Transactive Systems Studies @ LBNL

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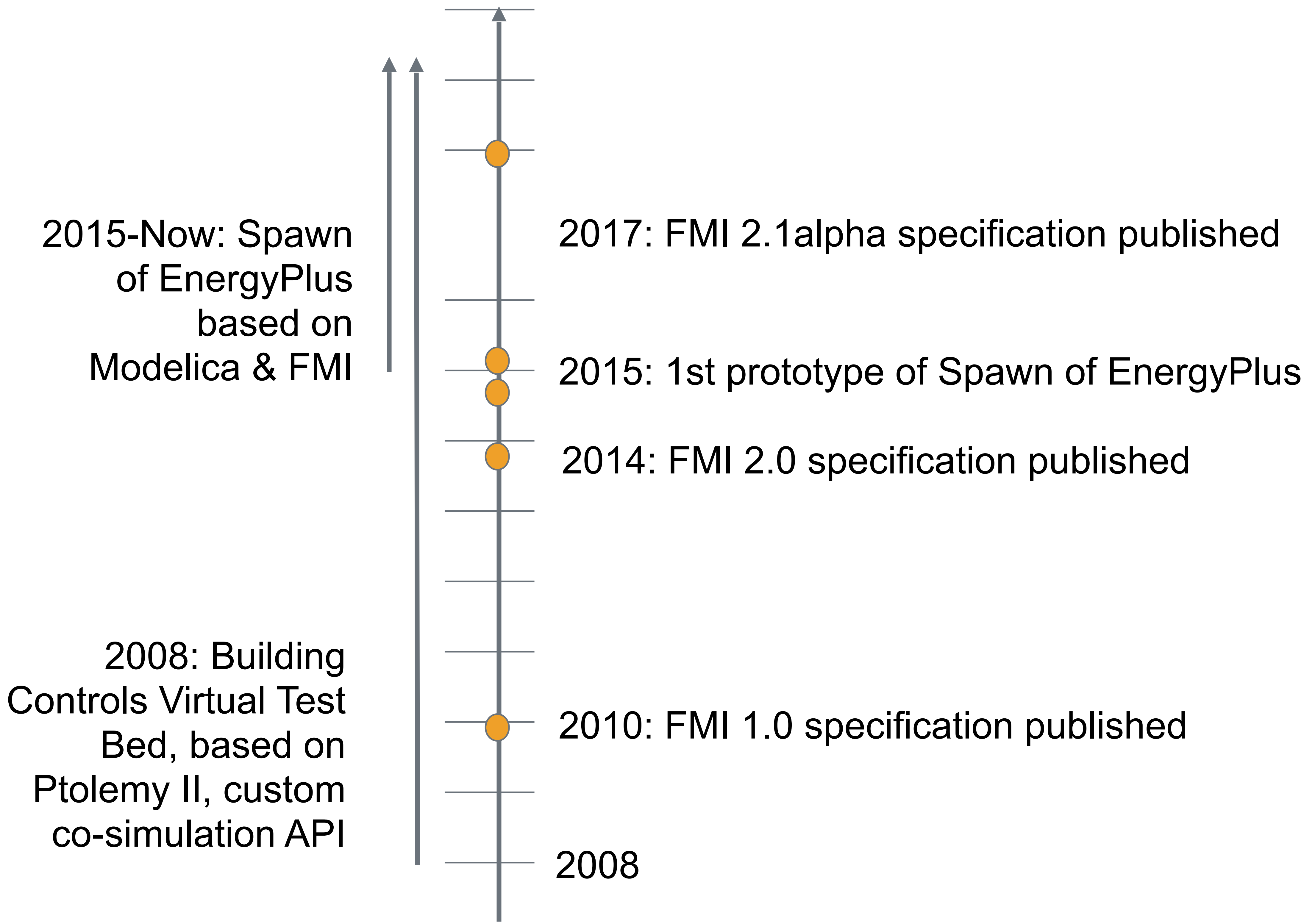
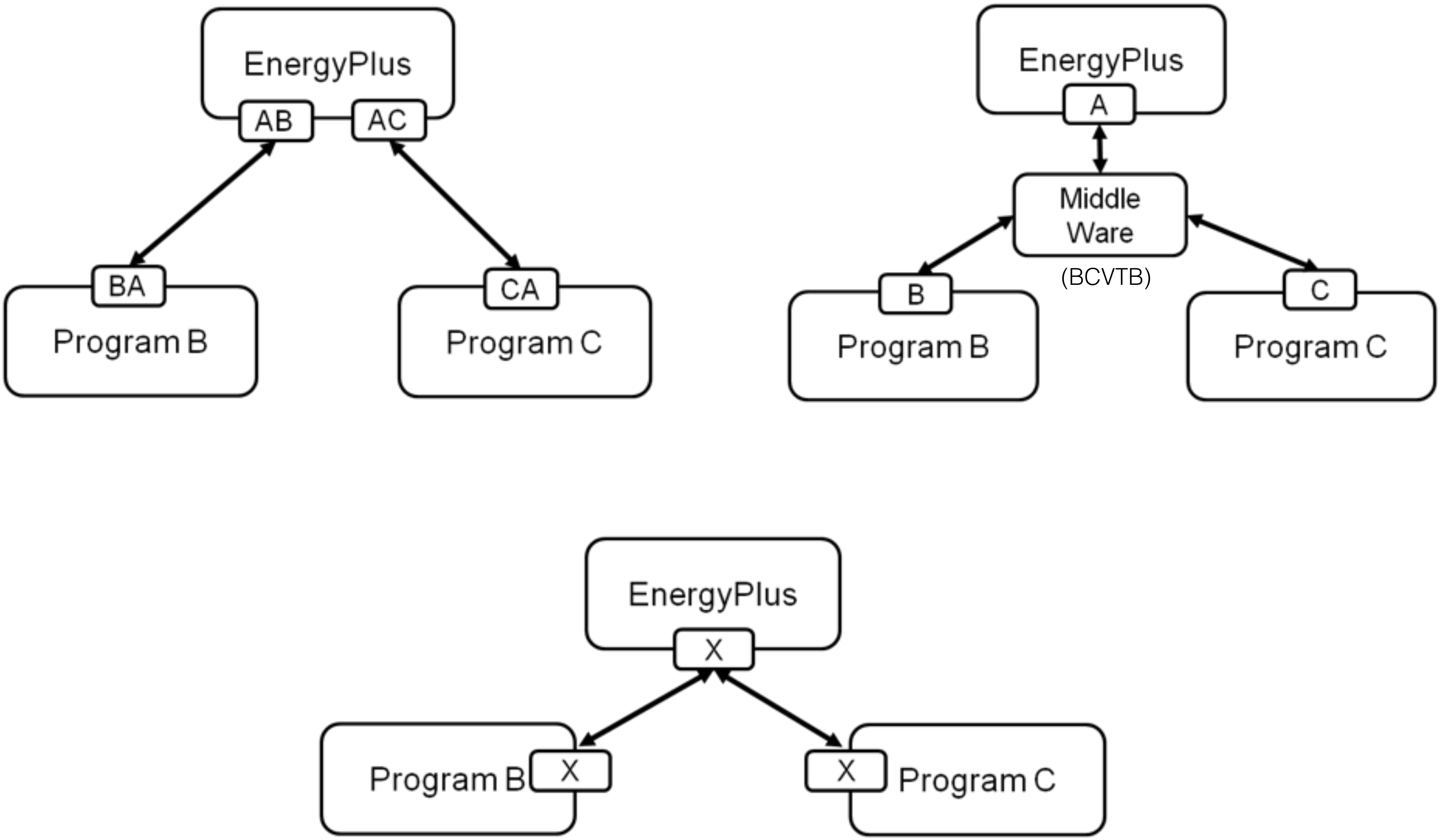
Timeline of Co-simulation Research @ LBNL



Co-simulation - One-to-One vs. Middleware vs. Standard

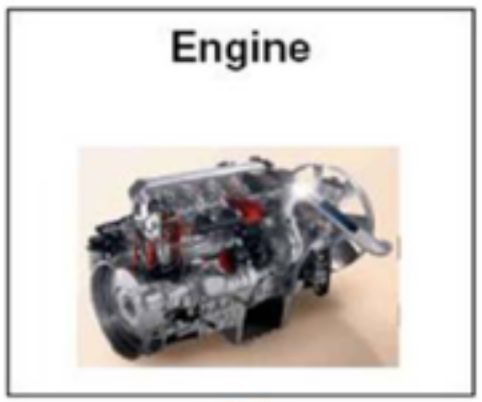


FMI Related Projects at LBNL

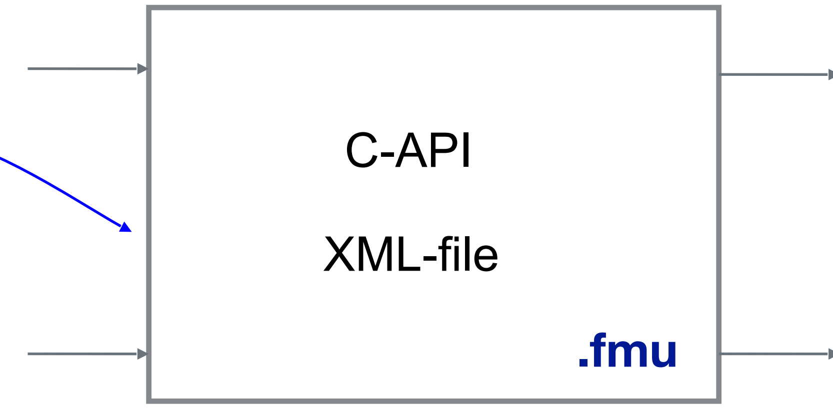
- FMI import interface in EnergyPlus (DOE)
- FMI Export Interface for EnergyPlus (DOE)
- FMI Import Interface in the Building Control Virtual Test Bed (DOE)
- Spawn of EnergyPlus (DOE)
- CyDER- Co-simulation Platform for Distributed Energy Resources (DOE)
- MPCPy (CERC)
- BOPTEST

What is the Functional Mock-up Interface (FMI)

The FMI Standard has been developed to encapsulate and link models and simulators



$$\frac{dx}{dt} = u - x$$
$$y = -x$$



An FMU is a .zip file with the extension .fmu

FMI standardizes

a) a set of C-functions to be implemented by a model/simulator

b) an XML-model description file to be provided by a model/simulator

c) the distribution file format to be used by a model/simulator

A model/simulator which implements FMI is called a Functional Mock-up Unit (FMU)

The FMI Standard has been developed to encapsulate and link models and simulators

XML-File

- Variable names
- Value references
- Causality/variability
- ...

C-functions

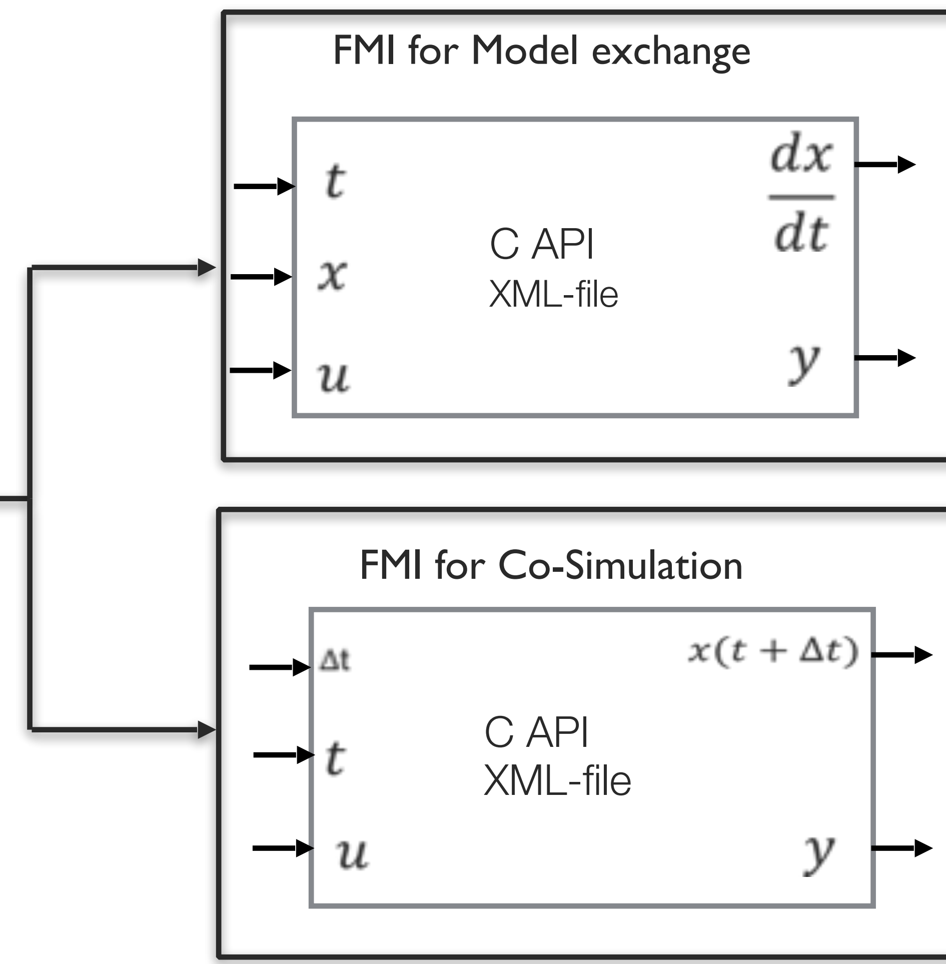
- fmi2Instantiate()
- fmi2SetReal()
- fmi2GetReal()
- fmi2GetDerivatives()
- fmi2DoStep()
- fmi2Terminate()
- ...

FMI for Model Exchange vs. FMI for Co-Simulation

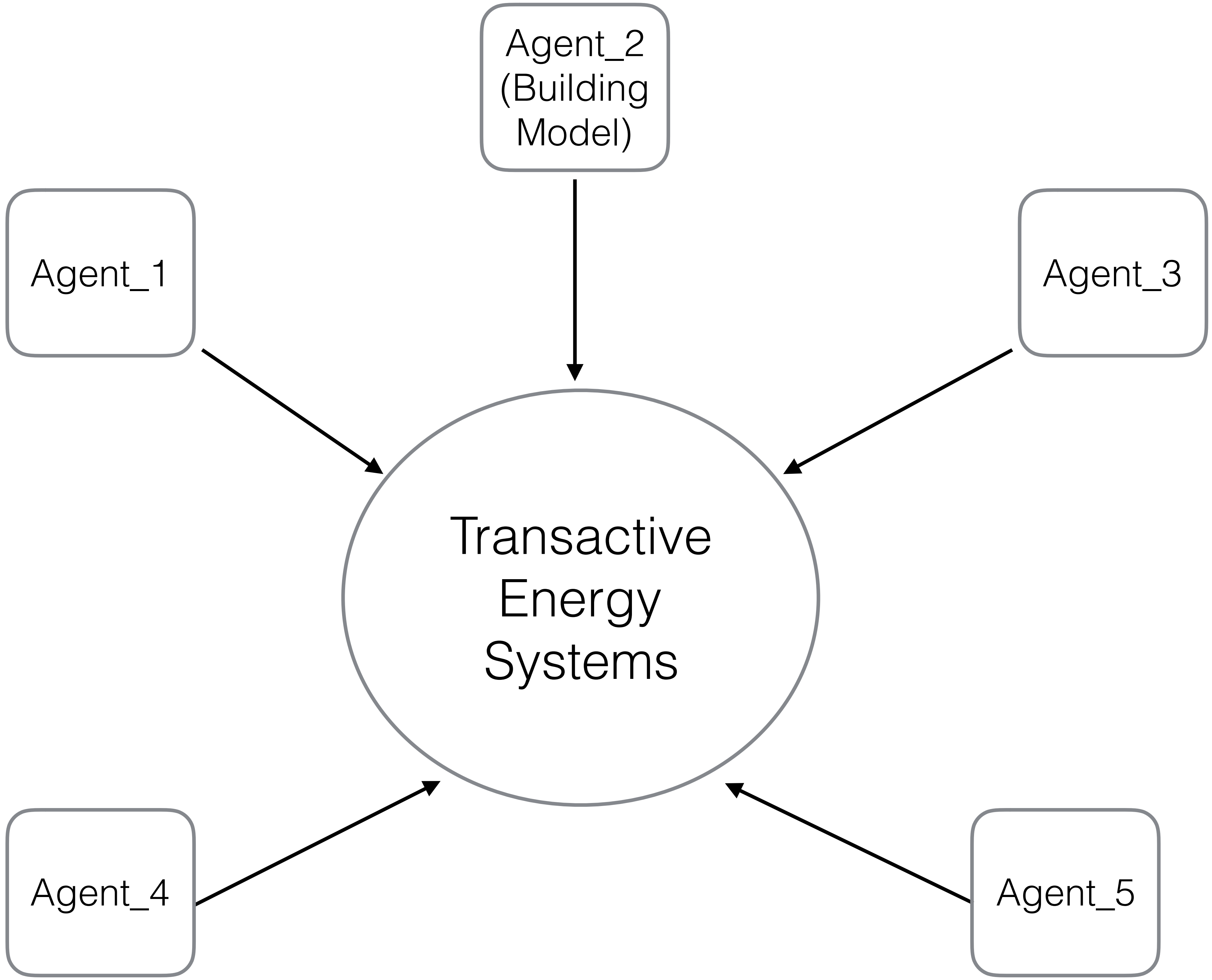
FMI defines two APIs which can be implemented by a model.
What is the difference between those two APIs?

u: Input, *x*: State, *y*: Output

$$\frac{dx}{dt} = u - x$$
$$x(0) = 1.0$$
$$y = -x$$



Workflow for Creating Reduced-Order Model (ROM) with HVAC system



<u>Requirements</u>

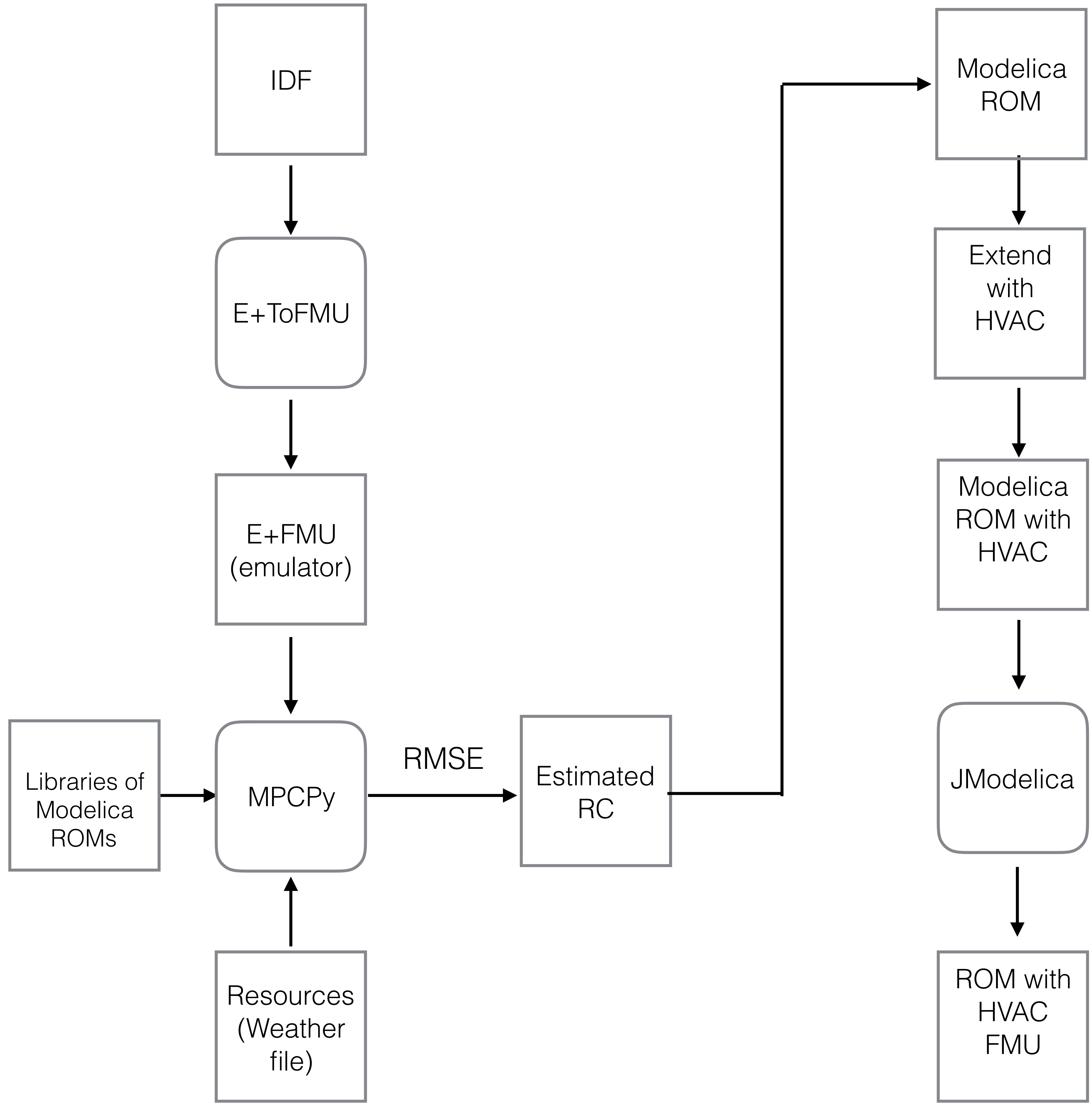
Good runtime performance
Detailed enough for analysis

<u>Approach</u>

Reduced-Order Model
Detailed* HVAC system

Tools:
MPCPy
EnergyPlus (E+)
EnergyPlusToFMU
Modelica Buildings Library
JModelica

Open-Source and
available on GitHub/SVN



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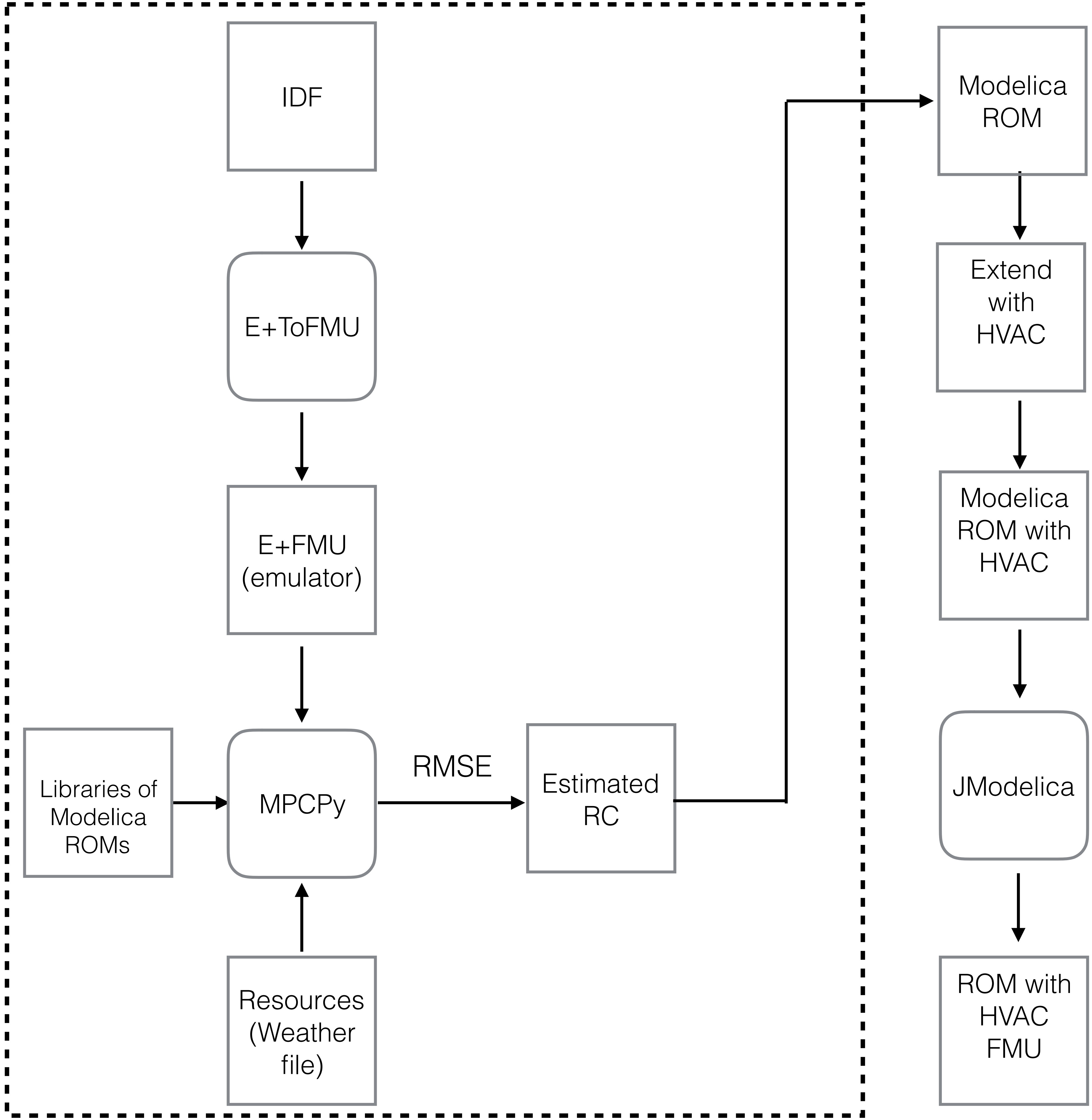
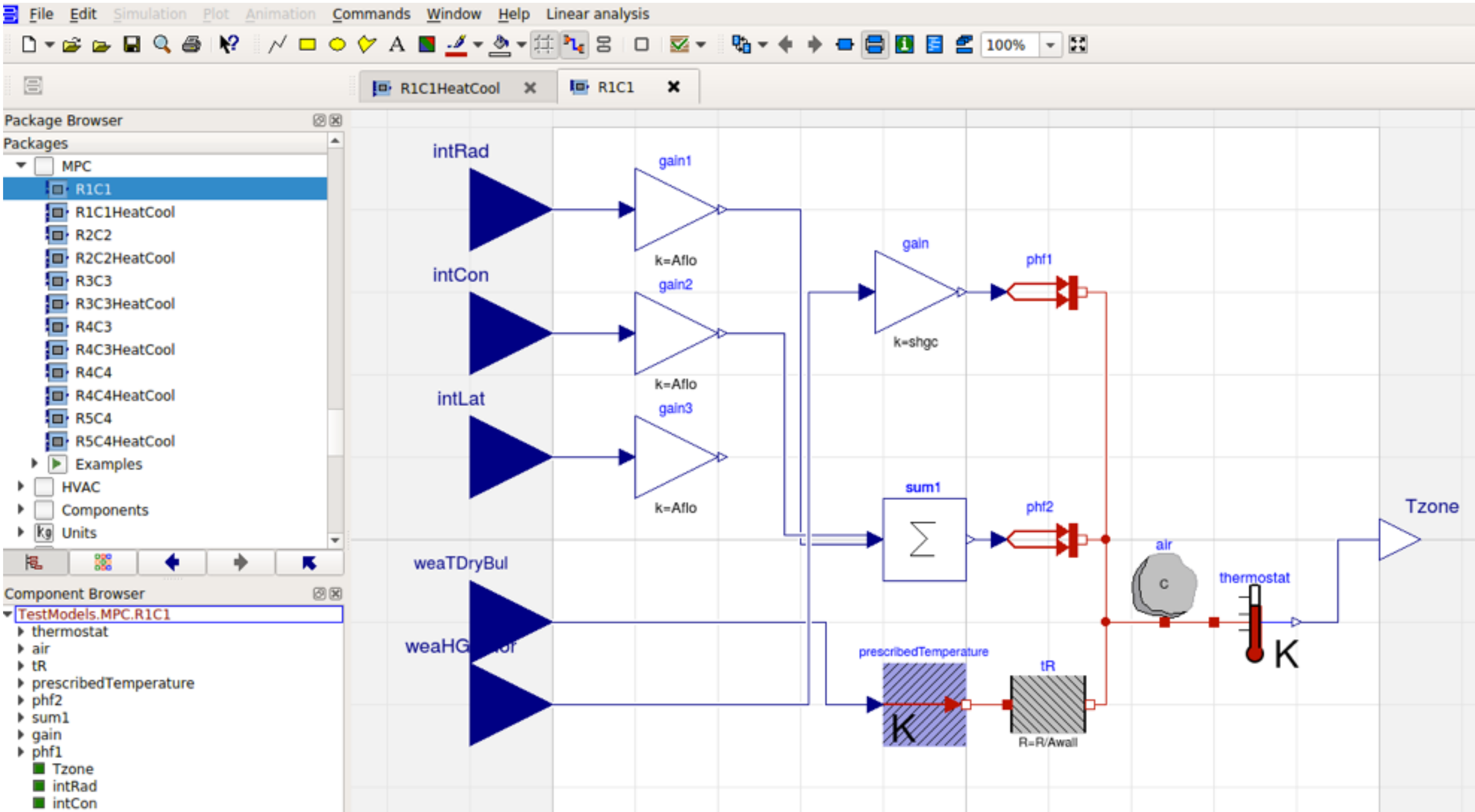
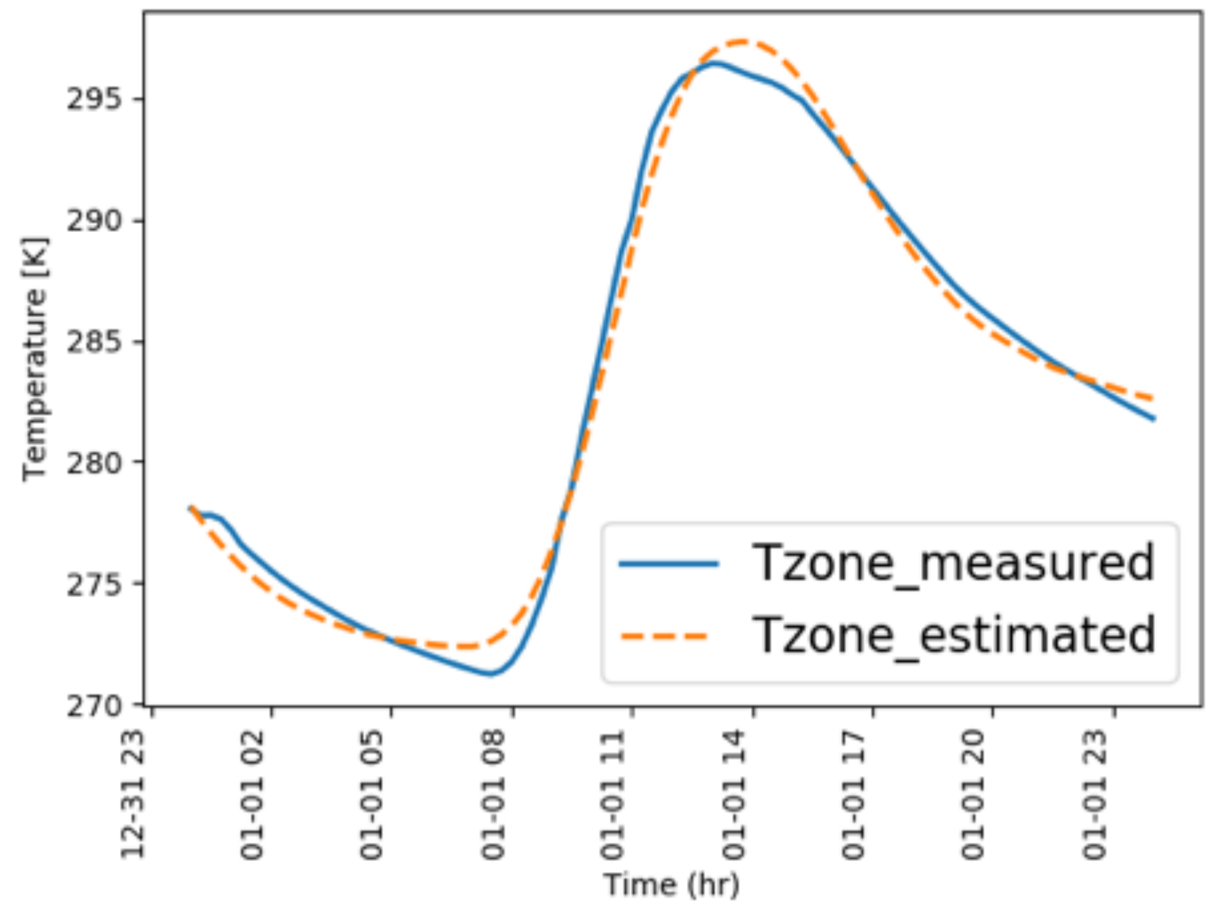


Library with Modelica ROMs

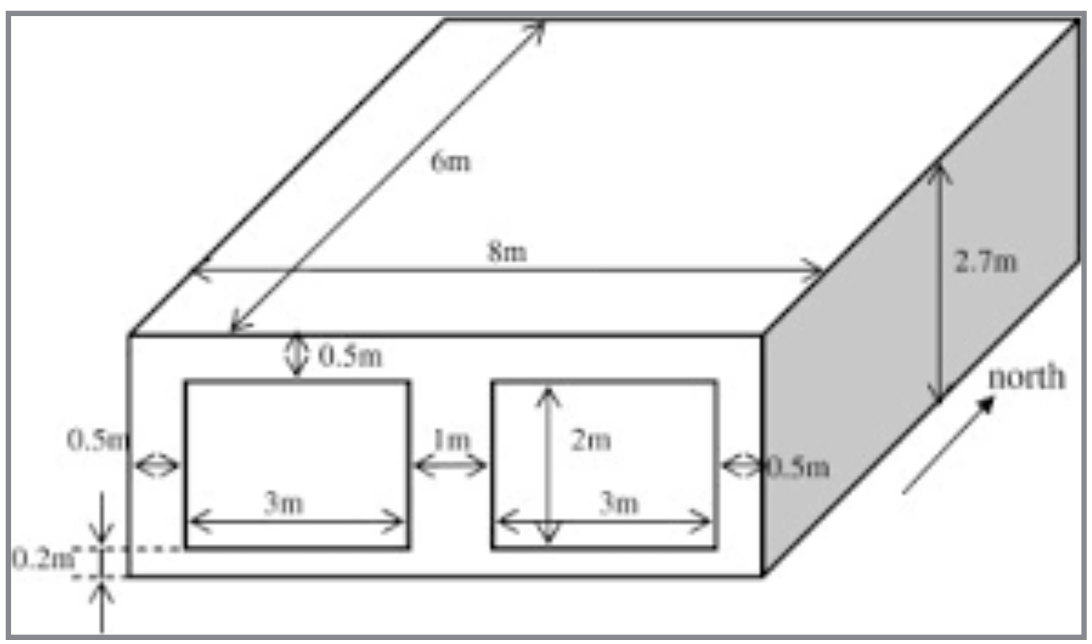


Preliminary Results

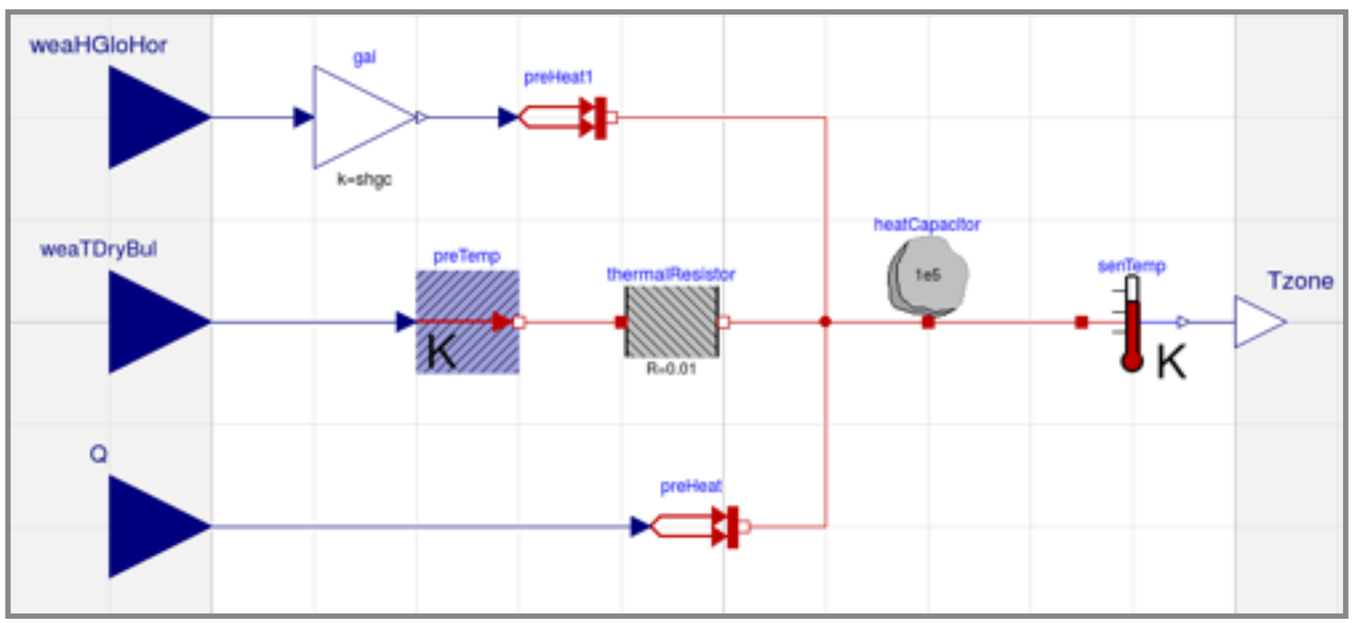
- Emulator: EnergyPlus BESTEST room
- R1C1 reduced order model
- Parameters: R, C, and shgc
- Parameter Estimation Time: 21 seconds for 1 day



EnergyPlus BESTEST Model



Model RC Model



Next Steps

- Develop docker files to automate the process of setting-up JModelica, MPCPy, EnergyPlusToFMU
- Develop scripts for running unit tests to create ROMs
- Set-up large office building in EnergyPlus so it can be exported as an FMU
- Improve scripts to generate best Modelica ROM
- Develop Modelica HVAC system which considers reactive power
- Generate Modelica model which includes ROM and the HVAC
- Export the ROM and the HVAC system as a Functional Mock-up Unit

Thank You

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	Input & Output Parameters Inputs marked in orange vary during simulation.			Defaults Needed from Building Model
Inputs	**Scalable Geometry**	Floor Area		
		Location		
		Roof	U-factor	
		Exterior Wall	U-factor	
		Floor	U-factor	
		Basement Insulation	NonRes R-Value	
		Fenestration	U-Value	
			SHGC	
			window-wall-ratio	
		Daylighting control		
		Infiltration		
	Internal Load Configuration	Interior Lights power density		
		Exterior Lights power density		
		Plug load power density (input the ZIPp and ZIPq coefficients?)		
		Plug load schedule		
		Occupancy schedule		
		Occupancy density		
		HVAC system efficiency (an array of efficency coefficient for major HVAC equipment)		
		HVAC operation schedule		
	Building Level	Interior Lights schedule		x
		Exterior Lights schedule		x
		Voltage from grid		
	HVAC Zone Level	Zone Thermostat setpoint		x
		VAV box minimum ventilation rate		x
	HVAC System Level	OA intake flow rate		x
		Economizer on/off		x
		AHU Supply Air Temp Setpoint		x
		Chilled Water Leaving Temperature Setpoint		x
		Cooling tower leaving water temperature setpoint		x
	Weather	Outside temperature		
		Outside pressure		
		Outside humidity		
		Outside wind speed		
		Solar irradiation (both direct and diffuse)		
	For Co-simulation (these can influence control inputs from the transactive agents)	Zone temperature		
		Number of occupant in each zone		
		AHU real and reactive power consumption		
		Fan real and reactive power consumption		
		Chiller real and reactive power consumption		
		Pump real and reactive power consumption		
		Total building real and reactive power consumption		
		OA intake flow rate		

Experimental Determination of the ZIP Coefficients for Modern Residential, Commercial, and Industrial Loads

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***Abstract*—This paper presents the experimental determination of the ZIP coefficients model to represent (static) modern loads under varying voltage conditions. ZIP are the coefficients of a load model comprised of constant impedance Z, constant current I, and constant power P loads. A ZIP coefficient load model is used to represent power consumed by a load as a function of voltage. A series of surveys was performed on typical residential, commercial, and industrial customers in New York City. Household appliances and industrial equipment found in the different locations were tested in the laboratory by varying the voltage from 1.1-p.u. voltage to 0 and back to 1.1 pu in steps of 3 V to obtain the individual P–V, Q–V, and I–V characteristics. Customer load tables were built using seasonal factors and duty cycles to form weighted contributions for each device in every customer class. The loads found in several residential classes were assembled and tested in the lab. It was found that modern appliances behave quite differently than older appliances even from only 10 years back. Models of the different customer classes were validated against actual recordings of load variations under voltage reduction.**

***Index Terms*—Commercial class, industrial class, load characteristic, load composition, load model, residential class, ZIP coefficients.**

I. Introduction

LOAD composition has changed substantially from a few years back. In the last 10 years, the proliferation of power-electronic supplies used in many household loads (for example: flat screen TVs, fluorescent compact lights (CFLs), laptop and cell-phone chargers) has modified substantially the way loads behave as the voltage varies [1]–[3]. The lighting industry has gone through a significant development in ballast technology, and today electronic ballasts are more popular than magnetic ballasts [1]–[5]. In addition to energy savings, electronic ballasts have constant power consumption under voltage variation, better power regulation, and color consistency. On the other hand, magnetic ballasts behave as constant impedance loads. Similarly, outdoor lighting is driving innovation in high-intensity lighting (HID). Within this segment, there has been a major technology shift from mercury vapor to high-pressure sodium and, finally, to metal halide lights. New types of indoor and outdoor lights are now being introduced to the market as, for example, induction lights and light-emitting diode (LED) lights, which are expected to dominate the lighting industry due to their better energy efficiency [3], [6]–[9].

The objective of this paper is to present a ZIP coefficients model which accurately describes the steady-state behavior of modern loads under varying voltage conditions. An investigation on the effect of varying load is introduced by analyzing individual and composite load structures by means of ZIP coefficients. The work described here is part of a project intended to estimate the impacts of conservation voltage reduction (CVR) for customers and utilities. CVR is a technique commonly used by power utilities to conserve energy by reducing the voltage delivered to the loads. The main idea is that loads (devices, appliances, etc.) consume less power when the applied voltage reduces. Validation of the composite load model and ZIP coefficients against field measurements are presented in [27].

The polynomial expression known as the ZIP coefficients model represents the variation (with voltage) of a load as a composition of the three types of constant loads Z, I, and P.Z, I, and P stand for constant impedance, constant current, and constant power loads, respectively. The expressions for active and reactive powers of the ZIP coefficients model are

$$P = P_0\left[Z_p\left(\frac{Vi}{V_0} + I_p\frac{Vi}{V_0} + P_p\right)\right] \tag{1}$$

$$Q = Q_0\left[Z_q\left(\frac{Vi}{V_0} + I_q\frac{Vi}{V_0} + P_q\right)\right] \tag{2}$$

where P and Q are the active and reactive powers at operating

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