IBPSA Project 1

Use Cases and KPIs

David Blum, Javier Arroyo, Yan Chen

Expert meeting: Rome, September 1, 2019

BERKELEY LAB

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

THERMAL SYSTEMS SIMULATION

KU LEUVEN

Agenda

- KPIs Action plan
    - Peak power (David Blum)
    - Indoor air quality (Yan Chen)
    - Yearly savings (Javier Arroyo)
    - Installation metrics (Javier Arroyo)
    - Flexibility (Javier Arroyo)
- MPC testing, comparison, and reporting (David Blum/Yan Chen)
- BOPTREE - looking into the future of BOPTEST (Javier Arroyo)
- Questions and Discussion (All)

KPIs Action Plan

Table 2 List of core KPI definition/calculation

Key Performance Indicators	Calculation formula / Definition	Nomenclature
Thermal discomfort	$D(t_0, t_f) = \sum_{z \in \mathbb{Z}} \int_{t_0}^{t_f} \lvert s_z(t) \rvert \, dt$	ϵ - total amount of CO_2 emissions ξ- the set of equipment in the system with an associated energy use of any type e_i- the emission factor of equipment i n- the number of iterations that take place between t_o and t_f p^τ- the price profile of equipment i with a tariff τ $s_z(t)$- the deviation (slack) from the lower and upper set point temperatures established in zone z t_o- initial time t_f- final time $t_c(k)$-the computational time at iteration k $T_s(k)$-the sampling time at iteration k z - the zone index for the set of zones in the building $\mathbb{Z}$ C^τ- the total cost with a tariff τ D- total discomfort time E- total amount of energy use P_i- instantaneous power use of equipment i
Total building energy use	$E(t_0, t_f) = \sum_{i \in \xi} \int_{t=t_0}^{t=t_f} P_i(t) dt$	
Total building CO_2 emissions	$\epsilon(t_0, t_f) = \sum_{i \in \xi} \int_{t=t_0}^{t=t_f} e_i(t) P_i(t) dt$	
Total operational cost	$C^\tau(t_0, t_f) = \sum_{i \in \xi} \int_{t=t_0}^{t=t_f} p_i^\tau(t) P_i(t) dt$	
Capability of the controller to steer flexibility	To be defined as capability of a controller to follow an artificial external signal within a predefined boundary conditions.	
Installation metrics	To be defined as a set of metrics to evaluate the effort and cost required to get the controller implemented and running.	
Maximum allowed capital cost	$CAPEX_{max}^{5years} = 5(C_{1year}^{old} - C_{1year}^{new})$	
Computational time ratio	$t_r(t_0, t_f) = \frac{\frac{\sum_{k=1}^{n} t_c(k)}{n}}{\frac{\sum_{k=1}^{n} T_s(k)}{n}} = \sum_{k=1}^{n} \frac{t_c(k)}{T_s(k)}$	

\+ **Peak Power** and **IAQ** based on CO_2

Peak Power

- Lowering peak power demand is often cited as an important advantage for MPC to benefit electric grids and lower commercial utility bill costs with significant demand charges (~ 30% of bill)
- U.S. utilities often charge commercial customers per month at $\boldsymbol{\Sigma}_t$(energy[t]*$/kWh[t]) + peak power*$/kW
- One utility, PG&E in CA, charges per month at $\boldsymbol{\Sigma}_t$(energy[t]*$/kWh[t]) + $\boldsymbol{\Sigma}_T$(peak power[T]*$/kW[T])
  where T is particular period of time
- It is dependent on the simulation period of test
- Simple version of max{P(t)} already in place at BOPTEST KPI calculation module, but not added as core KPI - PG&E Utility defines as peak 15 min average kW.
- Propose adding $\max\{P(t)\}_{15}$ or other reasonable x min average
- Think about application to cost calculation?

Indoor Air Quality

- We approved including IAQ as a KPI using CO_2 as a proxy, though we need to finalize how we will calculate the specific KPI.
- We will use the time above threshold as evaluation criteria, thus expressed in ppm-hours CO_2.
- If building with multiple zones, then calculate the value for each zone.

KPI - Indoor air quality

Acceptable indoor air quality (IAQ) are defined as the "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction." (ASHRAE 62.1-2016)

Major contaminants
carbon dioxide, carbon monoxide, formaldehyde, Lead, nitrogen dioxide, ozone, particles (<10 um)
particles (<2.5um), radon, sulfur dioxide, total VOCs, (ASHRAE G24-2015)

We propose to **use CO_2 concentration as an IAQ KPI** that represents the air exchange ratio in the building (indirectly represent the IAQ).

Unmet hour for CO2 setpoint (ppm-h)

$$Unmet_{CO2} = \sum_{z\in Z}\sum_{t=t_0}^{t_f} \max\{C\_z\ (t) - C\_r, 0\}$$

Where C denotes the concentration of carbon dioxide CO2 in ppm. For zone z , the carbon dioxide concentration is at time . Let a denote the ambient environment. Let C_r denotes the required CO2 concentration threshold from ASHRAE 62.1 (e.g., for office =700 ppm + C_a).

Unmet hour for CO2 setpoint (unmet-h)

$$Unmet_{CO2} = \Sigma_{z\in Z}\Sigma_{t=t_0}^{t_f} s(t_i)$$

Where $s(t_i) = 1, when\ C_{z(t)} > C_r;\ \ s(t_i) = 0, when\ C_{z(t)} \le C_r$.

Reference:
ASHRAE Standard 62.1-2016, Ventilation for Acceptable Indoor Air Quality
ASHRAE Guideline 24-2015 Ventilation and Indoor Air Quality in Low-Rise Residential Buildings
ASHRAE Guideline 36-2018 High-Performance Sequences of Operation for HVAC Systems

Questions and Discussion

- Which KPI for IAQ would be a better choice? CO_2 unmet hour or CO_2 ppm-hour?

- What are the relevant CO_2 threshold value specified in standards/guidelines at Europe or other countries?

Yearly savings

- We first proposed “maximum allowed capital cost”
- Then we allowed to change to “yearly savings” as is more comprehensive
- Need to compare against baseline controller →
- → Baseline controller results have to be stored within each test-case:
  - What? All simulation variables
  - How? CSV
  - Where? “wrapped/resources/baselineResults.csv”

Installation metrics

INSTALLATION METRICS					
Hardware installation time (measured in one person time and excluding any possible training period for the staff)	Less than one day	Between a day and a week	Between a week and a month	Between a month and three months	More than three months
Software development and installation time (measured in one person time)	Less than one day	Between a day and a week	Between a week and a month	Between a month and three months	More than three months
Hardware installation cost (included extra-sensors for training models or calibrating the controller and workforce)	There is not any extra cost	There is a negligible initial extra cost	The extra cost is less than 1% of the actual value of the building	The extra cost is estimated between 1% and 3% of the actual value of the building	The extra cost is estimated to be larger than 3% of the actual value of the building
Software development and installation cost (including any required software license and workforce)	There is not any extra cost	There is a negligible initial extra cost	The extra cost is less than 1% of the actual value of the building	The extra cost is estimated between 1% and 3% of the actual value of the building	The extra cost is estimated to be larger than 3% of the actual value of the building
Installation knowledge level/training requirement	Everyone can install the controller	Everyone can install the controller after a short training course of less than one day	Everyone can install the controller after a short training course of less than one week	Specific engineering knowledge is required like programming skills plus a short training course of less than one week	Only experts and very advanced engineers are able to install the controller
Intensity of extra excitations required to obtain the identification dataset.	There is not any need to excite the building because no monitoring data is required or the data can be gathered from the building working as business as usual.	Slight excitations are required. These excitations may have a minor influence in the energy use and there is no need to vacate the building during the training period.	Slight excitations are required that may have a noticeable influence in the energy use but there is no need to vacate the building during the training period.	Intense excitations are required. There is a considerable influence in the energy use and/or a need to vacate the building during the training period.	Intensive excitations are required that can only be obtained from detailed simulation models.
Required length of identification dataset (if possible, the client should specify the exact amount of data used and which period(s) are needed to obtain the training data sets)	There is no need of training from monitoring data.	Less than one day.	Between a day and a week.	Between a week and a month.	Several months.

Capability to steer flexibility

- Proposal: average energy shift with respect to the baseline controller when responding to an **extremely high/low cost signal** during the flexibility period that is **followed by a zero cost signal** during a rebound period. Every and from a state established by the baseline controller. Need to specify:
    - Flexibility period
    - Rebound period

First MPC Testing Scenario Definitions

What can we vary?

- Test Case (e.g. emulator model)
- Time period (e.g. specific weeks, yearly)
- Pricing (e.g. constant, dynamic, highly dynamic)

First MPC Testing Scenario Definitions

Proposal:

- Begin a spreadsheet for tracking

		Test Case = BESTEST Air				**Test Case = BESTEST Hydro**			
		Scenario 1 = Summer Week + Constant Price		**Scenario 2 = Summer Week + Dynamic Price**		**Scenario 1 = Winter Week + Constant Price**		**Scenario 2 = Shoulder Week + Constant Price**	
MPC Platform	**Developer**	**KPI 1**	**KPI 2**	**KPI 1**	**KPI 2**	**KPI 1**	**KPI 2**	**KPI 1**	**KPI 2**
MPCPy	LBNL	x	y	z	a	b	c	d	e

Testing scenarios: Assessing Building Energy Performance via Selection of Representative Simulation Days

Motivation

Detail model takes time to simulate → Need to find a way for robust testing yet reduce time-intensiveness

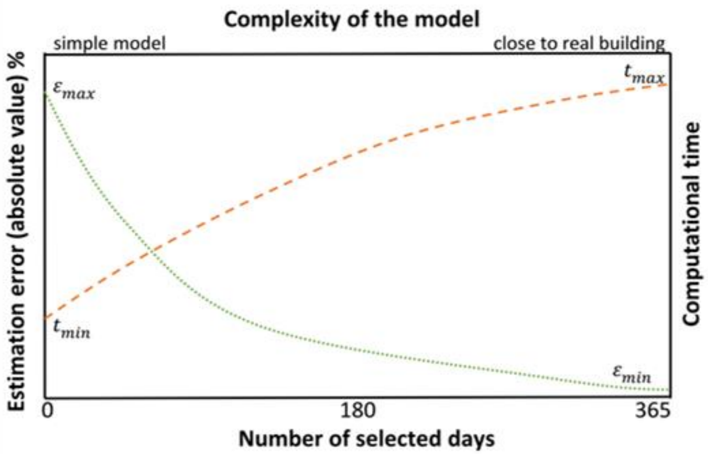
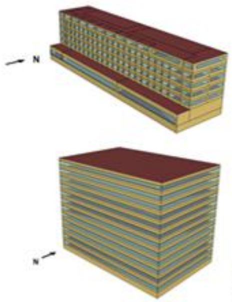


Figure 1: Computation time vs accuracy

Method

1. **Correlation analysis**
2. **Clustering analysis**
3. **Sampling**
4. **Aggregation**
5. **Comparison**

Case Study



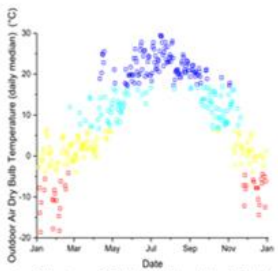


Figure 8: Cluster of daily median dry bulb temperature in Chicago

Cluster #	Selected date
1	30-Dec
2	2-Mar
3	16-May
4	31-Aug

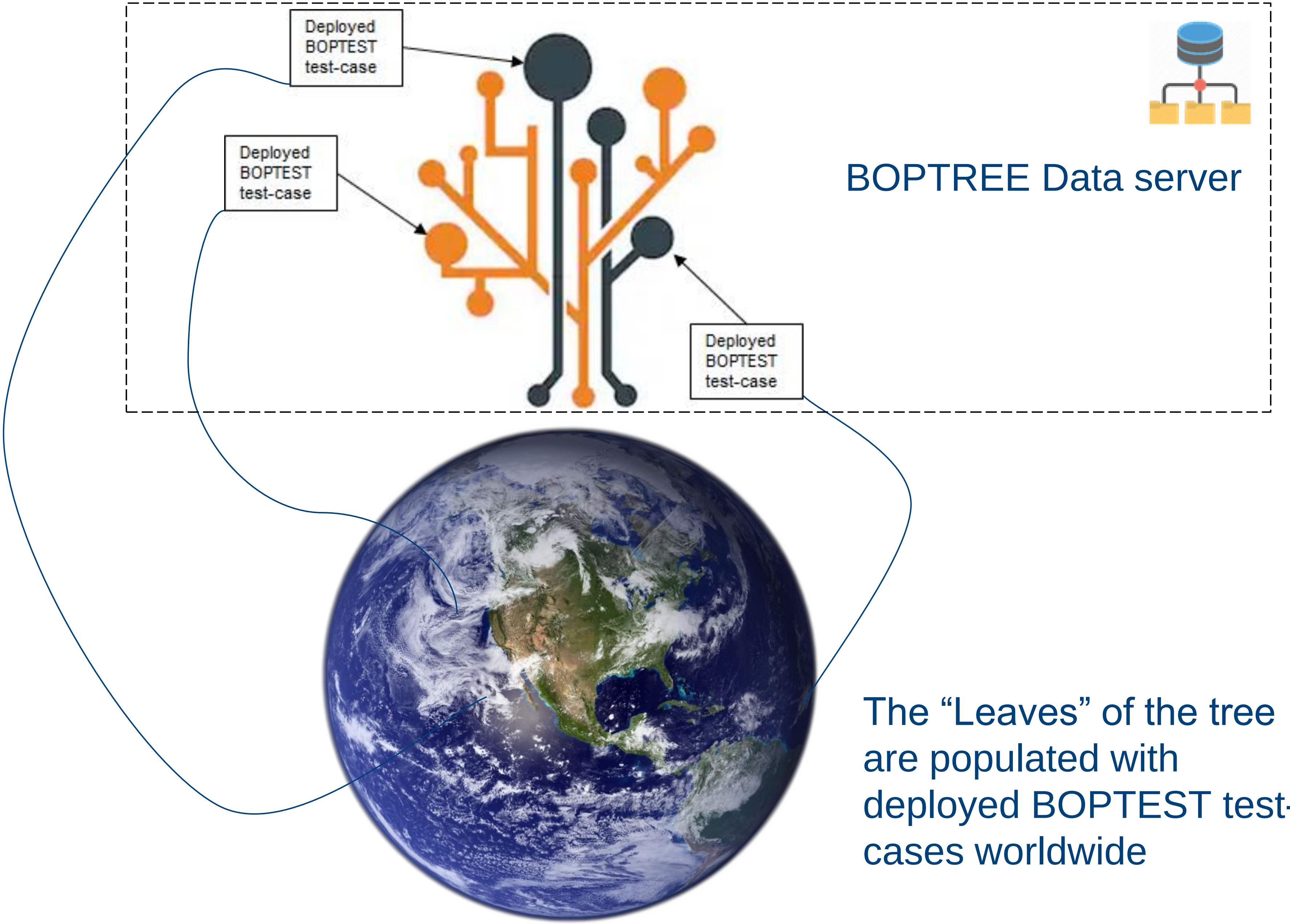
Table 7: Summary of the estimation error for different scenarios

Building Type and Location	Energy Usage Cat.	Ground Truth (GJ)	T mean	T median	T mean +STD T	T median +STD T	LR (T mean)	LR (T mean, RH mean)
Large Office, Chicago	HVAC	12652	11.0%	1.8%	5.2%	4.1%	-3.0%	5.4%
	Other	26826	5.3%	-1.4%	2.3%	-1.2%	2.8%	-0.6%
	Total	39478	7.2%	-0.4%	3.3%	0.5%	0.9%	1.3%
Large Hotel, Chicago	HVAC	3878	-10.3%	-6.2%	-5.0%	1.2%	0.8%	-0.3%
	Other	7862	0.1%	0.4%	-0.1%	-0.3%	1.1%	0.2%
	Total	11740	-3.4%	-1.8%	-1.8%	0.2%	1.0%	0.0%
Large Office, San Francisco	HVAC	4376	-12.4%	-9.0%	-0.9%	15.8%	0.6%	-3.7%
	Other	26787	-0.7%	8.4%	3.4%	-0.6%	-3.6%	3.5%
	Total	31163	-2.4%	6.0%	2.8%	1.7%	-3.0%	2.4%

Paper: Chen Y., S. Bhattacharya, Z. Pang, D. Sivaraman, and D.L. Vrabie. 2019. "Assessing Building Energy Performance via Selection of Representative Simulation Days." In *Building Simulation 2019*. PNNL-SA-141123.

Building Optimization Performance Tree (BOPTREE)

- **Motivation**: Conclusions in building control are extremely **case-sensitive**. Only statistics could serve as a decision-tree for future optimal control development
- **Concept**: Systematically store solutions (core KPI results) from deployed BOPTEST test-cases into a common data-server (if testers wish to make their results public)
- As in: http://plato.asu.edu/guide.html (By Prof. Hans Mittelmann)


Deployed BOPTEST test-case
Deployed BOPTEST test-case
Deployed BOPTEST test-case
BOPTREE Data server
The “Leaves” of the tree are populated with deployed BOPTEST test-cases worldwide

Building Optimization Performance Tree (BOPTREE)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Label	StartTime	StopTime	AvgTe	AvgTi	AvgIrr	PeakIrr	BuiSize	HVACType	ModType	Step	Horizon	nStates	tdis_tot	cost_tot
2	a678d6d	0	904672	275.36	295.87	133.75	374.28	653	Water	Grey	900	86400	23	7.52	236.54
3	48fd879	806500	1004672	278.45	296.79	150.43	483.15	1576	Water	White	3600	21600	274	2.43	1837.95
4	a978d78	709000	4004672	265.36	294.46	89.87	374.28	2757	Air	White	900	10800	586	1.53	1342.56
5	lj870d98	0	904672	288.94	297.37	202.45	457.98	1809	Air	None	300	10800	0	14.7	236.54
6	56q7k67	478900	5609400	279.12	296.15	180.36	356.98	923	Water	Black	1800	86400	23	8.64	236.54

- **Boundary condition variables**: Average outdoor temperature, average irradiation, peak irradiation…
- **Building description variables**: Size, HVAC type...
- **Control variables**: Type of controller, type of model, objective function, prediction horizon, control time step…
- **References**: author contact, associated publication (if any)…
- **Results**: (=core KPIs) thermal discomfort, total operational cost...

Building Optimization Performance Tree (BOPTREE)

- *BOPTREE, BOPTREE on the Cloud, for this building, for this weather, which is the fairest controller of them all?*

- Seems like a fairy tale, but many technical challenges arise:
  - Some data can be retrieved directly from the BOPTEST test-case, but some is to be specified by the controller developer. How this data is collected and reported?
  - How to authenticate results?
  - Where to store the data?
  - Who can have access to it? how?

IBPSA Project 1

THANK YOU

SINTEF

3E

IK4 TEKNIKER Research Alliance

NREL NATIONAL RENEWABLE ENERGY LABORATORY

SDU

engie Lab

BERKELEY LAB

THERMAL SYSTEMS SIMULATION

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

KU LEUVEN