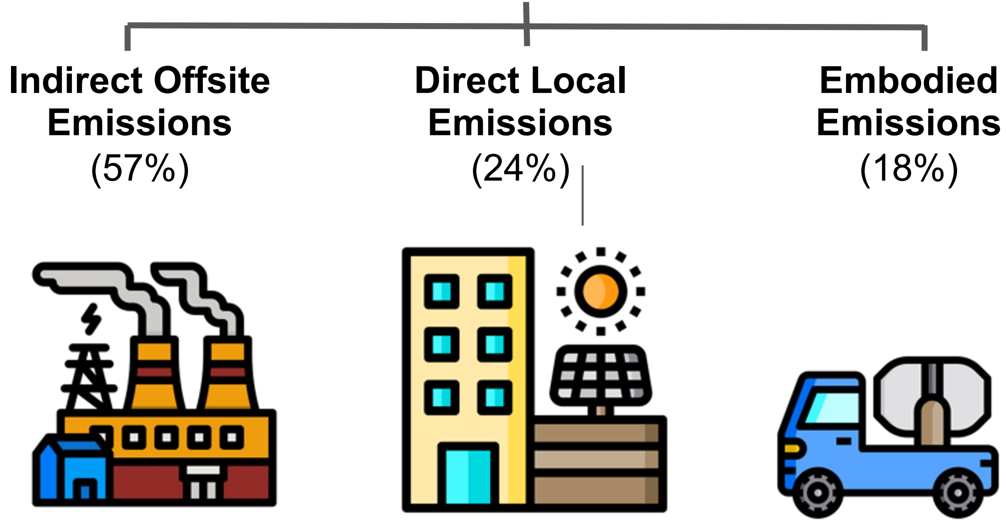
Buildings and Climate Change

Where do buildings play a role in climate change?

Buildings in Mitigation:

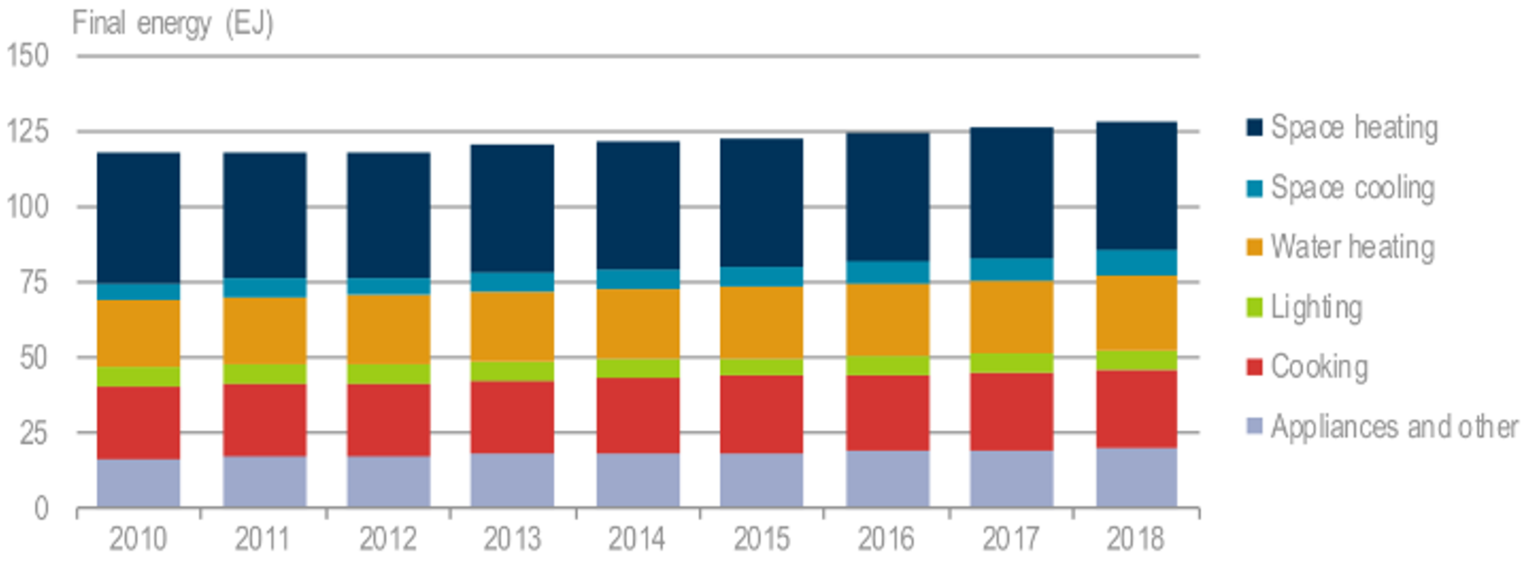
- buildings' **indirect emissions** from offsite generation of electricity and heat,
- **direct emissions** produced onsite and,
- **embodied emissions** from the production of cement and steel used in buildings.

Global GHG emissions from buildings were 12 GtCO2-eq in 2019, equivalent to **21% of global GHG emissions**.



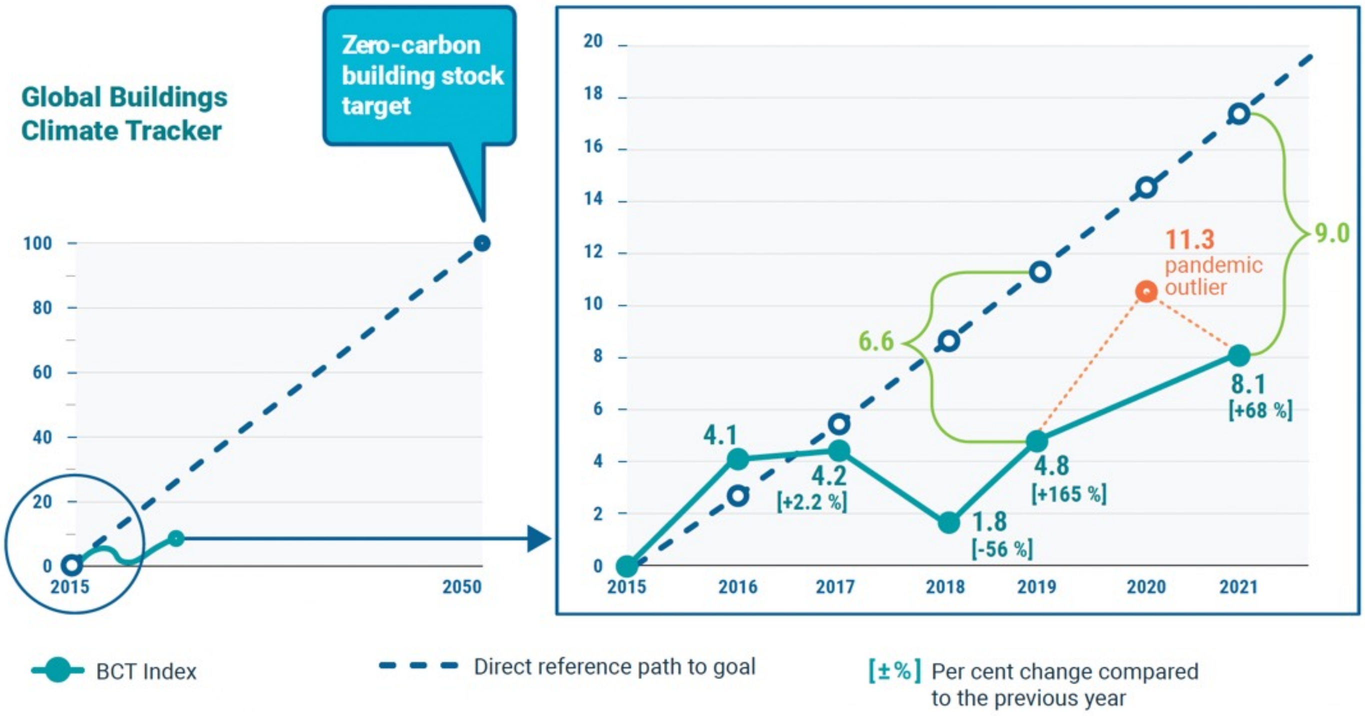
Source: IPCC WGIII (2022) AR6 Climate Change 2022: Mitigation of Climate Change. Technical Summary.
Image: Flaticon.com

Split of final energy consumption in buildings



Source: IEA, GlobalABC, and UN Environmental Programme. (2018)

Comparing the observed building decarbonization to Paris agreement

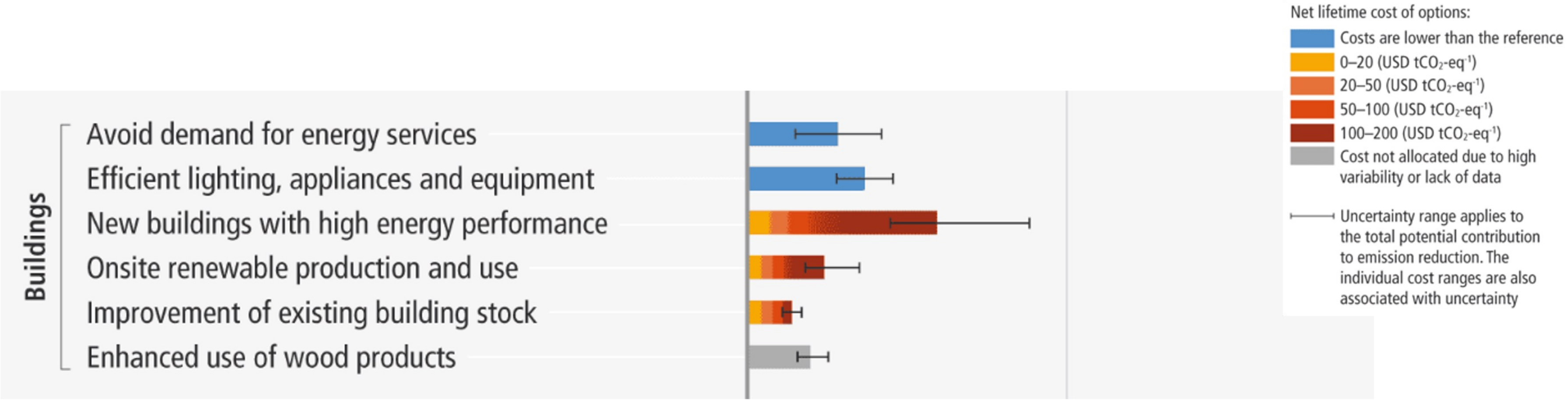


Source: United Nations Environment Programme (2022) Global Status Report for Buildings and Construction

Answer in the Google Form

What are effective strategies to mitigate the climate impact of buildings?

Climate mitigations impacts and costs in buildings



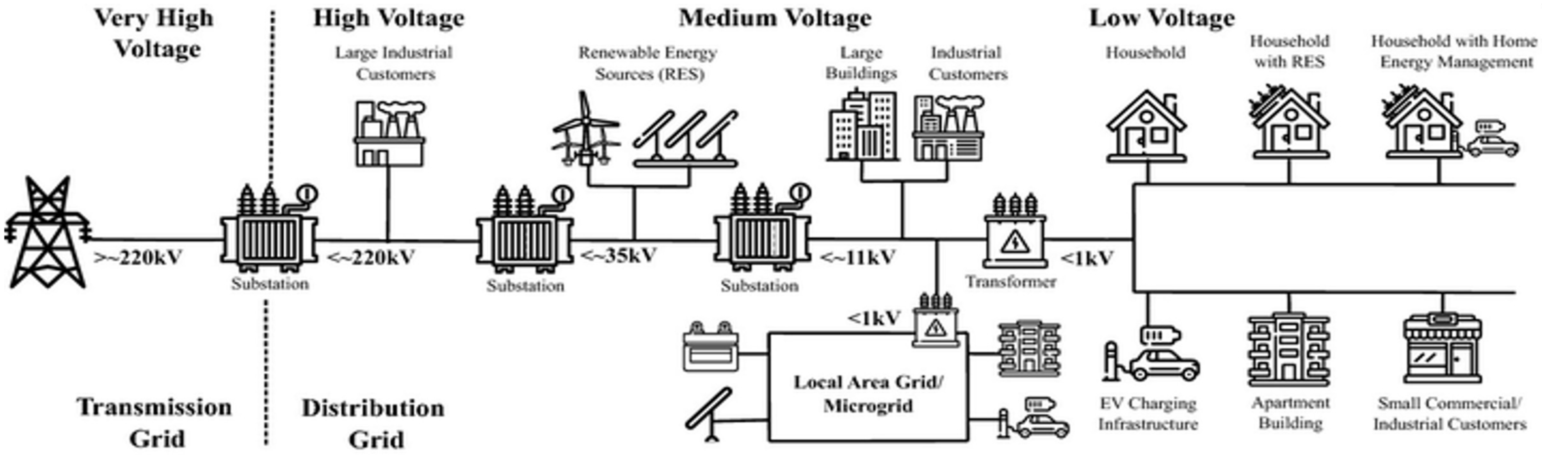
Intelligent building control is an efficient measure to **avoid demand for energy services** and **increase buildings energy performance** (new and existing) as well as **increase use of renewable energy** (on- and offsite).

Source: IPCC WGIII (2022) AR6 Climate Change 2022: Mitigation of Climate Change. Summary for Policymakers.

Building Control and Grid Interactive Buildings

How can intelligent control support energy savings and increase renewable use?

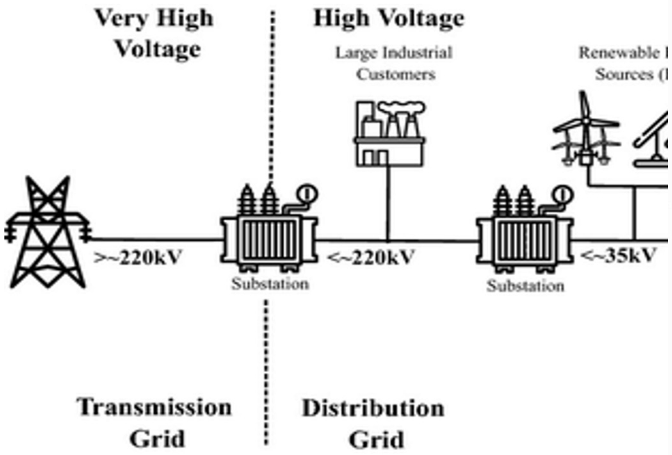
The electrification of heating and transportation introduces a „**coupling**“ of the heating, electric energy supply, and transportation **sectors**.

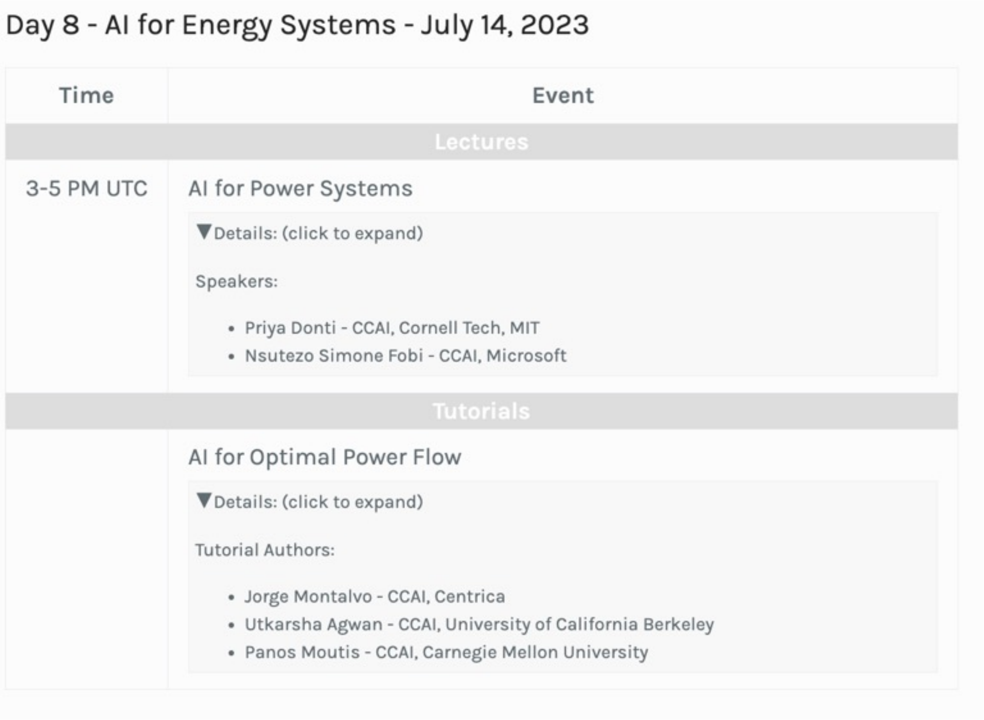


Source: Core Concepts and Methods in Load Forecasting: With Applications in Distribution Networks

How can intelligent control support energy savings and increase renewable use?

The electrification of heating and transport
energy supply, and transportation **sectors**.




Day 8 - AI for Energy Systems - July 14, 2023

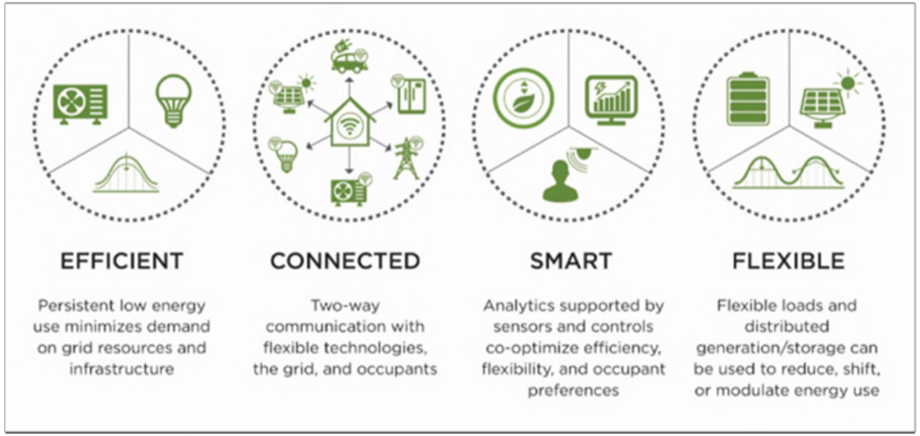
Time	Event
Lectures	
3-5 PM UTC	AI for Power Systems ▼Details: (click to expand) Speakers: • Priya Donti - CCAI, Cornell Tech, MIT • Nsutezo Simone Fobi - CCAI, Microsoft
Tutorials	
	AI for Optimal Power Flow ▼Details: (click to expand) Tutorial Authors: • Jorge Montalvo - CCAI, Centrica • Utkarsha Agwan - CCAI, University of California Berkeley • Panos Moutis - CCAI, Carnegie Mellon University

Source: Core Concepts and Methods in Load Forecasting: With Applications in Distribution Networks

How can intelligent control support energy savings and increase renewable use?

Buildings are changing **from passive** consumers **to active, connected parts** of the future energy system, introducing decentralized energy resources and even providing flexibility to the electric energy system.

The U.S. Department of Energy (DOE) introduces the term Grid-Interactive Efficient Buildings (GEB):

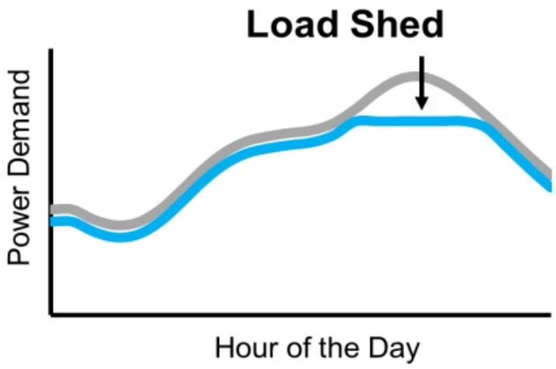


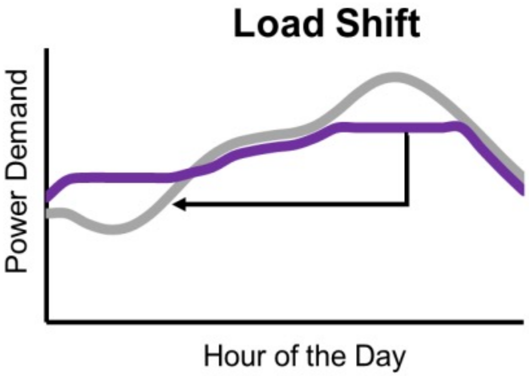
> *„[...] an energy-efficient building that uses smart technologies and on-site DERs to provide demand flexibility while co-optimizing for energy cost, grid services, and occupant needs and preferences, in a continuous and integrated way.“*

Source: Neukomm, M., Nubbe, V., & Fares, R. (2019). Grid-interactive efficient buildings technical report series: Overview of research challenges and gaps.

How can intelligent control support energy savings and increase renewable use?

Examples for demand side flexibility strategies (or demand-side management):



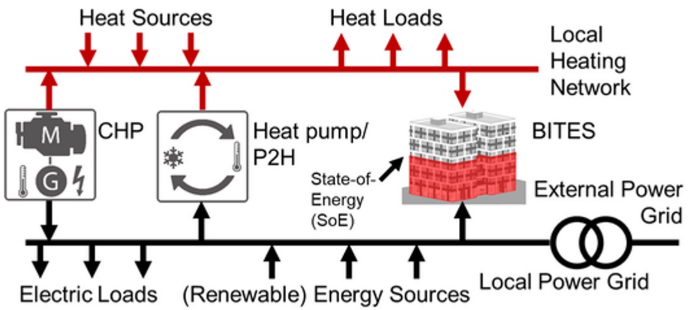


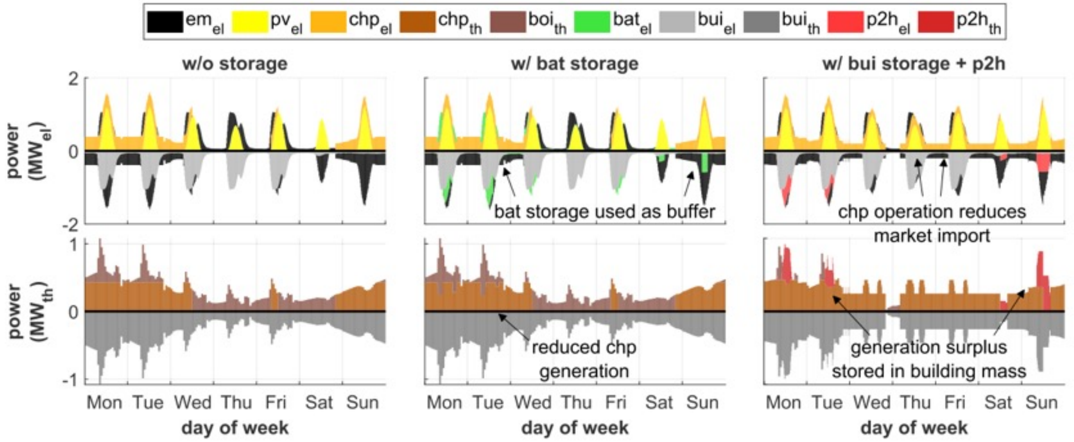
Source: Neukomm, M., Nubbe, V., & Fares, R. (2019). Grid-interactive efficient buildings technical report series: Overview of research challenges and gaps.

How can intelligent control support energy savings and increase renewable use?

By providing flexibility, buildings can essentially function as storage to balance renewables.

Example: Using Generalized Additive Modeling (GAM) to model the Building Inherent Thermal Energy Storage (BITES) for use in linear optimization models.

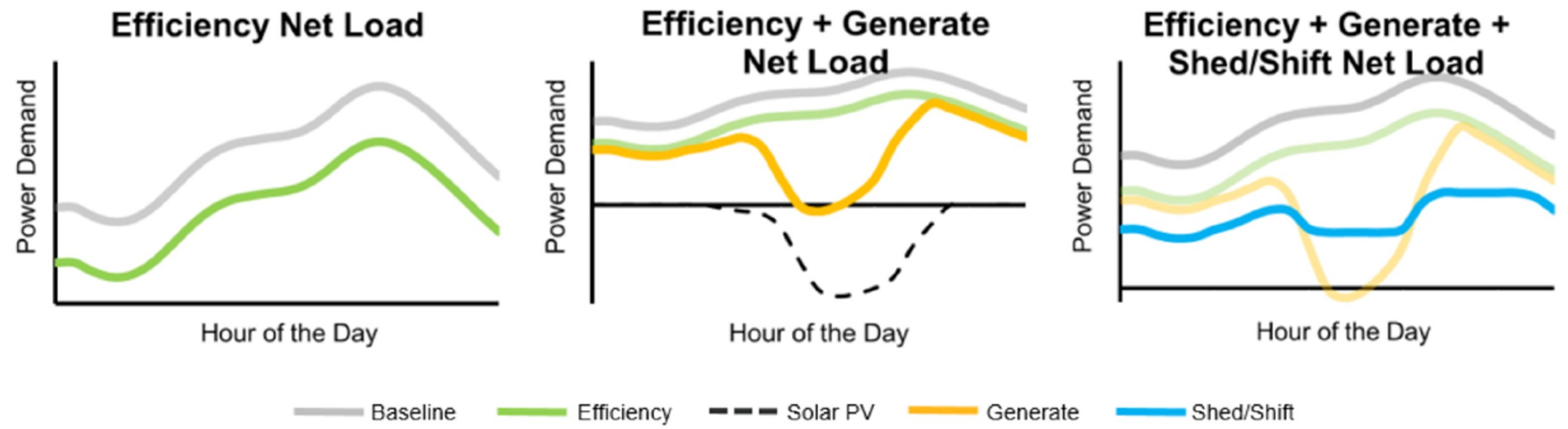




Source: M. Voss, J. F. Heinekamp, S. Krutzsch, F. Sick, S. Albayrak and K. Strunz, "Generalized Additive Modeling of Building Inertia Thermal Energy Storage for Integration Into Smart Grid Control," in IEEE Access, vol. 9, pp. 71699-71711, 2021, doi: 10.1109/ACCESS.2021.3078802.

How can intelligent control support energy savings and increase renewable use?

From energy efficient buildings to grid-interactive efficient buildings.

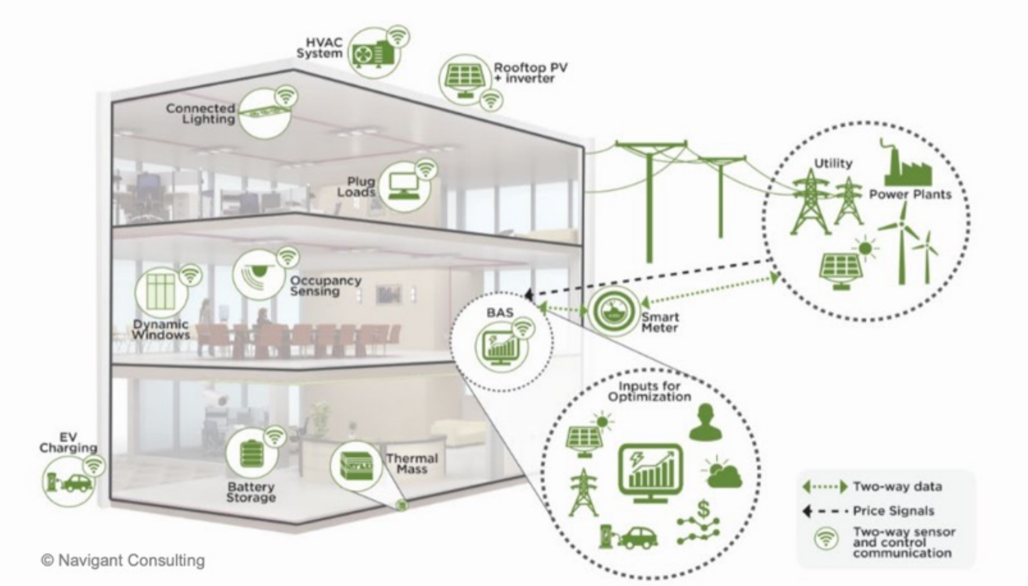


Increasing needs of advanced forecasting and optimization techniques for intelligent building control

Source: Neukomm, M., Nubbe, V., & Fares, R. (2019). Grid-interactive efficient buildings technical report series: Overview of research challenges and gaps.

How can intelligent control support energy savings and increase renewable use?

Despite increasing number of actors and relevant disturbances, current operation of buildings is mostly based on simple but inefficient ***logic rules*** and ***PID controllers***.



Simple reactive control

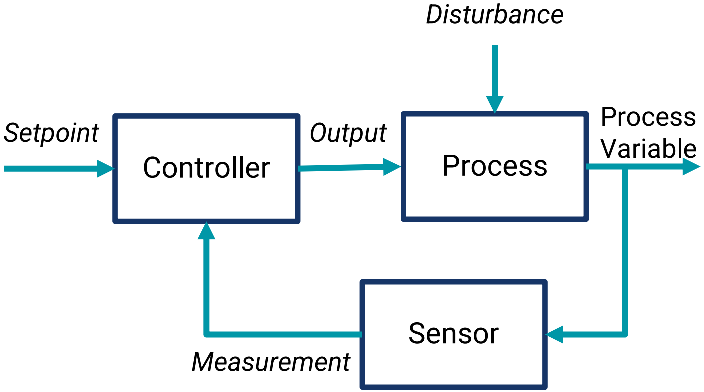


Image: Neukomm, M., Nubbe, V., & Fares, R. (2019). Grid-interactive efficient buildings technical report series: Overview of research challenges and gaps.

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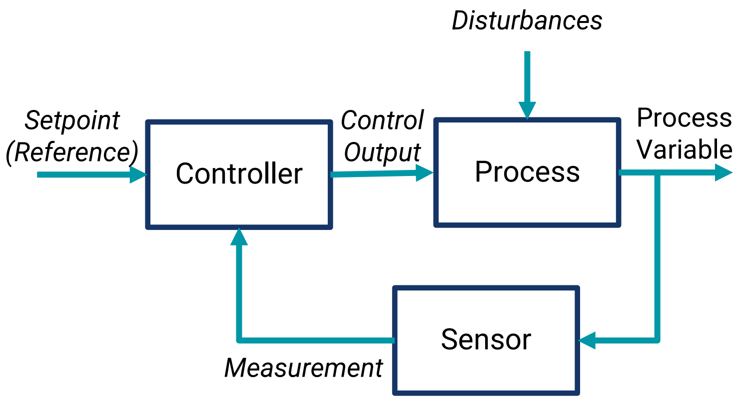
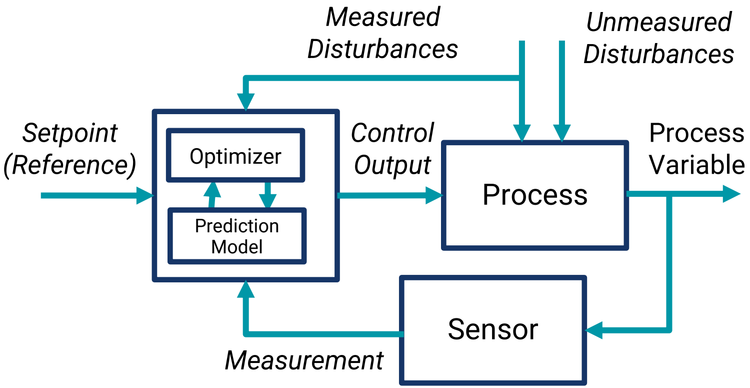
Simple reactive control



Example: Model Predictive Control



Requires accurate forecasts of disturbances!

Learn more: Drgoňa, J., Arroyo, J., Figueroa, I. C., Blum, D., Arendt, K., Kim, D., ... & Helsen, L. (2020). All you need to know about model predictive control for buildings. *Annual Reviews in Control*, *50*, 190-232.

Answer in the Google Form

How does climate change affect buildings?

How does climate change affect buildings and cities?

Buildings in Adaptation:

Buildings and cities are already experiencing severe impacts from sea-level rise, floods and climate variability.

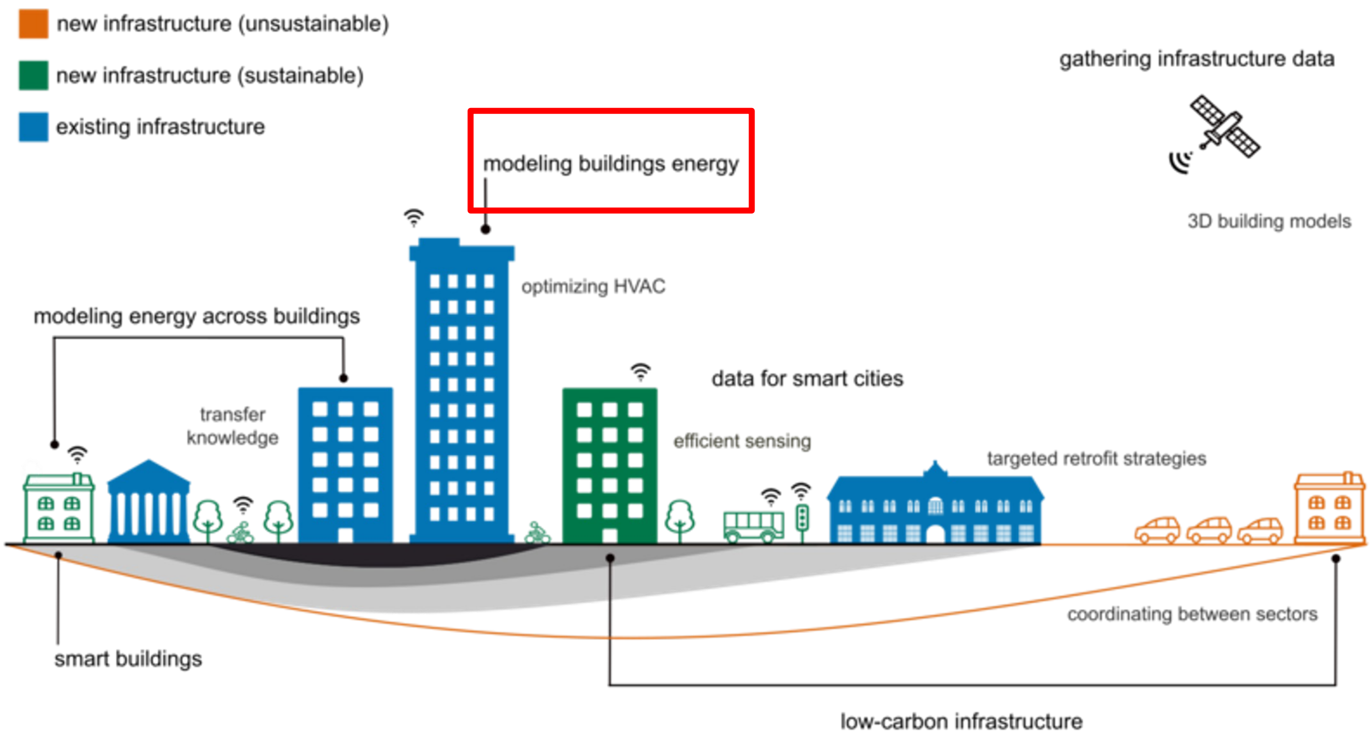
This leads to:

- Relocation and upgrades of buildings to avoid damages from sea-level rise and floods,
- Upgrading buildings and redesigning cities to meet increased cooling needs and ensure health of people.

Source: IPCC WGII (2022) AR6 Climate Change 2022: Impacts, Adaptation and Vulnerability. Technical Summary.
Image: https://www.flickr.com/photos/andrewkesper/5350087559/

Machine Learning Application Areas

Overview of machine learning applications areas for buildings



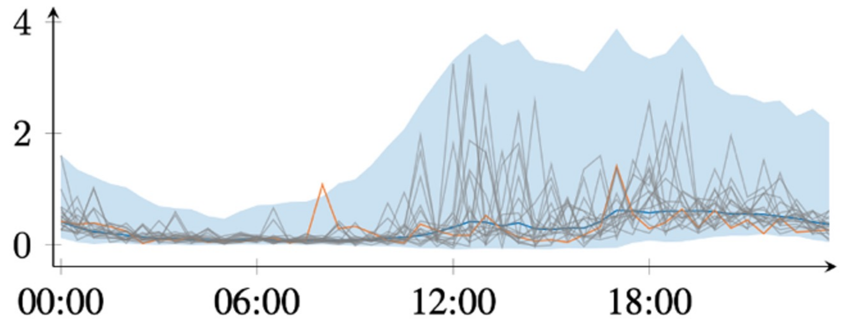
Source: Rolnick, David, et al. "Tackling climate change with machine learning." ACM Computing Surveys (CSUR) 55.2 (2022): 1-96.

Modeling Building Energy

ML-based time series models can be used to analyze, understand and predict the building’s energy consumption at different time and spatial scales.

Forecasting energy loads

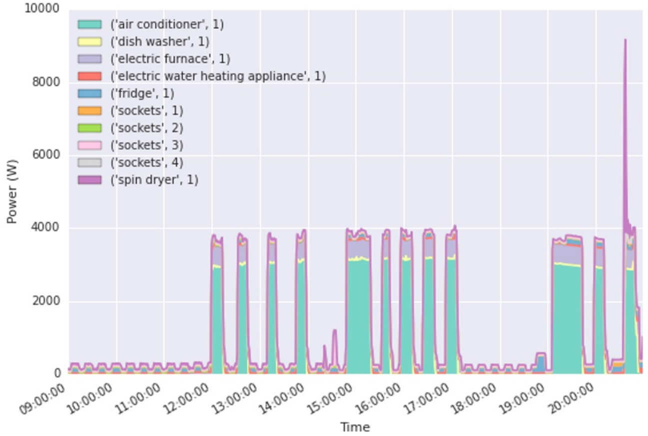
E.g., using Generative models to model marginal distributions and sample load scenarios.



Source: Arpogaus, M., Voss, M., Sick, B., Nigge-Uricher, M., & Dürr, O. (2023). Short-term density forecasting of low-voltage load using bernstein-polynomial normalizing flows. *IEEE Transactions on Smart Grid*.

Non-Intrusive Load Monitoring (NILM)

E.g., using regression or classification models to disaggregate the load signal.



Source: https://github.com/nilmtk/nilmtk

Tutorials on Modeling Building Energy with ML

Tutorial on Load Forecasting

Building Load Forecasting with Machine Learning

Marcus Voss, CCAI Summer School 2022

Accurate forecasts of energy demand and supply are essential to mitigate climate change. Discover how to train and evaluate building load forecasts using off-the-shelf ML models.

Buildings & Cities | Intermediate | Python | Time Series Analysis | Energy Management

Office Hours

July 7, 2023, 11:00 a.m. -1:00 p.m. UTC

AMA

July 13, 2023, 11:00 a.m. -12:00 p.m. UTC

See also after Summer School: https://www.climatechange.ai/tutorials

Tutorials on Modeling Building Energy with ML

Tutorial on (Tool Box for?) Smart Meter Data

Smart Meter Data Analytics: Practical Use-Cases and Best Practices of Machine Learning Applications for Energy Data in the Residential Sector

Tobias Brudermueller and **Markus Kreft**, ICLR 2023

A practical guide to current trends in smart meter data analytics with a focus on feature engineering and machine learning scenarios for energy data at 15-minute resolution. Gain insights into current trends and use cases in the energy field and get a sense of typical and atypical energy consumption in a residential building.

Electricity Systems | Introductory | Python | Time Series Analysis | Building Energy Management | Energy Flexibility

Office Hours

July 7, 2023, 1:00 p.m. -3:00 p.m. UTC

AMA

July 6, 2023, 9:00 a.m. -10:00 p.m. UTC

See also after Summer School: https://www.climatechange.ai/tutorials

3. **Best practices for visualizing smart meter data**
    1. Time-series visualizations of energy data
    2. Visualizing distributions of energy consumption
    3. Multi-dimensional visualizations
    4. Annotating visualizations with additional context informat
    5. Displaying aggregated demand

4. **Pre-processing smart meter data**
    1. Combining smart meter data with temperature data
    2. Add additional information for filtering timestamps
    3. Normalization methods
    4. Interpolation methods and downsampling
    5. Outlier detection with Hampel filter
    6. Simple baseload estimation
    7. Enhancing small activities
    8. Detecting switching activities
    9. Sliding window approaches
    10. Feature extraction
    11. Detecting peaks in distribution
    12. Frequency-based methods for low-resolution data

    See also after Summer School: https://www.climatechange.ai/tutc

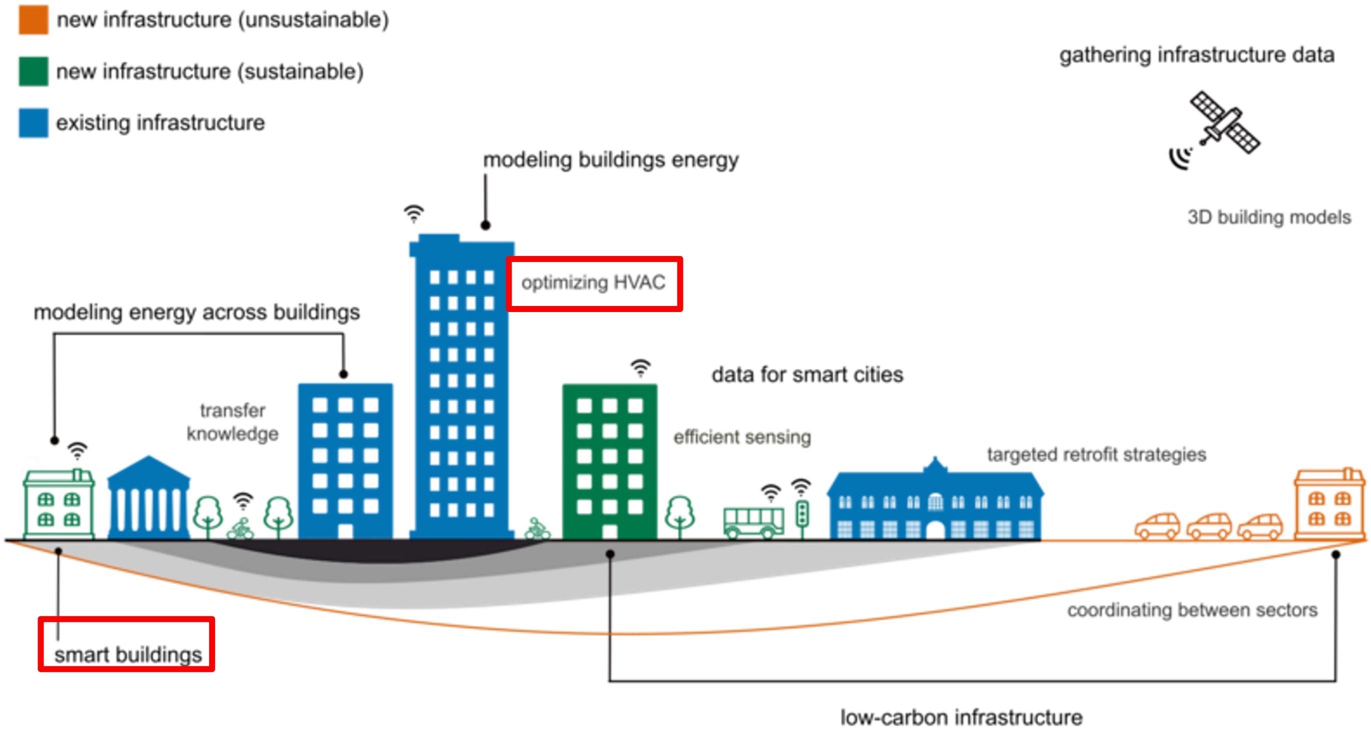
5. **Non-Intrusive Load Monitoring (NILM) / Load Disaggregation**
    1. Using classification algorithms to detect appliance installations
    2. Applying simple deep learning models for NILM
    3. Applying Hidden Markov Models for NILM
    4. Correctly evaluating NILM approaches
    5. Rule-based heuristics for pattern isolations

6. **Flexibility Estimation**
    1. Estimating load shifting potential of disaggregated appliances

7. **Anomaly Detection**
    1. Introduction to online vs. offline change point detection
    2. Finding state changes with offline change point detection
    3. Finding anomalies with sliding window
    4. Applying Symbolic Aggregate ApproXimation
    5. Finding discords and motifs

8. **Customer segmentation**
    1. Extraction of energy signatures through regression
    2. Extraction of average day profiles
    3. Applying clustering algorithms

Overview of machine learning applications areas for buildings



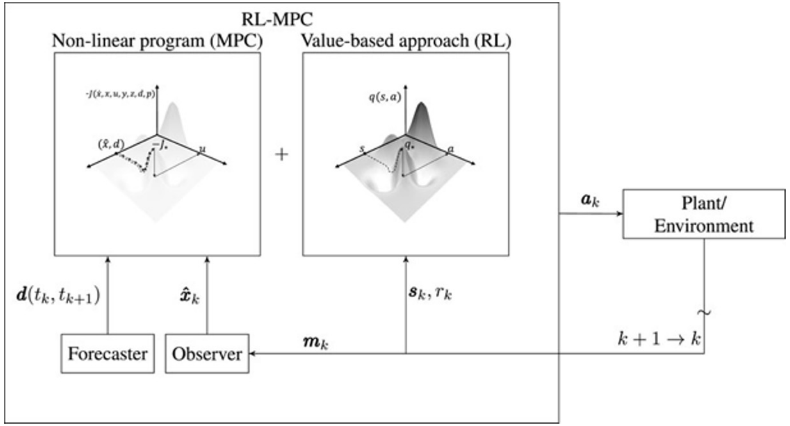
Source: Rolnick, David, et al. "Tackling climate change with machine learning." ACM Computing Surveys (CSUR) 55.2 (2022): 1-96.

Optimizing HVAC and Building Operations

Machine Learning can be used to inform operational systems (e.g. by forecasting) or directly optimize building operations.

Controlling HVAC and lighting systems

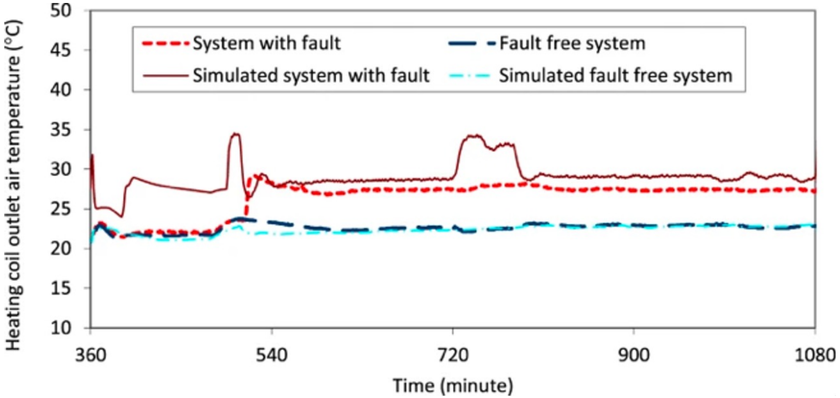
E.g., using RL to optimize Building Energy Management.



Arroyo, Javier, Fred Spiessens, and Lieve Helsen. "Comparison of Optimal Control Techniques for Building Energy Management." *Frontiers in Built Environment* 8.Artificial Intelligence Applications in Building's Thermal Management (2022).

Fault detection and predictive maintenance in building systems

E.g., using ML to detect faults (data from[11])



Granderson, Jessica, et al. "Building fault detection data to aid diagnostic algorithm creation and performance testing." *Scientific data* 7.1 (2020): 65.

More on Buildings in this Summer School

Tutorial on RL in Buildings

CityLearn: Reinforcement Learning Control for Grid-Interactive Efficient Buildings and Communities

Kingsley Nweye, Allen Wu, Yara Almilaify, and Zoltan Nagy, ICLR 2023

Learn how to design simple and advanced control algorithms to provide energy flexibility, and acquire familiarity with the CityLearn environment and its datasets for extended use in projects. The tutorial provides a walk-through on how to set up and interact with the environment using a real-world dataset in three hands-on control experiments.

Electricity Systems | Introductory | Python | Reinforcement Learning | Building Energy Management | Energy Flexibility

Office Hours

July 5, 2023, 7:00 p.m. - 9:00 p.m. UTC

AMA

July 12, 2023, 7:00 p.m. - 8:00 p.m. UTC

See also after Summer School: https://www.climatechange.ai/tutorials

More on Buildings in this Summer School

Tutorial on RL in Buildings

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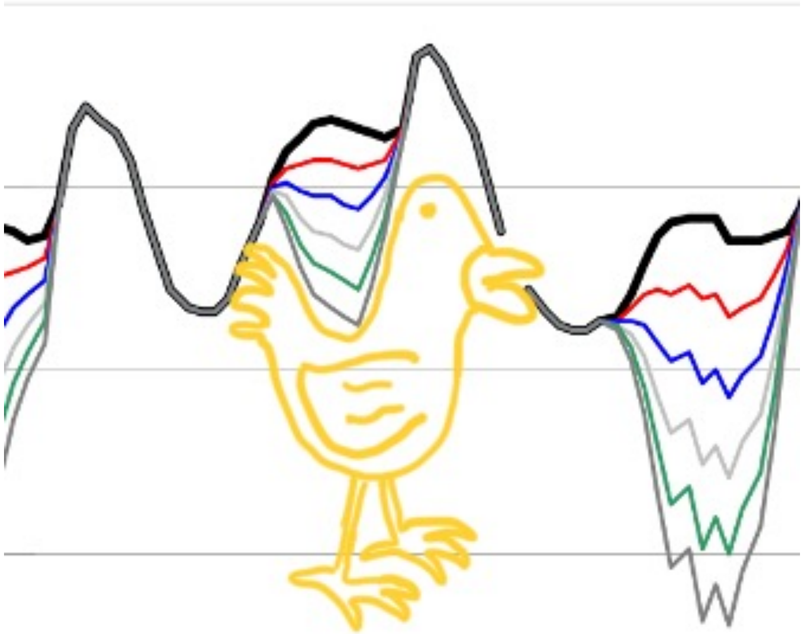
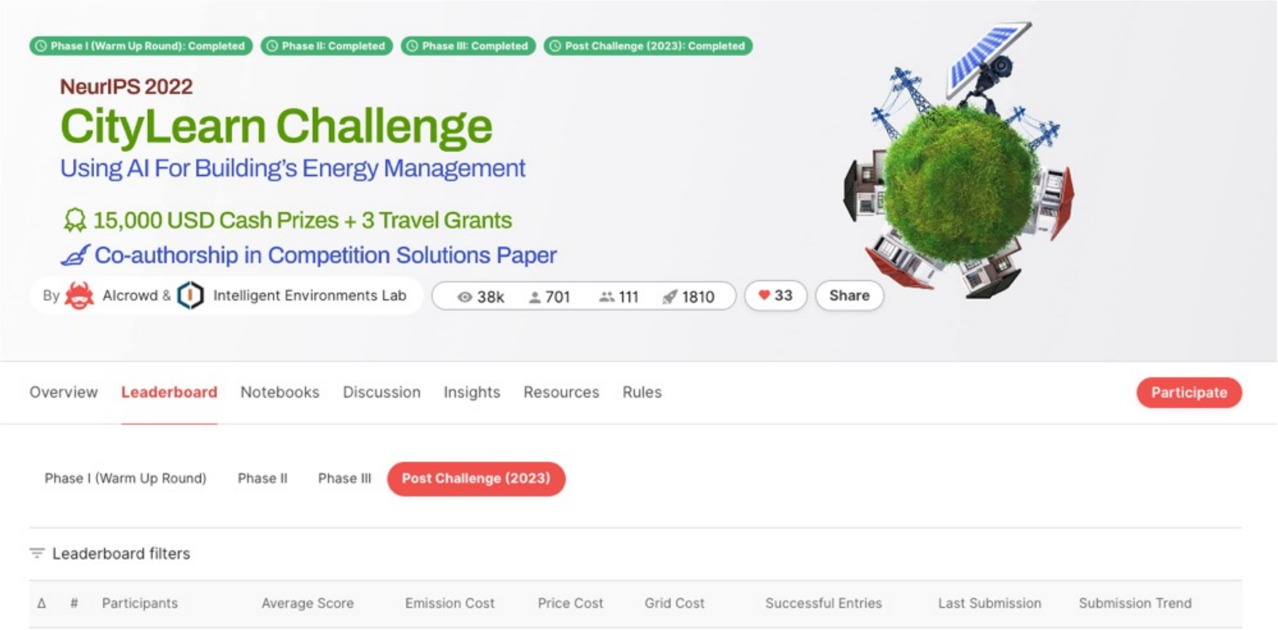


See also after Summer School: https://www.climatechange.ai/tutorials

More on Buildings in this Summer School

You can submit a learner to the CityLearn Challenge 2022 leader board to see where you would have scored in the last challenge (only in Post Challenge mode).



See also after Summer School: https://www.climatechange.ai/tutorials

Tutorials on Optimizing Buildings with Reinforcement Learning

Bonus: Another Tutorial on RL in Buildings (from last year's summer school!)

Building Control with RL using BOPTEST

Javier Arroyo, David Blum, Kyle Benne, and Iago Figueroa,
CCAI Summer School 2022

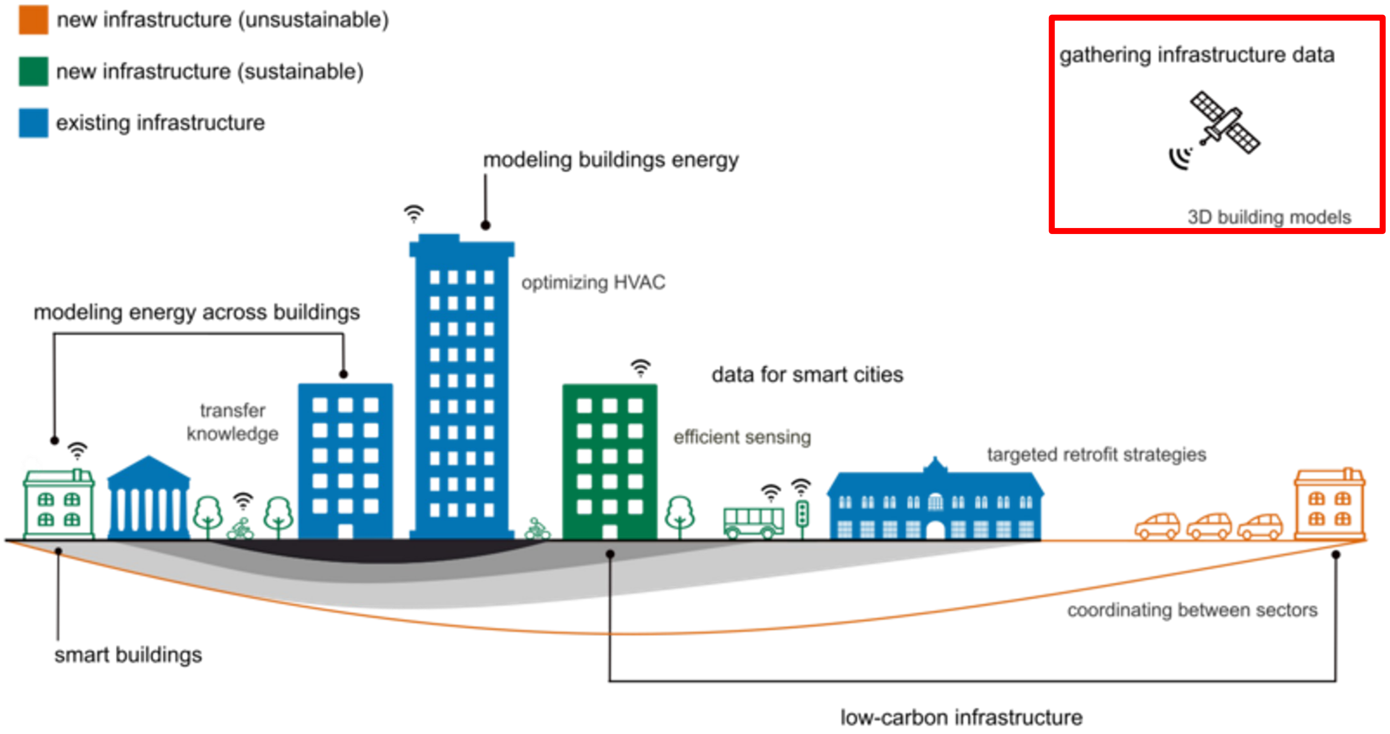
Apply reinforcement learning to a building emulator to intelligently control HVAC systems.

Check out the recorded talk for more information.

Buildings & Cities | Intermediate | Python | Reinforcement Learning | Energy Management

See also after Summer School: https://www.climatechange.ai/tutorials

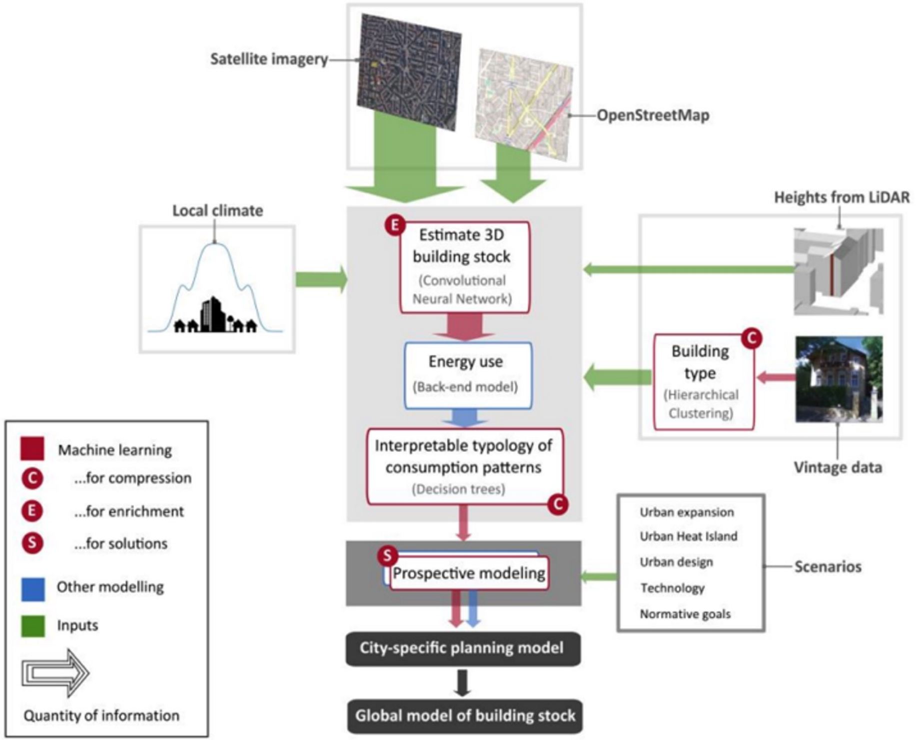
Overview of machine learning applications areas for buildings



Source: Rolnick, David, et al. "Tackling climate change with machine learning." ACM Computing Surveys (CSUR) 55.2 (2022): 1-96.

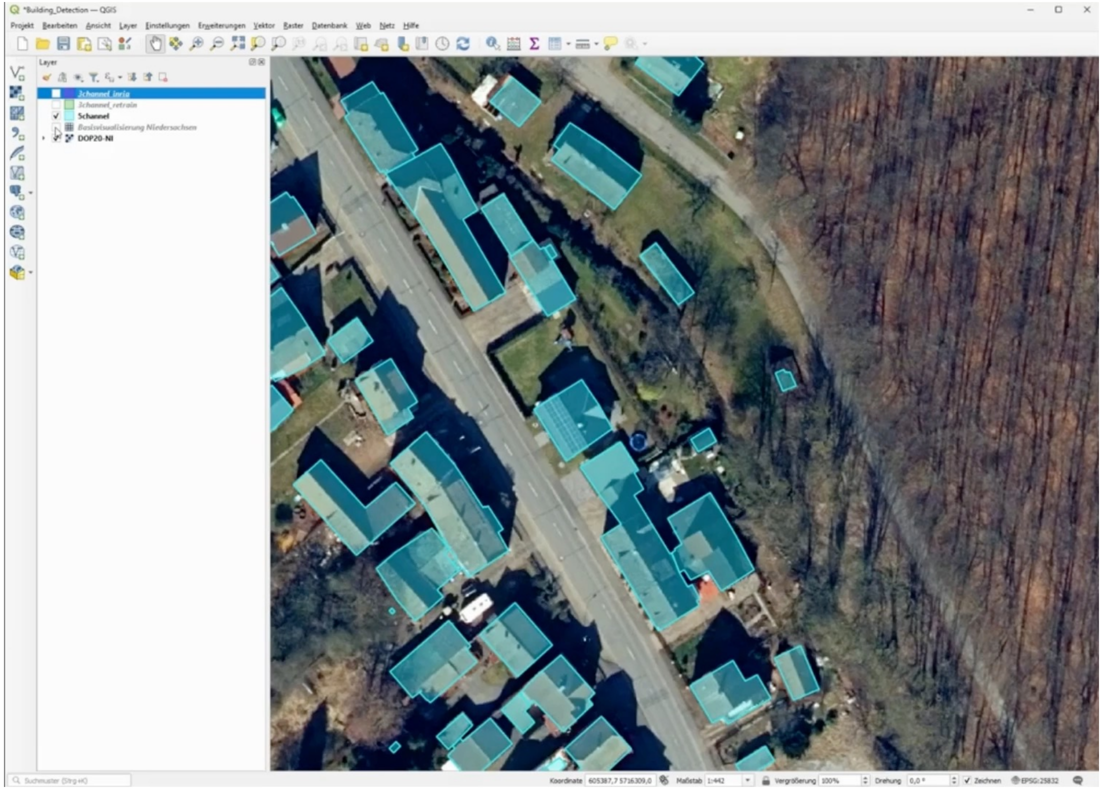
Mapping built-up and energy infrastructure

E.g., using CNNs and Decision Trees to estimate the building energy use at scale .



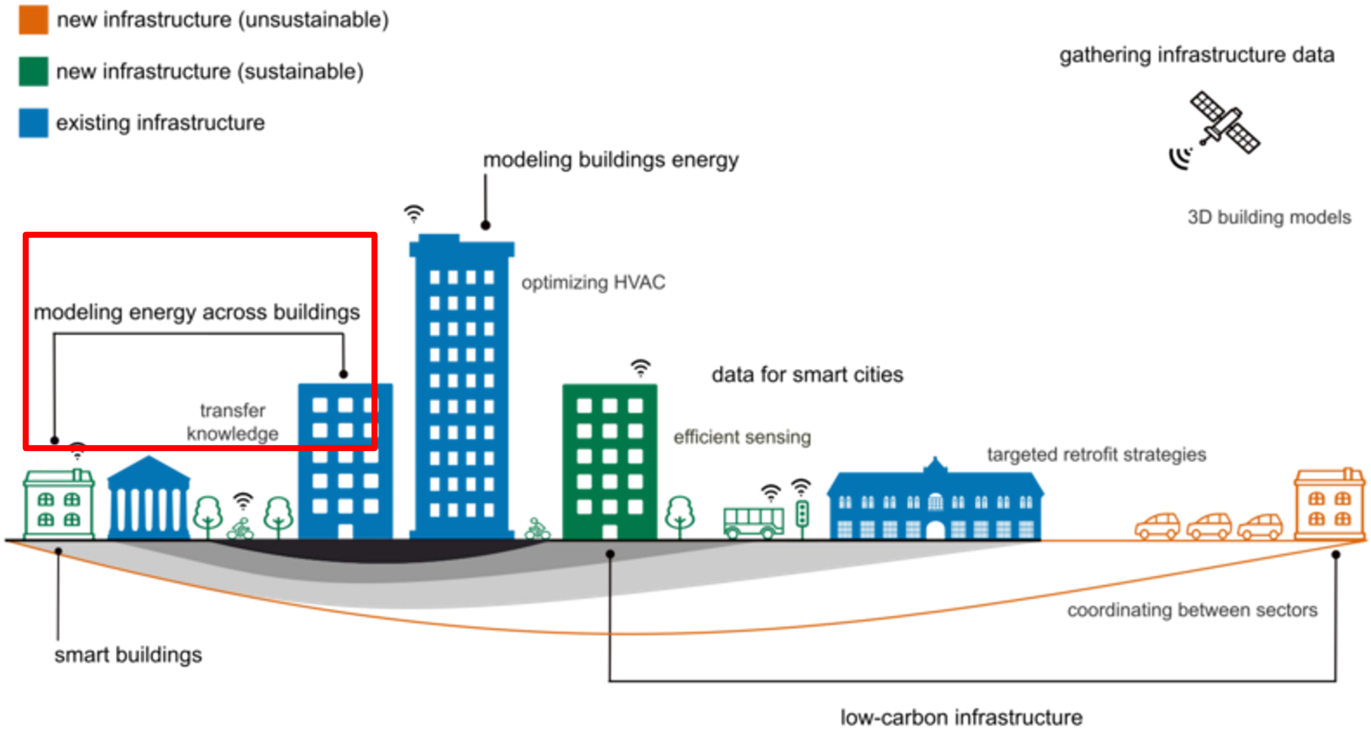
Milojevic-Dupont, Nikola, and Felix Creutzig. "Machine learning for geographically differentiated climate change mitigation in urban areas." Sustainable Cities and Society 64 (2021): 102526.

Mapping built-up and energy infrastructure



Source: https://twitter.com/JonasBostelmann/status/1626237769122222080, based on https://github.com/Lydorn/Polygonization-by-Frame-Field-Learning

Overview of machine learning applications areas for buildings



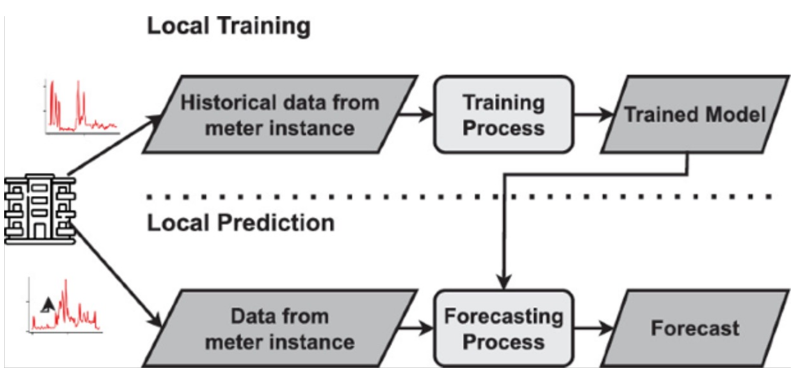
Source: Rolnick, David, et al. "Tackling climate change with machine learning." ACM Computing Surveys (CSUR) 55.2 (2022): 1-96.

Transfer Learning and Global Modelling

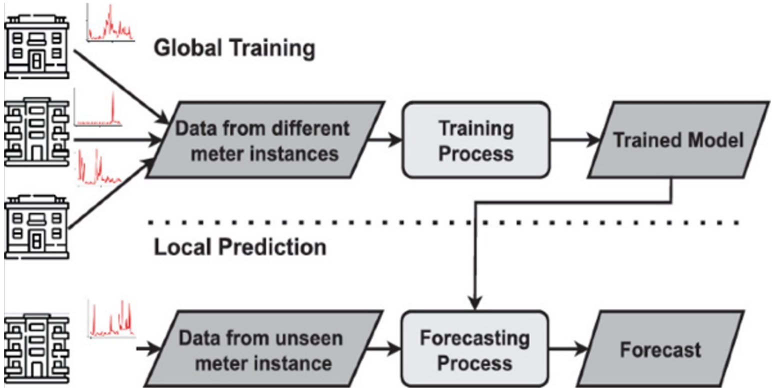
Source: Pinto et al.: Transfer learning for smart buildings: A critical review of algorithms, applications, and future perspectives. Advances in Applied Energy (2022).

Transfer Learning and Global Modelling

Local Modelling



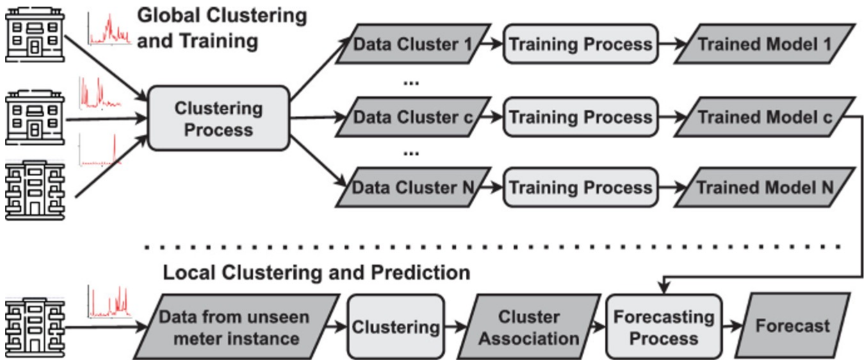
Global Modelling



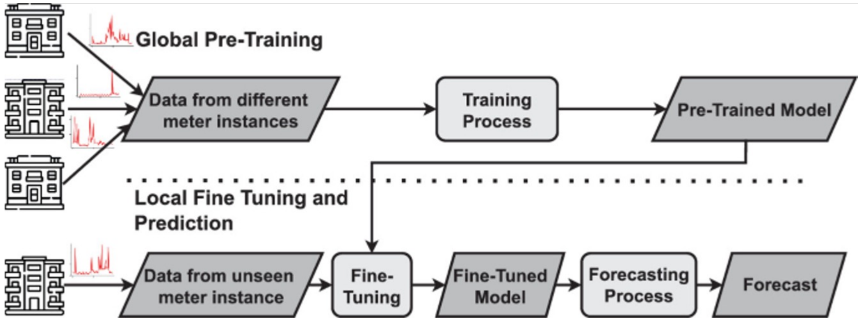
Source: Haben, S., Voss, M., & Holderbaum, W. (2023). Core Concepts and Methods in Load Forecasting: With Applications in Distribution Networks.

Transfer Learning and Global Modelling

Global Modelling with Clustering

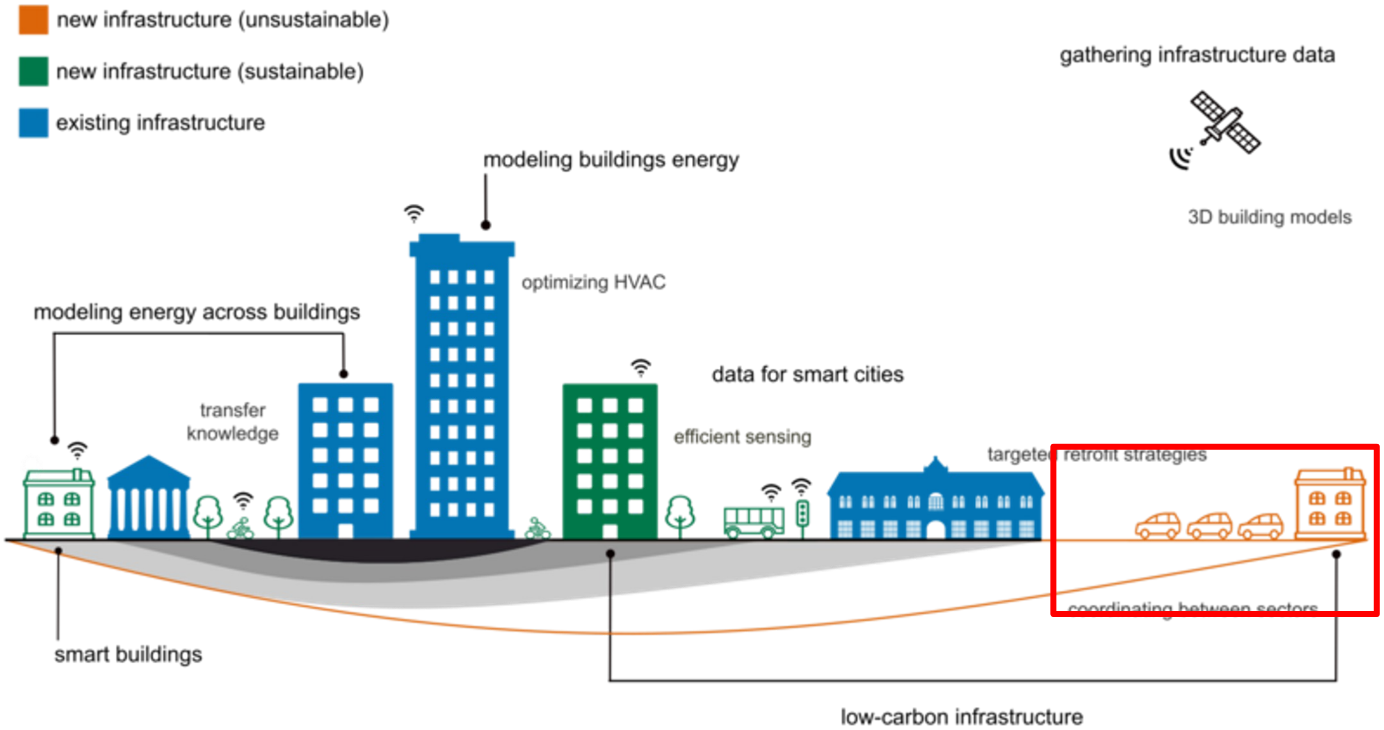


Fine Tuning a Model



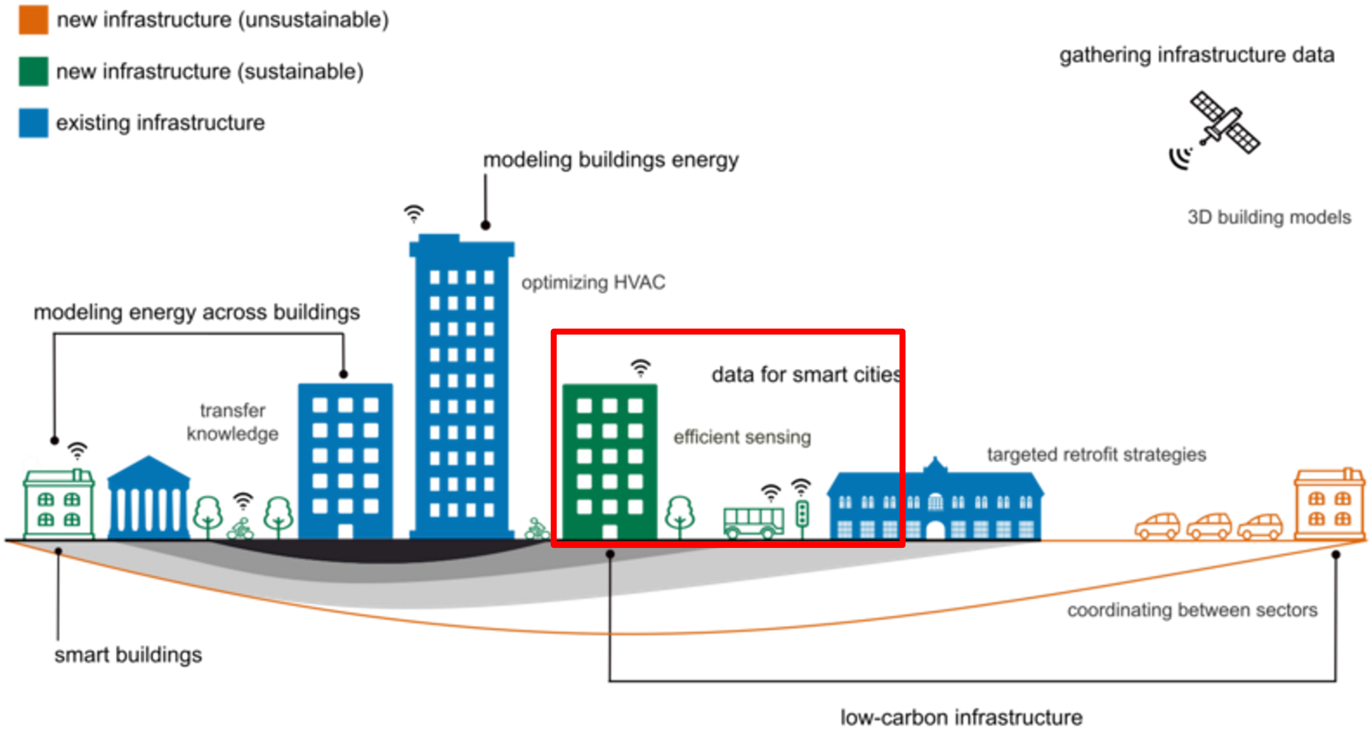
Source: Haben, S., Voss, M., & Holderbaum, W. (2023). Core Concepts and Methods in Load Forecasting: With Applications in Distribution Networks.

Overview of machine learning applications areas for buildings



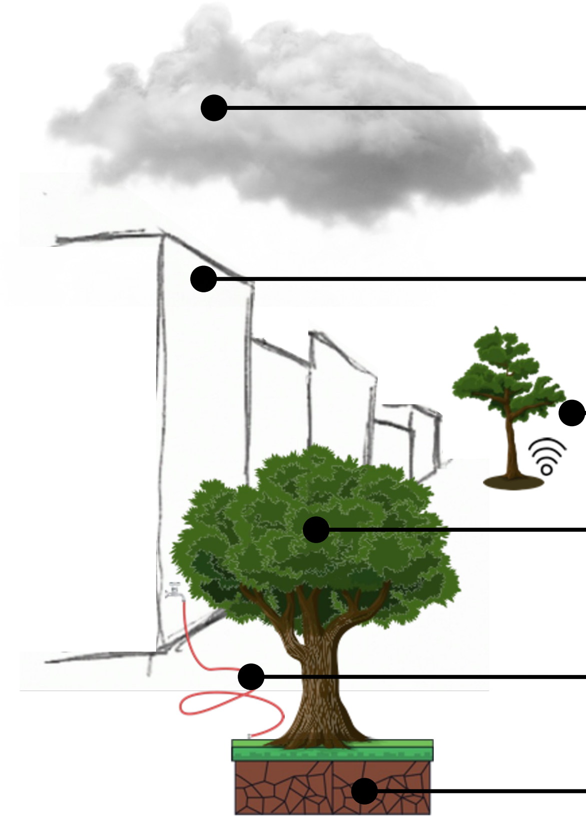
Source: Rolnick, David, et al. "Tackling climate change with machine learning." ACM Computing Surveys (CSUR) 55.2 (2022): 1-96.

Overview of machine learning applications areas for buildings



Source: Rolnick, David, et al. "Tackling climate change with machine learning." ACM Computing Surveys (CSUR) 55.2 (2022): 1-96.

Quantified Trees: Predicting City Tree Irrigation Requirements



Weather data
- Precipitation
- Temperature
- Radiation
- Grass reference evapotranspiration

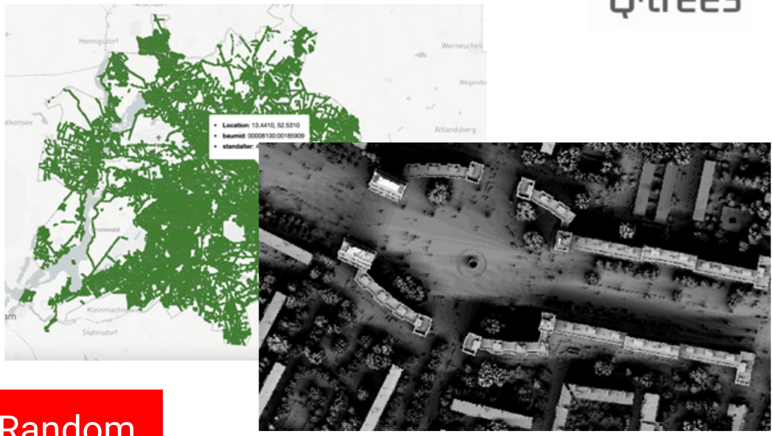
On-site information
- Shading of the trees

Sensors in the soils
- Suction tension
- Soil moisture

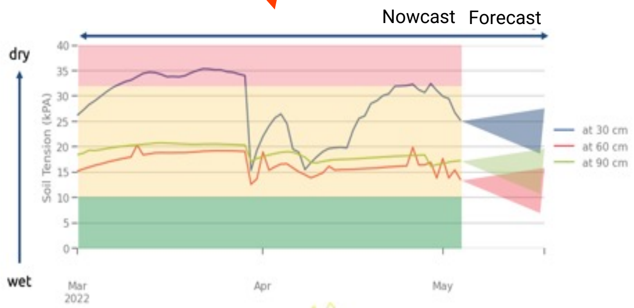
Tree master data
- Type of tree
- Age/ standing age
- Height
- Water requirement

Watering data

Soil data
- Composition
- Sealing
- Groundwater



Random Forest

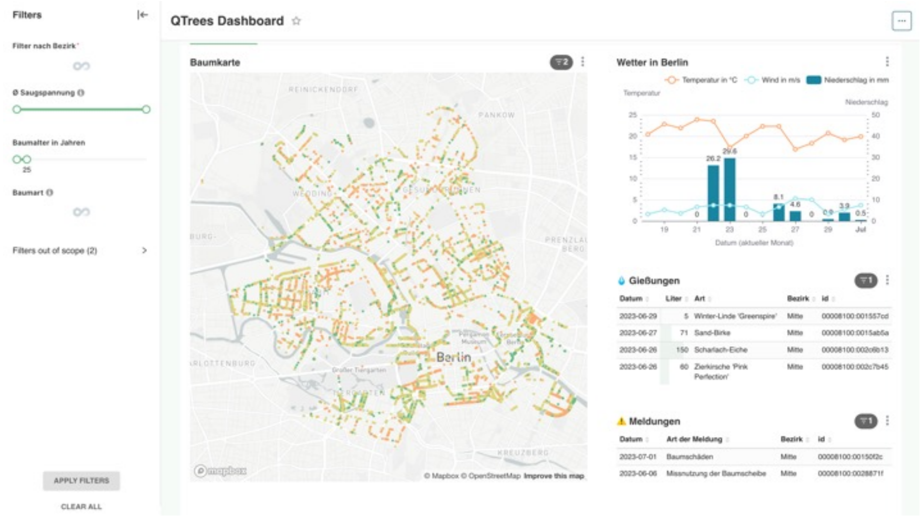


Watch an intro at Bits and Bäume Conference: https://www.youtube.com/watch?v=jtGre095uD4

Quantified Trees: Predicting City Tree Irrigation Requirements

q·trees

Dashboard for Greenery Departments



App for Berlin Citizens

q·trees

Project by

TECHNOLOGIE STIFTUNG BERLIN

birds on mars

Bezirksamt Mitte BERLIN

Supported by:

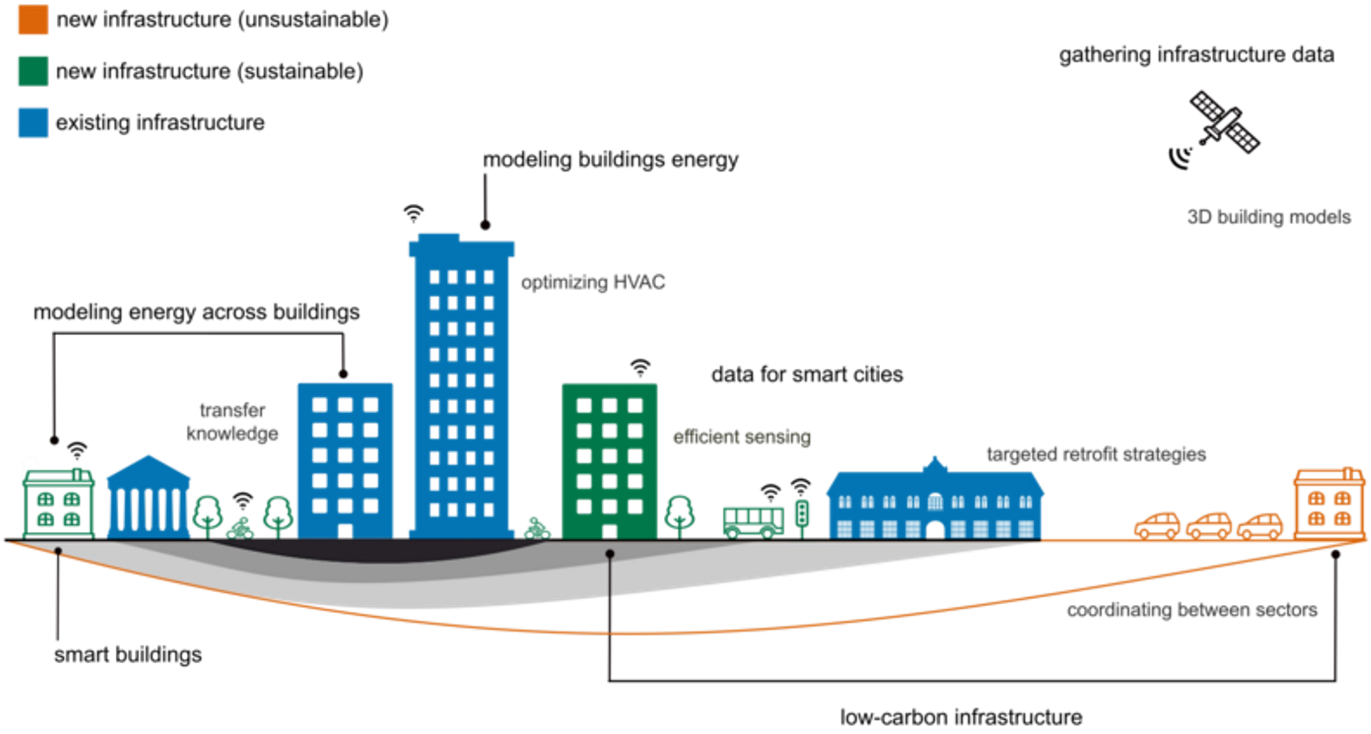
Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

based on a decision of the German Bundestag

Administrated by

Zukunft Umwelt Gesellschaft

Overview of machine learning applications areas for buildings



Source: Rolnick, David, et al. "Tackling climate change with machine learning." ACM Computing Surveys (CSUR) 55.2 (2022): 1-96.

Another Overview of Machine Learning applications areas for buildings

	Inter-Building	Building	Occupant
Control strategies • Reinforcement learning • Hard control and model-predictive control	• Power flow coordination • Smart energy storage and distribution	• HVAC, lighting control • Space scheduling • Demand response	• Occupant-centric environmental control
Learning Models • Supervised learning • Physics-based learning • Generative modeling	• Demand response prediction • Building load prediction	• Building control • Fault diagnosis • Occupancy detection	• Thermal comfort • Activity detection • Utility Function Learning
Markets • Automated pricing • Time-series forecasting • Gamification	• Aggregation & mechanism design • Energy allocation	• Demand response cost optimization • Smart load scheduling	• Mechanism design based on occupant utility

Source: Prasanna Das, Hari, et al. "Machine Learning for Smart and Energy-Efficient Buildings." *arXiv e-prints* (2022).
https://arxiv.org/pdf/2211.14889.pdf

Current Research Directions

Hybrid physical and data-driven modelling

Black Box

No Knowledge of the System Physics (Data-driven)

Grey Box

Partial Knowledge of the System Physics

White Box

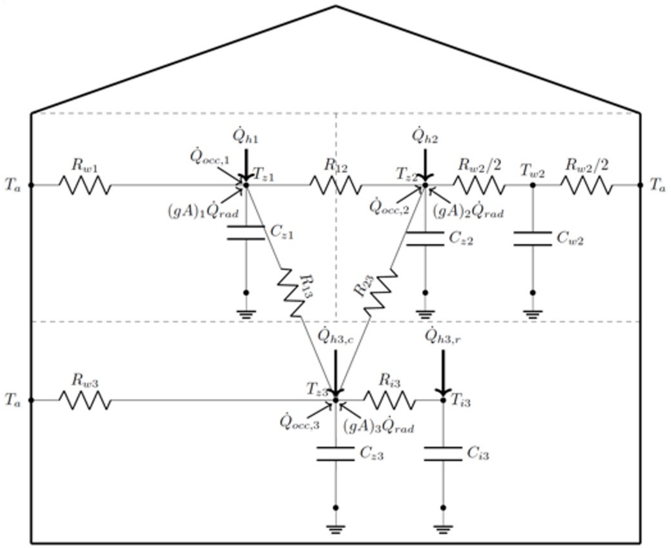
Complete Knowledge of the System Physics

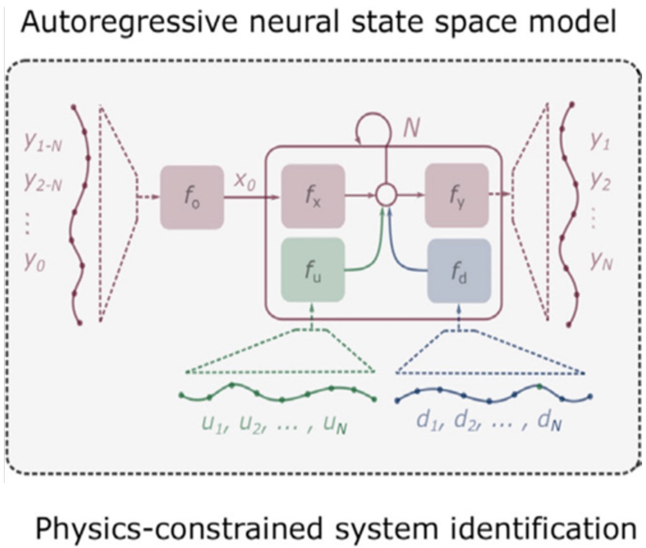
- Better Accuracy
- Better Transferability

- Suitable for small datasets
- Reliability

Source: Prasanna Das, Hari, et al. "Machine Learning for Smart and Energy-Efficient Buildings." *arXiv e-prints* (2022).
https://arxiv.org/pdf/2211.14889.pdf

Hybrid physical and data-driven modelling





Arroyo, J. Synergy between control theory and machine learning for building energy management. PhD Thesis, KU Leuven, Leuven, Belgium (2021).

Drgona et al.: Physics-constrained deep learning of multi-zone building thermal dynamics Energy and Buildings 243 (2021), 110992.

Hybrid optimal control methods

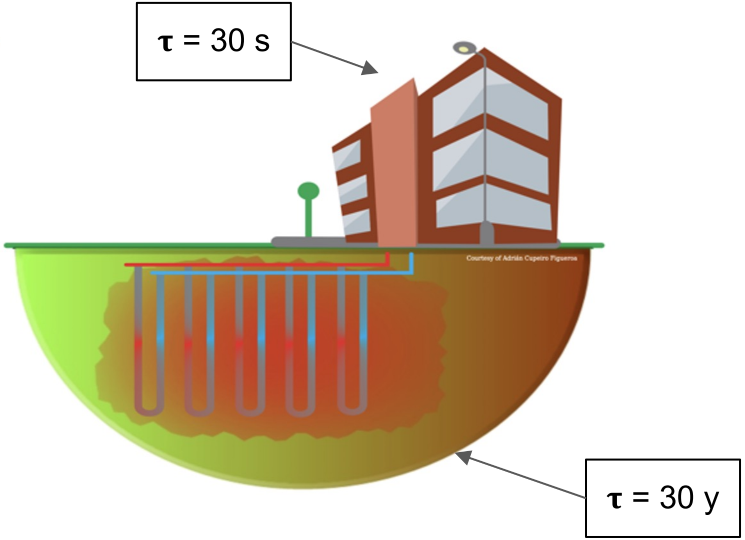
CONTROL THEORY	MACHINE LEARNING
Data efficiency	Data efficiency
Constraint handling	Constraint handling
Robustness	Robustness
Adaptive	Adaptive
Domain knowledge required	Domain knowledge required
Implementation cost	Implementation cost

Source: Javier Arroyo in Lecture from Summer School 2022.

- Approximate MPC, Drgoňa et al. (2018).
- Gnu-RL, Chen et al. (2019).
- DPC, Drgoňa et al. (2021).
- RL-MPC, Arroyo et al. (2022).

- Drgoňa, J., Picard, D., Kvasnica, M., Helsen, L., "Approximate model predictive building control via machine learning." Applied Energy 218 (2018) 199-216.
- Chen, B., Cai, Z., and Bergés, M. Gnu-RL: A Precocial Reinforcement Learning Solution for Building HVAC Control Using a Differentiable MPC Policy. In Proceedings of the 6th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation (BuildSys) (New York, New York, USA, November 2019), pp. 316–325
- Drgona, J., Tuor, A., Skomski, E., Vasisht, S., and Vrabie, D. Deep Learning Explicit Differentiable Predictive Control Laws for Buildings. arXiv (2021)
- Arroyo, J., Manna, C., Spiessens, F., and Helsen, L. Reinforced Model Predictive Control (RL-MPC) for Building Energy Management. Applied Energy 309 (2022), 118346.

Optimizing across different time scales



Source: Cupeiro Figueroa, I. Short- and long-term optimal control of hybrid GEOTABS Buildings. PhD Thesis, KU Leuven, Leuven, Belgium, 2021.

Challenges for Deployment of RL in Buildings

1. Being able to learn on live systems **from limited samples**
2. Dealing with unknown and potentially **large delays** in the system actuators, sensors or feedback
3. Learning and acting in **high-dimensional state and action spaces**
4. Reasoning about **system constraints** that should never or rarely be violated
5. Interacting with **systems that are partially observable**
6. Learning from **multiple, or poorly specified, objective functions**
7. Being able to **provide actions quickly**, especially for systems with low latencies
8. **Training off-line** from fixed logs of an external policy
9. Providing system operators with **explainable policies**

Read at: https://www.climatechange.ai/blog/2023-06-02-citylearn and Nweye, Kingsley, et al. "Real-world challenges for multi-agent reinforcement learning in grid-interactive buildings." Energy and AI 10 (2022): 100202.

And Large Language Models? Generative AI?

Answer in the Google Form

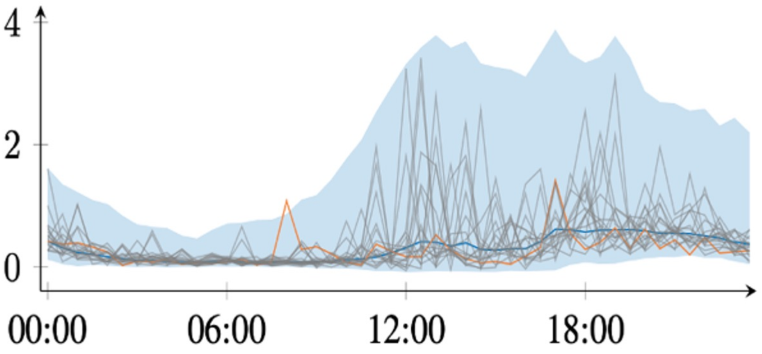
Any Ideas?

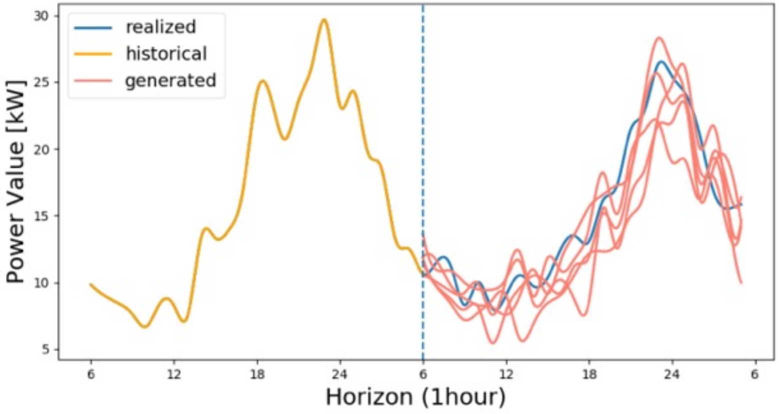
Generative AI for Images

Source: Generated by DALL-E 2

Generative AI for Time Series

Using generative machine learning for probabilistic load forecasting of scenarios and generating energy loads for simulations.





Arpogaus, M., Voss, M., Sick, B., Nigge-Uricher, M., & Dürr, O. (2023). Short-term density forecasting of low-voltage load using bernstein-polynomial normalizing flows. *IEEE Transactions on Smart Grid*.

Zhang, L., & Zhang, B. (2019). Scenario forecasting of residential load profiles. IEEE Journal on Selected Areas in Communications, 38(1), 84-95.

More Ressources

More on Buildings in this Summer School

Tutorial on Load Forecasting

Building Load Forecasting with Machine Learning

Marcus Voss, CCAI Summer School 2022

Accurate forecasts of energy demand and supply are essential to mitigate climate change. Discover how to train and evaluate building load forecasts using off-the-shelf ML models.

Buildings & Cities | Intermediate | Python | Time Series Analysis | Energy Management

Tutorial on RL in Buildings

CityLearn: Reinforcement Learning Control for Grid-Interactive Efficient Buildings and Communities

Kingsley Nweye, **Allen Wu**, **Yara Almilaify**, and **Zoltan Nagy**, ICLR 2023

Learn how to design simple and advanced control algorithms to provide energy flexibility, and acquire familiarity with the CityLearn environment and its datasets for extended use in projects. The tutorial provides a walk-through on how to set up and interact with the environment using a real-world dataset in three hands-on control experiments.

Electricity Systems | Introductory | Python | Reinforcement Learning | Building Energy Management | Energy Flexibility

See also after Summer School: https://www.climatechange.ai/tutorials

More on Buildings in this Summer School

Tutorial on (Tool Box for?) Smart Meter Data

Smart Meter Data Analytics: Practical Use-Cases and Best Practices of Machine Learning Applications for Energy Data in the Residential Sector

Tobias Brudermueller and **Markus Kreft**,
ICLR 2023

A practical guide to current trends in smart meter data analytics with a focus on feature engineering and machine learning scenarios for energy data at 15-minute resolution. Gain insights into current trends and use cases in the energy field and get a sense of typical and atypical energy consumption in a residential building.

Electricity Systems | Introductory | Python | Time Series Analysis | Building Energy Management | Energy Flexibility

Bonus: Another Tutorial on RL in Buildings (from last year's summer school!)

Building Control with RL using BOPTEST

Javier Arroyo, David Blum, Kyle Benne, and **Iago Figueroa**,
CCAI Summer School 2022

Apply reinforcement learning to a building emulator to intelligently control HVAC systems.

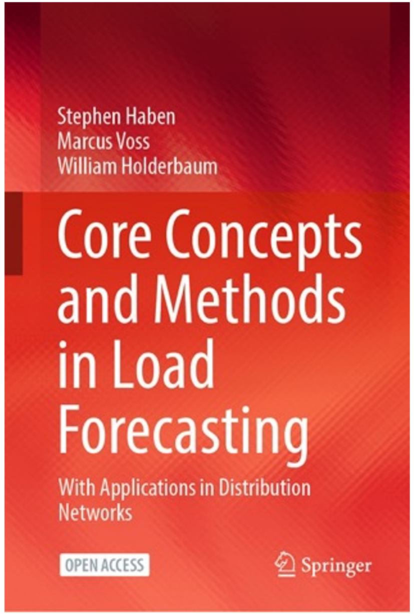
Check out the recorded talk for more information.

Buildings & Cities | Intermediate | Python | Reinforcement Learning | Energy Management

See also after Summer School: https://www.climatechange.ai/tutorials

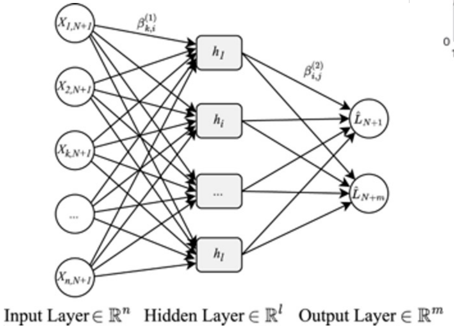
“Shameless plug”

An open access book on Load Forecasting

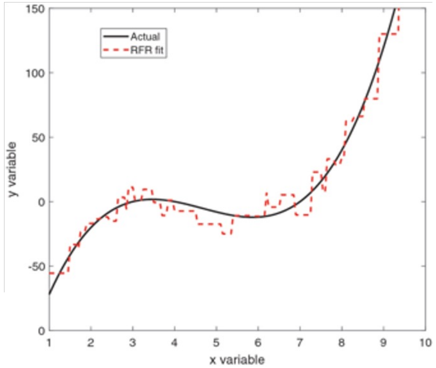


https://link.springer.com/book/10.1007/978-3-031-27852-5

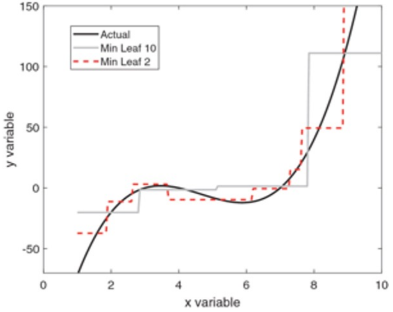
Vanilla ANN



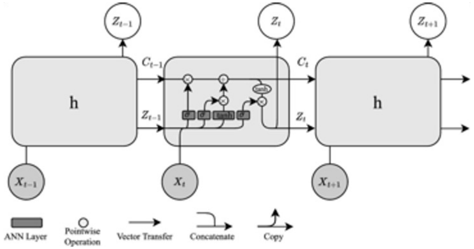
Random Forest



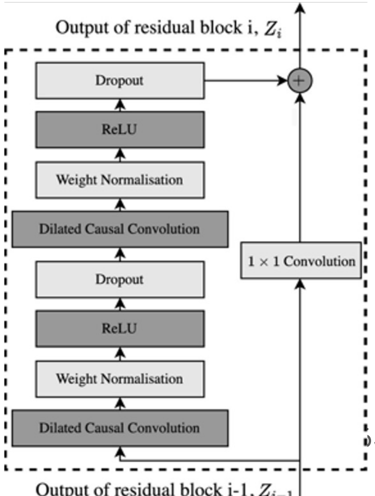
Decision Tree



LSTM



Temporal CNN



Other resources on AI and buildings

Surveys:
- Machine Learning for Smart and Energy-Efficient Buildings, https://arxiv.org/pdf/2211.14889.pdf

CCAI Entry Points:
- CCAI Wiki pages on buildings: https://wiki.climatechange.ai/wiki/Buildings_and_Cities
- TCML Paper Section on Buildings: https://dl.acm.org/doi/10.1145/3485128#d1e2765

Some interesting Frameworks:
- BOPTEST (there is the other CCAI tutorial) https://github.com/ibpsa/project1-boptest
- CityLearn (you will use that in this year's tutorial!): https://github.com/intelligent-environments-lab/CityLearn
- COBS: Comprehensive Building Simulator https://github.com/sustainable-computing/COBS
- ACTB: Advanced Controls Test Best: https://github.com/henze-research-group/MODRLC

Datasets:
- Building Performance Database: https://buildings.lbl.gov/cbs/bpd
- List of low-voltage level smart meter data (includes several datasets of households and buildings): https://low-voltage-loadforecasting.github.io/
- Several ressources of the SIG Energy interest group of ACM: https://energy.acm.org/resources/
- List of building data by Clayton Miller on Kaggle: https://www.kaggle.com/claytonmiller/datasets
- The Building Data Genome 2 (BDG2) Data-Set: https://github.com/buds-lab/building-data-genome-project-2
- BENCHMARK DATASETS of Building Environmental Conditions and Occupancy Parameters: https://bbd.labworks.org/

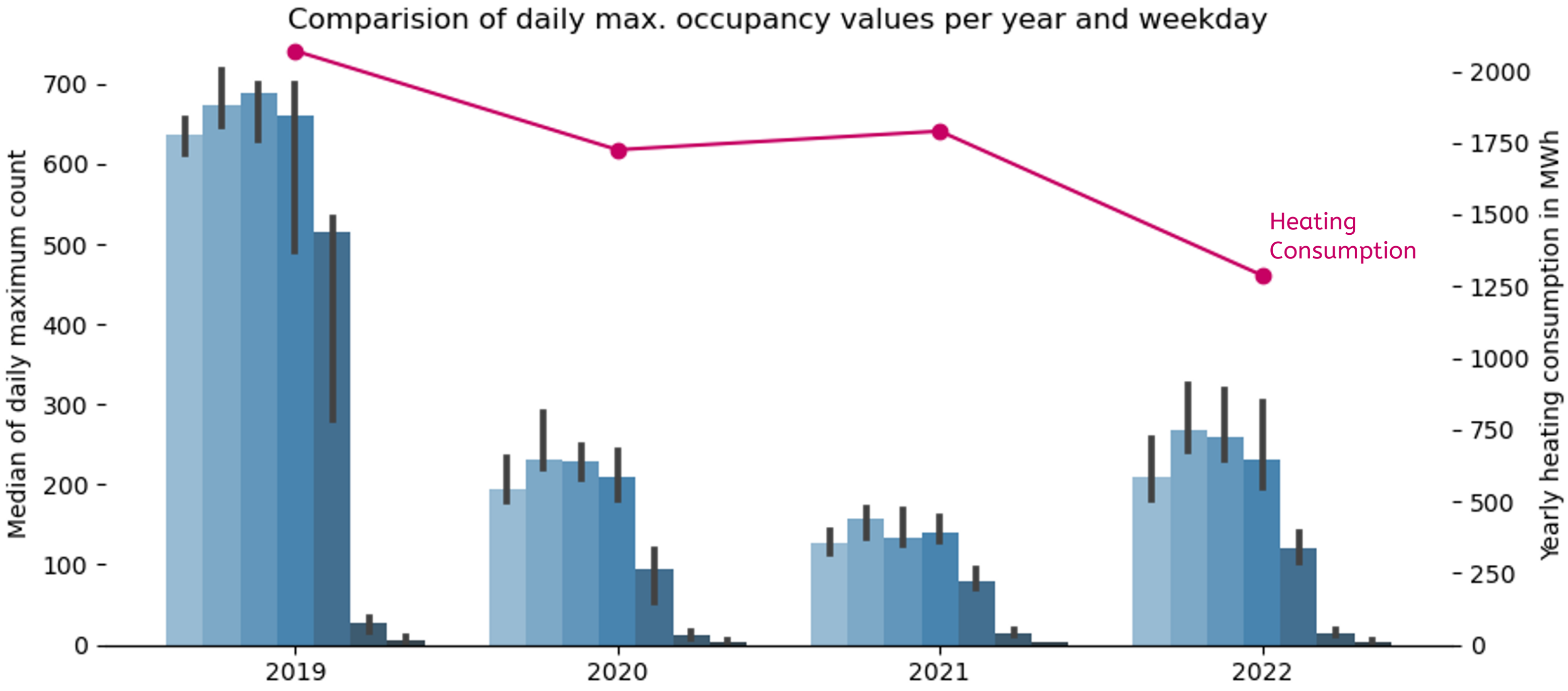
Concluding Thoughts

Some final thoughts

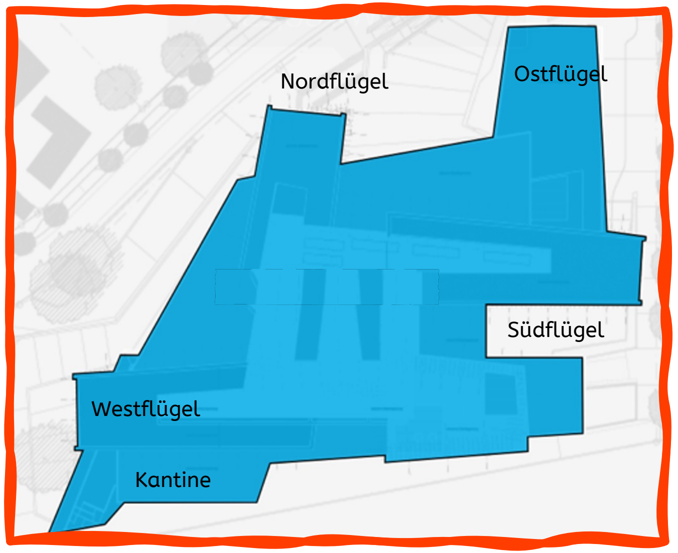
Remember

- ML is not a silver bullet and is only relevant sometimes
    - … an if so, only as part of an overall strategy.
- Sophisticated algorithms may be required, but aren't always
    - … sometimes out-of-the-box simple regression models can be of high impact.
    - … or even just Excel and getting the right people together.

Case study of energy savings of a real building



Case study of energy savings of a real building



Realizations:
- First, AI/ML was not needed to find low-hanging fruits,
- Idea: closing parts of the building.

However:
- Organizational constraints: some people can‘t (don‘t want to) move,
- Technical constraints: only large zones can be controlled independently,
- Building is already quite efficiently built, so that absolute savings are low

➢ Project was stopped, as relative savings for closing half of the building are "only" 10%-12,5%

➢ More could be saved with less effort by lowering temperature by one Kelvin altogether

➢ Easy 2-2.5% percent can be saved, when canteen closes on Fridays (and people go to neighboring buildings)

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  - … or even just Excel and getting the right people together.

Thanks!
Questions?