Overview of Building Optimization Testing Framework (BOPTEST)

Workshop at IBPSA Building Simulation Conference 2023

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International Collaboration and Community Development:

- BOPTEST development started with IBPSA open-source copyright (BSD) under IBPSA Project 1 (WP1.2): “BIM/GIS and Modelica Framework for building and community energy system design and operation”
- Continuing IBPSA Project 2: BOPTEST recently approved by IBPSA Board
- Collaboration of ~10 (so far) international industry, research, and academic institutions with expertise in modeling and advanced control in building and urban energy systems
- Coordinate design, software development test case development, outreach, and user-testing

https://ibpsa.github.io/project1

2018-2022

https://ibpsa.github.io/project1-boptest/ibpsa/index.html

2023-2027

International Collaboration and Community Development:

Institution	Team
Arup, Australia, USA, UK	Haico Schepers, Justin Prince, Robert Knight, Raffe Brennan
Builtwins, Belgium	Filip Jorissen
DeltaQ, Belgium	Roel De Coninck, Bart Merema, Iago Cupeiro,
Devetry, USA	Chris Berger, Philip Gonzalez, Amit Kapoor
ENGIE, France	Valentin Gavan
ETH Zurich, Switzerland	Esther Borkowski, Felix Bunning
Hong Kong University of Science and Technology, Hong Kong	Zhe Wang, Wanfu Zheng
Johnson Controls, USA	Erik Paulson (formerly)
KU Leuven, Belgium	Lieve Helsen, Javier Arroyo
Lawrence Berkeley National Laboratory, USA	David Blum, Michael Wetter, Ettore Zanetti
National Renewable Energy Laboratory, USA	Kyle Benne, Nicholas Long, Marjorie Schott, Tim Coleman, Jermy Thomas, Dave Biagioni, Yanfei Li
National University Singapore, Singapore	Sicheng (James) Zhan
Oak Ridge National Laboratory, USA	Yeonjin Bae, Piljae Im, Sen Huang
Pacific Northwest National Laboratory, USA	Yan Chen, Draguna Vrabie, Xing Lu, Jan Drgona, Robert Lutes
Politecnico di Torino, Italy	Davide Fop, Alfonso Capozzoli
Pure Control, France	Gauthier-Clerc Francois
R2M Solutions, Spain	Laura Zabala, Jesus Febres
RWTH Aachen, Germany	Laura Maier, Fabian Wullhorst
SINTEF, Norway	Harald Walnum
Southern Denmark University, Denmark	Krzysztof Arendt, Christian Veje, Tao Yang
Technical University of Denmark, Denmark	Peder Bacher, Konstantin Filonenko

Building Optimization Testing Framework (BOPTEST)

- Problem
- Concept and Approach
- Availability and Future Work

Problem

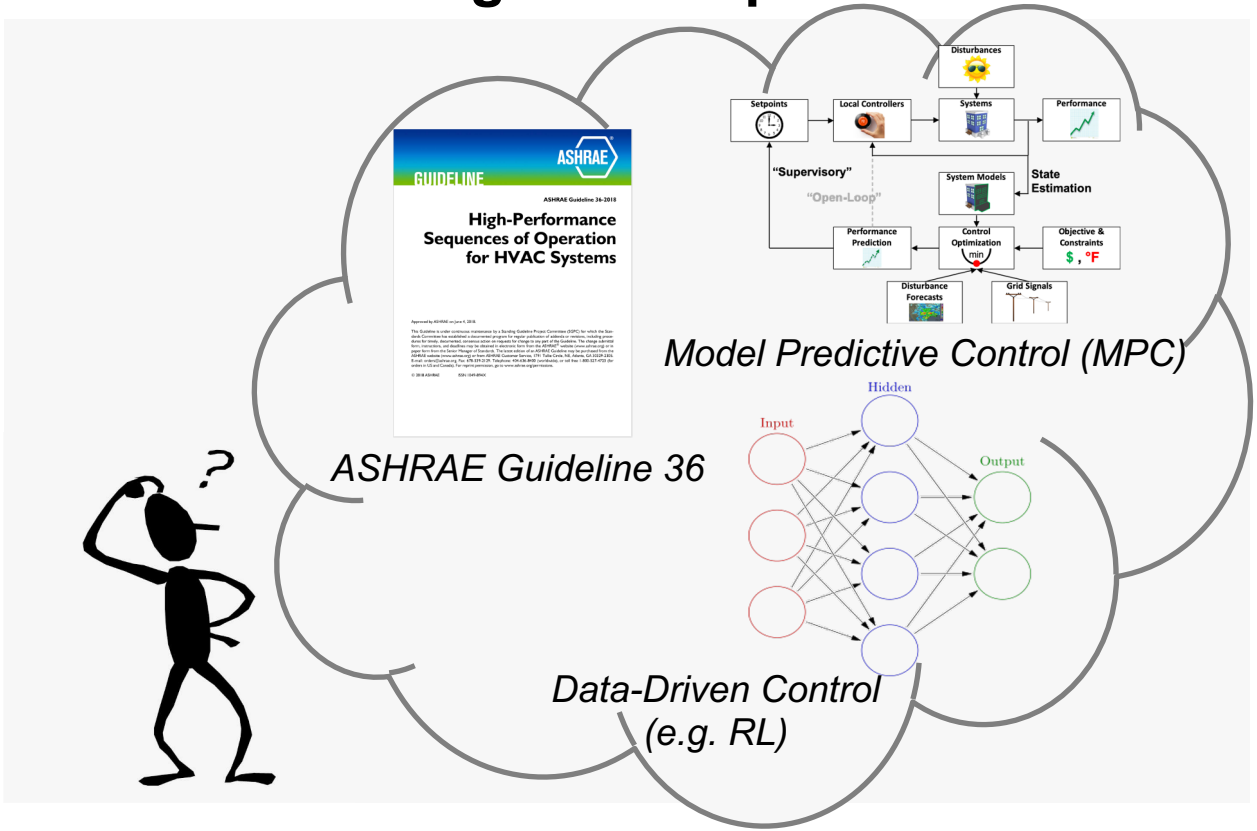
Many new and advanced control strategies hold promise …

But they all have different requirements for:

- Data
- Modeling
- Computation
- Expertise

How do they <u>compare</u> in terms of:

- Providing comfort
- Energy management
- Implementation cost
- Reliability

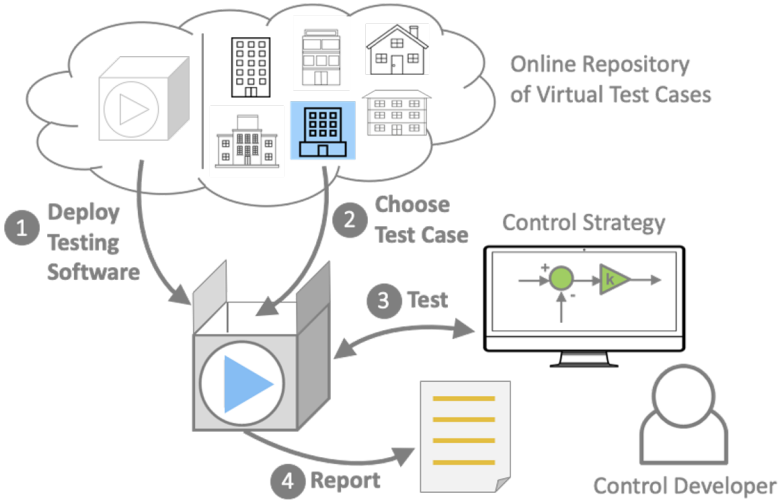


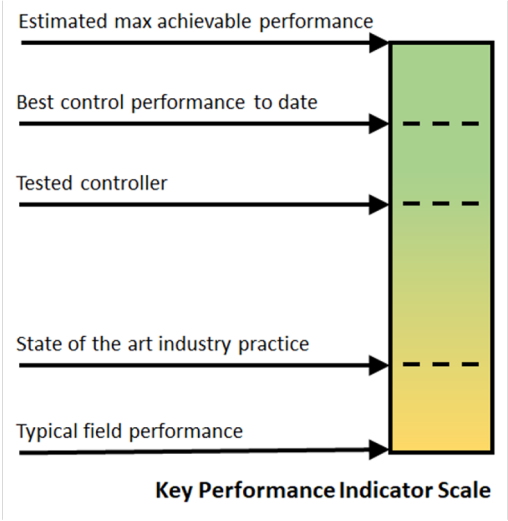
Concept

Building Optimization Testing Framework (BOPTEST)

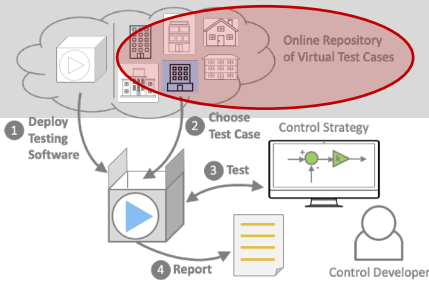
A Simulation-Based Controls Testing and Benchmarking Environment

- Deployable software runtime environment: rapidly, repeatably, and at scale
- Control-interactive high-fidelity emulator models with defined boundary conditions
- Standardized key performance indicators (KPI) that are auto-calculated



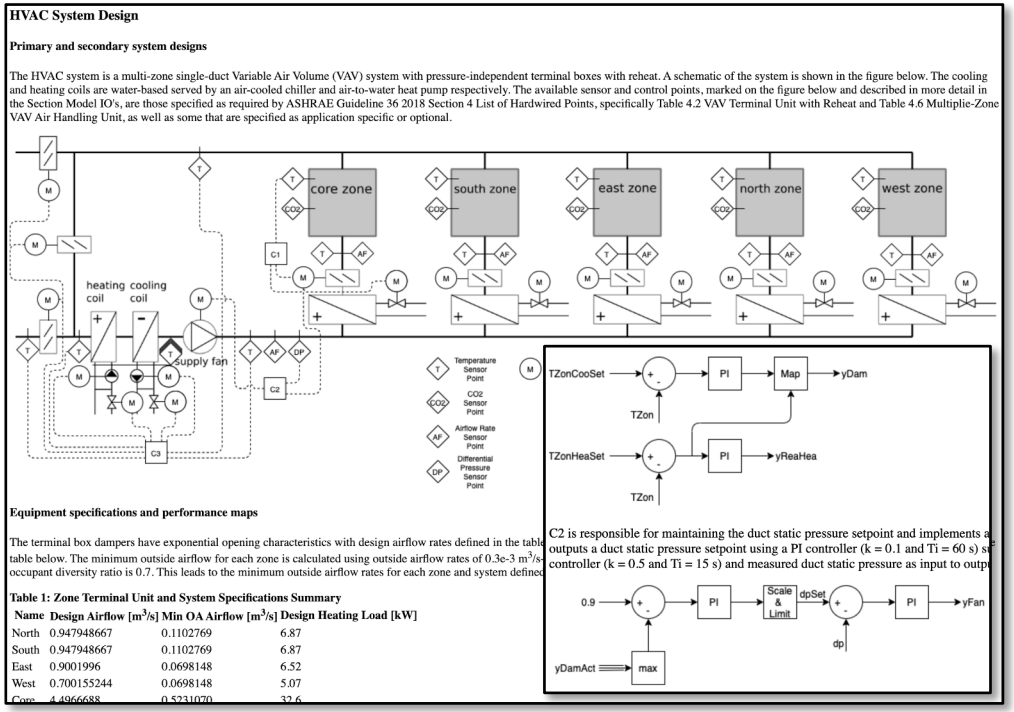


Approach



Building Emulators ("Test Cases")

- High-fidelity models with embedded baseline control in Modelica, Spawn, and CDL, exported as FMU
- Overwritable supervisory or local-loop control
- All boundary condition data defined (e.g. weather, schedules, electricity prices, carbon emission factors)
- Controlled exposure of sensor and control points
- Documentation and peer review to ensure quality and usability



HVAC System Design

Primary and secondary system designs

The HVAC system is a multi-zone single-duct Variable Air Volume (VAV) system with pressure-independent terminal boxes with reheat. A schematic of the system is shown in the figure below. The cooling and heating coils are water-based served by an air-cooled chiller and air-to-water heat pump respectively. The available sensor and control points, marked on the figure below and described in more detail in the Section Model IO's, are those specified as required by ASHRAE Guideline 36 2018 Section 4 List of Hardwired Points, specifically Table 4.2 VAV Terminal Unit with Reheat and Table 4.6 Multiple-Zone VAV Air Handling Unit, as well as some that are specified as application specific or optional.

Equipment specifications and performance maps

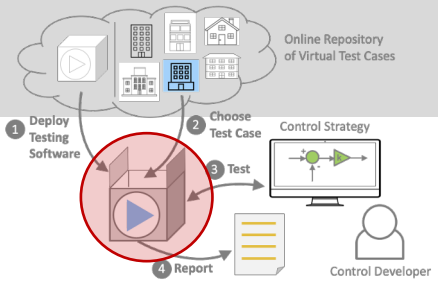
The terminal box dampers have exponential opening characteristics with design airflow rates defined in the table
table below. The minimum outside airflow for each zone is calculated using outside airflow rates of 0.3e-3 m^3/s-
occupant diversity ratio is 0.7. This leads to the minimum outside airflow rates for each zone and system define

Table 1: Zone Terminal Unit and System Specifications Summary

Name	Design Airflow [m^3/s]	Min OA Airflow [m^3/s]	Design Heating Load [kW]
North	0.947948667	0.1102769	6.87
South	0.947948667	0.1102769	6.87
East	0.9001996	0.0698148	6.52
West	0.700155244	0.0698148	5.07
Core	4.4966688	0.5231070	32.6

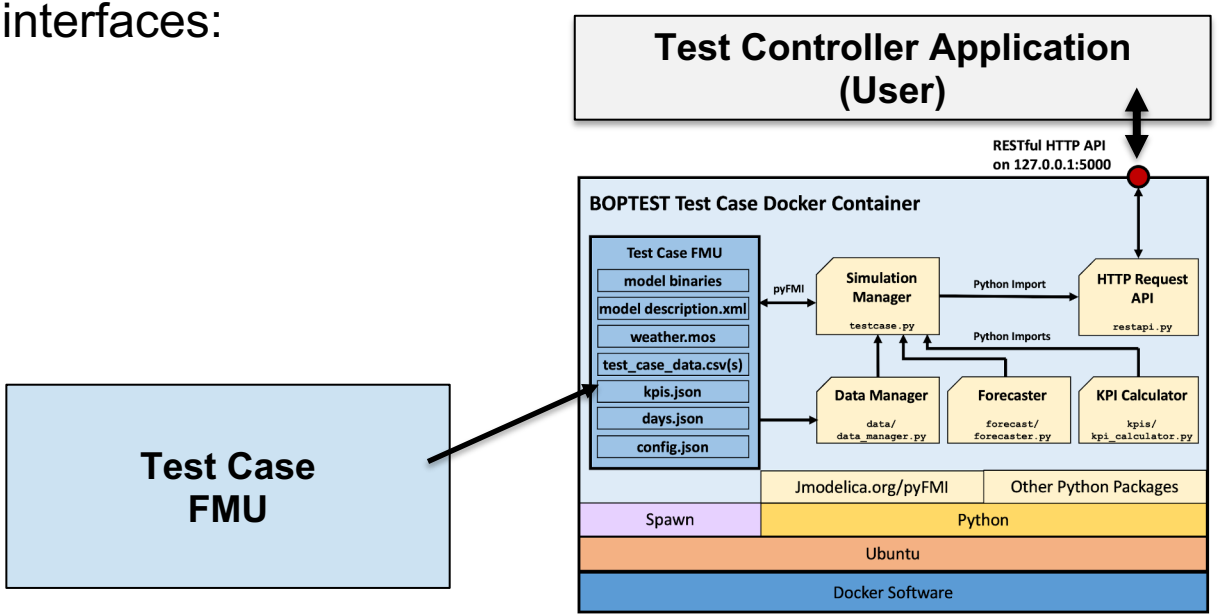
Example test case documentation snippets

Approach



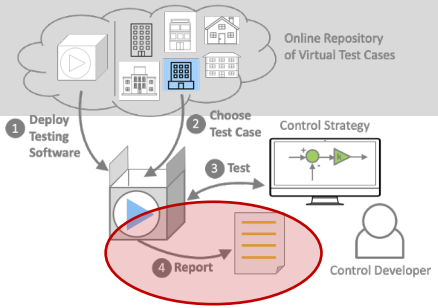
Run-Time Environment

- Rapid, repeatable deployment locally cross-platform or as web-service using Docker
- ”Native” HTTP RESTful API for test management and controller interaction. Additional interfaces:
  - OpenAI-Gym
  - BACnet
  - VOLTTRON



Run-time environment architecture (for local deployment)

Approach



Evaluation Design

- Set of KPIs calculated by framework
- Predefined test scenarios
  (e.g. time period and electricity prices)
- Developing online dashboard for collecting, viewing, and comparing KPI results

Description	Unit
Energy Use	kWh / m^2
Energy Cost	\$ / m^2
Emissions	KgCO2 / m^2
Thermal Discomfort	K.h / zone
IAQ Discomfort	ppm.h / zone
Peak Elec/Gas/District Demand	kW / m^2
Computational Time Ratio	[-]

KPIs calculated by BOPTEST

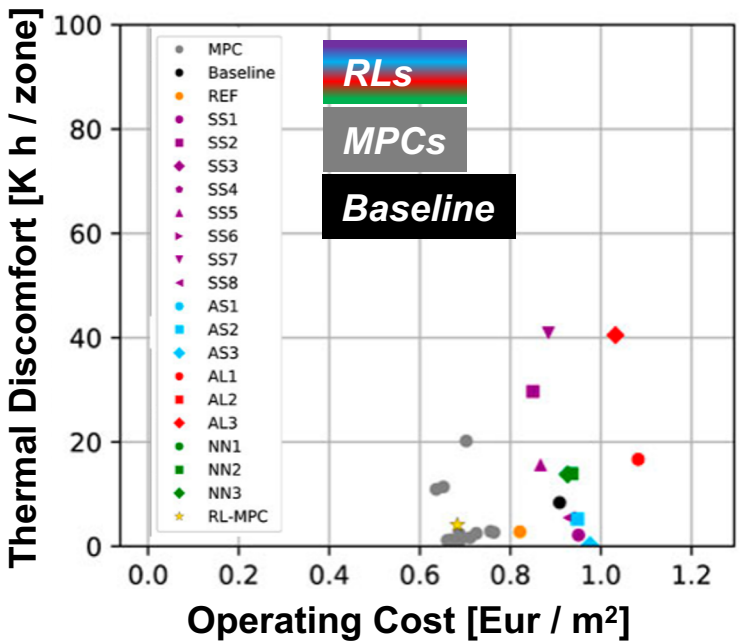
Framework Availability (https://ibpsa.github.io/project1-boptest/)

- BOPTEST v0.4.0 for core framework software and test cases
- BOPTEST-Service v0.2.1 deployed as public web-service serving users at scale

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, CO2 control	10-zone + 1 VAV RTU with reheat, DX, electric heating
	15-Zone + 3 VAV AHU with reheat, chiller, boiler

Available *Implemented, but not yet available*

Test case development progress within IBPSA Project



Example MPC and RL benchmarking (Arroyo et al. 2022 https://doi.org/10.3389/fbuil.2022.849754)

Ongoing and Future Work

Key Ongoing Software Development

- Maintain software and respond to user feedback (6-month release cycle)
- Semantic model integration
- Weather forecast uncertainty
- Extension to district network control testing (“DOPTEST”)

Test Case Development

- Finalize additional test cases currently under development
- Want to expand test case offerings for new applications, such as:
    - New building types, such as K-12, hospitals, or data centers
    - Buildings with DER or TES
    - District heating, cooling, electrical networks

Overview of Building Optimization Testing Framework (BOPTEST)

Thank you!

Questions?

For more information, go to
https://ibpsa.github.io/project1-boptest/

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