AGENT BASED FRAMEWORK TO SIMULATE INHABITANTS' BEHAVIOUR IN DOMESTIC SETTINGS FOR ENERGY MANAGEMENT

Ayesha Kashif [1,2], Xuan Hoa Binh Le [2]

[1] LIG – Laboratoire d'Informatique de Grenoble: 110, Av de la Chimie, 38400 Saint Martin d'Hères France

Ayesha.Kashif@ g-scop.inpg.fr , Xuan-Hoa.Le@g-scop.inpg.fr

Julie Dugdale[1], Stéphane Ploix[2]

[2] G-SCOP; ENSGI – INPG 46 Avenue Félix Viallet 38000 Grenoble, France

Julie.Dugdale@imag.fr,Stephan.Ploix@inpg.fr

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Abstract: Inhabitants' behaviour is a significant factor that influences energy consumption and has been previously incorporated as static activity profiles within simulation for energy control & management. In this paper an agent-based approach to simulate reactive/deliberative group behaviour has been proposed and implemented. It takes into account perceptual, psychological (cognitive), social behavioural elements and domestic context to generate reactive/deliberative behavioural profiles. The Brahms language is used to implement the proposed approach to learn behavioural patterns for energy control and management strategies.

1. INTRODUCTION

Europe's energy consumption within buildings is 40% of the total energy, however a major portion is needlessly wasted (Heel, 2009). Centralized and distributed approaches in buildings for power management have been proposed to improve energy efficiency, (Ha et al., 2006), (Abras et al., 2006) whereas energy waste related to human behaviour is not yet fully explored for energy efficiency. We argue that understanding inhabitants' behaviour is the key for energy saving.

The literature suggests that behaviour strongly influences energy consumption patterns and is an important factor for energy waste reduction in buildings (Raaij and Verhallen, 1982). (Mahdavi and Proglhof, 2009) conducted a study to find the user control actions taking into account indoor/outdoor environment. (Bourgeois et al., 2006) developed a sub-hourly occupancy-based control model (SHOCC) to track individual instances of occupants and occupant controlled objects to investigate lighting energy use in a single occupancy building. (Dong and Andrews, 2009) developed an event based pattern detection algorithm for sensor-based modelling and prediction of user behaviour. They connected behavioural patterns (Markov model) to building energy and comfort management.

The models discussed above focus on user behaviour in non-domestic spaces such as offices and they concern single users rather than group reactive/deliberative behaviour. Simulations based on static profiles or single user behaviour are limited in extending results to real life. A better management that coordinates and orchestrates the use of all kinds of energy according to inhabitant's needs and comfort remains an important factor.

In this paper we focus specifically on domestic situations and model dynamic group behaviour which we believe is the key for reliable simulation in energy efficiency. We have proposed a conceptual framework to simulate dynamic group behaviour based on an agent based approach. This approach is used to model humans interacting with their environment as agents are a natural and intuitive way to model humans and their characteristics and are a key towards implementing group behaviour. Agents like humans evolve in the environment, perceive it and act accordingly.

The proposed framework will help in developing energy efficient strategies to be implemented through social campaigns, ubiquitous computing or centralized/distributed approaches. Purpose of the proposed approach is to identify the sensitivity of behaviour for energy control and management which shall help in developing the smart environments as well as testing the design of new buildings or houses more suited to humans according to their behaviour. A simulation has been run in order to access human behaviour with energy consumption which otherwise cannot be done without experimentation.

This work is part of the SIMINTHEC (SIMulation and INteroperable software tools for the management of THermal and EleCtrical energy in buildings) project. The goal of SIMINTHEC is to design a multi-simulation environment to improve energy management in buildings by validating and improve energy-saving policies and programs.

2. LITERATURE REVIEW

The section covers three aspects: behaviour influence on energy consumption, home context and Human Behaviour Representation (HBR) models for possible integration in reactive/ deliberative group behaviour simulation.

Multitude of factors that influence energy consumption are reported as information on the energy problem, supply and efficiency, energy related personal interests, home characteristics, social norms and lack of knowledge about energy use (Raaij and Verhallen, 1982, Ouyang and Hokao, 2009). (Seryak and Kissock, 2000) conducted a study on university residential houses and showed that the same house occupied during 2 academic years by different occupants show different energy consumptions because of behavioural differences. (Masoso and Grobler, 2009) conducted an energy audit, results showed that more energy is consumed during non working hours than during working hours because of the occupant's behaviour of leaving lights and other equipment on at the end of the day.

In addition to behaviour, context is another important factor affecting the energy related activities of occupants. “The context of a task is the set of circumstances surrounding it that are potentially of relevance to its completion” (Henricksen, 2003). Context elements necessary to represent behaviour are categorized as individuality (state), activity (human needs expressed as ‘what’ and ‘how’), location (spatial arrangements) and time (current or any virtual time) and relations (Zimmermann et al., 2007). (Ha et al., 2006), presented a user behaviour modelling approach (5W: what, when, where, why & who and 1H: how) by mapping it in a home context (user, time, object, space & environment) (Fig.1.

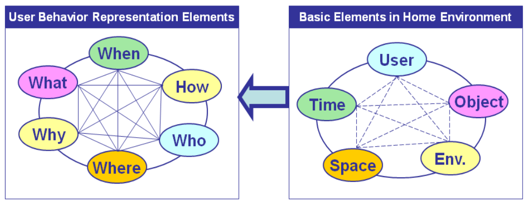

Fig. 1 5W1H approach to map user behaviour in home

It is evident from the above studies that human behaviour is the most important factor affecting the energy utilisation in buildings. In an urge to study this most important factor in more detail, to find out its different aspects affecting energy related activities directly or indirectly and to find a way to represent it for energy control and management, a study of existing human behaviour representation models has been conducted.

HBR models are analysed to find those that could represent reactive/deliberative and group behaviour including context elements. Atomic components of thought (ACT) (Anderson et al., 2004) focuses on cognition, perception and motor elements. (Freed, 1998) suggested Architecture for procedure execution (APEX) to model human behaviour in complex, dynamic environments, but focus only on individual tasks. (Sloman, 2001) presented Cognition and affect project (CogAff) that captures the reactive, deliberative & reflective mechanisms. Cognition as a network of tasks (COGNET) (Zachary et al., 1998), mainly focuses on cognitive behaviour, assuming that humans are capable of doing multiple tasks simultaneously. Concurrent activation-based production system (CAPS), (Thibadeau et al., 1982) is a production system where a declarative knowledge base consists of facts having a numerical activation value. (Eggleston et al., 2000) presented the Distributed cognition (DCOG) model, according to which cognition is distributed across the environment. Agents having different skilful behaviour use different strategies to accomplish the same task. Executive process/interactive control (EPIC), (Kieras and Meyer, 1995), focuses on perceptual, cognitive and motor processes that represent the procedures required to perform complex tasks. Man-machine integrated design and analysis system (MIDAS), (Corker and Smith, 1993), focuses on human system interactions. (Deutsch et al., 1997) suggested Operator model architecture (OMAR) with an assumption that human behaviour is proactive and reactive where tasks occur concurrently within and among multiple operators. State, operator, and result (SOAR) (Laird and Newell, 1983), states that 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. Business redesign agent-based holistic modelling system (Brahms), (Sierhuis et al., 2007) is a modelling/simulation environment to analyze work practices in organizations and represents people, things, places, behaviour of people over time, tools and artefacts used, when they are used. It focuses on communication between co-located and distributed people to support social behaviour.

Brahms supports social and behavioural elements necessary for dynamic behaviour. The objective for behaviour simulation is to find a model which can map human behaviour for reactive/deliberative group behaviour and the context. The mapping between user behaviour elements, context and Brahms is presented in Fig.2 below:

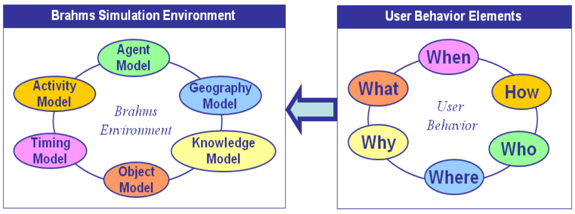

Fig.2 5W&1H approach mapped to Brahms

Workframes and throughtframes are key elements in Brahms. Thoughtframes are used to model the reasoning behaviour of agents and are represented as production-rules creating new beliefs of agents or objects whereas workframes (rule-based) perform agents and objects activities (simple or composite). Brahms includes an agent model that represent agents along with group hierarchy, and a communication model to exchange beliefs about agents and objects. It also provides means to model locations and objects (geographical and object models), that are important to establish the environment in which agents operate. Brahms can be used to model human beings interacting with a complex habitable environment as powerful, active, intelligent agents rather than passive participants for energy efficiency and it can represent the complexities found in real world human-environment interaction scenarios. In this paper inhabitants perception, cognition and reactive/deliberative group behaviour is simulated using home context (5W1H) and mapping it to Brahms. It provides an opportunity to learn context, beliefs and activities that influence energy consumptions and could play significant role in energy efficiency within domestic settings. Our proposed approach is different from the existing research to the extent that we have demonstrated dynamic behaviour simulation and results obtained shall be applicable to the real life situations.

3. PROPOSED FRAMEWORK

To simulate inhabitants' dynamic group behaviour an integrated definition (IDEF) model with two levels of abstraction (Fig.3 and Fig.4) is proposed:

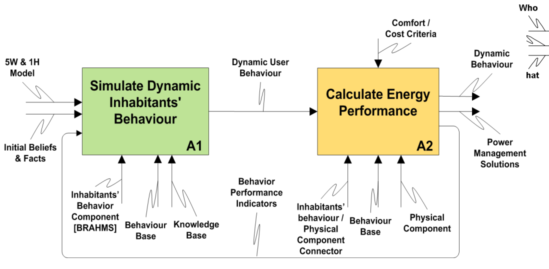

Fig.3 Conceptual framework for behaviour simulation

Functions A1 (simulate dynamic inhabitants' behaviour) and A2 (calculate energy performance/ physical component) represent the conceptual framework. A1 is the core element to simulate dynamic behaviour using an agent based approach where 5W1H (context), beliefs and facts are its inputs and its output (dynamic user behaviour) serves as input to function A2 for energy calculations. Function A2 uses cost/comfort criteria and the inhabitants' behaviour/physical component connector to calculate energy costs where behaviour base serves as data structure to store dynamically the generated behaviours. It is the first level of functional abstraction towards learning context and beliefs/ facts from energy related group behaviours.

The functional description of function "A1" as reactive/deliberative inhabitants' group behaviour is detailed below in Fig.4. Since our approach is based on Belief Desire Intention (BDI) agents, we can keep track of the initial and changing beliefs of agents about contextual elements.

(i) **Get context information (A1):** Function 'A1' gets information on three important context elements i.e. inhabitant as agents (who), objects as appliances (what) and their physical location (where) in domestic settings.

(ii) **Update knowledge base (A2):** This function takes 'Knowledge base' as its mean where all the beliefs, facts and context information is stored and updated every time an activity is performed or new beliefs are generated. Updated beliefs and facts serve as input to functions A3, A4 and A9.

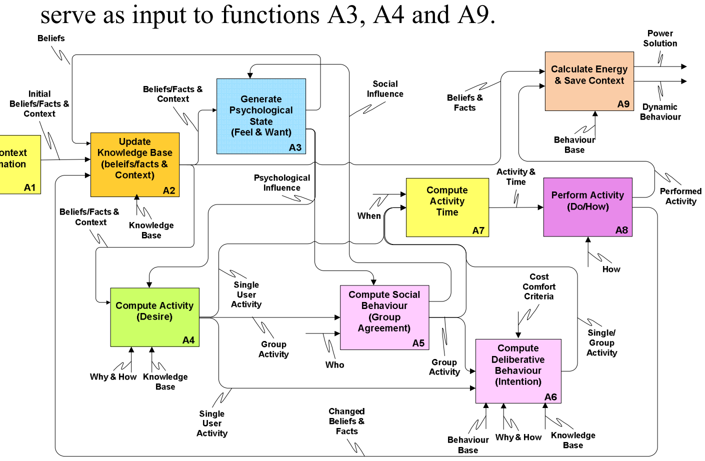

Fig.4 Functional model for dynamic behaviour simulations

(iii) **Generate psychological state (A3):** It generates psychological state based on the beliefs, facts and context elements available to it from the function A2. It also captures two important aspects of humans i.e. feel and want. For example, if temperature rises, a person in a room starts feeling hot and may want to open window based on his belief that the temperature is very high. This belief will influence the A4 function for the selection of appropriate activity. It takes the social behaviour from the function A5 as constraint to generate changed beliefs based on some social influence.

(iv) **Compute activity (A4):** It represents a reactive behaviour and selects an appropriate activity with(out) deliberation, based on changed beliefs and facts as input from A2 and a psychological influence as control from A3. It takes inhabitant from the "who" model as input and 'why/how' model serves as means which contains information about the activity. If selected activity is a single user activity and does not require deliberation, it is fed to A7 otherwise A6, however in case of a group activity it is always fed to A5 for the group agreement.

(v) **Compute social behaviour (A5):** It takes input from A4 in case of a group-activity and uses 'who' model as input to identify the inhabitants to perform group agreement. Output in case of group

agreement could be fed to A4 if deliberation is not required otherwise it serves as input for A6.

(vi) **Compute deliberative behaviour (A6):** Deliberation is a reasoning mechanism where an inhabitant decides which activity to be performed keeping in view the consequences of all possible choices. This function captures deliberation on different elements like cost, comfort etc. for the selection of an appropriate alternative activity. Changed beliefs and facts in the "Knowledge base" serves as means and choice of alternative actions based on information, cost, comfort etc. is stored in 'behaviour base' for future choices. The selected activity after deliberation is finally sent to A8.

(vii) **Compute activity time (A7):** This function computes the time when some activity is to be performed by the inhabitants, e.g. the start and end time etc. It computes activity duration and sends this information to A8. It receives activity information as input from the A4 or A5 and the timing information from "when" model, however activity time is computed only upon the receipt of the activity information.

(viii) **Perform activity (do/how) (A8):** Based on the single, group, reactive, deliberative behaviour the activity is performed by this function and the information is used to calculate the energy consumption of this activity. It takes as input, a single/group activity and its associated time from A7 and outputs the changed beliefs and facts to A2 and activity completion information to A9. It is important to note here that activity performed is not physically executed but simulated for execution and is represented as start and end time. Upon completion of the activity i.e. end time, outputs are further submitted as respective inputs.

(xi) **Calculate energy and save context (A9):**This function collects information about the performed activity and other context elements (beliefs and facts) from A2/A8 and calculates the energy consumed after performing the activity. Information about the activity performed, context elements and energy consumed is also saved in the behaviour base which could further be utilized to make choices based on cost/comfort criteria. Finally the dynamic behaviour and power solution is provided as output. The power solution will provide a series of calculated energy requirements on varying dynamic group behaviour and will help identifying min/max energy demand to balance the supply and demand equation.

4. SCENARIOS' DESCRIPTION

We have collected a workday activity profile (24h) of a family in France and a simple scenario from the collected profile is implemented using the Brahms language based on the model proposed in section 3:

"Stephan (father) comes back home from LAB at 19h48 and walks through the corridor to the kitchen for dinner. Anna (daughter) and Erik (son) are watching television in the lounge. They walk to the kitchen for dinner at 19h50. Katherine (mother) is already in the kitchen and is preparing the table for dinner and is interacting with the fridge in parallel. They have dinner together from 19h50 till 20h30. Stephan, Katherine and Anna move to the living room after finishing the dinner and start watching television there. Erik moves to the study room. The temperature increases slowly due to the presence of many people in the living room. Stephan feels hot and wishes to open the window to reduce the temperature. Before opening the window he asks Katherine and Anna. They agree and Stephan goes to the window to open it. He realises that there is a storm outside and opening window is not safe, so he evaluates between two options to identify the most comfortable, turn the AC on using the remote control or open the door linked to the study room."

5. SIMULATION RESULTS

The scenario in section 4 is implemented and simulated using the model (section 3) with the Brahms language. Only a part of the simulation results is presented in Fig.5 that takes into account the reactive, deliberative and group behaviour. Communication activities taking place between agents Stephan, Anna and Katherine are represented by vertical lines and the bulb represents the Brahms throughtframe (tf). The first throughtframe with reference to the agent Stephane highlights the temperature increase in living room beyond 30 degrees and Stephane feels hot and want to lower the temperature. In order to establish dynamic group behaviour in the presence of Katherine and Anna, Stephane decides to go for group agreement and starts communication. Upon agreement he moves and interacts with the window, he realizes the storm outside and this belief is implemented as a thoughtframe. This belief gives rise to the deliberative behaviour and now he wants to choose between opening the door or turning on the air conditioner based on Erik's presence in the study room. Since Erik is in study room and opening the door might disturb him, the final choice made is to turn on the air conditioner. Finally based on these thoughtframes the choice is implemented by workframe (wf) 'Turn_On_AC' which consists of the composite activity (ca) of first picking up the remote and adjusting the temperature. Horizontal lines beneath the primitive activities (pa) show the interaction with some appliance/object.

6. CONCLUSION

We have dynamically simulated social, perception, cognitive and psychological elements to generate inhabitants' behaviour over time. Agents are provided with potential consequences of possible actions learned from previous simulations in anticipation to find energy efficient behaviour and savings. Simulation is based on data collected from a single family; however future work will include data from a set of reference households. It could be extended to model patterns for different classes of household behaviours and analysis of energy impact due to correct behaviour (ergonomy). Simulation results start with the initialization of beliefs and facts as static values; hence based on fixed initial values we could have one behavioural pattern; however adjusting the list of beliefs and facts dynamically after each simulation within parametric space could be interesting to identify generalized energy related behaviour.

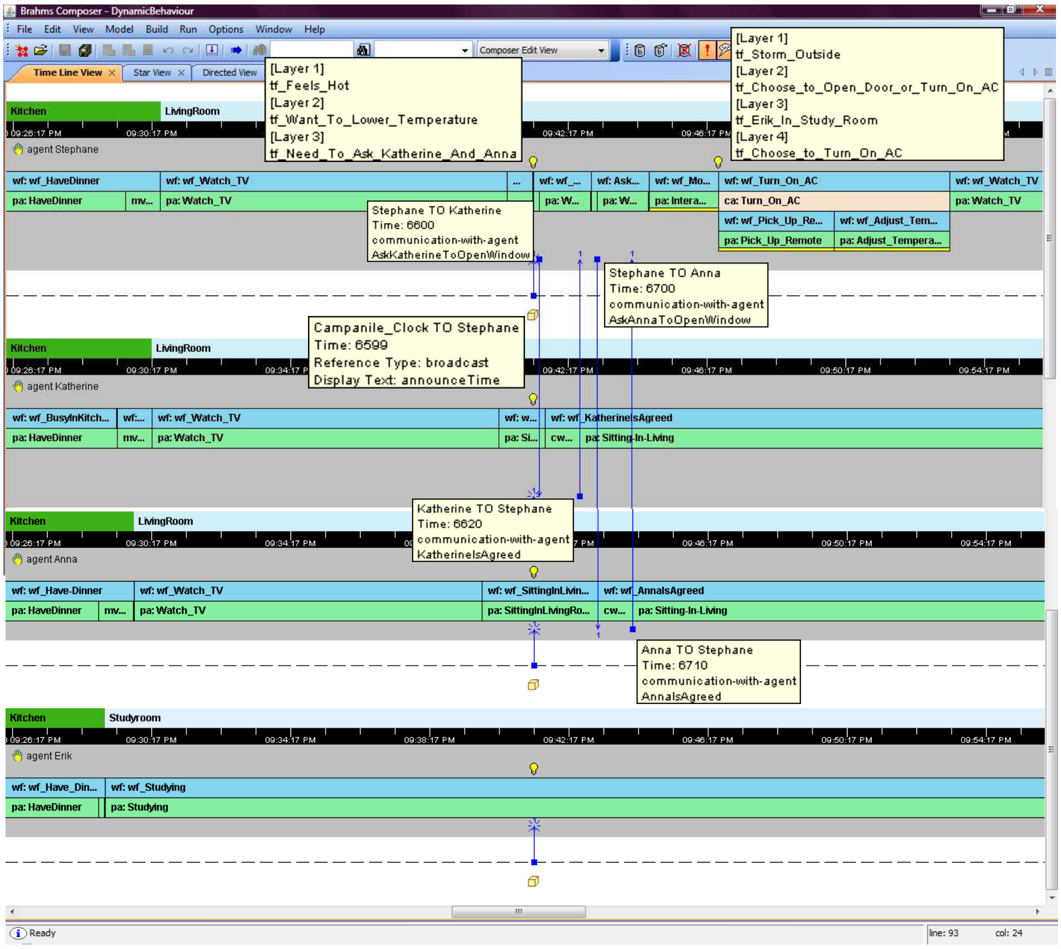

Fig.5 Communication and Group reactive/deliberative behaviour

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