Introduction to the Building Optimization Testing Framework (BOPTEST)

Workshop 1: Introduction to the BOPTEST framework for simulation-based benchmarking of advanced controllers

IBPSA Building Simulation 2021

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Workshop Sponsored By:

Introduction to the Building Optimization Testing Framework (BOPTEST)

- Motivation
- Approach
- Impact
- Progress
- Continued Development

Project Acknowledgements (A→ Z)

For direct contributions to software development, testing, and planning:

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Project Acknowledgements

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- **IBPSA Project 1**
    - https://ibpsa.github.io/project1
    - BIM/GIS and Modelica Framework for building and community energy system design and operation
    - Work Package 1.2 - MPC and BOPTEST

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- Engie

Motivation

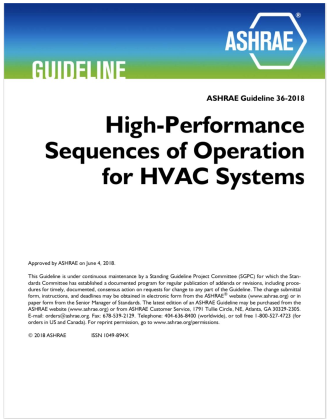
Needs for Improved Controls

- Energy efficiency, grid-interactivity, resiliency
- New system architectures and onsite generation and storage

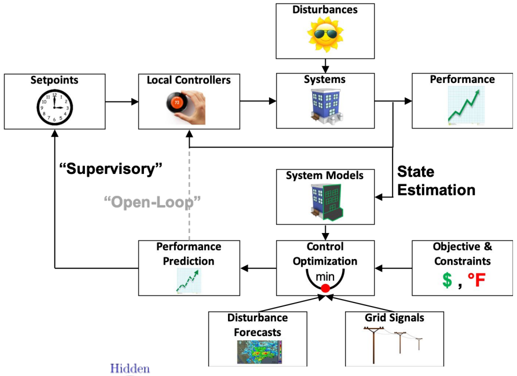
Challenge 1: Individualized Studies

- Different building, HVAC, climate, study period, performance metrics
- Demonstrated savings/advantages depend on comparative baseline [1]

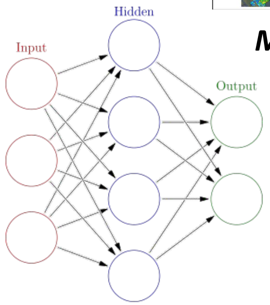
→ **Difficult to answer which approach is most effective and where more work needed**


ASHRAE
GUIDELINE
ASHRAE Guideline 36-2018
High-Performance Sequences of Operation for HVAC Systems

ASHRAE Guideline 36



Model Predictive Control (MPC)



Data-Driven Control

Examples of recent controls development

Challenge 2: Building Emulator Time and Effort

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

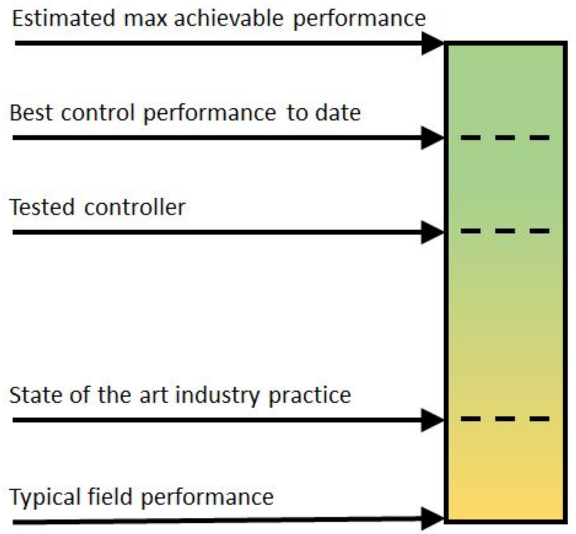
→ **Limits rapid prototyping and algorithm development opportunities from outside experts (e.g. process control, optimization, data science)**

[1] For example for VAV Systems, range of 12-67% savings of "good practice" controls depending on if compared to "average" or "poor" practices [1]

Approach

Goals

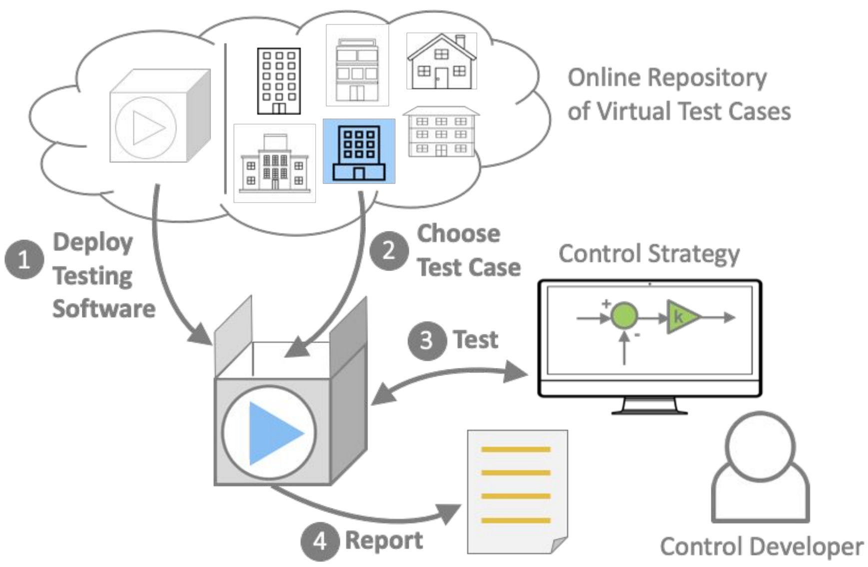
- Establish and benchmark state-of-the-art performance of control for building energy systems
- Accelerate building control software development and provide control developers with performance information
- Enable transition and encourage adoption of advanced building control algorithms



Key Performance Indicator Scale

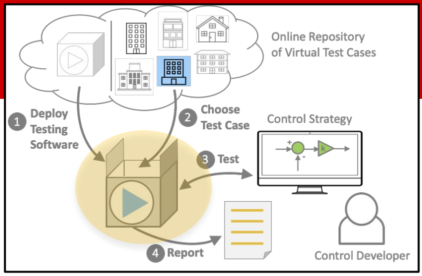
Achieved by:

- Developing a *software framework* for testing and evaluation of advanced building control
- Developing *common sets* of building emulators, test scenarios, and key performance indicators (KPI)
- User engagement to capture expected use cases and facilitate the utilization in the broad academic and industry R&D communities

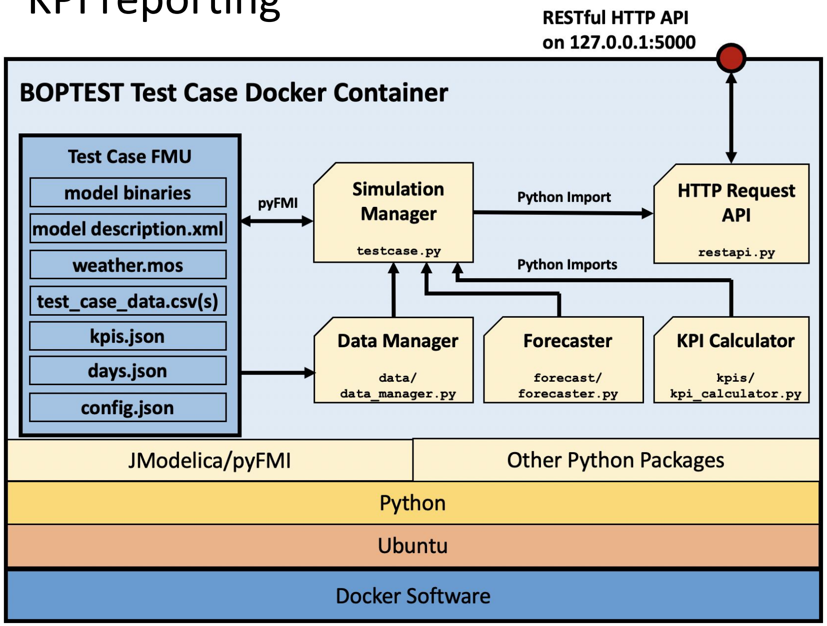


Approach

Software Framework



- Simulation management based on Functional Mockup Interface (FMI)
- Docker-based rapid, repeatable deployment locally cross-platform or as web-service
- HTTP-based RESTful API for test set up, emulator-controller co-simulation, and KPI reporting

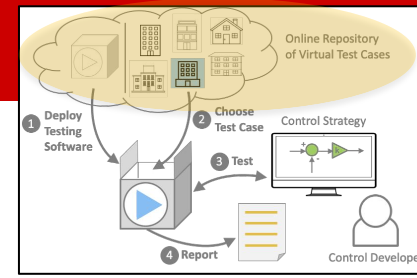


RTE Architecture

API Endpoint	Description
GET *measurements*	Receive available measurement points
GET *inputs*	Receive available input points
PUT *scenario*	Set test scenario
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

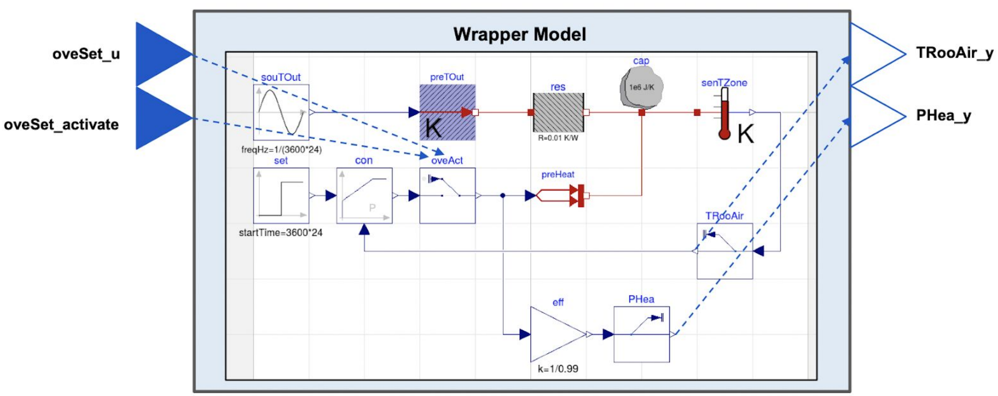
Key RESTful HTTP API Endpoints

Approach



Common Set of Building Emulators

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

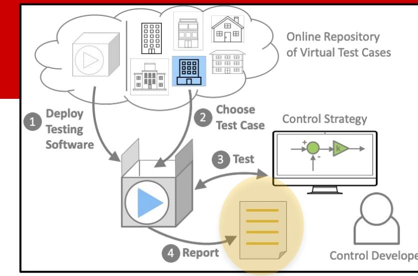


Example Modelica model with read/write points

Hydronic	Air
Single zone + Radiator	Single zone + FCU
Single zone + TABS	5-Zone + 1 VAV AHU (distr. only)
8-Zone + Radiators and split cooling	10-zone + 1 VAV with DX, electric heating (FRP)
Single zone class + Radiator, AHU	15-Zone + 3 VAV AHU, chiller, boiler
28-Zone office + TABS, AHU, Geothermal HPs	Single zone retail + RTU

- Completed and available in repo
- Implemented in Modelica but not finalized in repo
- To be developed

Subset of emulators under IBPSA Project 1

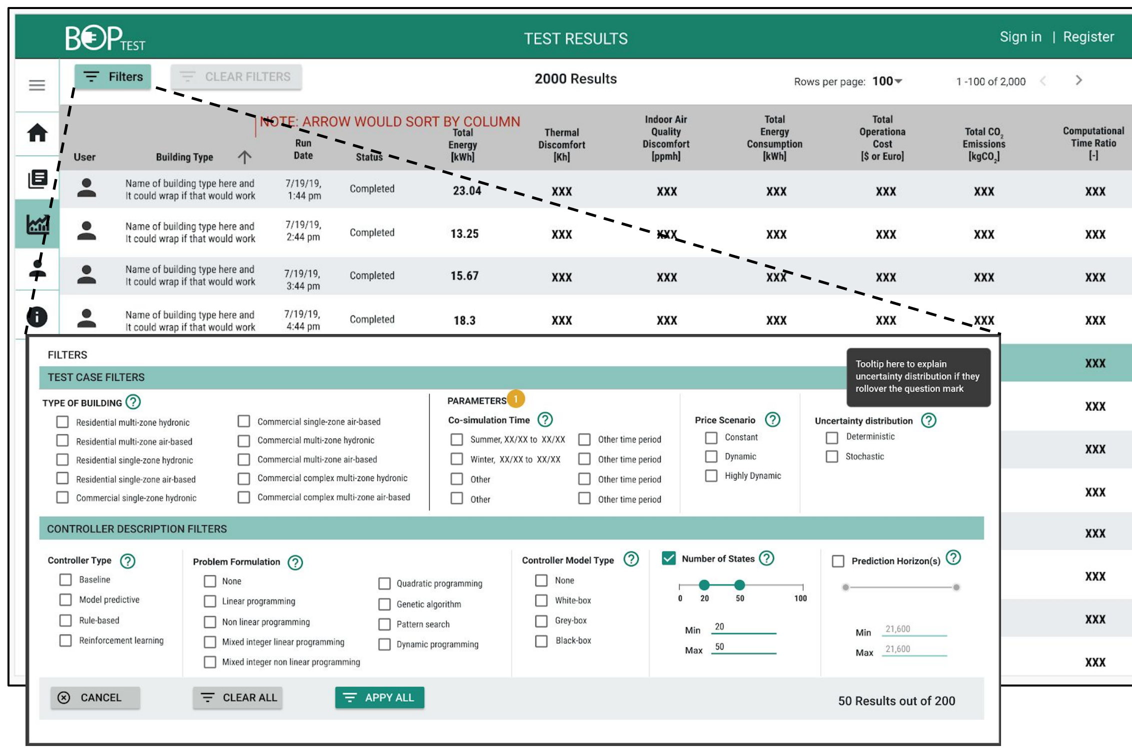


Common Evaluation Design

- Set of KPIs calculated by software framework for every test case
- Definition of testing scenarios for each emulator (e.g. time period and electricity prices)
- Capability for custom KPI calculation through access to test data
- Development of results sharing platform with initial implementation completed

1. Energy Use [kWh/m^2]
2. Energy Cost [\$/m^2]
3. Emissions [kg CO$_2$/m^2]
4. Thermal Discomfort [K h/zone]
5. IAQ Discomfort [ppm h /zone]
6. Computational Time Ratio [-]

Set of six KPIs evaluated for every test by software framework



Mockups of online results sharing dashboard

Impact

Accelerate Controls Development

- In the U.S. for example, improved rule-based controls for commercial buildings can save 2.7 quads/yr (3% 2015 U.S. primary energy) and reduce peak electricity demand by 16% [2]
- Optimization-based controls such as MPC and RL
  - HVAC and lighting energy savings typically range 15-30% [3-7]
  - Peak demand reduction, load shifting, and other grid services [8-9]

Enable Controls Benchmarking

- Common test cases and KPIs allow for comparison of different algorithms from different developers, informing investment by building owners and future R&D focus
- Reported results establish collective baseline for future comparison

Open Opportunities

- Reduce the barriers (risk, effort, cost, modeling expertise) for control algorithm evaluation on realistic test cases
- Encourage control development by experts outside buildings community, such as process controls, optimization, and data science

Impact

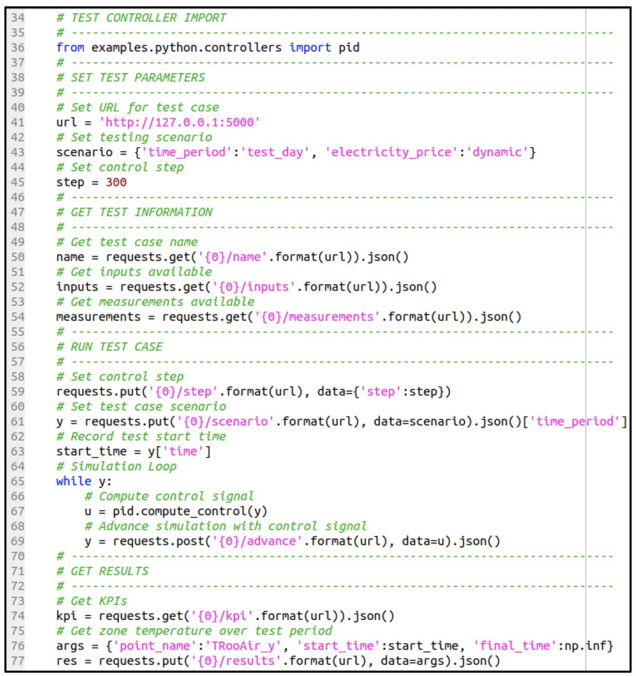
Advancing the State of the Art for Evaluation Frameworks

- Integration of high-fidelity building simulation with containerized software deployment capable of being deployed locally or on cloud serving multiple, remote clients
- Use of Modelica and FMI standards for emulator models allow for:
  - Leveraging ~10 years of international, open-source model development under IEA EBC Annex 60 and IBPSA Project 1 as well as tool development in other industries
  - Flexible control points from supervisory set points to local actuator signals
- Provision of forecasts (e.g. weather, electricity prices) enables testing with predictive control algorithms and eventual evaluation under specified uncertainty scenarios

Progress

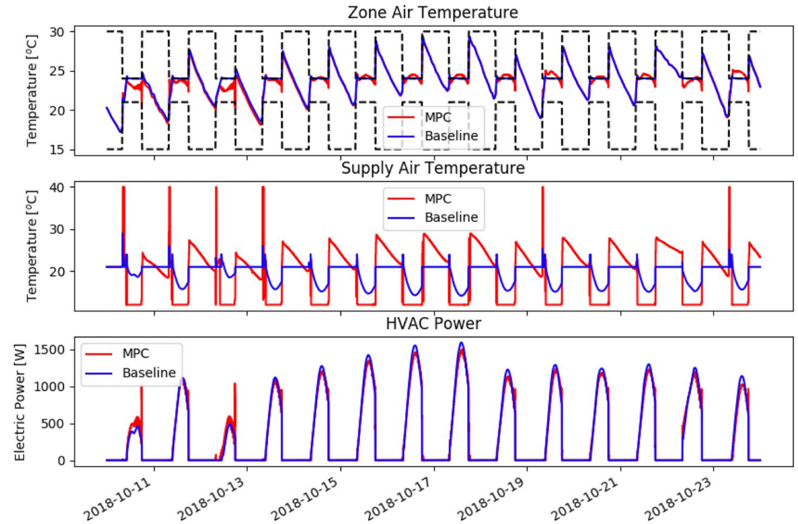
BOPTEST v0.1.0 (https://github.com/ibpsa/project1-boptest)

- Fully functional software framework deployable locally or on cloud as service serving multiple test controller clients (called “boptest-service”)
- Four building emulators available (+ three used for development purposes)
- Example test controllers in Python, Julia, and Javascript as well as MPC controller testing from 6 different institutions (IBPSA Project 1) validate the technical approach



```python
# TEST CONTROLLER IMPORT
# ------------------------------------------------------------------------------
from examples.python.controllers import pid
# ------------------------------------------------------------------------------
# SET TEST PARAMETERS
# ------------------------------------------------------------------------------
# Set URL for test case
url = 'http://127.0.0.1:5000'
# Set testing scenario
scenario = {'time_period':'test_day', 'electricity_price':'dynamic'}
# Set control step
step = 300
# ------------------------------------------------------------------------------
# GET TEST INFORMATION
# ------------------------------------------------------------------------------
# Get test case name
name = requests.get('{0}/name'.format(url)).json()
# Get inputs available
inputs = requests.get('{0}/inputs'.format(url)).json()
# Get measurements available
measurements = requests.get('{0}/measurements'.format(url)).json()
# ------------------------------------------------------------------------------
# RUN TEST CASE
# ------------------------------------------------------------------------------
# Set control step
requests.put('{0}/step'.format(url), data={'step':step})
# Set test case scenario
y = requests.put('{0}/scenario'.format(url), data=scenario).json()['time_period']
# Record test start time
start_time = y['time']
# Simulation Loop
while y:
    # Compute control signal
    u = pid.compute_control(y)
    # Advance simulation with control signal
    y = requests.post('{0}/advance'.format(url), data=u).json()
# ------------------------------------------------------------------------------
# GET RESULTS
# ------------------------------------------------------------------------------
# Get KPIs
kpi = requests.get('{0}/kpi'.format(url)).json()
# Get zone temperature over test period
args = {'point_name':'TRooAir_y', 'start_time':start_time, 'final_time':np.inf}
res = requests.put('{0}/results'.format(url), data=args).json()
```

Example controller interface code in Python



Controller	Energy [kWh/m^2]	Cost [\$/m^2]	Emission [kg CO_2/m^2]	Thermal Dis. [K h/zone]	IAQ Dis. [ppm h/zone]	Com. Ratio [-]
Baseline	2.226	0.1208	1.466	7.670	1222	1.192E-4
MPC	2.204	0.1186	1.442	23.69	1220	6.484E-3

Results of test using MPC with “BESTEST Air” case

Continued Development (Through September 2022)

Emulator Development

- Multi-zone emulators with air-based and hydronic-based HVAC systems
- Calibrated test case of ORNL Flexible Research Platform test facility (10-Zone VAV AHU)

Software Development

- Improved user guide and error handling/messaging
- Prototype adding semantic meta-data tagging for control and measurement points
- Forecast uncertainty
- Maintenance and updates to software stack for improved performance
- Results dashboard capable of filtering results by controller and test characteristics

Usage and Stakeholder Engagement

- Additional MPC and RL testing through IBPSA Project 1 and IEA Annex 81
- Responding to feedback from user community

References

BOPTEST Github Repository: https://github.com/ibpsa/project1-boptest

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Thank you!

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