

Control Design for Energy Efficient Buildings

Organizers:

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Every nation's energy savings goals contribute toward greater energy independence and a cleaner environment. In this context, improving the energy efficiency of new and existing buildings will have a significant contribution to this strategic goal of reducing national energy demand. While design of energy efficient building solutions, e.g., net-zero or net-positive energy buildings, will become the new state-of-the-art in commercial and residential architecture, for existing buildings, it is analyzing, selecting and implementing cost-effective retrofit solutions that have the largest impact on energy use.

Traditionally, building HVAC equipment and building management systems have been selected and installed in an-ad hoc fashion based on domain expertise. In a similar manner, control for building and HVAC systems has been implemented with the sole objective of satisfying the occupancy comfort. As a consequence, the present day building thermal comfort is satisfied at significantly lower efficiency compared to the new building designs that incorporate the most recent art in energy efficient technologies.

In order to achieve lower energy goals, in recent years, analysis, optimization and control methods developed in the systems theory and control engineering field have become pervasive and lead to a paradigm shift in the domain of HVAC system design and control. The results of these efforts have revealed that the potential for energy savings can be unleashed by systematic investigation of building systems supported by modeling, analysis and control architecture design.

This workshop aims to bring together researchers in the area of building systems and HVAC control to present the results of their work to the control community. The goal of the workshop is to present a clear and concise picture of the technological landscape of present enabling technologies for control architecture retrofit and design of energy efficient buildings.

Workshop Program

1. Ruchi Chaudary (rc488@cam.ac.uk): Energy Efficient Cities initiative

Abstract:

Energy efficiency of a city entails, to a large extent, improving its heterogeneous landscape of existing buildings, the characteristics and operation of which are generally highly uncertain or not known. Yet, within a pool of limited resources and budgets, it is necessary to forecast what kind of retrofits are likely to yield maximum benefits and where they should be implemented. We present hierarchical city-wide energy models of the built environment that quantify current and future energy demand of buildings in their urban context as a function of projected growth of buildings and populations, large-scale building refurbishments, and policy incentives. The urban context is important from an impact perspective, but at the same time, poses one of the most complex modelling problems due to the heterogeneity of existing buildings, missing data, computational expense, and extraneous influences. Using Bayesian inference, we demonstrate that data and simulation science must be leveraged together in order to enable real advances towards computationally realistic energy analyses of cities with full quantification of uncertainties.

2. Dimitrios V. Rovas (rovas@dpem.tuc.gr): Model-assisted control design methodologies for the operation of net-zero energy buildings

Abstract:

The building sector contributes significantly to total energy consumption. A significant part of the energy consumed in building is used to operate climate control devices to foster comfortable conditions in building interiors. Effective control strategies, which account for weather changes, inhabitant's actions and changes of the building dynamics hold the promise of reducing the buildings' total energy consumption. Good energy performance, combined with the availability of energy through renewable energy resources, pave the way towards positive- (or net-zero-) energy buildings, where the net-energy produced (NEP) meets or exceeds the total energy demand. A model-assisted control design methodology is presented that, given a thermal simulation model capable of capturing all pertinent building dynamics, and upon a selection of a relevant cost function used to evaluate performance, generates strategies for the effective operation of all pertinent building subsystems. To evaluate the potential of the proposed methodology to generate "good" strategies, corroborating simulation and experimental results in real buildings are presented.

3. Draguna Vrabić (dvrabić@utrc.utc.com): Model based control for energy efficient building retrofits: Implementation results and challenges

Abstract:

Model reduction. Building heating and cooling systems consume more than 30% of building energy, and provide great potential for savings by employing passive devices that exploit buoyancy and thermal stratification of indoor airflow. Most building energy models assume indoor air to be well-mixed and use a lumped nodal approximation, which fails in presence of

such passive systems. We present techniques to develop control-oriented models of indoor air, starting with detailed computational fluid dynamic (CFD) simulations.

Model predictive control. In addition to savings from passive devices, model predictive control (MPC) of building HVAC systems, which incorporates future knowledge of how buildings are used and operated, provides further potential for energy savings. We develop MPC algorithms using different modeling approaches, and show results of implementing them in real buildings. We present a case-study of a building in the USA, with a baseline HVAC system with heuristic controls, and demonstrate savings of over 15% using MPC.

4. Alberto Leva (leva@elet.polimi.it): Object-oriented modeling and simulation as a possible common framework for whole-building system studies

Abstract:

Optimizing the energy performance of buildings requires to address multi-physics modeling issues, together with large-size, multi-objective control problems. In this scenario, resorting to simulation tools as a decision aid is often a necessity. However, for such an aid to be effective, simulation needs to be available right from the beginning of a project, which calls for modularity, and above all scalable level of detail.

Object-oriented modeling and simulation (OOMS) has been emerging over the last years as a possible framework to build the required decision aids upon. The talk will give a minimal introduction to OOMS, illustrate a way of applying it to building optimization in a view to attaining the goals above, present some available research results, and sketch out possible future directions.

Biosketches of guest presenters

Dimitrios Rovas received his undergraduate degree in Mechanical Engineering from the National Technical University of Athens in 1998, and his Ph.D. in Mechanical Engineering from the Massachusetts Institute of Technology in 2003. From 2003 to 2006 he was an Assistant Professor in the Department of Mechanical and Industrial Engineering at the University of Illinois at Urbana-Champaign, USA. Since 2007 he is an Assistant Professor in the Department of Production Engineering and Management at the Technical University of Crete. In 2002 he was a research scholar in the Laboratory for Numerical Analysis of the University of Paris VI, France (UPMC), and in 2012 a visiting professor at the Fraunhofer Institute for Building Physics in Germany. His research interests are in the area of simulation and optimization of energy systems.

Ruchi Choudhary is currently Assistant Professor in the Department of Engineering, University of Cambridge. She specializes in building simulation and environmental characteristics of the built environment. Her research is embedded within a wider multi-disciplinary project called the 'Energy Efficient Cities Initiative', in which she leads the stream on built environment. Her recent research focuses on developing tools and methods for analyzing energy systems at the urban scale. These have resulted in two parallel investigations: one on how to instrument

relevant and large-scale policy questions through simulation models, and second, how to quantify uncertainties in model outcomes.

Alberto Leva was born in 1964 in Milano, Italy. In 1989 he received the MSc (Laurea) Degree in Electrical Engineering from the Politecnico di Milano, Italy. In 1991 he joined the Department of Electronics and Information of the Politecnico di Milano, where at present he is Associate Professor of Automatic Control. His main research interests are process modeling, simulation and control, object-oriented modeling and simulation, with particular reference to system-level methods and tools for energy efficiency, automatic tuning of industrial regulators, control and control-based design of computing systems, and innovative tools for education in Automatic Control.

Biosketches of organizers

Sunil Ahuja is a Senior Research Scientist at United Technologies Research Center, East Hartford, CT, USA. He received his Ph.D. in Mechanical Engineering from Princeton University in 2009, where he was awarded the Ray Grimm Memorial Prize in Computational Physics in recognition of his contributions to computational physics. Dr. Ahuja has industrial experience in modeling, control, and diagnostics of high-performance buildings, and his areas of expertise include high-performance computing, model reduction, dynamical systems, control, numerical analysis, and geometric mechanics. He is a member of SIAM, IEEE, AIAA and APS.

Veronica Adetola is a research scientist at United Technologies Research Center in East Hartford, Connecticut. She obtained her B.Sc. degree in Chemical Engineering from Obafemi Awolowo University, Nigeria, in 1999. She then worked as a process engineer for two years. She received the M.Sc. and Ph.D. degree in Chemical Engineering from Queen's University, Canada. In 2011 she received Best Methodology/Theory Paper published in the IFAC Journal of Process Control over the past three years from the International Federation of Automatic Control (IFAC). Her current research interests include nonlinear adaptive control, real-time optimization and model predictive control.

Draguna Vrabie is a research scientist at United Technologies Research Center in East Hartford, Connecticut. She graduated from University of Texas at Arlington with a Ph.D. in Electrical Engineering. She received her B.Sc. and M.Sc. in Automatic Control and Computer Engineering from “Gh. Asachi” Technical University Iasi, Romania. Prior to joining UTRC she was a research associate at the Automation & Robotics Research Institute in Fort Worth, Texas. She received the Best Paper Award at the International Joint Conference on Neural Networks (IJCNN'10). Dr. Vrabie serves as associate editor for IEEE Trans. Neural Networks, and U.K. Trans. Inst. Measurement & Control.