Advanced Engineering Informatics 27 (2013) 457–465

Contents lists available at SciVerse ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

Building simulation approaches for the training of automated data analysis tools in building energy management

Pieter de Wilde [a,*], Carlos Martinez-Ortiz [b], Darren Pearson [b], Ian Beynon [b], Martin Beck [a], Nigel Barlow [a]

[a] Plymouth University, Plymouth, United Kingdom
[b] C3Resources, Plymouth, United Kingdom

ARTICLE INFO

Article history:
Received 15 October 2012
Received in revised form 25 March 2013
Accepted 1 May 2013
Available online 27 May 2013

Keywords:
Energy management
Automated meter reading
Machine learning
Building Performance simulation
Benchmarking

ABSTRACT

The field of building energy management, which monitors and analyses the energy use of buildings with the aim to control and reduce energy expenditure, is seeing a rapid evolution. Automated meter reading approaches, harvesting data at hourly or even half-hourly intervals, create a large pool of data which needs analysis. Computer analysis by means of machine learning techniques allows automated processing of this data, invoking expert analysis where anomalies are detected. However, machine learning always requires a historical dataset to train models and develop a benchmark to define what constitutes an anomaly. Computer analysis by means of building performance simulation employs physical principles to predict energy behaviour, and allows the assessment of the behaviour of buildings from a pure modelling background. This paper explores how building simulation approaches can be fused into energy management practice, especially with a view to the production of artificial bespoke benchmarks where historical profiles are not available. A real accommodation block, which is subject to monitoring, is used to gather an estimation of the accuracy of this approach. The findings show that machine learning from simulation models has a high internal accuracy; comparison with actual metering data shows prediction errors in the system (20%) but still achieves a substantial improvement over industry benchmark values.

1. Introduction

The field of energy management aims to provide utilities performance information to facilities managers in order to enable them to monitor and control building performance. Tracking and controlling building performance in turn can lead to optimum building operation and thus reducing the waste of resources from building utilities [1–3]. Traditionally, the field of energy management has utilised monthly billing information or weekly meter readings to monitor energy usage. This data is subsequently used to keep track of historical consumption and detect usage trends. These trends are analysed applying weather correction: average weekly temperatures can be used to build correlation models for temperature and consumption [4].

Conventionally, historical monthly or weekly consumption has been used in conjunction with monthly and weekly weather data to produce an estimate of the expected consumption. Performance verification methodologies such as the International Performance Measurement and Verification Protocol (IPMVP) are based on this concept of producing an estimated consumption figure and comparing it with the actual consumption [5]. In typical energy management practice daily data has not been used extensively due to the intermittent schedules of buildings which typically have 5 day operation. In recent years however, automatic meter reading (AMR) technologies have become more wide spread and are now common place for many industrial facilities. AMR technologies provide building managers with high resolution building data, with hourly reads being commonplace [3]. In the UK, as a consequence of the government carbon reduction programme mandatory requirements, the half-hourly readings are now becoming the new standard [6]. Often useful data is readily available via the building energy management system (BEMS); however, there is typically a need to gain additional information through additional meters and sensors [7] in order to obtain data with sufficient resolution. The higher temporal resolution of hourly or half-hourly data allows energy analysts to move beyond benchmarking and general comparison, adding the identification of operational issues and fault detection diagnosis to their services. The availability of hourly data provides the possibility of constructing detailed building consumption profiles. These profiles can aid close monitoring of the performance of the building; with their help deviations such as excessive overnight consumption and increase in daily loads can be detected. Energy analysts monitor these profiles and can now identify changes in consumption patterns which could not be

* Corresponding author. Address: Drake Circus, Roland Levinsky Building, PL4 8AA Plymouth, United Kingdom. Tel.: +44 1752 586115; fax: +44 1752 586003.
E-mail address: pieter.dewilde@plymouth.ac.uk (P. de Wilde).

1474-0346/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.aei.2013.05.001

identified through monthly or weekly resolution data. For example, Fig. 1 shows two different changes in consumption profile: (1a) shows an increase in overnight consumption and (1b) shows an increase in base load consumption. These two changes in profile are characteristic of different types of faults: increase in overnight consumption may indicate equipment being left on during the night, while an increase in base load consumption may indicate that new equipment which runs throughout the day has been introduced. Monthly or weekly profiles would identify an increase in consumption in both cases, but would not provide any indication of the cause for the increase in consumption. Hourly profiles on the other hand would indicate an increase in consumption as well as some indication as to the nature of such increases, leading one step closer to the resolution of the problem.

As mentioned above, the availability of high frequency data allows energy analysts to identify the profile of consumption for a building. Such profiles provide a crude indication of the expected pattern of consumption of the building. Buildings with similar profiles may be classed together and expected to behave in a similar fashion, which can allow benchmarking provided some form of normalisation is carried out [8]. For example, looking at the energy profile, a specific building may be classified as behaving as a typical office block: high consumption during weekdays at regular time windows (e.g. 9 am–5 pm), with significantly reduced consumption during the night and the weekend hours. By comparing the energy profile of similar buildings, it may be possible to identify periods of abnormal behaviour, e.g. additional or reduced operation hours. Fig. 2 shows some sample profiles identified.

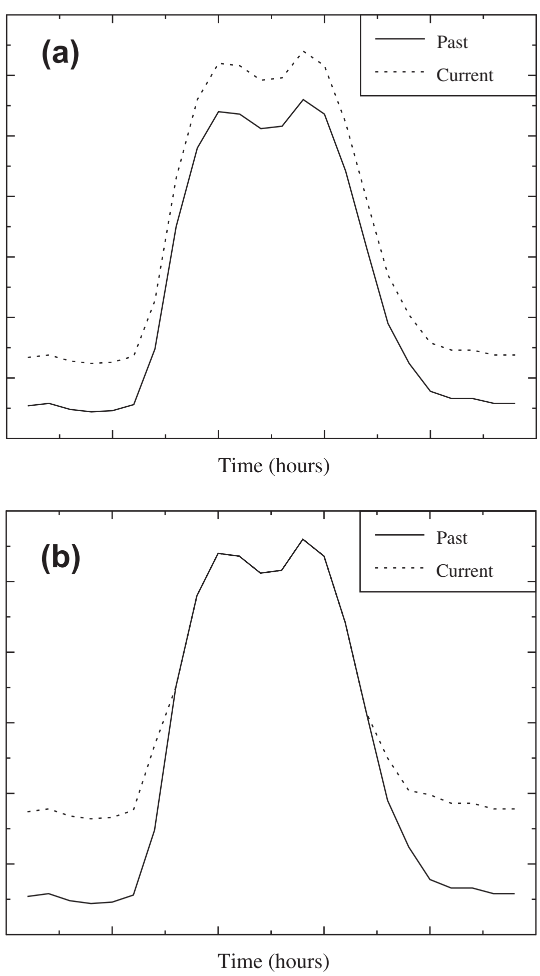

Fig. 1. Two different changes in building performance: increase in overnight consumption, and increase in base load.

The profiles shown in Fig. 2 represent 1 week's worth of electrical consumption, at hourly resolution, for different types of buildings. These profiles have been constructed based on the observed average consumption of real buildings.

Profile (a) is typical of an office building with higher consumption during office hours, and a reduced consumption during silent hours (i.e. at night and the weekend). This consumption during silent hours normally represents base load consumption, and is associated with equipment which runs 24/7 such as computer equipment, and emergency lighting. Notice that the base load during silent hours and peak load during active hours may be different for individual office buildings, however generally speaking most offices will have a similar shape profile. In contrast, profile (b) is typical of a hotel with very similar consumption patterns throughout the week, with no real differentiation between weekdays and weekends. Another point to be noted from profile (b) is the lack of regularity during active hours and the relatively short duration of the silent periods. Notice as well that there is a tendency to have peaks of activity during the early and late hours of each day – this is possibly due to higher activity as guests arrive or prepare to depart. Profile (c) is typical of a university, which displays two different patterns of behaviour during weekdays and weekends. In contrast with the office block profile, weekends are not completely silent: some activity can be observed during working hours on weekends, although it is less intense than during the week. Finally, (d) shows the profile of a building which does not have a clear weekly pattern of behaviour. This profile comes from an industrial printer. Other industrial buildings such as factories and processing plants would display similar behaviour which cannot be easily analysed. In such cases additional information such as working schedules and production numbers may help to understand the energy usage.

Hourly resolution also opens the opportunity for short term analysis; where monthly and weekly datasets require several months (or weeks) of data to be able to establish typical building behaviour patterns, hourly sets provide the possibility of identifying behavioural patterns on a shorter period (e.g. a few weeks). In comparison to weekly or monthly data, hourly sets provide more datapoints to establish reliable correlations. This can be useful when analysing a building for which long-term historical performance data is unavailable, or when the building undergoes modifications which alter its consumption pattern, such as improving insulation, and boiler control optimisation. As such, hourly datasets offer additional prospects to verify the savings derived from building improvement initiatives.

A different approach to building modelling stems from the domain of building physics. Here, models are constructed based on the representation of the fundamental energy flows in buildings (transmission, ventilation, solar gain, internal loads including heating cooling, and energy storage). While various degrees of sophistication are possible, with a simple (stationary or semi-stationary) version still allowing manual calculations, the main approach in the field is now to use computers and to run complex models that use multifaceted weather files, detailed geometry and system specifications, and hundreds of parameters to create a high-fidelity building model. This latter approach is typically known as building performance simulation. Good overviews of this discipline are provided by the seminal textbooks by Clarke [9], Malkawi and Augenbroe [10] and Hensen and Lamberts [11]. Building simulation models are typically used for the larger, more complex building projects, with a typical threshold of single building projects of twenty million pounds and over [12]. This type of model is mainly used for the following purposes: (A) to demonstrate compliance with building regulations; (B) to get buildings certified with