WP1.2:
Model Predictive Control

WP Leader: Lieve Helsen

Digital Expert Meeting

May 7, 2021

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 ACTION PLAN DEFINED IN MAY 2020

Focus points defined for the period after the October 2020 digital meeting:

- **Virtual Testing Framework (BOPTEST):**
  - Define test cases with fixed parameters and boundary conditions, start testing, and report issues
  - Characterize the controllers used (incl. meta data)
  - How to avoid cheating? Check box to declare the users comply with ethical rules
  - Outreaching: workshop @ BS2021 Conference (August 2021), workshop @NeurIPS 2021 (December 2021), journal paper on capabilities BOPTEST
- **Emulator Models:**
  - Further development, documentation and review
  - Extra case to be added with intermediate complexity: BESTEST Hydronic with modulating heat pump to see the effect of exploiting flexibility
- **Robustness towards uncertainties**
  - Continue the work dealing with uncertainties on weather predictions

THE WP1.2 TEAM

25 participants from 13 institutes / companies

Assign roles: leader, user or developer

Affiliation	Team members
KU Leuven	Lieve Helsen, Filip Jorissen, Javier Arroyo, Iago Cupeiro
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
DeltaQ	Roel De Coninck, Carlos Andrade
ETH Zurich / EMPA	Felix Bünning
NREL	Nicholas Long
University of Colorado - Boulder	Thibault Marzullo, Sourav Dey, Gregor Henze

STATUS WORK

Coordination meetings since October: 5 Monthly progress meetings

Chaired by Lieve Helsen

When? November 13, December 9, January 20, March 1, April 19

What?

1. Emulators
2. Controller characterization
3. Reporting results from BOPTEST testing, issues, software update
4. BOPTEST Workshop @ BS2021 Conference
5. BOPTEST methodology journal paper
6. Weather uncertainties
7. Break-out sessions for next on-line IBPSA Project 1 Expert Meeting

STATUS WORK

Task 1.2.1: Development of a framework to test and assess MPC performance BOPTEST

Virtual test bed - Architecture which allows control by whatever controller

- ✓ BOPTEST Workflow for use cases: ready (https://github.com/ibpsa/project1-boptest)
- ✓ Ongoing developments:
  - ✓ Define **scenario periods** (heating-peak, heating-typical, cooling-peak, cooling-typical, mix), API has been updated with a call to set the cases in a specific testing period
  - ✓ Expose the **initialization data** to the period that is used to warm up the test cases, API has been updated
  - ✓ **More efficient memory use,** e.g. revised API to request specific data points for specific time periods, like the typical operation of a timeseries database, save and report result trajectories at 30 second time intervals, save data for model variables only if needed by BOPTEST

STATUS WORK

Task 1.2.1: Development of a framework to test and assess MPC performance BOPTEST

Virtual test bed - Architecture which allows control by whatever controller

- ✓ Ongoing developments:
  - ✓ **More efficient implementation of KPI calculator**, which allows iterative calls with a computational cost that is independent of the integration time (relevant for RL algorithms)
  - ✓ Continuous **maintenance and feature enhancements**
  - ✓ Parameterize and implement **forecast errors** – generalizing forecast error model(s) with real forecasted and measured data, focusing on weather prediction uncertainty using autoregressive models and Q-Q mapping, analysis for Leuven, Denver and Norway locations is ongoing
  - ✓ **BOPTEST-Gym development**: an OpenAIGym environment for the BOPTEST framework to rigorously benchmark different reinforcement learning algorithms among themselves and against other controllers (such as MPC) by simulation.

STATUS WORK

Task 1.2.1: Development of a framework to test and assess MPC performance BOPTEST

Virtual test bed - Detailed emulator models

- ✓ Modelica template/guidelines for standardizing towards KPIs and inputs/outputs communication: ready
- ✓ 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
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	Tao/Konstantin
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	Yeonjin
Multi-zone prototype air-based (complex)	Sen Huang

- Merged to master. **Ready!**
- Almost there
- In pull request or review
- Emulator model under development

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: ready
- ✓ Core KPIs quantification - calculation module: ready
- ✓ List of **scenarios** to vary boundary conditions (e.g. weather, price profile energy vectors (consistent with emission factors), uncertainty on forecast …): ready for deterministic case
- ✓ **Internal testing**: ongoing
- ✓ Internal (spreadsheet) and public (centralized location) **reporting**: ongoing

STATUS WORK

MPC contest: targeted for 2022

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)

- ✓ Development of framework on first small models for unit testing: ongoing
- ✓ Development of guidelines for library use – like modelica-ibpsa wiki: to be started

OUTREACH

IBPSA Project 1 – WP1.2 journal publications

1. Iago Cupeiro Figueroa, Massimo Cimmino, Ján Drgona, Lieve Helsen. Fluid temperature predictions of geothermal borefields using load estimations via state observers. *Journal of Building Performance Simulation*, Vol. 14, No. 1, p. 1 - 19, 2021.
2. Iago Cupeiro Figueroa, Massimo Cimmino, Lieve Helsen. A Methodology for Long-Term Model Predictive Control of Hybrid Geothermal Systems: The Shadow-Cost Formulation. *Energies*, Vol. 13, No. 23, 2020.
3. Javier Arroyo, Spiessens, Lieve Helsen. Identification of Multi-Zone Grey-Box Building Models for Use in Model Predictive Control. *Journal of Building Performance Simulation*, Vol. 13, p. 472-486, 2020.
4. Gowri Suryanarayana, Javier Arroyo, Lieve Helsen, Jesus Lago. A Data Driven Method for Optimal Sensor Placement in Multi-Zone Buildings. *Energy and Buildings*, Vol. 243, 110956, 2021.
5. David Blum et al. Building Optimization Testing Framework (BOPTEST) for Simulation-Based Benchmarking of Control Strategies in Buildings. *Journal of Building Performance Simulation*, in preparation.

OUTREACH

IBPSA Project 1 – WP1.2 conference publications

6. Javier Arroyo, Carlo Manna, Fred Spiessens, Lieve Helsen. An OpenAI-Gym environment for the Building Optimization Testing (BOPTEST) framework, BS2021, revised version submitted.
7. Iago Cupeiro Figueroa, Lieve Helsen. A low-order semi-physical borefield model for optimal control applications, BS2021, revised version submitted.
8. Iago Cupeiro Figueroa, Lieve Helsen. Application of long-term MPC formulation to hybrid GEOTABS buildings, BS2021, revised version submitted.
9. Filip Jorissen, Damien Picard, Lieve Helsen. Automated workflows for model predictive control of buildings using Modelica, BS2021 project & valorization sheet, revised version submitted
10. Filip Jorissen, Damien Picard, Kristoff Six, Lieve Helsen. Detailed White-Box nonlinear MPC for Scalable Building HVAC Control, Modelica 2021 Conference, submitted
11. Harald Taxt Walnum, Igor Sartori, and Marius Bagle, Model predictive control of District Heating substations for flexible heating of buildings, BuildSim-Nordic 2020, Available Online
12. Tao Yang, Konstantin Filonenko, Krzysztof Arendt, Christain Veje, Implementation and performance analysis of a multi-energy building emulator, 2020 6th IEEE International Energy Conference (ENERGYCon)

OUTREACH

Other (external) publication that use BOPTEST (so it is known ;-))

1. Authors not known (anonymous as reviewer)
   Comparing Machine Learning based Methods to standard Regression Methods for MPC on a virtual Testbed, BS2021, revised version.

Other initiatives

1. **VOLTRON** (operating system to help implementation of building control):
   implements controller as an agent, they have agents for EnergyPlus simulation, they work on an agent to be coupled to BOPTEST
2. Igor Sartori (SINTEF) is engaged in **IEA Annex 81** and is preparing an **ERANET proposal** on a competition focused on ML and data-driven analysis and control (2021-2023), competition in 2023, wants to use BOPTEST for this competition. A separate emulator will be developed for this competition (funded by industry). Prize: winning-controller will be implemented.

BREAKOUT SESSIONS

	Content - title	Presenter/Leader	time
Session 1 (Day 1)	**BOPTEST trials**		**55 min**
	sharing experience of trials	Javier, Dave, Iago, Harald, ...	
	internal reporting: controller and KPIs	All	
	external reporting: controller and KPIs	All	
	feedback to BS2021 workshop organizers	All → Javier & Dave	
Session 2 (Day 1)	**Emulators**		**50 min**
	those that are ready - results from trials	Filip, Javier Dave, Valentin, Tao, Sen	
	those that need further development - plan	Valentin, Dave, Filip, Iago, Yeonjin	
	scenarios and boundary conditions	All	
Session 3 (Day 2)	**New developments & Outreaching**		**45 min**
	New developments in BOPTEST	Dave	
	--> technical issues, new KPIs (peak power)		
	Workshop introducing BOP-TEST at BS2021	Dave & Javier	
	Initiatives for joint papers	All	
	Where have we seen BOPTEST popping up?	All	

International Building Performance Simulation Association

BOPTEST workshop

BS 2021
1-3 SEPT
BRUGES

SAVE THE DATE

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

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www.bs2021.org

Talent in music as well?

Prepare to be awarded author of the BS2021 Bruges Belfry theme

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