

WP1.2: Model Predictive Control

WP Leader: Lieve Helsen
Master of ceremony: David Blum

Digital Expert Meeting
May 6, 2020

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 WORK PLAN

WP1.2 Model Predictive Control (MPC)

Task 1.2.1:

Develop a framework to test and assess MPC performance

Taks 1.2.2:

Compare and benchmark MPC algorithms

Task 1.2.3:

Develop a Modelica library for MPC

THE ACTION PLAN DEFINED IN ROME

Focus points defined for the period between Rome and Montréal:

- **Virtual Testing Framework (BOPTEST):**

Continued development and prototype testing, start testing first controllers, reporting

- **Emulator Models:**

Development, documentation and review (including checklist for review process), aim to have 4 emulators ready to start testing BOPTEST

- **Key Performance Indicators (KPI):**

Add indicators for IAQ, peak power in operational cost, use of representative weeks/days

- **Modelica Library for MPC:**

Use of modelica-ibpsa models, unit testing, develop guidelines for library use

THE WP1.2 TEAM

19 participants (+ 3 guests) from 10 institutes/companies

Affiliation	Team members
KU Leuven	Lieve Helsen, Filip Jorissen, Javier Arroyo, Iago Cupeiro
LBNL	David Blum, Michael Wetter
ENGIE Lab	Valentin Gavan
SDU	Toa Yang, Konstantin
PNNL	Huang Sen, Jan Drgona, Chen Yan
IK4 Tekniker	Laura Zabala, Jesus Febres, Aritz Bengoetxea
SINTEF	Harald Tax Walnum
Politecnico de Milano	Ettore Zanetti
ORNL	Piljae Im, Yeonjin Bae
Argonne NL	Qi Li (moved to Siemens)
Guests	Moritz Lauster (Viessmann), Jing Wang, Jes Stershic

STATUS WORK

Coordination meetings since Rome

7 Monthly progress meetings

Chaired by Lieve Helsen

When?

October 8, November 12, December 10, January 16, February 20, March 19, April 21

What?

1. Progress and discussions on emulators, KPIs & scenarios, BOPTEST, MPC Library
2. Dissemination and joint papers
3. Next phase
4. Miscellaneous

STATUS WORK

Task 1.2.1: Development of a framework to test and assess MPC performance BOP-TEST

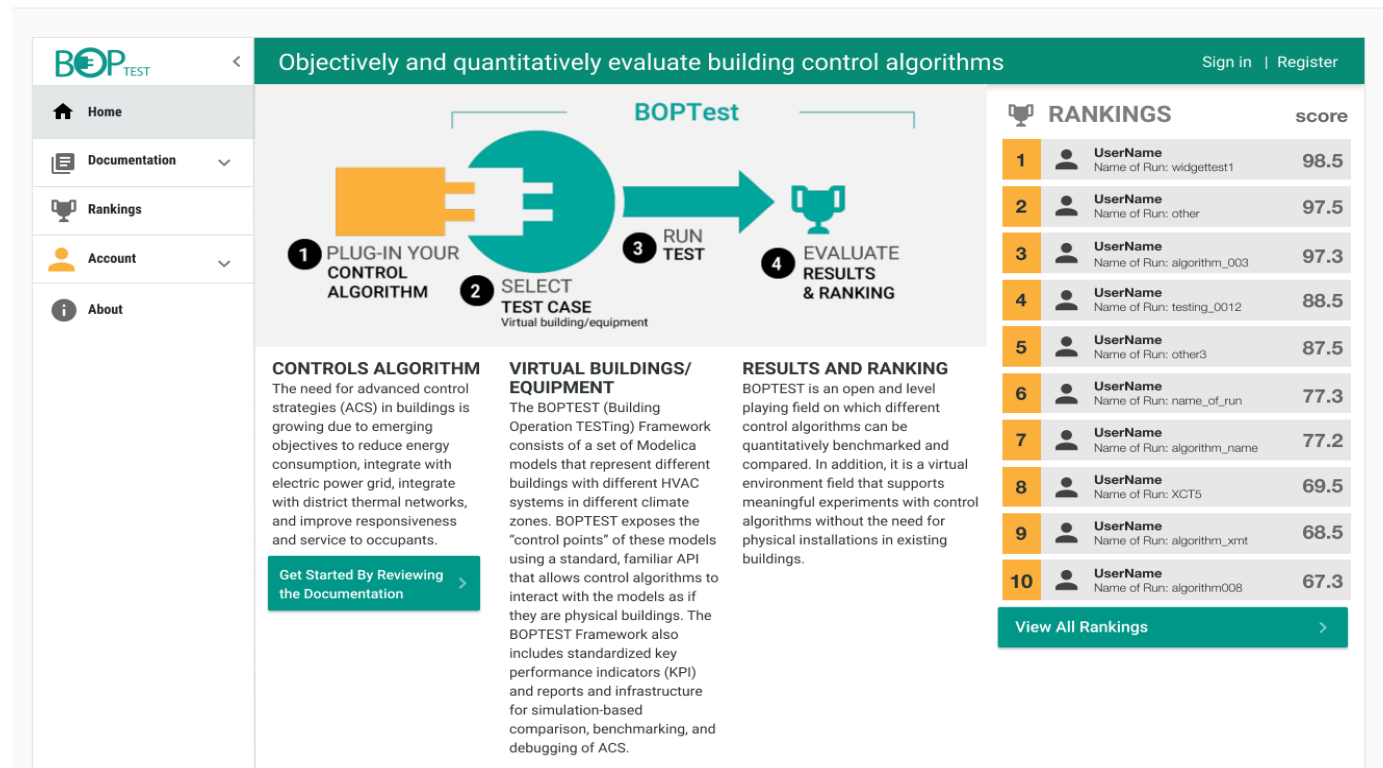
Virtual test bed - Architecture which allows control by whatever controller

- ✓ Workflow for use cases: ready
- ✓ Prototype: ready and tested in different environments (<https://github.com/ibpsa/project1-boptest>)
- ✓ Documentation of development requirements and guide: finalized 1st version
- ✓ Ongoing developments:
 - ✓ parameterize and implement forecast errors – internal working group generalizing forecast error model(s) with real forecasted and measured data.
 - ✓ parameterize and implement measurement noise – on hold.
 - ✓ define workflow for training data for grey-black-box models different than testing data - need to create “previous” year data, particularly weather data. Consider using historic data or determine how to create new TMY.
 - ✓ Continuous maintenance and feature enhancements.

STATUS WORK

- ✓ Proposed web-based interface for creating accounts and sharing results

<https://xd.adobe.com/view/0e0c63d4-3916-40a9-5e5c-cc03f853f40a-783d/>



STATUS WORK

Task 1.2.1: Development of a framework to test and assess MPC performance BOP-TEST

Virtual test bed - Detailed emulator models

- ✓ Modelica template/guidelines for standardizing towards KPIs and inputs/outputs communication: implemented as Modelica blocks in `IBPSA.Utilities.IO.SignalExchange` and further extended towards multi-zone models for zone name designation
- ✓ Peer review process by checklists (v1.0, 1.1, 1.2) and unit tests (in BOPTEST repository, using the whole BOPTEST toolchain): ready
- ✓ Emulators (in BOPTEST repository - directory Testcases): development, documentation and review: nicely progressed – see next slide

Emulator	Developer	Developed	Documented	Reviewed by	BOP-TEST ready	In Repository
BESTEST hydronic (1z)	Filip	Ready, from IDEAS	ready	Dave: ready	ready	PR
BESTEST air-based (1z)	Dave	Ready, from BUILDINGS	ready	Filip: ready	ready	Branch
8z residential hydronic heating	Valentin	ready	ready	Tao: ready	Zone-identifiers	PR
8z residential hydronic heating + air cooling	Valentin	ready	1 st version	Tao: ongoing	Almost finalized	
Air-based commercial (1z)	Dave	Almost ready	In development	Jesus		
Hydronic commercial (1z)	Tao	ready	ready	Dave: ready	ready	PR
5z air-based commercial	Dave/Javier	Internal review from BUILDINGS	1 st version	Yanfea (Filip)	1 st version	
mz hybrid office (simple)	Iago	Ready, from IDEAS	ready	Valentin: ready	Almost finalized	Branch
10z air-based commercial	Yeonjin	In progress	In development	Konstantin		
mz hybrid office (complex)	Filip	In progress	In development	PNNL?		
mz air-based prototype (complex)	Sen	ready	1 st version – occupancy profile missing	Iago: ready	Almost finalized	

STATUS WORK

Task 1.2.2: Comparison and benchmarking MPC algorithms

Virtual test bed developed in Task 1.2.1 is used to **test MPC formulations and solvers** on common emulators, which allows benchmarking the MPC algorithms using selected performance indicators

- ✓ MPC description template (control engineering versus physical notation): ready
- ✓ Core KPIs quantification - calculation module (with input/output requirements): ready, IAQ (CO₂ concentration violation in ppm-hours) has been added
- ✓ Use of representative days/weeks: ongoing
- ✓ List of scenarios to vary boundary conditions (e.g. weather, price profile energy vectors (consistent with emission factors), uncertainty on forecast ...): ongoing
- ✓ Start internal testing!
- ✓ Internal (spreadsheet) and public (centralized location) reporting: to be set up (Montréal)

STATUS WORK

Internal testing has started!

- **spreadsheet** to post results of BOPTEST test cases will be later integrated in the website.

<https://docs.google.com/spreadsheets/d/1E-5wR7nasW8h6kEtrXnUzcRrEA6f7TlxjbtSdB1Cz3w/edit>

References					Test case description variables						Controller description variables					KPIs				
Identifier	Simulation date	Contact	Notes	Link to associated publication	Start co-simulation time [s]	Stop co-simulation time [s]	Control step [s]	Price scenario	Uncertainty distribution	Type of building	Controller type	Problem formulation	Controller model type	Number of states	Prediction horizon [s]	Thermal discomfort [Kh]	Energy use [kWh]	Cost [EUR]	Emissions [kgCO ₂]	Time ratio
BMH-bas-jan	2019-12-12 16:25	javier.arroyo@kuleuven.be	Baseline control of the residential multi-zone building in January	None	5.18E+05	3.02E+06	900	Price constant *	Deterministic *	Residential multi-zone hydronic *	Baseline controller *	None *	None *	-	-	456.38	1,119.32	86.09	241.72	3.29E+06
BMH-mpc-grey-con	2019-12-15 12:29	javier.arroyo@kuleuven.be	Centralized multi-zone grey-box model for model predictive control in January	None	5.18E+05	3.02E+06	900	Price constant *	Deterministic *	Residential multi-zone hydronic *	Model predictive controller *	Non linear programming *	Grey-box *	20	21,600	52.60	1,345.15	97.41	276.53	1.82E+03
BMH-mpc-grey-dec	2019-12-17 14:53	javier.arroyo@kuleuven.be	Decentralized multi-zone grey-box model for model predictive control in January	None	5.18E+05	3.02E+06	900	Price constant *	Deterministic *	Residential multi-zone hydronic *	Model predictive controller *	Non linear programming *	Grey-box *	18	21,600	604.12	1,080.92	78.91	223.69	1.36E+03
BMH-bas-nov	2020-02-10 10:47	javier.arroyo@kuleuven.be	Baseline control of the residential multi-zone building in January	None	2.67E+07	2.92E+07	900	Price constant *	Deterministic *	Residential multi-zone hydronic *	Baseline controller *	None *	None *	-	-	417.43	883.28	69.24	193.77	3.91E+06
BMH-mpc-grey-con	2019-12-17 11:06	javier.arroyo@kuleuven.be	Centralized multi-zone grey-box model for model predictive control in January	None	2.67E+07	2.92E+07	900	Price constant *	Deterministic *	Residential multi-zone hydronic *	Model predictive controller *	Non linear programming *	Grey-box *	20	21,600	49.37	1,049.39	76.71	217.38	5.96E+03
								*	*	*	*	*	*	*	*					
								*	*	*	*	*	*	*	*					
								*	*	*	*	*	*	*	*					
								*	*	*	*	*	*	*	*					

STATUS WORK

MPC competition: to be set up (Montréal)



Source: Darwin management Consultants

STATUS WORK

Task 1.2.3: Development of a Modelica library for MPC

Library of models that can be used to efficiently solve optimal control problems for building and district energy systems (& that can be combined with parameter and state estimation algorithms)

- ✓ Separate MPC Library that implements the IBPSA Library: prototype script and process for modelica-ibpsa merging developed and tested on small models to handle 3 issues:
 1. Direct copy of model
 2. Direct copy with parameter changes
 3. Copy with edited code/equations
- ✓ Compliant with JModelica → no integer problems, but JModelica is no longer open-source
- ✓ Development of framework on first small models for unit testing: ongoing
- ✓ Development of guidelines for library use – like modelica-ibpsa wiki: to be started

STATUS WORK

Publications

➤ BS2019 Conference paper published

D. Blum, F. Jorissen, S. Huang, Y. Chen, J. Arroyo, K. Benne, Y. Li, V. Gavan, L. Rivalin, L. Helsen, D. Vrabie, M. Wetter, and M. Sofos. (2019).

Prototyping the BOPTEST framework for simulation-based testing of advanced control strategies in buildings.

In *Proc. of the 16th International Conference of IBPSA*, Sep 2 – 4. Rome, Italy.

Available from <http://www.ibpsa.org/building-simulation-2019>

STATUS WORK

Publications

➤ MPC Review paper submitted

Ján Drgoňa, Javier Arroyo, Iago Cupeiro Figueroa, David Blum, Krzysztof Arendt, Donghun Kim, Enric Perarnau Ollé, Juraj Oravec, Michael Wetter, Draguna L. Vrabie, Lieve Helsen (2020)

All you need to know about model predictive control for buildings

Journal submission: *Annual Reviews in Control*

STATUS WORK

Other interesting initiatives

- IBPSA Newsletter: contribution of WP1.2
- IEA-EBC Annex 81 'Smart Data-Driven Solutions for High Performance Buildings' – Dave participates
- Broaden the user space (e.g. to Machine Learning people). How to reach these people? Cfr OpenAIGym
- BS2021 organized by Flemish-Dutch team (incl. Lieve & Dirk) – workshops!



International
Building
Performance
Simulation
Association

SAVE THE DATE

Get ready, team
up with practice,
industry, policy
and research
to create a real
impact with BES

info@bs2021.org
www.bs2021.org

Talent in music
as well?

Prepare to be awarded
author of the BS2021
Bruges Belfry theme

@ Giorgio Galeotti

BS 2021

1-3 SEPT
BRUGES



IBPSA
NVL

KU LEUVEN



daidalos peutz
boydens engineering