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Advanced Simulations of Building Energy and Control Systems with an Example of Chilled Water Plant Modeling

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SUMMARY

This paper introduces the Modelica Buildings library which has been developed for the advanced simulation of building energy and control systems. Modelica offers benefits compared to conventional approaches for integrating models from different domains, and for simulating systems with largely varying time responses such as building energy systems and control algorithms. This paper demonstrates these features using as an example a chilled water plant with a water-side economizer and a detailed control sequence.

Keywords: Modelica, Energy and Control Systems, Chilled Water Plant

INTRODUCTION

Buildings consume more than 40% of primary energy in the US. In addition to load reduction and equipment performance improvement, advanced control algorithms can provide a cost-effective measure to increase system level efficiency and peak demand reduction. However, conventional building energy simulation tools have been designed for estimation of annual energy consumption. Their controls representations are different from how control sequences work in real systems. In these programs, the controls input and output variables often do not correspond to the variables available in actual control system. The dynamics of control and HVAC equipment is often neglected. Controls are often idealized and may be part of an overall solution algorithm used by the simulation program. The numerical methods are not adequate to efficiently solve stiff differential equations that arise when coupling detailed models of controls and of building heat transfer. Finite state machines that can facilitate the modeling of supervisory control algorithms are generally not supported.

On the other hand, various innovative HVAC systems as well as advanced controls have been proposed to reduce building energy use. To reduce the risk of adopting these new technologies, the industry needs a tool that can quickly quantify the performance and potential savings of the new approaches. Unfortunately, conventional building energy simulation tools cannot meet this requirement for rapid inclusion of new technologies as it takes often too long to add new models.

To support the development of advanced controls for building energy system and to accelerate the innovation in building technologies, we developed the Modelica *Buildings* library for building energy and control systems. The library is open source and freely available at https://simulationresearch.lbl.gov/modelica. This paper briefly introduces the *Buildings* library and demonstrates its features by using an example of a chilled water plant with a water-side economizer (WSE).

MODELICA BUILDINGS LIBRARY

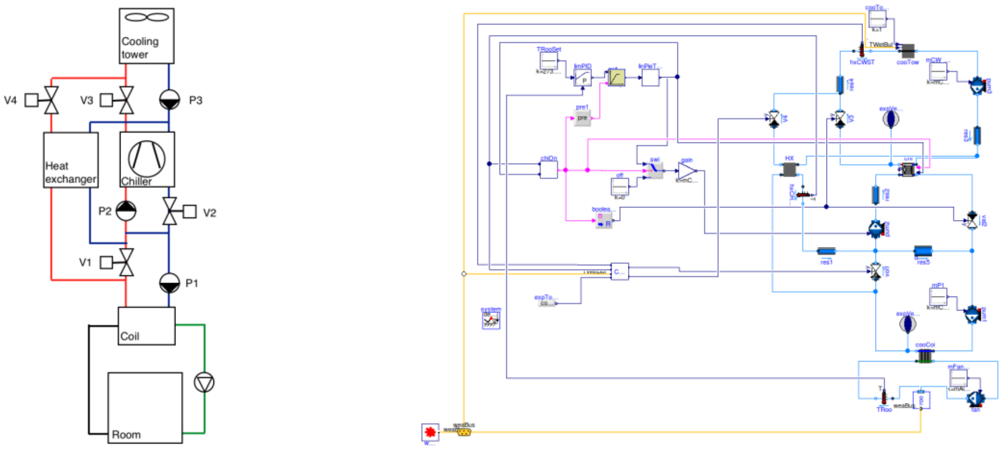
The *Buildings* library is based on Modelica language (https://www.modelica.org/), which is an equation-based, object-oriented modeling language. A major difference between Modelica and procedural languages, such as FORTRAN and C, is the separation of concern between modeling and simulation. Modelica users can describe physical phenomena using acausal models that do not need to specify the input and output causality. Symbolic algebra is used to reduce the dimension of the systems of coupled equations, and the lower-dimensional systems are then coupled to numerical solvers. Modelica simulation environments typically implement implicit differential equation solvers with variable time step size, which are essential for the efficient simulation of stiff systems.

Various free and commercial Modelica libraries are available at http://www.modelica.org/libraries/, including a *Buildings* library for building energy and control systems developed by LBNL (Wetter 2009, Wetter et al. 2011). The latest released version, 0.10.0, has 129 non-partial models and blocks and 39 functions. It has 6 packages for building systems, including airflow, controls, fluid, heat transfer, media and utilities.

CASE STUDY: DESIGN AND CONTORL OF A CHILLED WATER PLANT

The Modelica *Buildings* library has been used in various applications. This section shows our recent work in control of a chilled water plant with a WSE. Similar as an air-side economizer, a WSE can provide free cooling, but it is located at the water-side of the chiller plant (Figure 1a). It is difficult to evaluate the performance of this system since its performance depends on weather and HVAC temperatures, non-linear equipment part-load performance curves, the interaction of various HVAC components and the control sequence. The simulation of such system is also challenging since the time scale varies from seconds for control systems to hours for loads. Furthermore, the system contains continuous control for setpoint tracking and discrete time control for setpoint reset of chilled water temperature and flow rates. This study demonstrates the capability of Modelica by evaluating the performance of the control sequence proposed by Stein (2009).

Figure 1(a) shows the schematic diagram and Figure 1(b) shows the implementation of the model in Modelica in a schematic graphical editor. Using this model, a user can simulate the system and vary any control parameters, such as the chiller supply water temperature and the chiller setpoint reset range, to increase the usage of the WSE and to reduce the usage of the chiller. Also, new control algorithms can be added using block-diagrams, textual code or finite state machines. For instance, our preliminary results show that for the San Francisco climate, by increasing the room temperature or the maximum supply temperature of the chiller, energy consumption can be significantly reduced.



(a) Schematic Drawing (b) Implementation in Modelica

Figure 1: HVAC system with chilled water plant and water-side economizer.

CONCLUSIONS

To support the development of sustainable buildings, building simulation should consider lighting, HVAC, envelope heat transfer, indoor environment and their controls. These systems involve different physical domains, length and time scale. How to efficiently integrate these multi-physics, multi-scale systems will be an interesting but challenging topic for building simulation researches.

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