Title: Towards a Sustainable, Intelligent, and Energy-Autonomous Nanogrid Buildings: A Holistic Systemic Multi-Objective Optimization Approach

Scientific fields: Electrical engineering, Control Engineering, and Computer science

Keywords: Energy efficient buildings, Multi-objective controllers, Nanogrids, Optimization, Renewable energies

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Research Work

Thesis abstract

Buildings energy autonomy has become a major issue, motivating numerous research and development efforts, mainly in energy management, particularly through ICT in smart buildings. To achieve sustainable, intelligent, and energy-autonomous nanogrid buildings, it is essential to implement multi-objective controllers. These controllers must consider various factors, including renewable energy sources (i.e., PV, geothermal, fuel cell) and peak shaving (i.e., storage), to optimize energy consumption and comfort via a holistic and systematic approach.

Thesis scientific context

France's carbon neutrality objective for 2050 aims to align the country with the 1.5°C target. This goal is defined as achieving a balance between the greenhouse gases (GHG) emitted each year and the quantity of GHGs absorbed by "carbon sinks" within the national territory. Buildings are key components of society as they host human activity, but they are also a major contributor to its environmental footprint [1]. Brittany is a region that suffers from energy insecurity and is highly dependent on energy imports: it produces only about 12% of its consumption. Faced with this critical issue, the Region and other partners (State, ADEME, RTE, and ANAH) signed the Breton Electricity Pact 9 years ago, which aims to secure the electricity supply in Brittany. Moreover, Brittany has real opportunities [2]: significant potential in terms of energy savings and the development of renewable energies, particularly marine ones, which in short term could cover more than 20% of the region energy consumption and 34% of electricity consumption alone. Brittany wishes to position itself as one of the major French regions in the building and smart grid market (i.e. Smile project).

The current state of building management highlights the necessity for a transformation towards intelligent buildings. An optimal trade-off is necessary between comfort and energy savings by optimizing the multi-objectives of buildings [3]. Traditional Building Energy Management Systems (BEMS) are primarily used as automation and simulation platform tools for simple optimization operations. However, these conventional controllers do not consider all the dynamics of the buildings, particularly occupancy factors [4]. Their performance is also heavily dependent on the accuracy of building models. In literature, there are mainly three types of models that are used: 1) white-box (physics-based) models, 2) black-box (data-based), and 3) grey-box (hybrid) models [5]. Both the black-box and grey-box models have shown promising results with low computational costs and design simplicity [6].

The occupants of the building are active participants in the system, and their interaction with the building, like HVAC (heating, ventilation, air conditioning) control, plug-loads, lighting, etc., significantly influences the overall performance of the buildings [7]. Additionally, integrating renewable energy sources into buildings to reduce their grid dependency positively influences sustainable development. However, this integration complicates optimization challenges for BEMS, making their operation increasingly difficult.

Traditional interaction between occupants and buildings tends to be unidirectional, with manual regulation by the occupants. In contrast, the concept of intelligent buildings has evolved. Unlike automated systems that merely regulate based on monitoring, an intelligent system is based on several agents that are able to communicate with each other, learn, and act adaptively [8].

The emergence of cost-effective IoT systems, coupled with the availability of data and advanced computational power, has created the way for the implementation of data-driven or hybrid approaches. Intelligent control systems can be categorized into several levels of intelligence based on their functionality and services: from basic monitoring, where users control the environment based on their needs, to advanced systems that monitor, propose solutions, and act autonomously, continuously learning from new patterns and interactions [9, 10].

The objective of this research work is therefore to:

- Address the challenges in developing thermal models for controllers by conducting a state-of-the-art comparison of data-driven and hybrid methods, highlighting their advantages and areas for improvement through the application of one of these approaches,
- Develop an occupancy-centric and hybrid energy systems multi-objective intelligent controller for the buildings,
- Integrate the dynamic information of the energy management system into the BIM.

This intelligent system should facilitate two-way communication between the occupants and buildings, for example, buildings indicating their present condition and future actions to the occupants and vice versa, making it an essential tool for the development of sustainable buildings and achieving the France's carbon neutrality objective for 2050 aims. This intelligent controller system should be developed as an open-access tool, facilitating broader adoption and innovation in building management.

This thesis project builds on previously obtained research results, particularly the thesis work [11], where a thermal model was developed using a hybrid method for buildings. This model was validated by integrating it into an MPC controller, achieving significant energy savings of 31% compared to traditional controllers. Subsequent ongoing research funded by UBO and CESI Brest [12] further investigates the integration of occupancy prediction models, developed using a data-driven method to predict both short- and long-term occupancy. Additionally, other research works in progress aims at the dynamic control of HVAC systems [13] and the development of sensor fusion techniques for estimating occupancy and evaluating the influence of information systems (EIS) on energy in intelligent buildings.

The aim of this thesis project is to build on this work and integrate it into a holistic, multi-objective intelligent building controller. The aim is not only to improve optimization strategies for energy consumption and comfort, but also to integrate demand response and energy transactions for greater profitability. A key aspect of our approach is the development of an open-access system, evaluated by a demonstrator [14], taking advantage of the OPAL-RT loop hardware installation (at IRDL) to simulate real-world scenarios.

Expected scientific/technical outcomes

Scientific articles:

- Publication of 1 to 2 journal articles on the development of the model and the application of multi-objective controllers in the context of RES-integrated buildings.
- Writing and presenting an article at an international conference.

Tools:

- The developed models and multi-objective controllers must be made available as an open-source tool.

Organization of the thesis

Funding: Région Bretagne (50%) and CESI Brest (50%)

Place of work: CESI Brest.

Laboratories: CESI LINEACT (https://lineact.cesi.fr/) and IRDL (https://www.irdl.fr/)

Start date: 01/10/2024

Recruitment

Selection process: on the basis of a candidate's application file and interview. Please send your application to kbeddiar@cesi.fr, Mohamed.Benbouzid@univ-brest.fr, and aboodi@cesi.fr with the subject of the email: ***"[Application] Title of the thesis"***

Your application should include:

- A detailed Curriculum Vitae of the candidate. In the event of a break in the university course, please give an explanation,
- A cover letter explaining their motivations for pursuing a doctoral thesis
- The transcripts from master M1 and M2, and
- Any other documents that you deem useful.

Please send all the documents in a zip file titled ***FIRSTNAME_LSTNAME.zip***.

Required skills:

Scientific and technical skills:

- The applicant must be from a Electrical/Control engineering with computer engineering skills.
- Knowledge of building physics, building energy, or HVAC systems is preferred.
- Experience in data mining, analysis, and management is required.
- Experience in optimization techniques is preferred.
- Experience in programming environments (eg. Python).
- Good written and spoken English knowledge

Social skills:

- Be autonomous, have a spirit of initiative and curiosity,
- Know how to work in a team and in autonomy, and have good interpersonal skills,
- To be enthusiastic and self-motivated,
- To be rigourous.

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