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Computational intelligence modelling based on variables interlinked with behavioral tendencies for energy usage profile – A necessity

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ABSTRACT

Major determinants (climate, occupancy activities, social-economic factors, building energy consumption related characteristics etc.) and their impact on energy consumption patterns for proficient estimation of load profile are highly crucial. However, their impact are not reflected or frequently assumed (fixed conditions) in most energy assessment methodologies. These variables need to be identified and proficiently modelled. Studies have shown that behaviour is interlinked with other variables, however there is the need for better understanding of such in terms of analysis, impact and correlation for better predictive output. To investigate such an approach, review of both qualitative and quantitative methodologies was undertaken. Furthermore, computational intelligence technique for load profile development and estimation with respect to periods of use was applied as a case study. Relative analysis was also undertaken with respect to existing simulation approaches. The proposed method based on the basic concept of adaptation, learning and mathematical computation, inspired by the non-linearity, random and variable nature associated with energy usage due to behavioural changes interlinked with variables gave better prediction accuracy. This exhilarates the need for computational approach technique with behavioural tendencies for energy profile development.

1. Introduction

Adept estimation of load profiles is crucial for demand side management (DSM) and implementation of proposed energy efficient project across board. The impact of major variables on energy consumptions pattern in buildings could assist in the load profile development and evaluation of demand management initiatives highlighted above. However, identification of major energy consumption determinants in buildings with a good understanding of their impacts on energy consumption patterns would assist in energy performance and reduction of greenhouse gases [1]. Some of these determinants are climate (outdoor air temperature, solar radiation, wind velocity etc.), building occupants' behavioural activities, social -economic factors, building type, area and orientation, etc. Other simulation tools are based on actions of residential occupants on assumptions rather than being based on measured observations or resulting prediction models thus providing a poor tool to evaluate and predict demand initiatives outcomes. [2]. As a result the resultant energy efficiency assessments outcome in buildings are not reflective of these variables due to limitation in current simulations. This limitation may have arisen due to the interaction of an individual being difficult to predict; however behavioural trends and patterns for building occupants can be extracted from long-term historical data [3]. Simulation tools need to have prediction models that reliably calculate the energy consumption according to the actual utilization of those buildings [2]. While improvement has been made in the simulation of other factors, occupancy behaviour "has been based on fixed profiles of typical occupant presence and associated implications of their presence". The incongruity that arises between the simulated and real performances of buildings or homes based on such practice is highly as a result of the randomness linked to occupants, that is, the result of differences in behaviour between occupants and "variation in time of each behaviour".

Occupant behaviour (occupancy) is an important aspect of the usage of energy. Much of the discrepancy in energy consumption among buildings of similar constructions can be attributed to occupancy patterns and occupant behaviours [4]. The need of building occupant behaviours when designing energy programs or models and the attention to the difficulty associated with doing such have also been emphasized [5,6]. While occupants are considered as robots, the true nature of human behaviour is complex [7]. Factors such as physical properties, equipment installed to maintain the desired internal environment (heating, ventilation and air-conditioning system), auxiliary production of electricity and hot water, the outdoor environment and the behaviour of the occupants play vital roles in the energy consumption of a building [7]. A study on energy behaviour and modelling behaviour approaches using peer review publications with particular emphasis on

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end-use energy behaviour in residential and service buildings categorized energy behaviour models as follows namely energy models for quantification of energy use, behavioural models made of quantitative and qualitative approaches for the establishment of energy behaviour profiles, and behavioural framework that includes theories and explanatory models of energy behaviours. The potential savings from energy behaviour are said to be 20%, but values differ up to 100% between various studies and investigations [8]. This is as a result of the complexity associated with energy behaviour; fragmented and disciplinary studies from wide thematic areas of engineering, economics, sociology and psychology. These approaches are limited by their own assumptions and often neglect important energy behavioural components; hence the need for the integration of these multi-disciplinary approaches particularly social studies and engineering (combination of qualitative and quantitative approach), thereby advocates the need for additional studies to quantify behavioural savings [8]. However, behaviour is interlinked with other variables and cannot be optimally deduced in isolation. One of this variables is income. Numerous studies have shown that energy consumptions in the residential household are income correlated. A study conducted to explore patterns of UK household energy use and associated carbon emission in relation to socio-economic and demographic characteristics at both national and local level showed that different segments have widely differing patterns [9]. The investigation showed that energy use and carbon emission are related to income but not exclusively [10]. Furthermore, studies have shown that electricity usage caused by different appliances and electric lighting being used by the occupants is strongly influenced by the outdoor global irradiance [11]. Outdoor irradiance levels significantly influence domestic electricity demand, particularly lighting coupled with the design of the building and activities [12].

Occupant's actions are strongly dependent on the occupant's behaviours, responsibilities and other factors [2]. These actions are mostly necessitated by the impact of the environment. The complexity, nonlinearity and characteristics associated with energy usage have created a need for more research interest in modelling techniques that can generate load profile with such characterisation and factors like occupant presence, income (comfort level), outdoor environmental factors (natural light or solar irradiance level), which are basically interlinked with behavioural issue. This study presents a computational intelligence model based on such variables (occupancy, income and climatic condition) interlinked with behavioural tendencies. These three input variables natural lighting (irradiance level), occupancy (active), and income earning were considered in relation to environmental factors, daily activities and social status within the society. The outline of the study consists of literature reviews on various modelling on energy usage in buildings and residential homes, environment and demographics factors in energy usage and lighting profile developments and; behavioural impact investigation using lighting as a case study. Lastly, the result obtained is discussed and model impact evaluated and deduction made in relation to the need for such models.

2. Literature reviews – modelling

2.1. A review of energy load modelling in buildings and residential homes

Existing techniques available for load profile development and prediction include statistical method, analytical method, empirical method and modelling methods. Wong et al. modelled the energy use of existing buildings or initiative using the "inverse or data-driven approach by means of artificial neural network (ANN) for establishing baselines and calculating retrofits savings [13]. The primary aim of the work was the development and evaluation of artificial neural networks for prediction of fully air-conditioned office buildings with day lighting scheme for daily energy use in sub-tropical Hong Kong. Nine variables were used as input parameters; daily average dry-bulb and wet bulb temperature, "daily global solar radiation and daily average clearness index". Others include daylight aperture, solar aperture, overhang and side-fins projections" (factors related to the building envelopes); and lastly day type "(Weekdays, Saturday and Sundays)". Error analyses showed that among the others (cooling, heating and total electricity usage), lighting electricity had the smallest errors with excellent predictive power. From the study, there was no clear distinction or pattern to show whether the ANN model tends to over or under estimate. Another study undertaken used neural network (NN) to model residential energy consumption that includes appliances, lighting, space heating etc. The study input determinants of the predictive model include the effect of cooling degree-days, heating degree-days, house construction and some social economic characteristics of the occupants [14]. According to the authors, the output of the study showed that the model was able to predict the average electricity consumption of appliances such as fans/boilers pumps using natural gas or oil and propane-heated households, central air conditioners and boiler pumps. However, the appliance lighting and space-cooling model failed to give a rational estimate use to a higher degree of saturation e.g. main refrigerator appliance, because of the inability of the NN algorithms to isolate energy consumption when the saturation is high. No mention of good prediction of the individual lighting related load profile was made in the study. A weighted evolving fuzzy neural network for monthly electricity demand forecasting was developed by Chang et al. [15]. The study adopted a weighting factor for each of the seven parameters used in calculating the importance of each factor among different rules in the evolving fuzzy neural network framework (EFuNN framework). This approach gave a better forecasting accuracy than the other approaches (evolving neural network model, multiple regression analysis models, back propagation model and winter's exponential smoothing method).

A method for assigning typical load profiles to a particular consumer group based on their activities was presented by Gerbec [16]. The approach is centred on probabilistic neural network use. The process involves obtaining and pre-processing of end-user data; clusters of consumers using Fuzzy C-Means (FCM) clustering algorithms and validation procedure; and load profiles allocation to applicable group(s). This is expected to assist distribution companies to attribute deviation arising between the forecasted and actual consumption to responsible end users or suppliers who do not have proper time–interval metering devices. Another work using the artificial neural network (ANN) was presented by Hsu and Chen [17]. Due to the liberation and privatization being envisaged in Taiwan Electrical Power industry, bringing about optional choices for end-users (consumers), there is the need for power utilities to consider regional differences in their marketing policy. This is expected also to alleviate issues around aggregate load forecastings such as the inability to locate where "power load" is being utilized or facilities planning, construction and location. As a result of the above mentioned issues and expected impact, regional load forecasting is very important in the Taiwanese utility market as pointed out by the authors. The proposed ANN model according to the study yielded more accurate results for annual regional peak load forecasts in comparison with the regression model using the same variables. Humidity in addition to ambient temperature were included as input variables in the neural network model of the study. This is to account for the air conditioner component impact of the load at three different substations (residential, commercial and industrial) [18]. Use of function link network argon terms (combination of time series and back propagation algorithms) to train the network, due to its higher convergence speed and accuracy, load forecasting errors were reported as 1.93%, 2% and 2.87% respectively for residential, commercial and industrial substations respectively.

A stochastic approach to simulate residential building occupants' activities that can be used for occupant's presence and as input to models of occupant behaviour was undertaken [6]. The model is based on three time dependent quantities: (i) the probability to be at home, (ii) the conditional probability to start an activity whist being at home and (iii) the probability distribution function for the duration of the