The Use of Modelica and the Functional Mockup Interface for the Building Optimization Testing Framework (BOPTEST)

American Modelica Conference 2022

User Presentations 1

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Polytechnic University of Milan, Italy	Ettore Zanetti *(now at LBNL)*
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The Use of Modelica and the Functional Mockup Interface for the Building Optimization Testing Framework (BOPTEST)

- Introduction
- Framework Components
- Example Usage
- Conclusions and Next Steps

Background

Future (Additional) Requirements of Building HVAC Systems

- Energy and carbon reduction
- Electric grid integration
- Resilience

Broader Ideas:

→ There's a growing need for **improving controls for energy management** and in response to dynamic operating conditions and objectives

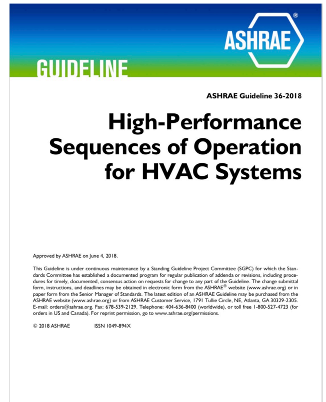
→ What **new tools** are needed for new development and adoption of new control technologies and methods?

Challenges to Control Evaluation

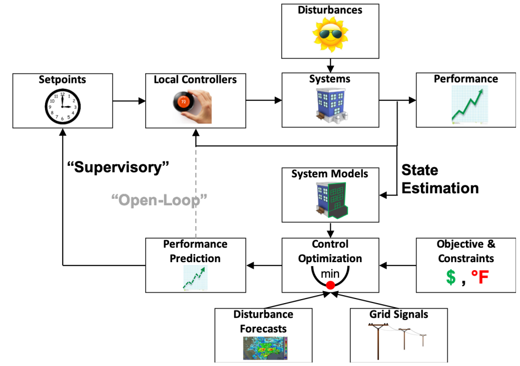
1. Individualized Studies

- Different building, HVAC, climate, period, performance metrics
- Different comparative baselines [1]

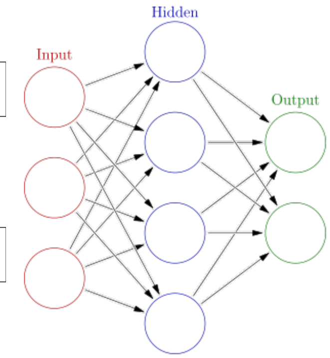
→ **Difficult to answer which approach is most effective and where more work needed**



ASHRAE Guideline 36



Model Predictive Control (MPC)



Data-Driven Control (e.g. RL)

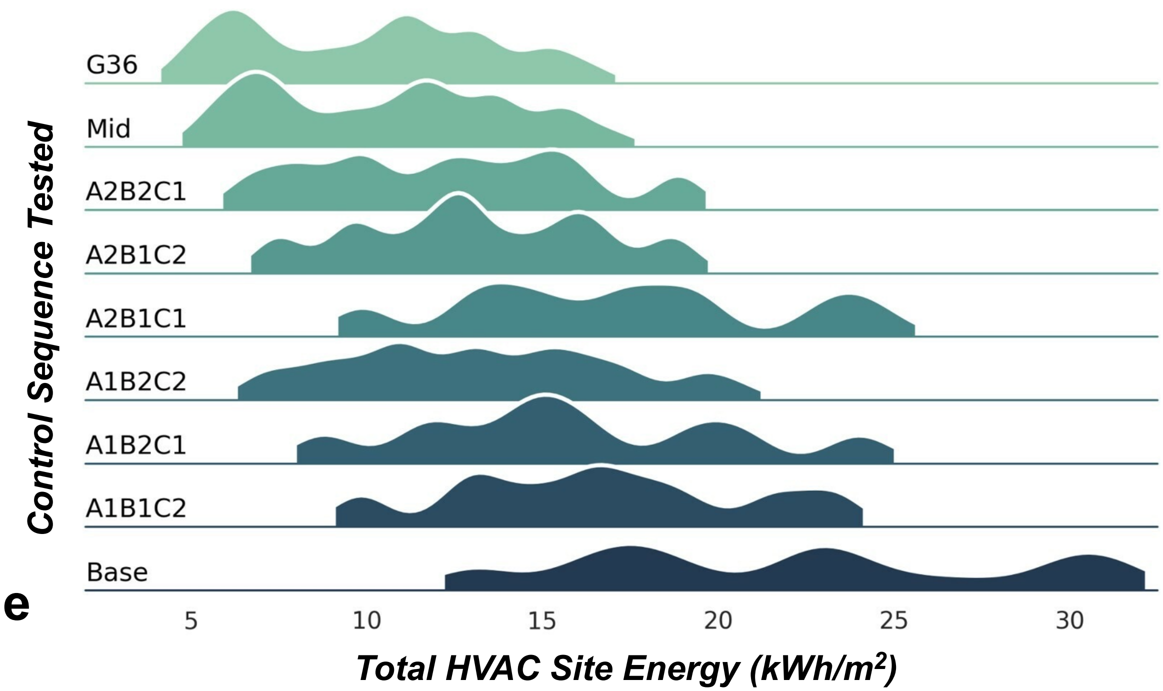
Examples of recent controls development

2. Setup Time and Effort

- Real buildings pose operational risks and have slow-changing operating conditions
- Realistic simulations require building modeling expertise and effort

→ **Limits rapid prototyping**

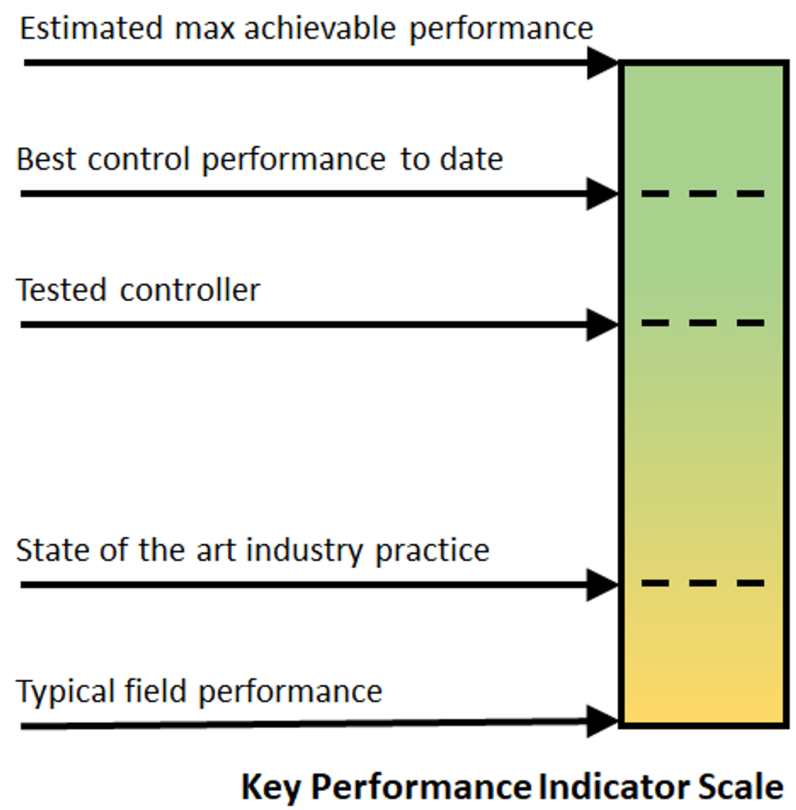
→ **Limits opportunities from outside experts (e.g. process control, optimization, data science)**



[1] Variability of energy consumption based on controls (Zhang et al. 2022 https://doi.org/10.1080/19401493.2021.2021286)

Goals

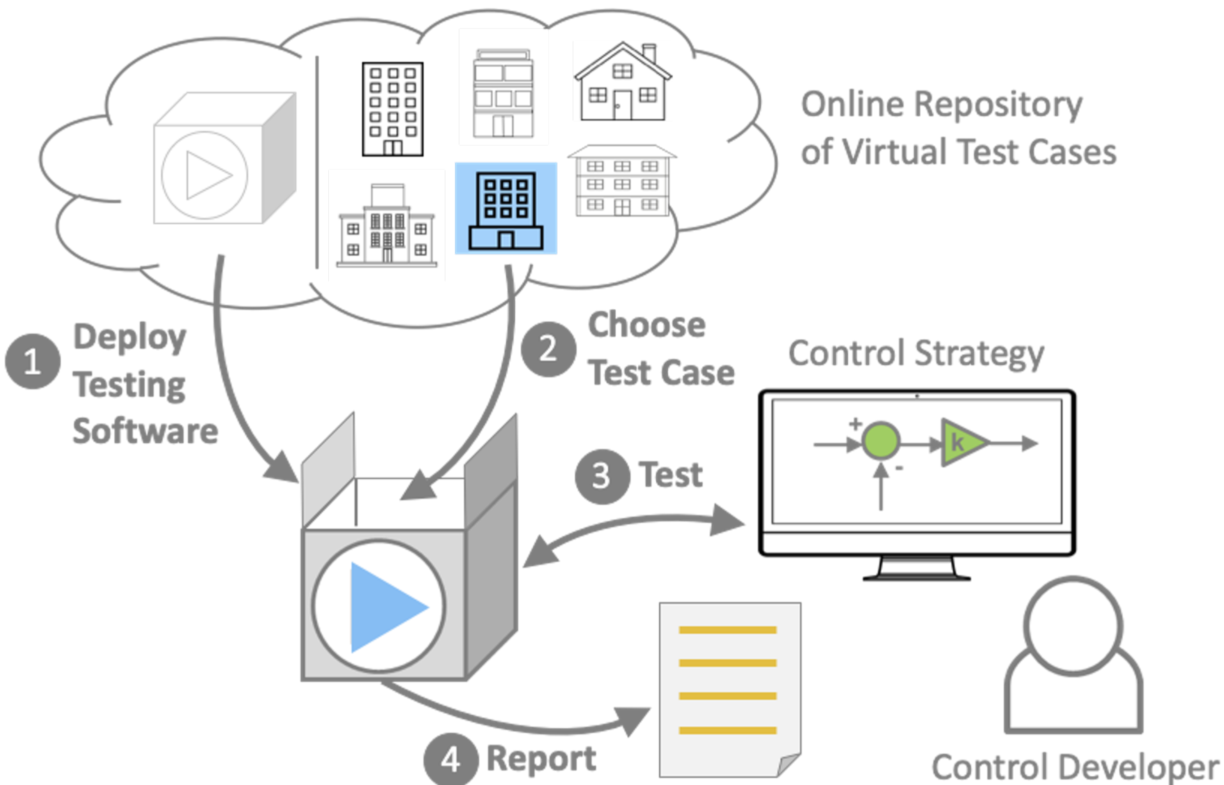
- Enable benchmarking state-of-the-art control performance for building energy systems
- Accelerate building control software development and deployment
- Enable transition and encourage adoption of advanced building control algorithms



Approach

Building Optimization Testing Framework (BOPTEST): A Complete and Open Virtual Testing Environment

- Deployable, controlled software runtime environment
- Repository of reference test cases with emulator models and boundary conditions
- Standardized key performance indicators (KPI) that are auto-calculated



Homepage: https://boptest.net

GitHub: https://github.com/ibpsa/project1-boptest

Journal Paper: *Blum et al. (2021)* https://doi.org/10.1080/19401493.2021.1986574

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Framework Components

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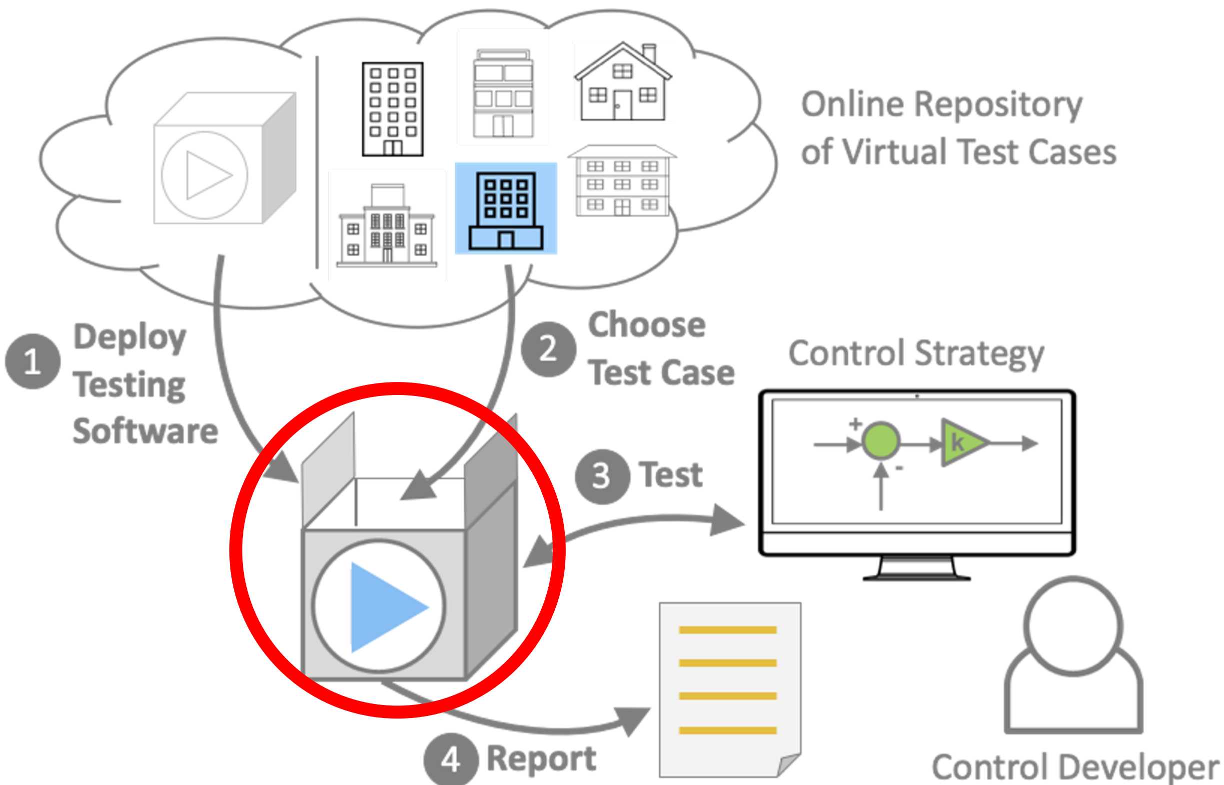

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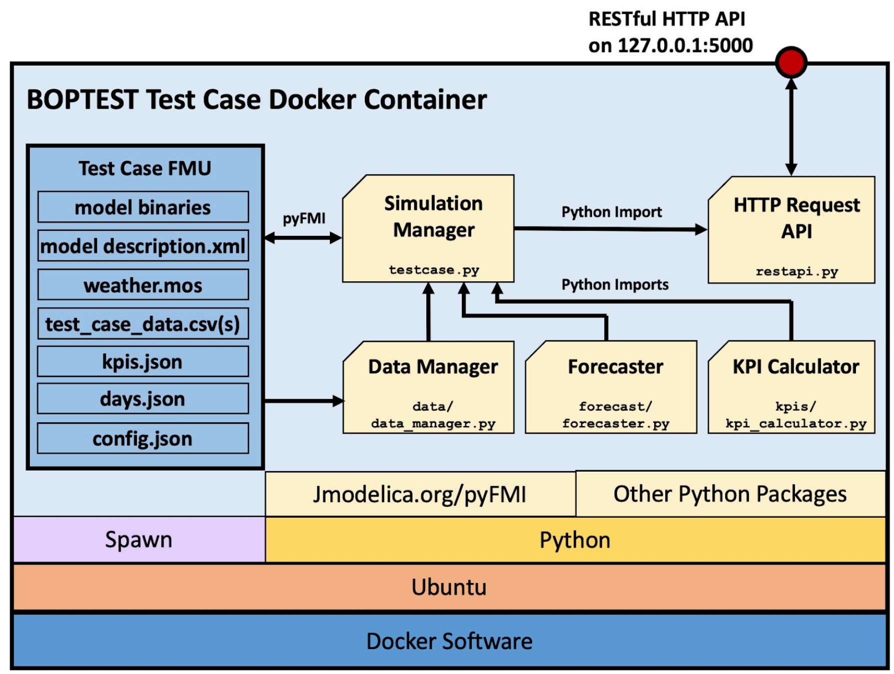
Framework Components

Run-Time Environment

- Functional Mockup Interface (FMI) for simulation management
- Docker for rapid, repeatable build and deploy locally cross-platform or as web-service
- HTTP-based RESTful API for test set up, emulator-controller co-simulation, and KPI reporting
- Standard API return formats including request status, messages, warnings, and errors
- Interface wrappers:
  - OpenAI-Gym by KU Leuven
    Arroyo et al. 2021 (https://doi.org/10.26868/25222708.2021.30380)
  - BACnet/Brick with Johnson Controls and Colorado School of Mines
    (Fierro et al. 2022, BuildSys '22, Accepted.)

API Endpoint	Description
GET *measurements*	Receive available measurement points
GET *inputs*	Receive available input points
PUT *scenario*	Set test scenario (time period, ele. price)
PUT *initialize*	Initialize simulation
PUT *step*	Set control step
GET *forecast*	Receive forecasts
POST *advance*	Advance simulation with control input
PUT *results*	Receive historic point trajectory
GET *kpi*	Receive KPI values
POST *submit*	Submit results to online dashboard

Key API endpoints and functions



Run-time environment architecture

Framework Components

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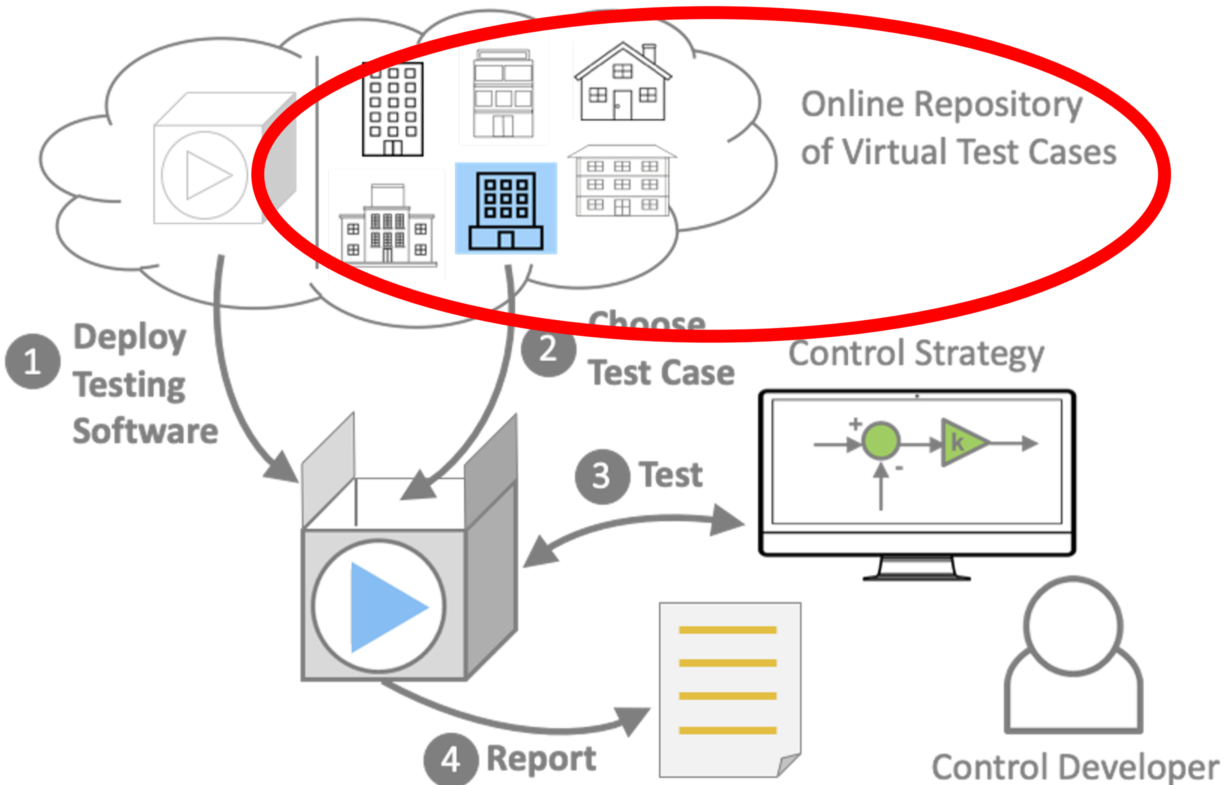

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Framework Components

Common Set of Building Emulators

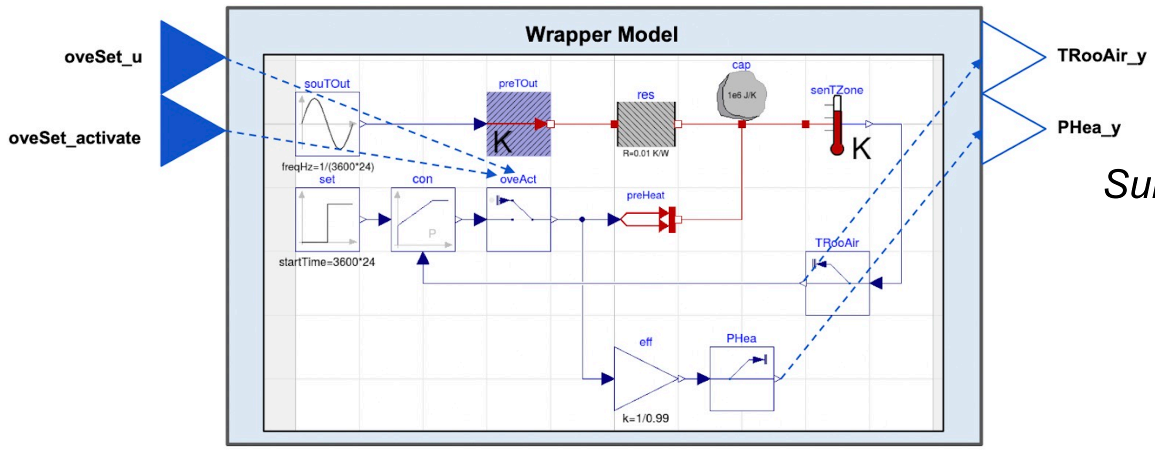
- High-fidelity models with embedded baseline controllers in Modelica and Spawn exported as FMUs
- All boundary condition data included (e.g. weather, schedules, electricity prices)
- Overwrite supervisory or local-loop points
- Practical control and measurement points
- Documentation
- Peer reviewed

Hydronic	Air
Single zone + Radiator	Single zone + FCU
Single zone + Floor heat and heat pump	Single zone + RTU with DX, gas furnace
2 zone + Floor heat and heat pump	2 zone + FCUs + AHUs with gas boiler, chiller
8-Zone + Radiators, boiler, and split cooling	5-Zone + 1 VAV AHU with reheat with chiller and heat pump
Single zone class + Radiator, AHU, CO_2 control	10-zone + 1 VAV RTU with reheat, DX, electric heating (ORNL FRP)
	15-Zone + 3 VAV AHU with reheat, chiller, boiler

Completed and available in repo

Implemented in Modelica but not finalized in repo

Subset of planned building emulators defined under IBPSA Project 1



Example Modelica model with read/write points

Framework Components

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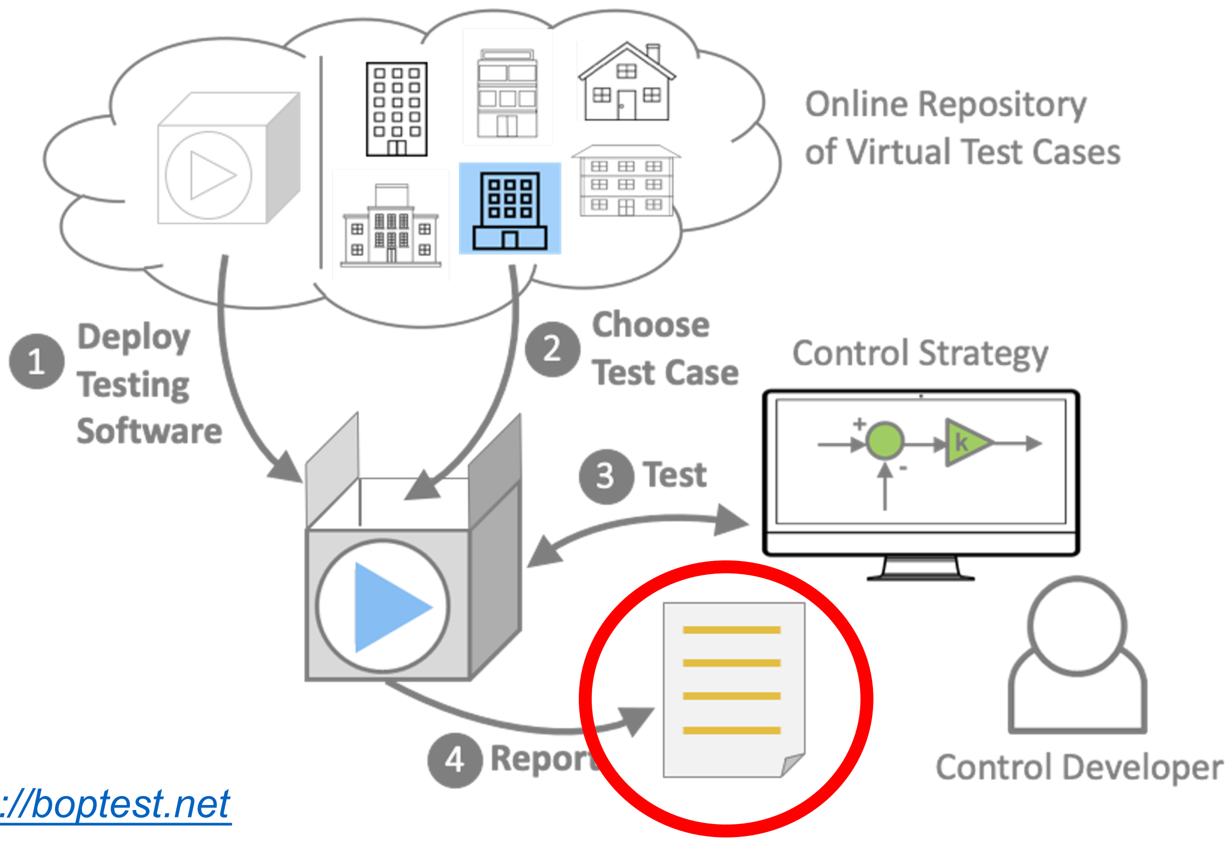

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Framework Components

Common Evaluation Design

- Set of KPIs calculated by software framework for every test case, accounting for HVAC system energy
- Definition of testing scenarios for each emulator (e.g. time period and electricity prices)
- Capability for custom KPI calculation through access to test data
- Submission of KPIs and controller information to online dashboard

1. Energy Use [kWh/m^2]
2. Energy Cost [$\$/m^2$]
3. Emissions [kg $CO2/m^2$]
4. Thermal Discomfort [K h/zone]
5. IAQ Discomfort [ppm h /zone]
6. Computational Time Ratio [-]
7. Peak Electricity Demand [kW/m^2]
8. Peak Gas Demand [kW/m^2]
9. Peak District Heating Demand [kW/m^2]

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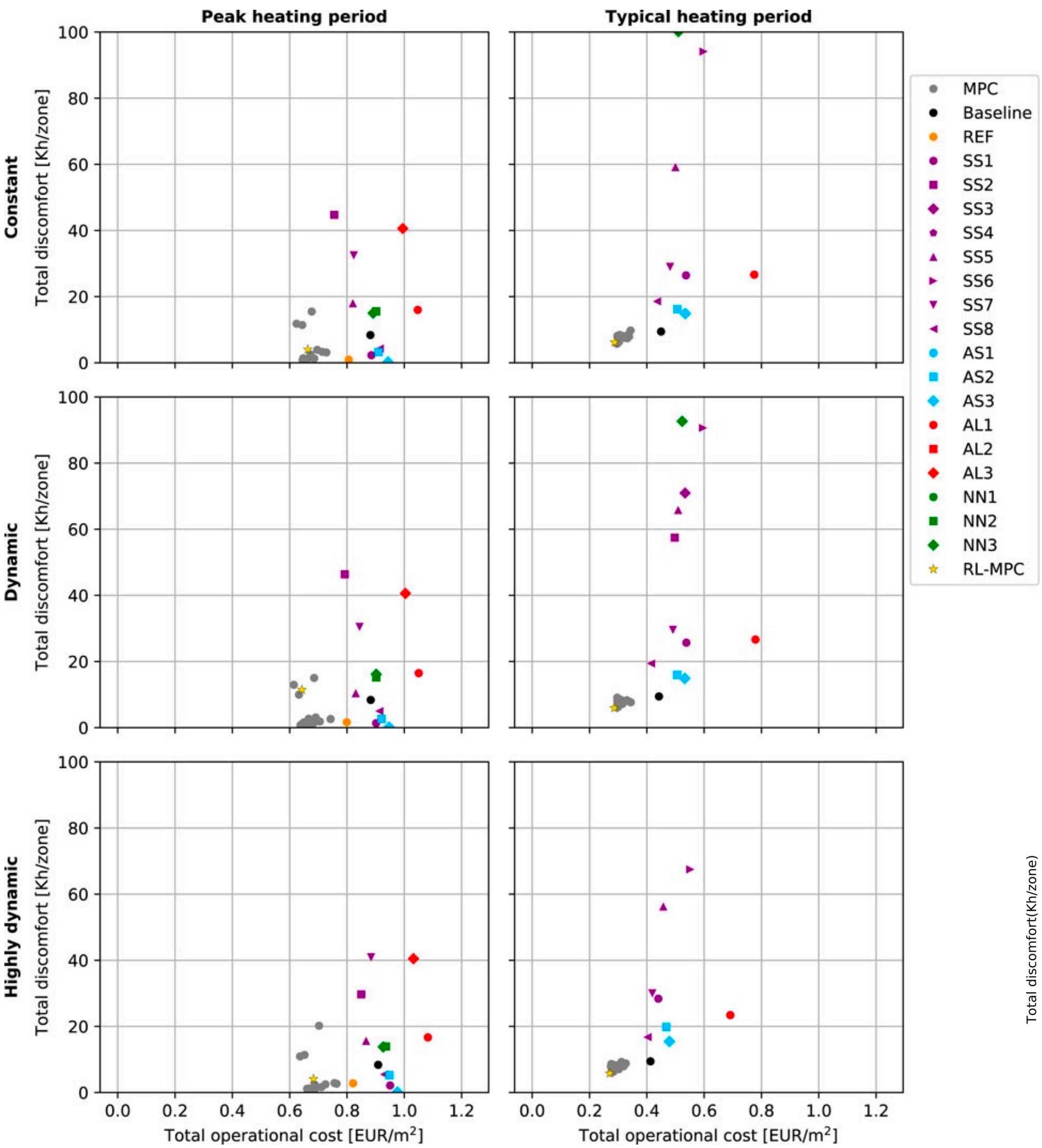
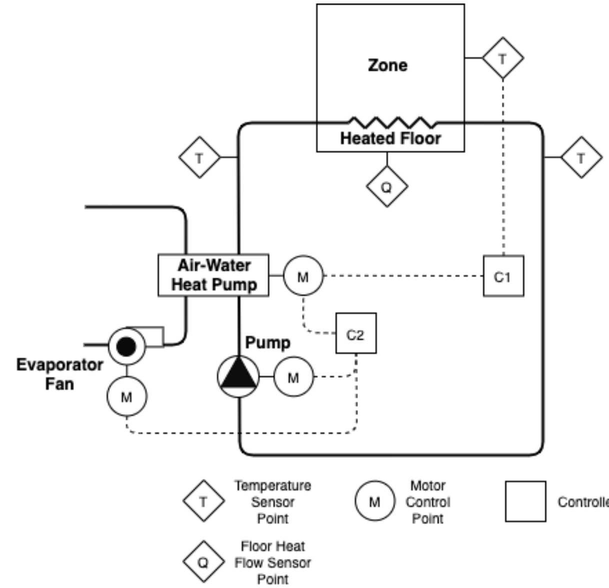
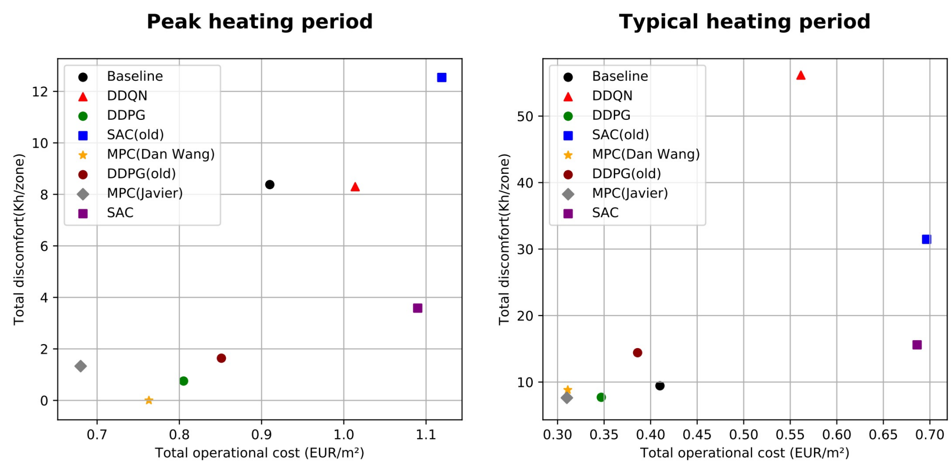
Control Comparison





"bestest_hydronic_heat_pump" case in BOPTEST

Different institutions
and different versions of MPC and RL



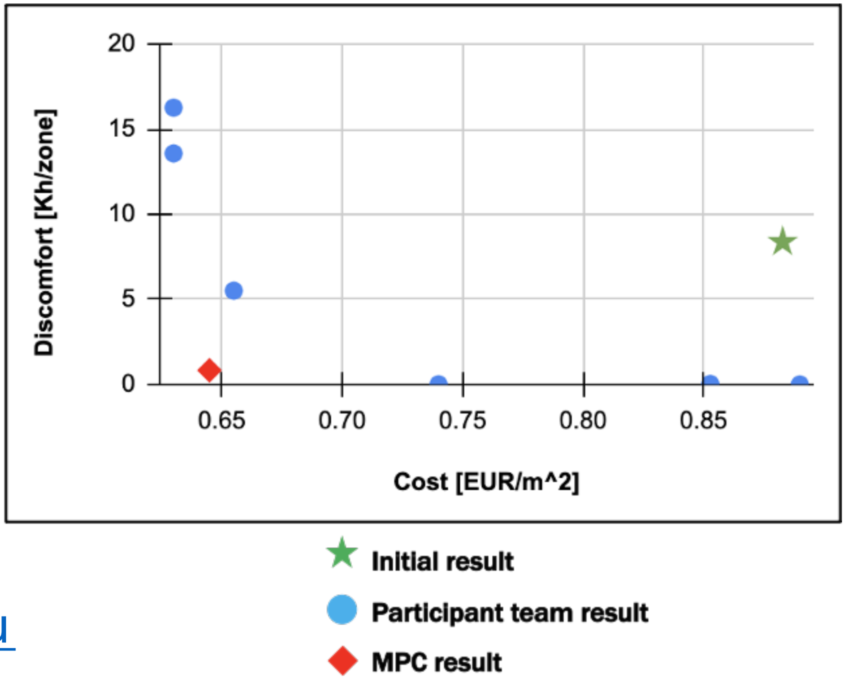
*Comparison of MPC and RL controllers using BOPTEST from **(left)** Arroyo et al. (2022, https://doi.org/10.3389/fbuil.2022.849754) and **(right)** Z. Wang, W. Zheng, and D. Wang (presented at IEA Annex 81 meeting 10/13/22, reproduced w/ permission)*

Example Usage

Training

- **IBPSA Building Simulation in August 2021**
    - 15 participants
    - Tutorial material: https://github.com/ibpsa/project1-boptest/tree/master/docs/workshops/BS21Workshop_20210831
- **Energyville in October 2021**
    - 17 participants
    - Tutorial material: same as above
- **Climate Change AI Summer School in August 2022**
    - ~60 participants
    - Tutorial material: https://github.com/ibpsa/project1-boptest-gym/tree/master/docs/tutorials/CCAI%20Summer%20School%202022

IBPSA Building Simulation 2021 workshop



IBPSA Building Simulation 2021 exercise results

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Conclusion

Why Modelica for BOPTEST Test Cases?

- High fidelity building systems modeling with realistic HVAC network pressure-flow and control dynamics
- Realistic representation of control points available, including supervisory and local-loop control
- Variable time-step solvers allow for small simulation step sizes and data resolution
- Open-source, validated component library availability and development through IBPSA Modelica community

A Key Takeaway for Modelica Community

- Modelica does not need to be the end-user-facing technology, which assumes all users climb the learning curve.
- Modelica can serve as fundamental technology to new modeling use cases that reach a broader audience, which can also drive further adoption of Modelica.

Next Steps

DOE Project

- New industry partners:
  - Arup
  - Johnson Controls
- Concentrations on framework software development to facilitate usage within industry:
  - BACnet communication interface (FY23) and semantic models (FY24)
  - Scenarios representing realistic building operation (e.g. internal load schedules, faulty operation, DR signals)
- Improve web-service to ensure robustness, stability, and usability as user number and industry-orientation grows
- Finalize emulators under development and update existing with latest Modelica libraries and open-source compilers
- Continued maintenance and feature enhancement as needed and in response to user feedback

Next Steps

IBPSA Project

International
Building
Performance
Simulation
Association

- Continuation from IBPSA Project 1 WP1.2 to focus on BOPTEST (pending board approval)
- Coordinate international community development and engagement
- Four main tasks:
    1. Community engagement and outreach
    2. Methods and infrastructure development
    3. Test case development (for additional building types and applications)
    4. Control benchmarking
- 5-year project starting in late 2022/early 2023

Thank you!

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