# Overview of Building Optimization Testing Framework (BOPTEST)

Workshop at RLEM 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 17 (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 (All Time):

| 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

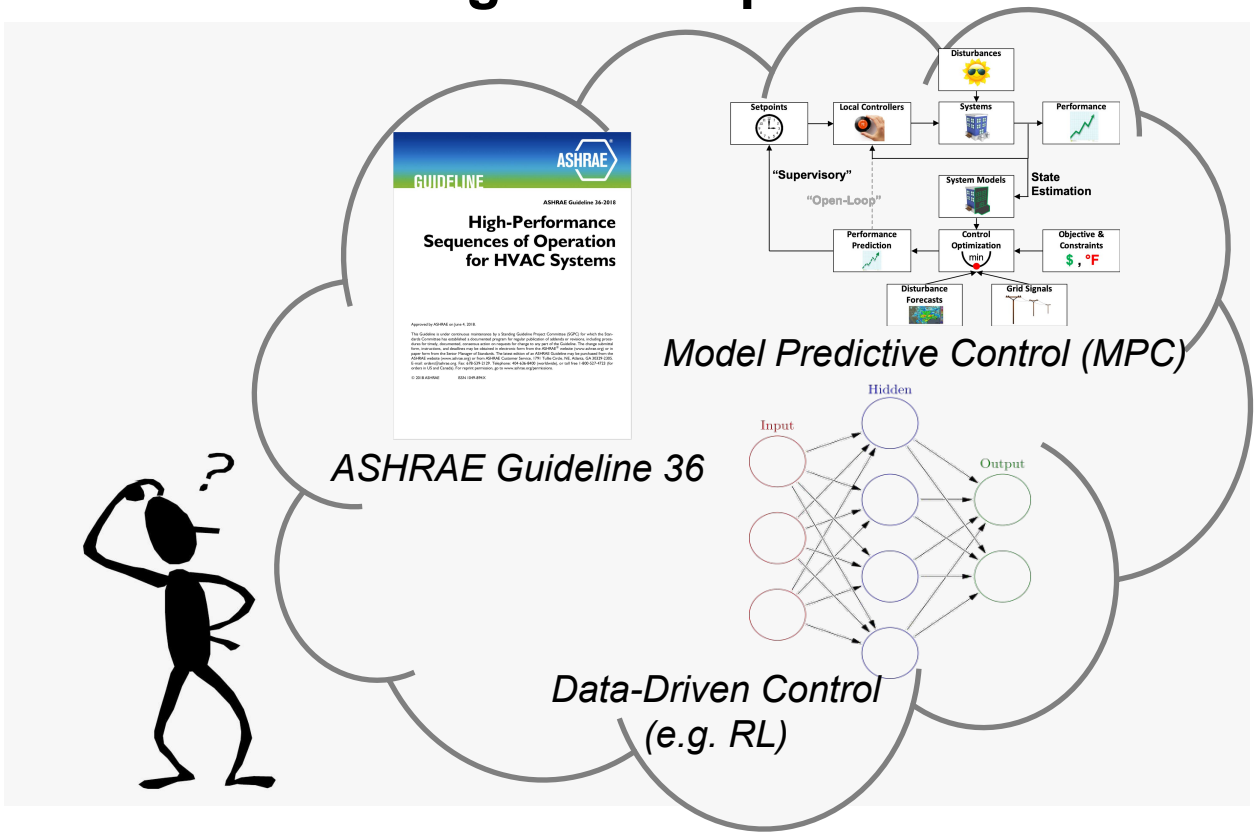
## Many new and advanced control strategies hold promise …

**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

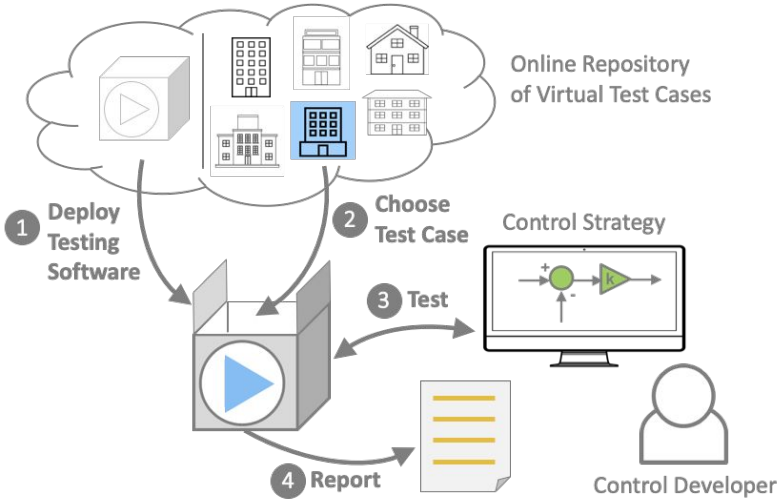


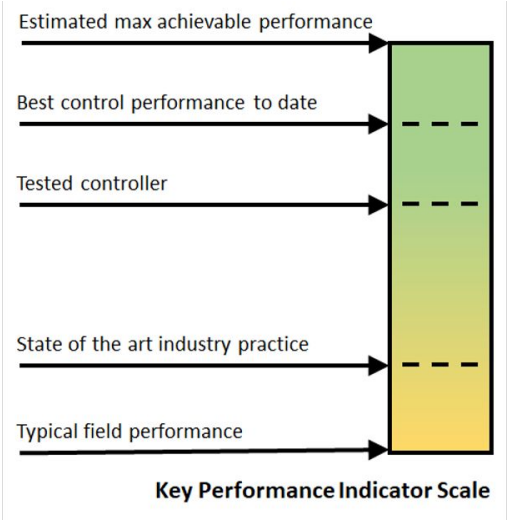
# Concept

## Building Optimization Testing Framework (BOPTEST)

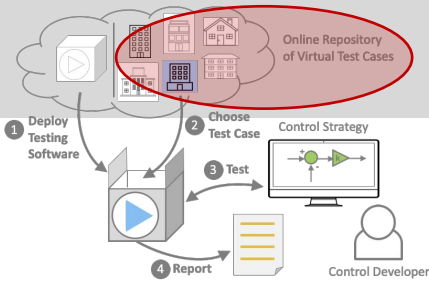
A Simulation-Based Controls Testing and Benchmarking Environment

- 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



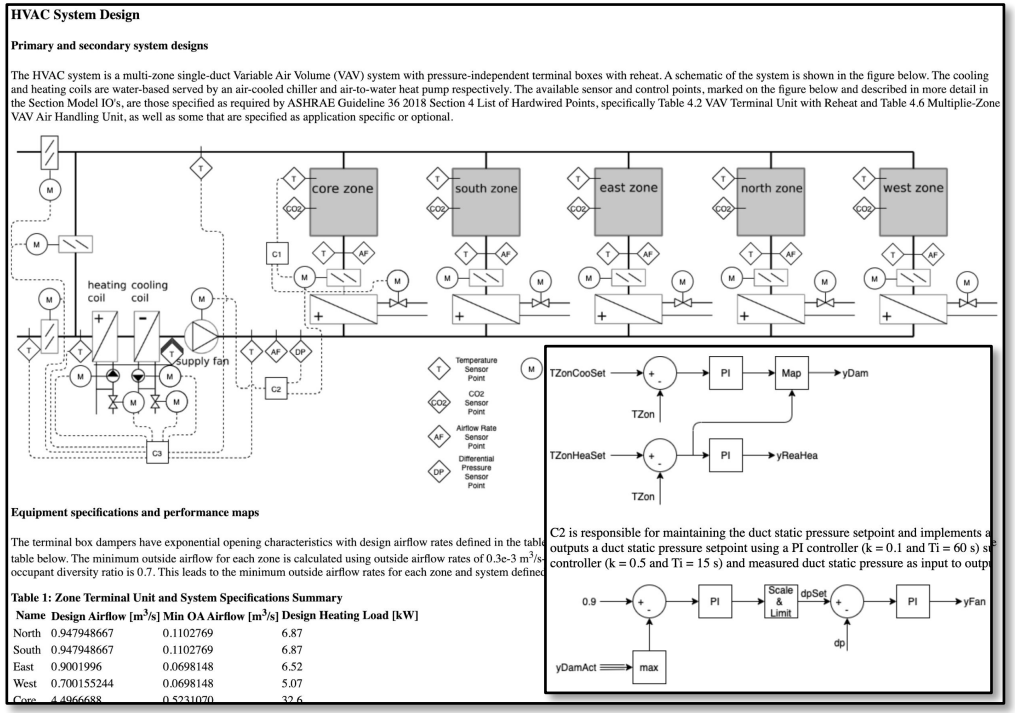



# Approach




## 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**

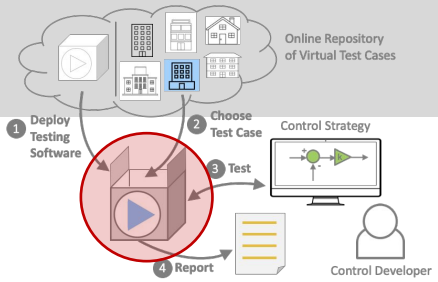
The terminal box dampers have exponential opening characteristics with design airflow rates defined in the table
table below. The minimum outside airflow for each zone is calculated using outside airflow rates of 0.3c-3 $m^3/s$-
occupant diversity ratio is 0.7. This leads to the minimum outside airflow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

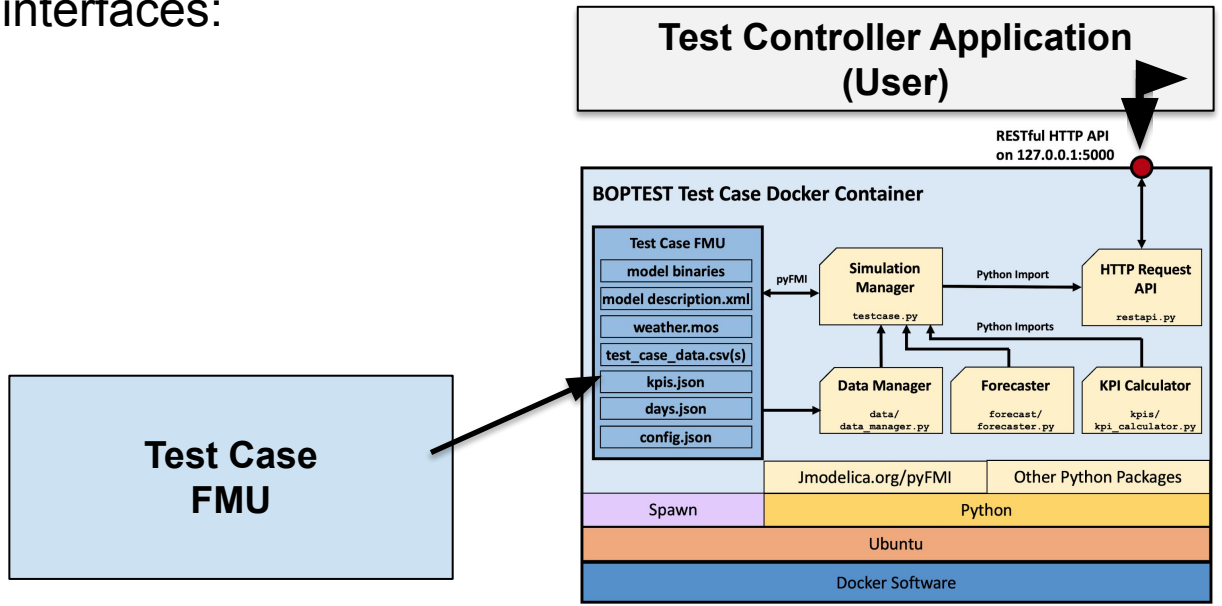
*Example test case documentation snippets*

# Approach



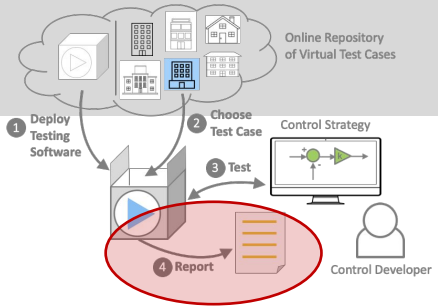

## Run-Time Environment

- 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*

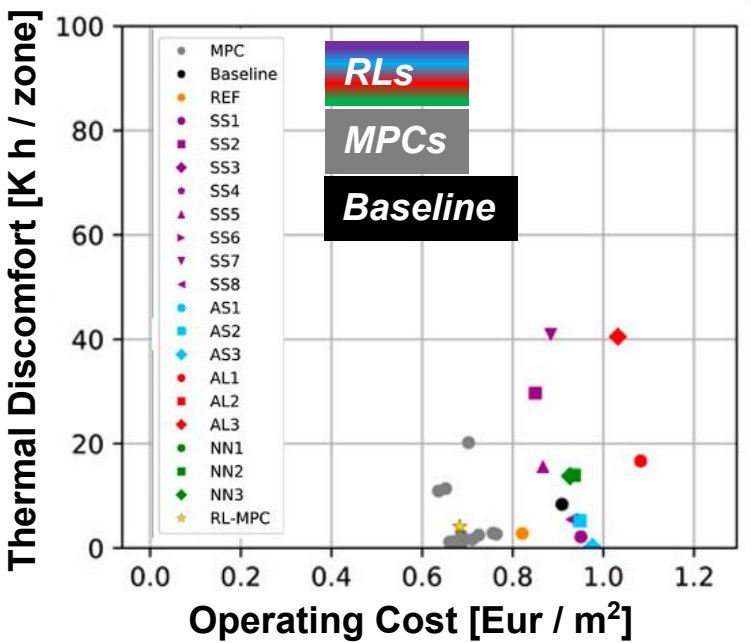
# Framework Availability (https://ibpsa.github.io/project1-boptest/)

- BOPTEST v0.5.0 for core framework software and test cases
- BOPTEST-Service v0.3.0 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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