Simulating inhabitant behaviour to manage energy at home

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RESUME. Cet article présente un modèle causal de comportement des habitants à la maison qui prend en compte leur comportement réactif. Ce modèle est indispensable pour le développement d'un nouveau type d'outil de simulation évaluant des solutions possibles de gestion d'énergie, étant donné la diversité et la variation des besoins des habitants.

MOTS-CLÉS : comportement des habitants, modélisation, simulation.

ABSTRACT. This paper presents a causal model of inhabitants behaviour at home that takes into account their reactive behaviour. This model is necessary to develop a new kind of simulation tool for evaluating possible power management solutions, given the diversity and the variation of inhabitants needs.

KEYWORDS : inhabitants behaviour, modeling, simulation.

1. INTRODUCTION

In France, the residential sector represents the highest sector of primary energy consumption: 39.7% (Observatoire de l'Énergie, 2007). There are four factors that play a role in the energy consumption of a house: its physical properties (e.g. performance of thermal insulation), the appliances dedicated to general usages (the heating, ventilation and air-conditioning system, auxiliary production of electricity systems or hot water boiler), the appliances dedicated to specific usages and the outdoor environment. Up to now, improving home energy performance focuses mainly on improving thermal insulation and on integrating renewable energies (solar photovoltaic, thermal and geothermal). However, inhabitants behaviour determines the energy consumption of two above factors: the appliances dedicated to general usages and the appliances dedicated to specific usages (Seryak et al., 2000; Masoso et al., 2009). Therefore a better management that coordinates and orchestrates the use of all kinds of energy according to inhabitants' needs and comforts, and to current weather, remains an important progress factor. In this perspective, studies on power management in home situations are developed: scheduling the starting time of domestic electric appliances to avoid peak consumption (Ha, 2007; Abras, 2009) or further anticipating the energy demand at home (Lamis et al., 2010). Given the diversity and the variation of inhabitants needs, a new kind of simulation tool for evaluating possible power management solutions is needed: a simulator that takes into account the reactive behaviour of inhabitants (e.g. opening a window, a group of inhabitants congregating in a room, etc). In order to develop this simulator, inhabitants behaviour in real home situations has been analyzed by identifying the context within which their energy-related requests are carried out. A behaviour model related to inhabitant needs at home has been developed. An instance of this model is transformed into a language and simulated to evaluate a possible power management solution. In comparison with the classic "static scenario" of other existing simulators (TRNSYS, COMFIE PLEIADES, ENERGY+, etc.), inhabitants reactive behaviour have been introduced in this simulator.

Our current work is a part of a project named SIMINTHEC (SIMulation and INteroperable software tools for the management of THermal and EleCtrical energy in buildings). This project focuses on designing a co-simulation environment to improve energy management in buildings. This simulation environment will provide co-simulations that help to validate and improve the energy-saving policies and programs instead of building expensive platforms. In this simulation environment, there are five modules: two modules with models describing the thermal and electrical aspects within the building, a module dedicated to control algorithms and energy-saving policies, and the module presented here that deals with the simulation of inhabitants behaviour and a fifth module for predicting the outdoor environment. The interoperability between these modules is presented in Figure 1.

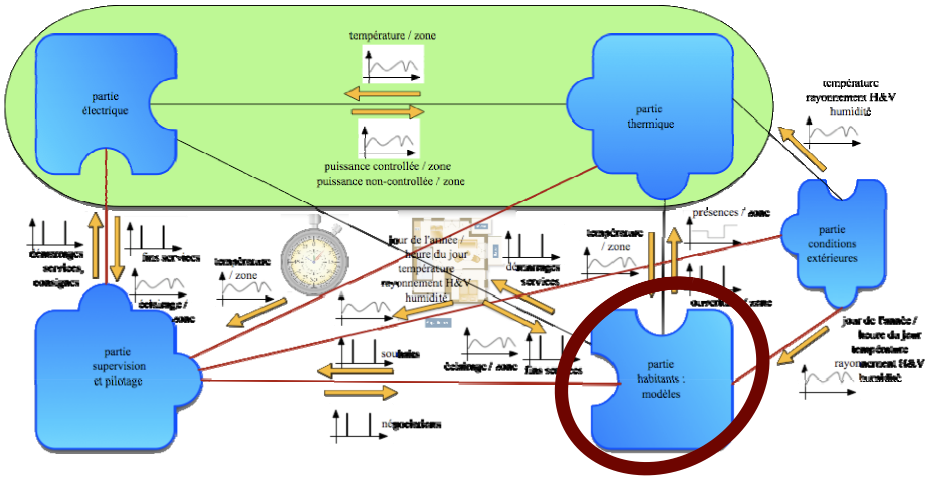

Figure 1: Interoperability between the modules in project SIMINTHEC.

In the following parts, this paper continues with the summary of related work on human behaviour modeling and simulation, following by the development of our model of inhabitants behaviour, its simulation with some results and finishes with the conclusion and some perspectives for this study.

2. RELATED WORK

The studies in literature can be classified into two groups:

- modeling and simulation of inhabitants behaviour at home or in building (for the purpose of energy management, home automation, etc.)
- modeling and simulation of human behaviour and human cognition in general

As examples of the first group, (Hunt, 1980; Newsham et al., 1995; Reinhart, 2004) used lighting models to build occupant presence model because they supposed that the use of a lighting appliance is linked to the presence of its user. (Capasso et al., 1994) applied Monte-carlo extraction on average daily availability at home to derive the daily presence profile of inhabitant. (Yamaguchi et al., 2003; Page, 2007) used Markov model to simulate the occupants presence by using weekly profile of the presence probability as input. For modeling and simulation of electric appliances usage at home, (Capasso et al., 1994; Paatero et al., 2006) established daily usage profile of the most common appliances in a household (a percentage distribution of usage during the day) or daily profile of the activities in which the appliance service is implicated. (Page, 2007) proposed a stochastic model based on occupants level of tolerance towards the concentration of pollutants and level of discomfort (thermal, visual) to model and simulate occupant interaction with building (opening window, using blind, etc.).

In the second group, most of existing human behaviour representation models capture the perceptual, cognitive and psychomotor elements of human behaviour (Wherry, 1976; Card et al., 1983; Corker et al., 1993; Lehman et al., 1996; Kieras et al., 1997; Freed, 1998; Sloman, 2001; Anderson et al., 2002; Sierhuis et al., 2007). Only some of the proposed models take into account multitasking capabilities of human behaviour (Corker et al., 1993; Deutsch et al., 1997; Kieras et al., 1997). Some proposed models use sequential tasks where as may divide tasks into subtasks (Pritsker et al., 1974; Card et al., 1983; Wherry, 1976). Some models cover the emotional aspects of human behaviour (Sloman, 2001) and some others also consider the social aspects of behaviour (Corker et al. 1993; Lehman et al., 1996; Deutsch et al., 1997; Sierhuis et al., 2007).

3. DEVELOPING INHABITANT BEHAVIOUR MODEL

In this section, an approach to develop a reactive behaviour model related to inhabitant needs at home is presented.

3.1. INHABITANT CONTEXT AT HOME

The term "context" is defined as any information that can be used to characterize the situation of an entity. Inhabitant context at home is the information that is necessary to characterize the situation of an inhabitant at home. (Ha et al., 2006) identified five elements of inhabitant context at home, which are: inhabitant, time, space, environment and object, presented in Table 1:

Context element	Definition and classification	Example
Inhabitant	It is person who is present at home. It includes family members and visitors.	Family (father, mother, son, daughter) Visitors (friends, neighbors, relatives) Temporary visitors (distributor, inspector)
Time	It is day/month/year and hour:minute:second. It includes weekday time, weekend time and holiday time.	Meal time, working time, sleeping time
Space	It is home space and includes indoor and outdoor space.	Main hall, kitchen, bedroom, entrance, bathroom, garden, terrace
Environment	It includes indoor and outdoor environment.	Factors of environment : temperature, humidity, lighting, noise
Objects	They are household objects. They include domestic electric appliances and others (furniture, etc.)	Microwave, hot plate, heating system Window, blind

Table 1: Context elements at home.

Each context element is described by some characteristics. For example, an inhabitant is described by his identity (name, age, sex, etc.), health state, presence state at home, current location, and current activity. A domestic electric appliance is described by its identity (name, function, average power consumption, etc.), location and functioning state (on, off, etc.).

The context can affect inhabitant behaviour. Inhabitant may not follow the same behaviour as usual when one of the context elements has been changed. For example, because of the presence of visitors, inhabitant can use more time to prepare and eat meals than usual and consume more electricity. In order to develop a reactive behaviour model of inhabitant, the context in which the inhabitant behaviour happened must be identified and recorded. To collect the context and information of inhabitant behaviour, this study used "5W and 1H" questions (Who and with who – subjects of behaviour, When – time of behaviour, Where – space where behaviour happened, What – household object used in behaviour, Why – purpose and reason of behaviour, and How – way of doing). The questionnaire presented in Figure 2 is used to collect the context and information of inhabitant behaviour at home.

Journal d'activités à remplir par chaque membre de la famille et par invités :

Date :											
Prénom :			Age :		Rôle dans famille :			Métier :			
Déplacement			**Activité principale**				Activités secondaires			Avec qui	Action sur fenêtre, store, rideau
de	vers	heure	nom	début	fin	type[1]	nom et équipements utilisés	début	fin		

Figure 2: Questionnaire for collecting the context and information of inhabitant behaviour at home.

3.2. INHABITANT NEEDS AND BEHAVIOUR

The term "behaviour" refers to the actions or reactions of an object, usually in relation to its environment. (Milliken, 1965) deduces human behaviour in terms of physical needs: « There are certain physical needs that people must meet in order to survive. There are other needs that make people more comfortable. In the specific ways they strive to meet these needs, people are different ». Inhabitant behaviour at home is considered to correspond to the inhabitants activities which purpose is to satisfy their needs according to their contexts.

By observing inhabitant behaviour through the above questionnaire, the various types of behaviour and needs of inhabitant and the way inhabitant uses household objects to satisfy a need can be identified. Some physical needs of inhabitant have been identified (e.g. drinking, eating, going to toilet, sleeping, taking a bath, dressing, etc). Each inhabitant tends to repeat the behaviour that has been successful in satisfying these needs. This repetition becomes a behaviour pattern and forms the daily activities of inhabitant with a timetable fairly regular. These behaviours can be modeled and simulated by a stochastic process with an approximated timetable.

However, for evaluating possible power management solutions, not only the time, duration and location of the daily activities are necessary but also the detail informations about which and how domestic electric appliances are used in these activities. For example, an inhabitant wants to have dinner; he goes to the kitchen and prepares the dinner by warming food in microwave for 30 seconds at 500 Watts, cooking food on hot plate for 10 minutes at its maximal power and then he eats the meal in 5 minutes; in all the time, he turns on 100 Watts light in the kitchen. The information about power consumption in each period of this inhabitant behaviour is necessary for evaluating power management solutions.

The inhabitant behaviours for satisfying environmental comfort needs (e.g. thermal comfort, visual comfort, etc.) are also important and have to be considered. These behaviours are not triggered at regular times. They depend solely on the value of some environmental factors, one of the context elements. When the physical state of environment exceeds the inhabitant comfort tolerances, it causes a psychological state (belief) in the inhabitant. This belief induces the inhabitant to desire to have activities to adjust environment around him. For example, inhabitant enters into a room; room's temperature is higher than 30 °C; inhabitant believes that he is feeling hot and wants to open window or turns on ventilator to lower room's temperature. These behaviours can change power consumption at home hence it is necessary to model and simulate these behaviours for evaluating power management solutions. If there are many inhabitants at home, an inhabitant can demand others to perform activities to satisfy his need. For instance, the inhabitant in the above example can demand the others in the same room to turn on a ventilator. This behaviour has also to be modeled.

For modeling these various types of behaviour and needs of inhabitant, a causal model of inhabitants behaviour is proposed and presented in detail in the next section. A causal model is an abstract model that uses cause and effect logic to describe the behaviour of a system (Anthony, 2006).

3.3. INHABITANT BEHAVIOUR MODEL

An inhabitant living at home has some needs. To satisfy his need, inhabitant can do one or many activities. To do an activity, inhabitant can use one or several household objects. The causal model representing these relations is presented in Figure 3.

Figure 3: Causal model of inhabitant behaviour to satisfy a need.

The above model shows that an activity can cause other activities. An example of this relation is when an inhabitant prepares a meal, he needs to warm, cut and cook the food. These are actions of inhabitant in relation with household object (e.g. turn on, turn off, open, close, etc.).

In Figure 4, two causal inputs of inhabitant need are introduced to the above model: usual time and environmental factors.

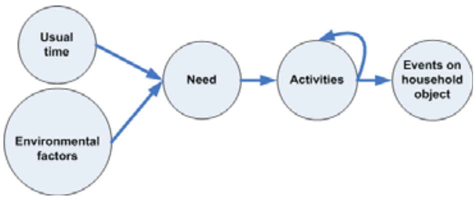

Figure 4: Causal model evolved of inhabitant behaviour.

Inhabitant need contains the belief, desire and intention. The notions of belief, desire and intention (BDI architecture) are presented in (Rao et al., 1991). When the usual time comes up, it may cause an inhabitant need (e.g. getting up, going to work, having dinner, sleeping, etc.). When an environmental factor changes and exceeds the inhabitant comfort tolerances, it causes an inhabitant comfort need. Both usual time and environmental factors are elements of inhabitant context at home. The change of other context elements (inhabitant, space and object) can also cause an inhabitant need. For example, when a visitor is present, inhabitant stops working and starts preparing a meal for the visitor.

The context elements and inhabitant psychological state are considered respectively as outside and inside cause of inhabitant need. The complete causal model of inhabitants behaviour is presented in Figure 5.

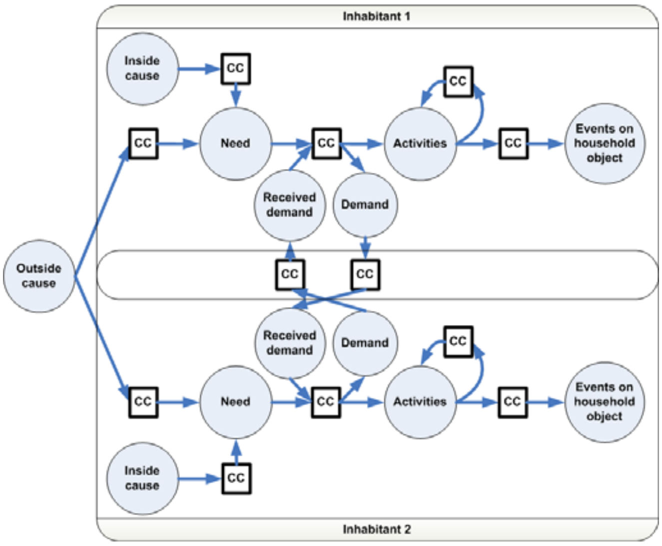

Figure 5: Complete causal model of inhabitants behaviour at home.

In the above figure, CC stands for the causal condition: if a cause is satisfied, an effect is created. In the case of many inhabitants, a need of an inhabitant can cause not only personal activities but also activities of other inhabitants. For instance, in a family the parent demands their children to go to the table to take dinner all together.

4. SIMULATION AND SOME RESULTS

The schema of inputs and output of the behaviour simulator is presented in Figure 6.

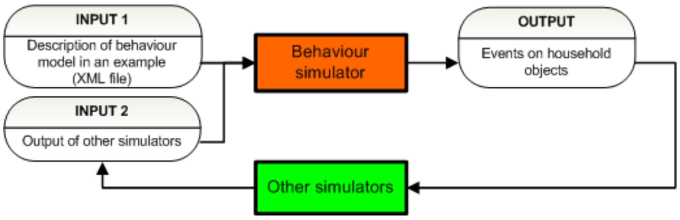

Figure 6: Schema of inputs and outputs of behaviour simulator.

The behaviour simulator exchanges data with other simulators (e.g. thermal simulator, electrical simulator, etc.) to make a co-simulation environment. In one hand, it sends time of some events such as turning on/off electric appliances, opening/closing a window, etc. In the other hand, it receives the value of some environmental factors such as temperature or humidity. (cf. Figure 1).

A descriptive language to record causal relations of inhabitant behaviour is needed to simulate the causal model of inhabitants behaviour at home. Brahms language (Sierhuis et al., 2009) is compatible with our requirements. It is a full-fledged multi-agent, rule-based, activity programming language. It has similarities to belief-desire-and-intention (BDI) architectures and other agent-oriented languages, but is based on a theory of work practice and situated cognition. It has an activity subsumption architecture which can model an activity that causes other activities. It supports also multi-agents paradigm which makes it possible to define the communication of need between inhabitants. For all these reasons, Brahms language is chosen to describe our causal model. Its corresponding simulator is also used to interpret the model in each concrete example. Figure 7 presents the transformation of the causal model into Brahms language.

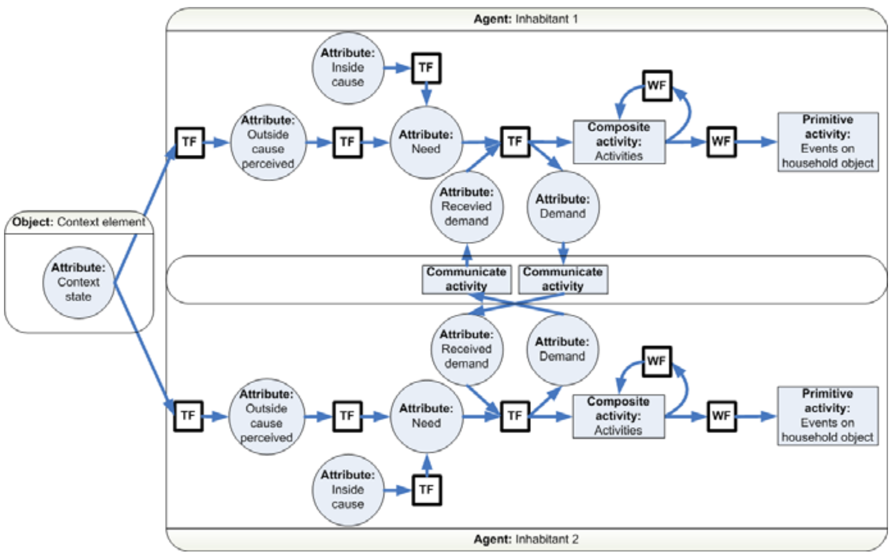

Figure 7: Transformation of the causal model into Brahms language.

In the above figure, TF and WF correspond respectively to the thoughtframe and workframe in Brahms language. Figure 8 presents the simulation results of a simple example of inhabitants behaviour.

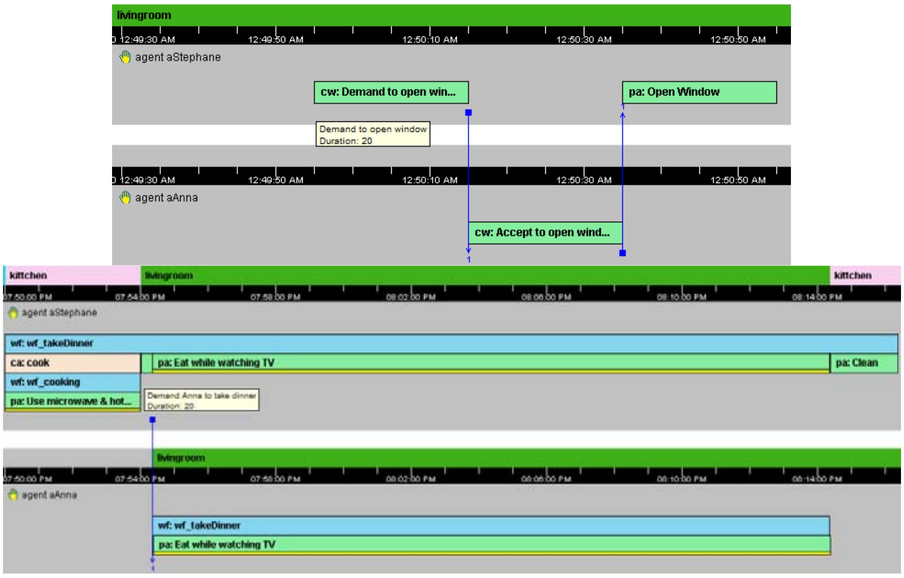

Figure 8: Simulation result of an example of inhabitants behaviour.

This example introduces two inhabitant behaviours: in the first one, when the temperature rises up, one inhabitant communicates with the other to have an agreement before opening the window; in the second one, when the dinner time comes up, one inhabitant ask the other to have dinner together, they take dinner while watching TV in the living room.

5. CONCLUSION AND PERSPECTIVES

The proposed causal model of inhabitants behaviour makes it possible to reproduce the usual behaviours of inhabitants at home. The behaviour simulator can connect to other simulators to have a co-simulation. The use of the Brahms language leads to a similar declarative language to Modelica in physics. It means that a simulation of building with occupants reactive to their environment can be managed with one global declarative file and two co-simulators like Brahms and JModelica. The next step of this work is to determine a set of typical reactive characters and typical reactive families like “the sims” from the game holding the same name that could be used to validate the global efficiency of control strategies without requiring any experimentation.

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