Improving Energy Efficiency in Buildings Using Machine Intelligence

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Abstract. Improving the detection of thermal insulation in buildings –which includes the development of models for heating and ventilation processes and fabric gain - could significantly increase building energy efficiency and substantially contribute to reductions in energy consumption and in the carbon footprints of domestic heating systems. Thermal insulation standards are now contractual obligations in new buildings, although poor energy efficiency is often a defining characteristic of buildings built before the introduction of those standards. Lighting, occupancy, set point temperature profiles, air conditioning and ventilation services all increase the complexity of measuring insulation efficiency. The identification of thermal insulation failure can help to reduce energy consumption in heating systems. Conventional methods can be greatly improved through the application of hybridized machine learning techniques to detect thermal insulation failures when a building is in operation. A three-step procedure is proposed in this paper that begins by considering the local building and heating system regulations as well as the specific features of the climate zone. Firstly, the dynamic thermal performance of different variables is specifically modelled, for each building type and climate zone. Secondly, Cooperative Maximum-Likelihood Hebbian Learning is used to extract the relevant features. Finally, neural projections and identification techniques are applied, in order to detect fluctuations in room temperatures and, in consequence, thermal insulation failures. The reliability of the proposed method is validated in three winter zone C cities in Spain. Although a great deal of further research remains to be done in this field, the proposed system is expected to outperform conventional methods described in Spanish building codes that are used to calculate energetic profiles in domestic and residential buildings.

1 Introduction

Machine Intelligence represents a collection or a set of various technologies involving non-linear dynamics, computational intelligence, ideas drawn from physics, physicology and several other computational frameworks. It investigates, simulates, and

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analyzes very complex issues and phenomena in order to solve real-world problems: one such problem is the detection of thermal insulation failure in buildings [1], [2], which requires a multidisciplinary approach [3].

On the one hand, local building regulations need to be analysed in order to profile the premises and the legal specifications for the physical parameters. In the case of a European country such as Spain, building and heating system regulations are adapted to five winter climate zones and five summer climate zones across the entire country. Building materials, insulation widths, materials, and so on, are calculated according to these <winter-zone, summer-zone> parameters. Further market-related factors should also be included: the geometric design and orientation of a building, aesthetic aspects and its internal layout, all of which have a significant impact on thermal dynamics. Taken together, they define what is known as the topology of the building. Nevertheless, predicting the thermal dynamics of a building is a complex task. The dynamic thermal performance of a building has mainly been used to estimate its power requirements. As an example, the difficulties of obtaining a black-box model for a generic building are documented in [4]. The influence of thermal efficiency is also analysed for a specific building component in [5], which examines the dynamic thermal performance of an aluminium roof and compares it with standard roofing materials.

A three-step procedure for testing and validating the model is proposed: firstly, the dynamic thermal behaviour of a specific configuration is calculated using HTB2 software [6]. The outcome of the HTB2 should then be post-processed to obtain a suitable dataset. Subsequently, the dataset is analysed using Cooperative Maximum-Likelihood Hebbian Learning (CMLHL) [7] to extract the dataset structure and key relationships between the variables. A model is then produced, at the modelling stage, to estimate the room temperature at a specific configuration. Finally, thermal insulation failure is identified when the temperature error, measured as the difference between the room temperature and the model output temperature, rises above a pre-set threshold.

This paper is organised as follows. Section 2 introduces the unsupervised connectionist techniques for analysing the datasets in order to extract their relevant internal structures. Section 3 deals with classical identification techniques used in the system modelling. Section 4 describes the problem details and the multi-step procedure. Finally, the conclusions are set out and comments are made on future lines of work.

2 System Analyses Using Unsupervised Learning

2.1 Data Structure Analysis Using Connectionist Techniques

CMLHL [7] is used in this research to analyse the internal structure of datasets that describe the heating process, so as to establish whether it is "sufficiently informative". In the worse case, the experiments have to be performed again in order to gather a sufficiently informative dataset.