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Simulating the dynamics of occupant behaviour for power management in residential buildings

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ABSTRACT

Inhabitant's decisions and actions have a strong impact on the energy consumption and are an important factor in reducing energy consumption and in modeling future energy trends. Energy simulations that take into account inhabitants' behaviour are benchmarked at office buildings using controlled activity profiles and predefined scenarios. In this paper we have proposed a co-simulation environment for energy smart homes that takes into account inhabitants' dynamic and social behaviour. Based on this kind of complex behaviour, the setpoints for different controllers are adjusted in the physical simulator. In this platform, human behaviour is modeled using the Brahms environment and the thermal model and controllers for different appliances are modeled as a physical simulator. The thermal model computes the temperature decrease/increase in a room based on the contextual information resulting from the behaviour simulator. This information is then given to the controller to act upon.

1. Introduction

In Europe, buildings account for 40–45% of total energy consumption, contributing to a significant amount of CO_2 emissions [1]. Inhabitants' behaviour in buildings has a strong impact on the energy consumption and is an important factor for energy waste reduction [2]. Existing behavioural models that are used for prediction are based on controlled activity profiles and predefined scenarios. Furthermore they are specifically aimed at predicting power consumption in office buildings. Results from these models cannot be extended to the residential buildings since human behaviour is more unpredictable and complex in home settings. In this paper, we focus on residential buildings to model and simulate behaviour dynamically through a human behaviour simulator module. This human behaviour simulator generates dynamic behaviours and is connected to a physical simulator where the setpoints for different appliances are stored and adjusted. The setpoint is the target value that an automatic control system aims to attain. Changes in the environment are perceived by the agents in the behaviour simulator, who then take actions dynamically to change the state of the objects and appliances in the building. The purpose of the proposed approach is to assess the sensitivity of human behaviour for energy control and management. This will help in developing smart environments as well as testing the design of new buildings or houses so that they are more suited to human needs.

1.1. Energy simulations state of the art

The majority of works focus on energy simulations in office buildings; in this section a brief overview of those works are presented. Claridge and co-workers [3] compiled a library of schedules and diversity factors based on measured electricity consumption data for energy simulations and peak cooling load calculations in office buildings. They derived multiple sets of diversity factors from measured data in 32 office buildings. [4] used the occupancy and lighting diversity profiles and found a strong correlation between these two variables through linear regression. [5] however modeled the lighting and occupancy in buildings using a Monte Carlo approach based on survey statistics of how people use office spaces. [6] suggested that more attention should be given to occupant behaviour in order to increase the accuracy of building thermal models in office buildings. [7] proposed stochastic 'lightswitch2002' algorithms to predict the manual and automated control of lights and blinds in single and two person offices. These algorithms were used in a lighting simulator called DAYSIM that demonstrated the impact of manual control on predicted lighting energy requirements. [8] proposed a, sub-hourly occupancy-based control model as a self contained simulator module. This integrated the stochastic lightswitch2002 algorithms into a whole building energy simulator ESP-r. [9] developed an event based pattern detection algorithm for sensor-based modeling and

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prediction of user behaviour. They connected behavioural patterns (Markov model) to building energy and comfort management systems through EnergyPlus simulation software for energy calculations.

Simulations based on static profiles or single user behaviour are unrealistic. Typically in building simulators only the thermal heat generated by appliances and occupants is considered. Moreover, the occupants are considered only as being present or absent, as shown in Fig. 1, without taking into account the way they behave to consume energy.

In energy simulations, instead of drawing simple curves for the presence or absence of inhabitants, taking into account the actual behaviour of humans that affect energy consumption could help in testing building design in a more realistic way. A better management that coordinates and orchestrates the use of all kinds of energy according to inhabitants' needs and comfort remains an important progress factor. In this paper we focus specifically on domestic situations and model dynamic behaviour, which we believe is the key for reliable simulation in energy management.

2. The importance of occupants actions regarding energy consumption

In order to understand how inhabitants' behaviour affects energy consumption an experiment has been performed on the IRISE database[1]. In this experiment 2 different categories of houses are selected based on the number of occupants: 2 person houses in category 1, 5 person houses in category 2. Also all houses in both categories have the same appliances.

It can be seen in the results below in Fig. 2, that in the 1st category in house "H2000902", the inhabitants have the highest consumption for the washing machine as compared to other appliances. This maybe due to their behaviour of frequently washing a small volume of clothes compared to washing a large volume less often.

In the 2nd category, it can be seen in Fig. 3 that inhabitants in house "H2000945" have the highest consumption for the TV as compared to the other house possibly because of their behavioural differences with the inhabitants in the other house. The above experiments show that the occupants' behaviours vary frequently and have a strong influence on energy consumption.

3. Context and human behaviour representation

The models discussed in Section 1.1 were designed specifically for office buildings where the occupants follow more or less the same routines and where their behaviour is not as complex and unpredictable as it is in home settings. In addition to behaviour, context is another important factor affecting the energy related activities of occupants. "Context is any information that can be used to characterize the situation of an entity" [10]. [11] analysed user behaviour through contextual factors including user, time, space, environment and object. These authors presented a user behaviour modeling approach called 5W1H for: what, when, where, who, why and how, which they then mapped to a home context (object, time, space, user and environment). Since human behaviour is one of the most important factors affecting energy utilization in buildings, it is explored in more detail. Human behaviour can range from being very simple to very complex. The purpose here is to capture the behaviour that not only represents a simple presence or absence of an inhabitant in an environment but also represents a realistic interaction of the human with the environment. The environment does not only includes the different objects and appliances but also includes the other inhabitants. This means that the dynamic, reactive, deliberative and social behaviour of inhabitants must also be taken into account in order to fully understand it's possible affect on energy consumption. Since behaviour varies from one inhabitant to another, we need a way to generalize and model it for all inhabitants, so that it is representative of actual energy consuming behaviour in the home. Existing theories and behaviour models have been explored in order to fully understand and capture various aspects of human behaviour. This will help to consider the inhabitants as reactive, intelligent agents instead of simply "fixed metabolic heat generators passively experiencing the indoor environment" [6]. The term "behaviour" refers to the actions or reactions of an object, usually in relation to its environment. In the literature, perception, cognition, memory, learning, social and emotional behaviour and psychomotor are considered to be the basic elements of human behaviour [12–14].

Cognition and the organization of knowledge within humans is captured by many behaviour representation models. [15] proposed ACT (atomic components of thoughts) in order to represent human behaviour. ACT mainly focuses on human cognition and shows how humans organize their knowledge in order to behave intelligently. [16,17] proposed CAPS (concurrent activation based production system) which is a production system whose procedural knowledge consists of productions, each specifying the conditions and consequent actions. [18] proposed COGNET (cognition as a network of tasks) that mainly focuses on cognitive behaviour of humans, which is modeled by assuming that humans are capable of performing multiple tasks simultaneously. [19,20] proposed CCT (cognitive complexity theory) as a model of cognition that is based on the concept of GOMS, which models human performance as Goals, Operators, Methods and Selection rules. [21] proposed DCOG (Distributed cognition), which argues that cognition is not confined into an individual rather it is distributed across the environment.

In addition to human cognition many of the behaviour models also focus on the perceptive and motor processes within humans. [22] proposed EPIC (executive process/interactive control) model that focuses on the perceptual, cognitive and motor processes. It also captures another important factor of human performance which is multitasking. [23,24] proposed APEX (architecture for procedure execution), to model human behaviour in a complex and dynamic environment. It makes an abstract sketch of future actions and fills out a plan in the form of procedures as soon as the information is available and manages the tasks accordingly. [13] proposed Cogaff (cognition and affect project) which is a human information processing architecture divided into three levels, reactive, deliberative, and reflective. [14,25], proposed Brahms (Business redesign agent-based holistic modeling system) as a modeling and simulation environment for analyzing human work practices. It is able to represent people, things, places, behaviour of people over time, tools and artifacts used etc. It also focuses on the social behaviour. [12] proposed SOAR (state operator and result), according to which behaviour is captured as a search or movement through the problem space at a particular time and a goal state which represents a solution for the problem.

There are many Human behaviour representation models that take into account the human–system interactions. [26] proposed HOS (human operator simulator) which provide a model of human capabilities and limitations to support the design of human-machine systems. [27] proposed OMAR (operator model architecture), in this model human behaviour is modeled as interactions among agents. These agents can represent different people or different functions within a single person. But there is no central executive or scheduler that controls these parallel activities.

[1] This is part of the European Residential Monitoring to Decrease Energy Use and Carbon Emissions (REMODECE) project. It contains energy consumption data, for each appliance from 98 French houses, recorded at every 10 min, over a one year period