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A modular optimisation model for reducing energy consumption in large scale building facilities ☆

Ioan Petri [a,*], Haijiang Li [a], Yacine Rezgui [a], Yang Chunfeng [b], Baris Yuce [a], Bejay Jayan [a]

[a] BRE Institute of Sustainable Engineering, School of Engineering, Cardiff University, United Kingdom
[b] State Key Laboratory of Structural Analysis for Industrial Equipment, Department of Engineering Mechanics, Faculty of Vehicle Engineering and Mechanics, Dalian University of Technology, China

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ABSTRACT

With the pressing regulatory requirement to increase energy efficiency in our built environment, significant researching efforts have been recently directed towards energy optimisation with the overall objective of reducing energy consumption. Energy simulation and optimisation identify a class of applications that demand high performance processing power in order to be realised within a feasible time-frame. The problem becomes increasingly complex when undertaking such energy simulation and optimisation in large scale buildings such as sport facilities where the generation of optimal set points can be timing inefficient.

In this paper we present how a modular based optimisation system can be efficiently used for running energy simulation and optimisation in order to fulfil a number of energy related objectives. The solution can address the variability in building dynamics and provide support for building managers in implementing energy efficient optimisation plans. We present the optimisation system that has been implemented based on energy saving specifications from EU FP7 project – *SportE*^{2} (Energy Efficiency for Sport Facilities) and evaluate the efficiency of the system over a number of relevant use-case scenarios.

Contents

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* Corresponding author.
E-mail addresses: petrii@cardiff.ac.uk (I. Petri), LiH@cardiff.ac.uk (H. Li), RezguiYi@cardiff.ac.uk (Y. Rezgui), chunfeng.yang@gmail.com (Y. Chunfeng), YuceB@Cardiff.ac.uk (B. Yuce), JayanB@cardiff.ac.uk (B. Jayan).

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1. Introduction

Recent research has revealed that buildings are significantly contributing to global warming. Energy usage in buildings has grown in the last 20 years due to the growing demand for buildings, associated services and comfort levels. This increase comes with the people tendency to spend more time in buildings to which is added the continuous increase of the global population leading to higher energy consumption. As these underlying factors are not attenuating, energy efficiency in buildings represents a prime objective for energy policy at regional, national and international levels. Although people and organisation are often aware of the benefits of using energy more efficiently, a variety of social, cultural, and economic factors have precluded the adoption of energy efficient systems. As latest building equipments and control systems are transformed to be energy efficient, there are significant amount of savings that can be achieved [1–3]. With the continuous development, energy consumption in buildings is projected to rise substantially in the fastest-growing countries and especially in Europe. Such an increase of energy efficiency in buildings has three major objectives:

- a market assessment of the challenges, opportunities, and perceptions of energy efficiency in buildings;
- a thorough qualitative and quantitative evaluation of how to transform the building sector based on various market and regulatory mechanisms including codes and regulations, economical aspect, design and technology, skills upgrading and behaviour;
- commitment from the facility managers to do more to improve their energy use in their own buildings.

With the recent technological developments and knowledge as available today, dramatic reductions in building energy consumption can be achieved. In the new European Union regulations, there is a special directive for promoting energy performance in buildings, taking into account cost-effectiveness and local conditions and requirements (energy consumption in buildings is highly influenced by local climates and cultures).

In order to maintain a comfortable living/entertainment built environment, it is essential to meet multi-objective but often conflicting targets, e.g. minimum energy consumption, minimum CO2 emission, or maximum comfort level. Optimisation for building operation stage requires different methodologies/approaches compared to design stage, e.g. some key design variables are no longer available for changing (to find the most optimum solutions for design). It needs to take the as-built building environment to find the optimum solutions either against single or multi-objectives [4–6]. To provide practical real time decision making in building energy management according to the real time monitored data first the 'behaviour' of building energy systems by using various simulation tools must be understood. During the process, the iterative energy audition and involvement with end user/domain experts are needed in order to identify the main use cases and scenarios with associated input parameters and feasible outputs. It is therefore important to identify the required optimisation objectives which can be further confirmed via sensitivity analysis. Further, in the modelling process different relevant components have to be assessed and calibrated iteratively, and the developed building energy simulation model is then executed (as the calculation engine) within a generic optimisation program. For most of the existing simulation tools, e.g. EnergyPlus, TRNSYS, etc., the simulation process (for a comprehensive analysis) is normally very time consuming; and for an optimisation process, it normally needs tens/hundreds repeating simulation runs. An alternative solution is to speed up the 'calculation engine' for optimisation either by simplifying the simulation model or by utilising high power computing techniques. A preferred option is to use artificial intelligence instead such as neural network with heuristic learning algorithms applied on large amount of historical monitored data/simulated (manufactured) data sets.

In this paper we propose a modular optimisation system for deploying building optimisation by having as an objective the reduction of energy consumption in large scale building facilities. We develop the optimisation framework and provide a comparison analysis between: (i) modular optimisation system – where different objectives are achieved by the combination of three different optimisation modules and (ii) prediction based optimisation – where the actual optimisation process is undertaken by a artificial neural network (ANN). By deploying these optimisation modules on a high performance computing infrastructure we explore different scenarios as identified in a pilot sport facility. We demonstrate that our optimisation framework can deal with various input parameters and pre-determined optimisation objective and can greatly contribute to the overall process of enhancing energy efficiency in buildings.

The reminder of this paper is organised as follows: Sections 1–3 outline the development and use of optimisation systems, providing a key motivation for our research (and analysing several related approaches in this area). In Section 4 we present the computing infrastructure and applications supporting the optimisation framework. Section 5 presents the model explaining the methodological details of the optimisation. We validate the approach in Section 6 and present our conclusions in Section 7.

2. Previous studies

Energy optimisation in buildings has been widely investigated over the last few years. There are a number of researching attempts seeking to address energy efficiency in buildings [4–6] alongside with numerous researching projects that have been undertaken trying to identify best practises in the field of energy efficiency.

Cleanex [7] is a research project aiming to develop an innovative projectile based on-line cleaning and injection system that can work under the required operating conditions to mitigate foulant build-up throughout the heat exchanger. The proposed solution provides the industry with significant energy savings of over 10% and reduces the CO2 foot print across a wide range of industrial sectors [8]. NanoBAK [9] project approaches energy efficiency aspects in manufacturing industry. Bakeries are energy intensive, using large amounts of electricity and natural gas to operate the refrigeration system, compressed air system and ovens. Overall aim of the NanoBAK collaborative project is to facilitate efficient energy management in the baking industry and saves up to 50% of energy compared to conventional humidifiers. Thermonano [10] is another researching project aiming to develop nanofilled-polymer-based heat exchangers with the following objectives: (i) effective heat conductivity; (ii) cost reduction compared to metal materials and (iii) design flexibility for an intensive volume exploitation. Within the project, three main applications are devised such as (i) intercoolers increasing the efficiency of large diesel engines, (ii) heat recovery systems from combustion flue gases and (iii) application in the chemical and process industries. Enercom [11] project aims to demonstrate high-efficient polygeneration of electricity, heat, solid fuels and high-value compost/fertilisers from sewage sludge and greenery waste mixed to biomass residues. The project seeks to offer a new, safe, environmentally friendly and cost-effective path for the disposal of sewage sludge, maximising energy output. Setatwork [12] project