WP1.2:
Model Predictive Control

WP Leader: Lieve Helsen
Co-Leader: David Blum

Digital Expert Meeting
March 28, 2022

THE GOALS

Using Modelica,

an equation-based object-oriented modelling language

1. To develop an open-source **Library for MPC**
2. To develop a **framework** to test and assess MPC performance
3. To compare and **benchmark** different **MPC formulations**

THE WP1.2 TEAM

34 participants from 16 institutes / companies

Typically 13 participants in meetings

Affiliation	Team members
KU Leuven	Lieve Helsen, Filip Jorissen, Javier Arroyo
LBNL	David Blum, Michael Wetter, Zhe Wang
ENGIE Lab	Valentin Gavan
SDU	Toa Yang, Konstantin Filonenko, Christian Veje
PNNL	Huang Sen, Jan Drgona, Chen Yan, Draguna Vrabie
IK4 Tekniker	Laura Zabala Urrutia
SINTEF	Harald Tax Walnum
Politecnico de Milano	Ettore Zanetti
ORNL	Yeonjin Bae, Piljae Im
DeltaQ	Roel De Coninck, Carlos Andrade, Iago Cupeiro Figueroa
ETH Zurich / EMPA	Felix Bünning
NREL	Nicholas Long, Kyle Benne
University of Colorado - Boulder	Thibault Marzullo, Sourav Dey, Gregor Henze, Mingzhe Liu
RWTH Aachen	Laura Maier, Fabian Wullhorst
DTU	Peder Bacher, Christian Anker Hviid
Modelon	Hubertus Tummescheit

STATUS WORK

Coordination meetings since October 2021: 3 Monthly progress meetings

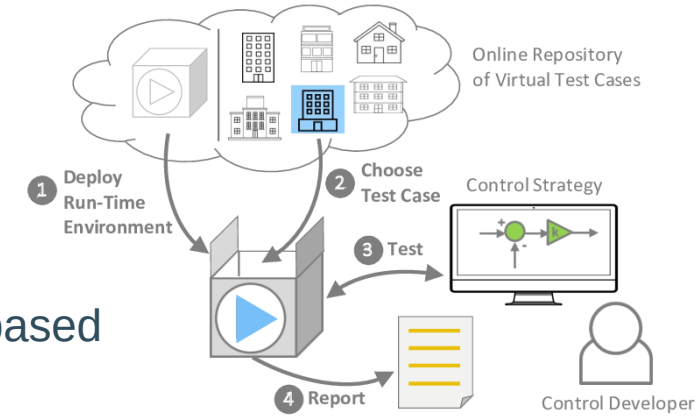
Chaired by Lieve Helsen

When? December 13, January 18, March 8, next is planned on April 26

What?

1. BOPTEST developments (https://github.com/ibpsa/project1-boptest)
2. BOPTEST Dashboard
3. Controller characterization
4. Emulators
5. Quantification of weather uncertainties
6. BOPTEST trials and Outreaching

FOCUS & PROGRESS – BOPTEST developments



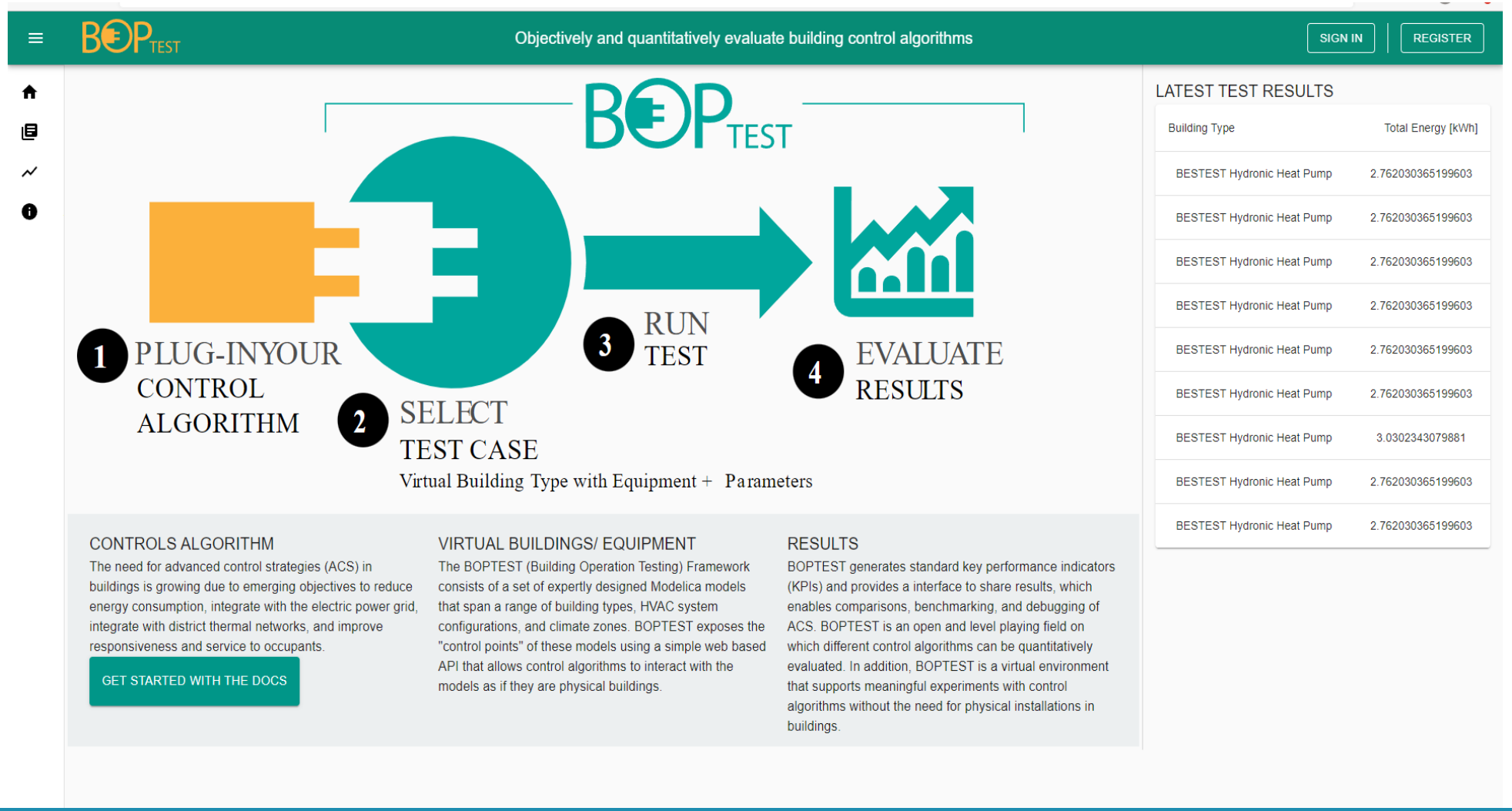
BOPTEST v0.2.0 released:

- *Results API* always returns the control values used in the emulation
- Use of *docker-compose* when launching test cases results in efficiency gains
- New Emulator added: single-zone commercial building with radiator and CO_2-based AHU control (by SDU)

New developments underway:

- New KPI *peak power*
  - for each energy vector (used today) separately (electricity, heat, gas)
  - 15-minutes average (maxima of 15-minutes intervals)
  - Peak demand pricing scenarios will be incorporated later (monthly charging vs. 2-weeks scenarios)
- Better messaging and error handling
- Documenting the API
- Metadata tags, compliant with standards: first implementation ready
- Continuous maintenance and feature enhancements

FOCUS & PROGRESS – BOPTEST dashboard



FOCUS & PROGRESS – BOPTEST dashboard

BOPTEST dashboard capabilities

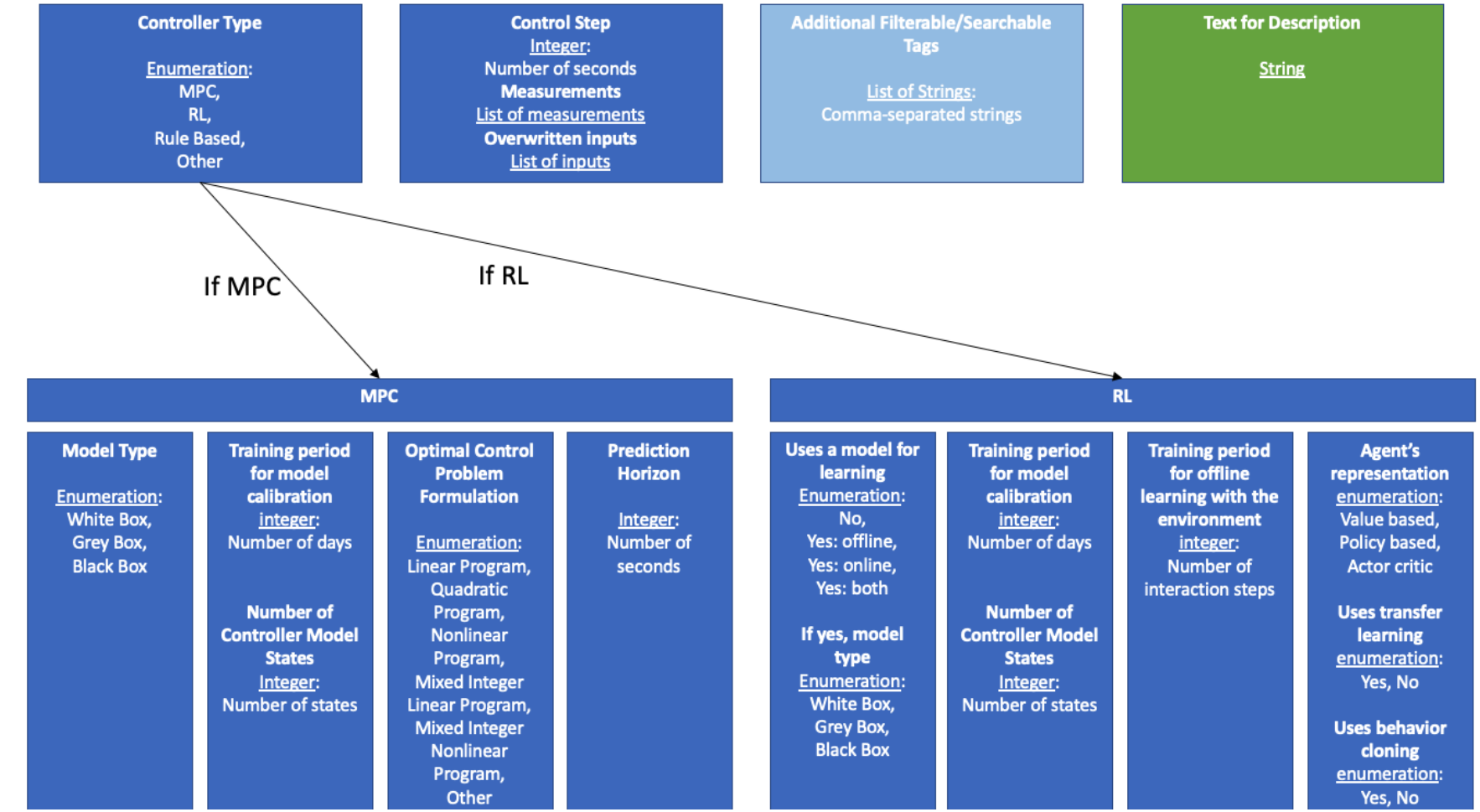
- Automatic transfer of test case results to dashboard through API key, if BOPTEST is run on server and when the full test has run. Separate API to push data to dashboard.
- User can choose what is shared publicly (all results, selection or no results).
- Documentation for each test case available, also as download to PDF.
- Filtering in test results, top level by building type and scenario parameters, narrow down to slices of KPIs.
- Additional meta data, together with KPI ranges (when double clicking on test results).
- Tailored error messages still to be developed.
- Notion of tags, free-form tags API exists, to be extended to more structured tags, nomenclature will be forced.

FOCUS & PROGRESS – Controller characterization

- Implementation of metadata for enabling tagging
- Filtering with respect to test case scenarios and controllers based on tags
- Controller characterization is a combination of
  - Structured search from a drop-down menu (based on guided classification)
  - Free format text
- Next step: define how the data structure looks like in Json as starting point for defining the API

FOCUS & PROGRESS – Controller characterization

Schema



FOCUS & PROGRESS - Emulators

- Merged to master. Ready to be used!
- In pull request → Under peer-review (working on latest changes and documentation)
- In pull request → BOPTEST Additions needed (like IO blocks, test case data or unit-tests)
- In pull request → Model changes needed
- Emulator model under development

Emulator	Developer
Single-zone BESTEST hydronic	Filip & Javier
Single-zone BESTEST hydronic (modulating HP)	Javier & Filip
Single-zone BESTEST air-based (gas boiler)	Dave
Multi-zone (8z) residential hydronic heating (gas boiler)	Valentin & Javier
Multi-zone (8z) residential hydronic heating + air cooling	Valentin
Single-zone commercial air-based	Dave
Single-zone commercial hydronic	Krzysztof / Tao
Multi-zone (5z) commercial air-based	Dave
Multi-zone office hybrid (simple)	Iago & Javier
Multi-zone office hybrid (complex)	Filip
Multi-zone commercial air-based + FIELD TESTS available!	Yeonjin
Multi-zone prototype air-based (complex)	Sen Huang

FOCUS & PROGRESS – Stochastic scenario

Quantification of weather uncertainties

- Aim: to add stochastic scenarios to the current deterministic BOPTEST framework
- First uncertainties on weather forecast (temperature and solar radiation), then occupant behaviour
- Method: generalize forecast error model
  - Gaussian distribution with mean and standard deviation is superimposed on the deterministic forecast using an autoregressive model (many (real forecasted and measured) data needed!)
  - For each hour a 24-hours forecast is created
  - Different uncertainty scenarios based on data collected from different locations?
  - A random seed is established for the emulator of uncertainty to provide consistent forecasts across tests

FOCUS & PROGRESS – Trials & Outreaching

- BOPTEST workshops @ BS2021 and @ EnergyVille
  - Attendees: 17 + 3 (September 2021) and 10 + 7 (October 2021) very positive feedback and request for district scenarios
- Follow up session in December 2021: request for stochastic scenarios
- BOPTEST paper - methodology
  - Blum, David; Arroyo, Javier; Huang, Sen; Drgona, Jan; Jorissen, Filip; Walnum, Harald Taxt; Chen, Yan; Benne, Kyle; Vrabie, Draguna; Wetter, Michael; Helsen, Lieve (2021) Building optimization testing framework (BOPTEST) for simulation-based benchmarking of control strategies in buildings. *Journal of Building Performance Simulation* 14(5) 586 – 610

BEST PAPER AWARD JBPS (last 2 years)

FOCUS & PROGRESS – Trials & Outreaching

- Presentations
  - David Blum @ BuildSys workshop
  - Lieve Helsen @ NeurIPS workshop
- Intensive use by:
  - DeltaQ (for teaching purposes to non-technical people, and BOPTEST integrated in full test setup)
  - RWTH Aachen – Control Group
  - UGent interested (data-driven control for residential buildings)
  - Interest from Industry (US):
    EcoBee (possibly own test cases), EnergyStar, Johnson Controls, Arup
  - …

FUTURE PLANS

1. Reaching out to AI Community
   (NeurIPS Conference Climate Change AI workshop, International Conference on Learning Representations, American Control Conference workshop, American Society of Mechanical Engineers Conferences)
2. Controller competition
3. Follow-up project (IBPSA umbrella) – Lead taken by David Blum
4. Towards D(istrict)OPTEST
5. Beyond virtual - MPC experience in real buildings: share insights

BREAKOUT SESSIONS

	Content - title	Presenter/Leader	time
Session 1 (Day 1)	**BOPTEST Forecast Uncertainty**		**50 min**
	First trials of solar radiation with auto-regressive model	All WP1.2 members/Laura	
	Implementation in BOPTEST	Dave/Javier	
	Occupancy	All WP1.2 members	
Session 2 (Day 1)	**Emulators & Outreaching**		**55 min**
	Emulator update	Emulator developers	
	Workshop preparation for AI community	Javier/Jan	
	Joint papers	All WP1.2 members	
Session 3 (Day 2)	**New BOPTEST Developments and Plan to End**		**1 hr 45 min**
	New developments	Dave	
	Plan for final months of IBPSA Project 1	All WP1.2 members	
	Concentrations of interest for future	All WP1.2 members	