MIT Portugal

PROGRESS REPORT

Project Title: *Continuing Continuous Commissioning for Energy Efficient Buildings*

Principal Investigator: ***Steven B. Leeb**, Professor, EECS/RLE at MIT*

Co-investigators: ***Ricardo Gomes**, IST RC, Instituto Superior Tecnico, Lisboa*
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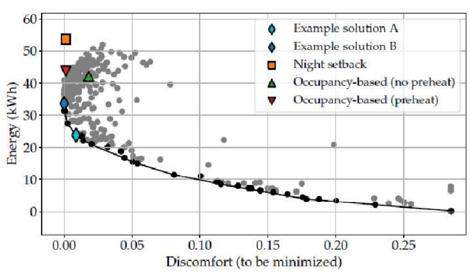
***Luis Miguel Silveira**, Professor, Instituto Superior Tecnico*
***Goncalo Arujo**, Post-Doctoral Assoc.,Instituto Superior Tecnico*
***Daisy H. Green**, Assistant Professor, University of Hawai'i*

Proposal Research Area: *Sustainable Cities*

Grant renewal application: *Yes*

Layperson's Description:

A significant portion of building energy consumption is wasted due to improper operation and control. A key component for tackling climate change is ensuring that buildings are energy efficient and sustainable. In our previous seed project, we have succeeded in demonstrating remarkable control improvements and the ability to detect energy faults in building machine plant (HVAC) systems. Our approach uses a Pareto analysis to determine optimum equipment operating configurations and also to detect deviations from optimum caused by building electromechanical systems with faults. In essence, this project is developing a new approach for "continuous commissioning" of building facilities to ensure that buildings operate at peak efficiency with a minimum expense in sensors and computation. Our Pareto approach has been demonstrated in operating buildings on both the MIT and Instituto Superior Tecnico campuses. We have assembled an interdisciplinary team to continue this work and to extend control opportunities both with further development of Pareto-based control and also with the development of "smart" loads that exploit intelligent and controllable power electronic interfaces to the building grid.



The Pareto surface shown above is a result of our collaborative research. The curve reveals optimum solutions for operating a building on the MIT campus. The "diamonds" indicate "best solutions" for minimizing energy consumption while maximizing occupant comfort. A facilities manager can use the curve to optimally trade energy and occupant comfort.

Abstract

A key component for tackling climate change is ensuring that buildings are energy efficient and practical to operate; that is, sustainable. Our previous seed project has developed a remarkable technique for evaluating the trade-off between energy consumption and occupant comfort using Pareto optimization. This technique has been demonstrated by the two teams in MIT and Portugal for both ensuring optimal building operation on a daily basis and also for building retrofits, ensuring the optimal use of every dollar spent on maintaining and operating a building. In essence, Pareto optimization provides “continuous commissioning” for a building. We have demonstrated these techniques in a series of publications, and have begun using them to operate campus buildings in collaboration with facilities management. A vista of opportunities for exploiting and expanding these control techniques has opened before us, and we make this new proposal to expand our collaboration and advance the application of our monitoring and control technologies for economizing the operation of comfortable, beautifully operating buildings.

Status Report

THANK YOU! We have made exciting progress in all of our research areas, and have opened the door to several new directions during the performance period. Our most recent round of zoom meetings between the MIT and Portugal teams occurred during the first week of September, 2025. We are demonstrating a new approach that allows continuous optimization and minimization of building energy consumption and proper operation while maintaining occupant comfort. We have established a framework for multi-objective Pareto optimization of building retrofits and also daily operation. For any particular target building, a building information database is compiled regarding existing or planned building envelope thermal and operating models, and also possible building envelope retrofits. From the building information database, a surrogate model is developed. The results of a surrogate model are used to predict daily and annual energy consumption as well as costs for various building envelope retrofits. To evaluate the effect of building retrofits on day-to-day operation, heating and cooling have been used as an illustrative example in our initial work. Results of Pareto analyses can be used not only for retrofit optimization but also to develop a multi-zone thermal circuit model to compare day-ahead energy consumption and thermal comfort. That is, the effect of retrofits on both long-term (i.e., annual) and short-term (i.e., daily) performance objectives have been demonstrated in two IEEE publications (one accepted, one in preparation). Two new frontiers for building sustainability have opened based on this work, and we are pursuing these opportunities with an expanded collaboration between MIT and Instituto Superior Technico in Lisboa. Specifically:

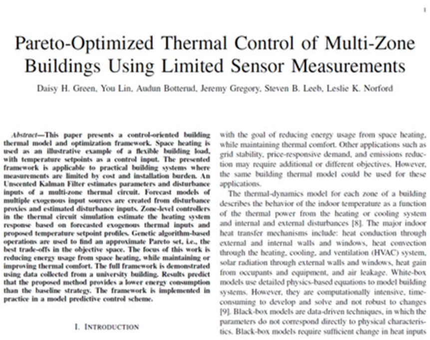
1. **Nonintrusive electrical load monitoring** is being developed and deployed for database development, model verification, and to further develop the Pareto approach for fault detection and the identification of operating inefficiency by comparing observed behavior to deviations from the Pareto optimum. We intend to determine the impact of equipment pathologies on the cost of operating a building. We will provide the facilities manager with a window into understanding the cost of diagnostic and pathological conditions in building equipment and when best to schedule maintenance. A paper on machine learning enhancements and data collection guard-rails for nonintrusive monitoring has been submitted and is under review at the IEEE Transactions.
2. We are actively demonstrating **Pareto optimization and adaptive control for HVAC loads** that mitigate acute demands on the utility and bring the building in as a partner in both running efficiently while also supporting reliable utility operation. Distributed generation (including solar installation)

creates new dynamics in a building electrical distribution grid that complicate the challenge of operating a building efficiently while maintaining occupant comfort. Currently, building machine (HVAC) plants typically run with a "greedy" strategy of consuming energy when needed without regard to the state of the electric utility – an unsustainable approach as the utility runs with less "excess" power capacity above demand. Our control strategies will provide new design approaches for HVAC components that allow loads to work "hand-in-glove" with the state of the local electrical supply. Two new papers have been written on this Pareto approach, one published in IEEE Smart Grid, and the other in review at IEEE Access Transactions.

3. We have developed fast **behavioral simulations** for grid and microgrid power systems that permit fast "what-if" studies for Pareto optimization of proposed building and power system designs that are notional, i.e., in the design stage but not yet built. Several publications have been made during the performance period demonstrating our approach, including two papers (one published, one submitted) on behavioral simulation for microgrids on ships as a representative example.

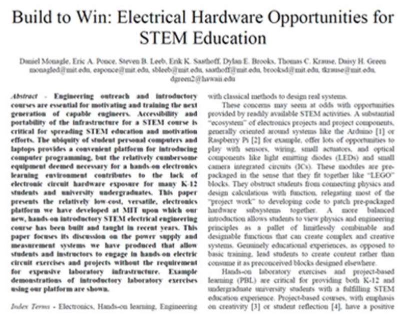
A visual summary of some of our work product during the performance period is shown in the montage on the following page. All of these activities and deliverables are the joint results of the project team. We have engaged closely with Lisbon graduate students Joao Rodrigues and Sergio Andre, as well as close collaboration amongst the faculty including Professors Leeb (MIT), Gomes (IST), Pinto (IST) and Silveira (IST). We have a long history of working well together (going back 30 years in the case of Professors Leeb and Silveira). We are leveraging our outstanding working relationship and common research interests in buildings, energy, and power electronics to create more deliverables and interactions.

In particular, we are currently in the planning stages for Professor Leeb to visit Lisbon in January 2026 and potentially offer a workshop to Instituto students on Variable Speed Drives and their application in advance building control. A photograph of our workshop prototype that we are developing as a "kit" for use with the students is shown in the montage on the next page, following from our previous workshop (also shown) that was offered in 2024.

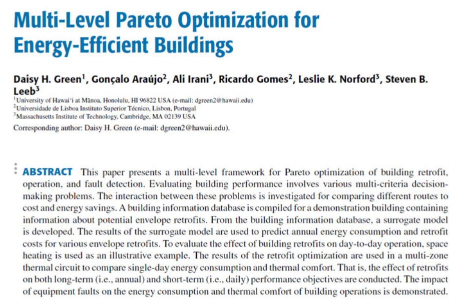

Pareto-Optimized Thermal Control of Multi-Zone Buildings Using Limited Sensor Measurements

Daisy H. Green, You Lin, Audun Botterud, Jeremy Gregory, Steven B. Leeb, Leslie K. Norford

Published in IEEE Transactions on Smart Grid 2024


Build to Win: Electrical Hardware Opportunities for STEM Education

Published: IEEE Integrated STEM Education Conference (ISEC), Princeton, NJ, USA, 2024.

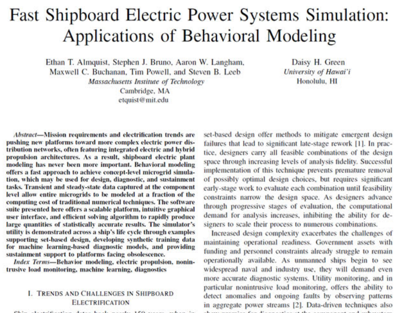

Multi-Level Pareto Optimization for Energy-Efficient Buildings

Daisy H. Green[1], Gonçalo Araújo[2], Ali Irani[3], Ricardo Gomes[2], Leslie K. Norford[3], Steven B. Leeb[3]

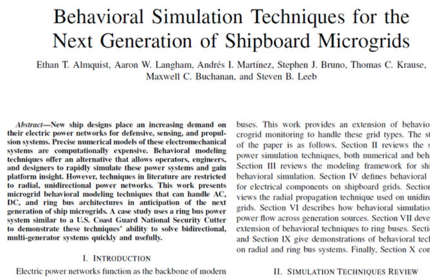
Submitted for review: IEEE Access Journal, September 2025.


The Price of Undersampling Nonintrusive Electrical Data

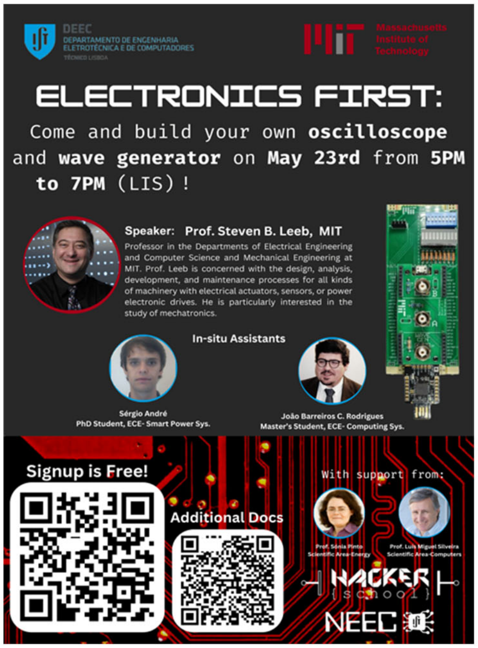
Submitted for review: IEEE Transactions, June 2025.


Fast Shipboard Electric Power Systems Simulation: Applications of Behavioral Modeling

Published in ASNE Intelligent Ships Symposium, August 2025.


Behavioral Simulation Techniques for the Next Generation of Shipboard Microgrids

Submitted for review: Naval Engineer's Journal, June 2025.



JOINT Conference on Sensing and Measurement Technologies organized by this project team and offered by ZOOM on May 23, 2024! Students in Lisbon each built a high performance measuring system using a "Programmable System on Chip".

We are IN PLANNING for a NEW Workshop to be delivered by Professor Leeb in Lisbon at the Instituto. This workshop will discuss the role of variable speed drives in modern building and HVAC control, and involve the participants in constructing a VSD prototype as shown below: