

TRADITIONAL VS. COGNITIVE AGENT SIMULATION

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ABSTRACT

This paper illustrates the difference between the cognitive approach and the traditional (deterministic) approach in building energy simulation, and benefits from the cognitive agent-based simulation (ABS). In this study, the cognitive agents were simulated to have a set of behavior patterns and mimic real humans under certain circumstances. The agent model includes stochastic occupant movement between multiple zones in a building. The authors coupled two applications (NetLogo and EnergyPlus) using Building Control Virtual Test Bed (BCVTB) that supports runtime data exchange between different applications. The results show that there is a significant difference between the ABS and the traditional simulation run. Accordingly, it has been concluded that for better simulation and performance prediction, the inclusion of agents into traditional building simulation is indispensable.

INTRODUCTION

It has been widely acknowledged that human dimension is a critical factor for reliable building performance prediction. Building energy use and indoor environment are dependent on occupants' level of understanding and reactions to indoor built environment (Pierce et al., 2010; Santin, 2011). However, inclusion of occupants' behavior into the building simulation tools has not been sufficiently developed. It is not easy to develop a mathematical model of human beings who make independent judgment and rational decisions based on their unique experiences, knowledge, habits, and recognition (Page et al, 2008). Many studies treat occupants in a straightforward manner such as occupation's schedule or statistical probabilities (Kim et al., 2009; Mahdavi and Proglhof, 2009; Zhun et al., 2011). Modeling of occupants can be classified into three approaches as follows:

- *Deterministic approach*: currently, most of the building simulation tools (e.g. EnergyPlus, eQUEST, ESP-r, TRNSYS, etc.) rely on a fixed schedule for occupants (e.g. 85% at 2:00 p.m.) and they don't take into account occupant responses and dynamic reactions (e.g. changing setpoint temperature or opening windows). Accordingly, this approach does not sufficiently

reflect human beings, who think, judge and react freely and intelligently. This is one of the causes for the gap between the simulation prediction and reality.

- *Stochastic approach*: occupant schedule and behavior are modeled in stochastic fashion. One of the most popular methods is Markov Chain (Kim et al., 2009; Dong and Andrews, 2009; Liao et al. 2012; IBPSA-Asia 2012). This approach is more plausible compared to the deterministic approach. Nevertheless, what follows must be in mind: (1) this approach does not consider the attributes of occupants (e.g. experience, knowledge, sensation, desire, etc.). (2) In this approach, there is no interaction between occupants and thus, it becomes still unrealistic.
- *Cognitive approach*: this approach considers human's sensation, perception, cognition, and psychomotor. This approach can be realized in Agent-Based Simulation (ABS) (Fujii and Tanimoto 2004; Page et al., 2008; Zhengwei et al., 2009; Clinton et al., 2011; Kashif et al, 2011). ABS combines the dynamics of built environment (or systems) and agents who respond to physical environment based on their autonomous judgment (Bonabeau et al., 2002; Helbing, 2012).

Firstly, this study aims to construct realistic occupants with the use of cognitive approach. In this regard, occupant behavior, decision-making process, and occupant movement were modeled using NetLogo, one of the popular ABS programs (Tisue and Wilensky, 2004). In other words, the agents were simulated to freely move between rooms and change opening windows/doors or room setpoint temperature. Secondly, this study aims to illustrate the difference between the cognitive approach and the deterministic approach, and benefits from the ABS. The authors coupled NetLogo and EnergyPlus using Building Control Virtual Test Bed (BCVTB) environment that supports runtime data exchange between two applications.

AGENT BUILDING SIMULATION

There have been many ABS studies in areas of socio and economic science (Helbing, 2012). In this section,

the ABS studies in area of building simulation are addressed.

Fujii and Tanimoto (2004) suggested an agent modeling approach based on the level of attributes (sensation, perception, and desire). An agent was characterized by type of perception, desire and belief. The characterised agent decides his/her action based on the state of indoor environment (temperature, humidity, etc.) and the surroundings.

Kashif et al. (2011) developed a causal model to simulate occupant's behavioural patterns to use domestic equipment. The agents were formed with five W's and one H using Brahms language (Sierhuis et al., 2007). The agents were programmed to operate air conditioners, television, windows and luminaires under given indoor environment. Kashif et al. (2011) showed a strong diversity of occupant behavior. Kashif et al. (2011)' study was limited to the behavioural pattern of domestic equipment only.

According to Page et al. (2008), occupants' location influences occupants' responses. Occupants act differently based on where they are. It implies stochastic and cognitive nature of occupants, which should be carefully considered in building simulation. Zhengwei et al. (2009) configured organizational simulation for HVAC design in a hospital. Patients were simulated to move around inside the hospital and the worst-case ventilation rates were compared to that of the traditional procedure. It was shown that the traditional procedure can cause poorly designed HVAC system.

Clinton et al. (2011) conducted LEED lighting assessment using agents that were classified into four types in terms of inclination of environmental friendliness. Clinton et al. (2011) showed that to some extent users exhibit heterogeneous behavior and preferences and accordingly lighting design allowing greater local control is far more preferred.

As noted earlier, the ABS reflects socio-economic, psychological interaction of occupants in building simulation, in contrast to a traditional energy simulation fashion. The following section gives details of our agent modeling approach and processes.

MODELING APPROACH

In this study, the agent model developed by Fujii and Tanimoto (2004) was used. The agent has the following characteristics: the agent senses indoor environment and perceives it as thermal sensation. Secondly, the agent derives an intention to satisfy his/her desire based on his/her experience, belief and the perception. Finally, the intention is expressed as an action.

Let us suppose that an agent is in a room in which an air conditioner is off and a window is closed, and the room air temperature is 28.5°C, outdoor air temperature is 30°C. Under this situation, inference scenario of the agent is as follows: the agent senses room air temperature of 28.5°C, and perceives it as

hot. He has a desire to cool. He finds some actions to cool (e.g. turning on the air conditioner or open the window) based on his belief (causal relation). Next, the agent recognizes the system states (e.g. on/off or open/closed) and infers the best actions to achieve his desire. Because he does not know that the outdoor air temperature (30°C) is higher than room air temperature (28.5°C), he opens the window. Again, he feels hot. Finally, he turns on the air conditioner.

According to Fujii and Tanimoto (2004), each agent can be categorized using three sensation types, three thermal perception types, two space perception types, three desire types; a total of 54 agent types (3×3×2×3). Unfortunately, in Fujii and Tanimoto (2004), interaction between agents was not considered. In this study, interaction of the agents and co-simulation of EnergyPlus and NetLogo (Tisue and Wilensky, 2004) were implemented.

Interactions between agents

The occupants under the same environment react differently depending on their background; hence a conflict occurs between occupants. According to Karp (1996), it is possible to categorize pro-environmental behavior of people along two dimensions. The first dimension extends from self-enhancement to self-transcendence, and the second dimension extends from openness to change to conservation. Based on the two dimensions, it is possible to divide agents into four: *green activist* (I), *healthy consumer* (II), *traditional consumer* (III), *good citizen* (IV) as shown in Figure 1 (Karp 1996; Clinton et al., 2011). The meaning of the four quadrant is described in Table 1.

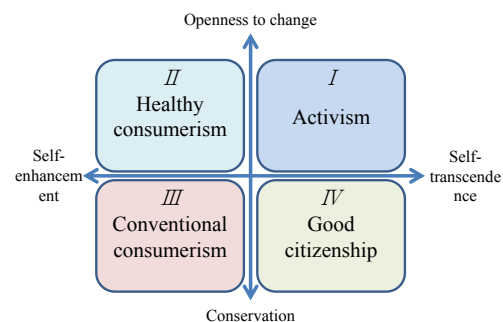


Figure 1 Two dimention of pro-environmental behavior (Karp 1996; Clinton et al., 2011)

Table 1. Meaning of four quadrant (Karp, 1996)

TYPE	MEANING
I	Individuals who strongly value both self-transcendence and openness to change will engage in pro-environmental behavior
II	Individuals who strongly value self-enhancement and openness to change will engage in pro-environmental behavior only when there is a clear link between self-interest and pro-environmental behavior.
III	Individuals who strongly value self-enhancement and conservation are the least likely to be pro-

	environmental.
IV	Individuals who strongly value both self-transcendence and conservation will engage in pro-environmental behavior, but will do so when the behavior is a normative standard

The conflicts between agents occur because of the different background and preferences (Table 1). In this study, their attitude to trade-offs between conflicting objectives was realized using Multi-Attribute Utility Function (MAUF) suggested by Clinton et al. (2011).

MAUF has been developed to provide a formal structure for rational decision making. The core of multi-attribute utility theory is the use of ‘a pragmatic aggregation function’ by combining the single-utility functions from each of the system components (Meyers et al., 2008). The general expression of this aggregation is a multiplicative form. The preference of the decision maker is expressed in the form of a weight constant, which is elicited by field survey data. The calculation procedure of the MAUF is as follows.

- Step 1: the agents are categorized as *green activist* (I), *healthy consumer* (II), *traditional consumer* (III), and *good citizen* (IV). Each agent has four attributes (*benefit to self*, *benefit to others*, *cost to self*, and *cost to others*) which are related to intentions (e.g. self-enhancement, self-transcendence, openness to change, conservation) and outcomes (e.g. gas or electric rates, comfort, energy use)
- Step 2: each attribute may be defined operationally as something that occupants *do not want* (Clinton et al. 2011). This operational choice also reflects observed behavior, because building users “tend not to worry about comfort as such, but discomfort... they react when a ‘crisis of discomfort’ has been reached” (Leaman and Bordass, 2007). Therefore operationally, occupant disutility can be made a function of *lack of benefit to self*, *lack of benefit to others*, *cost to self*, and *cost to others*. Occupants prefer scenarios with less disutility (Clinton et al. 2011). Therefore, MAUF of an Agent A can be expressed as Eq.1

$$U_A(x_1, x_2, x_3, x_4, x_5, x_6) = \sum_{i=1}^6 k_{i,A} u_i(x_i) \quad (1)$$

where, $U_A(x_1, x_2, x_3, x_4, x_5, x_6)$ is the total utility, which is function of *lack of benefit to self* (x_1 : % of time desired service is unavailable), *lack of benefit to others* (x_2 : energy use), *cost to self* (x_3 : effort, x_4 : discomfort, x_5 : cost), *cost to others* (x_6 : environmental impact). A single attribute utility, $u_i(x_i)$, has a value of 1 if the meaning of x_i fits to a certain context. For example, if the agent A turns on the air

conditioner to cool, then

- $u_1(x_1) = 0$: the air conditioner capacity is enough to serve, thus service always will be satisfied,
- $u_2(x_2) = u_6(x_6) = 1$: the electric energy is used, and it environmentally impacts such as CO₂ generation,
- $u_3(x_3) = 1$: the action is taken,
- $u_4(x_4) = 0$: the air conditioner maintains room air temperature accordingly,
- $u_5(x_5) = 1$: electric bill should be paid.

- Step 3: $k_{i,A}$ is a weighting constant (or preference) for each attributes x_i . It has a range from 0 to 1 with $\sum_{i=1}^6 k_{i,A} = 1$. $k_{i,A}$ is made to consider decision-maker’s preferences based on the surveyed samples of 91 responses of building occupants (Clinton et al., 2011).
- Step 4: finally, the MAUF of the agent A is calculated considering the attribute utilities which can be changed by seven kinds of occupant actions, for example, opening and closing of a window and turning on and off of an air conditioner, decreasing and increasing setpoint temperature of the air conditioner, and keeping still (Fujii and Tanimoto, 2004). The calculated U_A is used to decide the final action in comparing total utilities of agent B (e.g. $U_A > U_B$). If the utilities of agents (e.g. $U_A = U_B$) are the same, one is chosen randomly.

The decision-making process of the agents is shown in Figure 2.

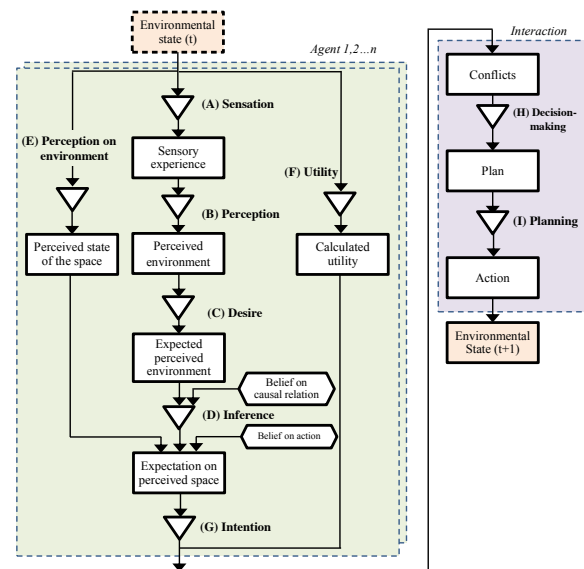


Figure 2. Decision-making process of cognitive agents

Movement of the agents

The following studies (Hillier et al., 1993; Turner and Penn 2002; Pelechano and Malkawi, 2008;

Zhengwei et al., 2009) on movement of occupants were conducted for the cases that have a strong direction path such as evacuation, a museum or a hospital. The results of the previous studies might not be applicable for the cases of multifamily houses, apartments or office buildings. Liao et al. (2012) showed that that a stochastic movement model could successfully be applied to BS in an office building. In a similar manner, a probabilistic model of the agent movement was developed in Korea based on the survey data of 30 households (Hyun et al., 2008). A floor plan of the target building is shown in Figure 3 (Hyun et al., 2008). The survey data includes information on schedule and location of each member (age, sex) at every hour. The occupants were categorized into four agent types: man (hereafter defined as Agent A), woman (Agent B), middel/high school student (Agent C), elemantary school student (Agent D).

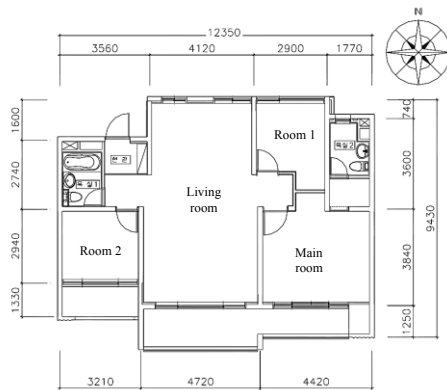


Figure 3. Floor plan of the apartment (Hyun et al., 2008)

For example, a probability of Agent A being present in room 1 is calculated as follows:

$$P_{A,rm1}(t) = \frac{N_{A,rm1}(t)}{S_A} \quad (2)$$

where, $P_{A,rm1}(t)$ is a probability of Agent A being present in room 1 at time t . $N_{A,rm1}(t)$ is the number of men who are in room 1 at time t , and S_A is the total number of people in all 30 households.

So far, 864 types of agents (3 [sensation types] $\times 3$ [thermal perception types] $\times 2$ [space perception types] $\times 3$ [desire types] $\times 4$ [pro-environmental behavior types] $\times 4$ [movements types]=864) are realized in this simulation study. Rather than attempting to simulate all possible combinations, the authors made a scenario: a typical traditional Korean family composed of two adults (a man, a woman) and two children in an apartment. The details are shown in Table 2.

Table 2. Agent type of this study

MOVE	THERMAL SENSATION*	THERMAL PERCEPTION*	SPACE PERCEPTION*	DESIRE*	ATTRIBUTE	MEMBER
A	S2	P3	PS2	D2	traditional consumer	Adult man
B	S2	P3	PS2	D3	good citizen	Adult woman
C	S1	P2	PS2	D2	healthy consumer	Student
D	S2	P3	PS2	D3	healthy consumer	

The Asterisk mark (*) means that they are same as those of Fujii and Tanimoto (2004)

COUPLING OF AGENT SIMULATION AND ENERGY SIMULATION

The target building is a typical apartment having three bedrooms, two baths, and a living room (Figure

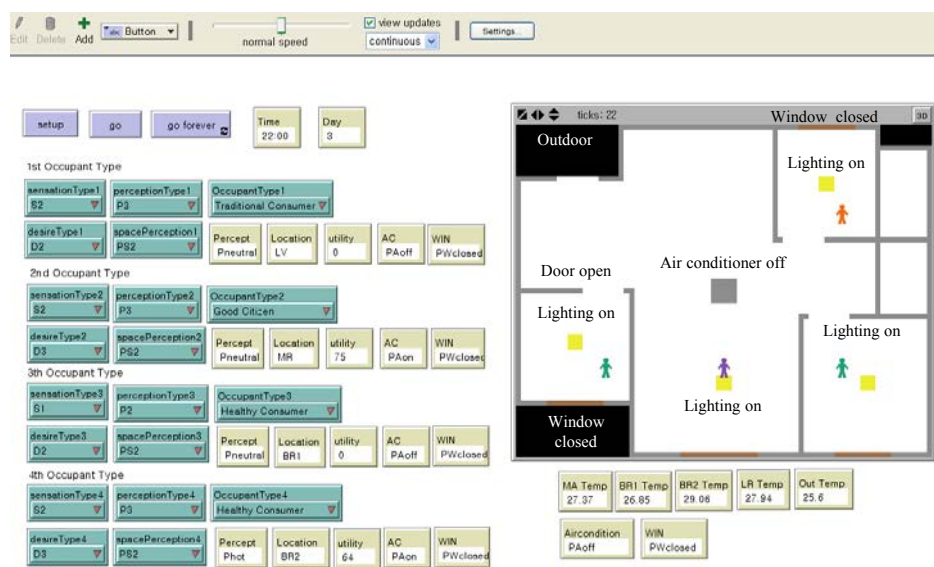


Figure 4. Screenshot of NetLogo

3). Figure 4 shows NetLogo model (version. 4.1) of the target building. The left side of Figure 4 shows the inputs of four agents. The right side of Figure 4 shows the floor plan and four agents graphically. There is an air conditioner in the middle of the living room and each room has a window and a luminaire (Figure 4). Simple logics below were made to explain operation of luminaires in the ABS (Hunt et al., 1979; Levy et al., 1980; DOE, 2006).

- Luminaire schedule is same as occupant schedule.
- A luminaire in the room is turned on regardless of the room illuminance level if occupants exist.
- Once, the luminaire is turned on, it is not turned off until all occupants go out.
- All luminaires are off at bedtime.

In NetLogo, each agent can feel five sensations (cold, cool, neutral, warm, and hot) and does seven types of action (opening and closing of a window and turning on and off of an air conditioner, decreasing and increasing setpoint temperature of the air conditioner, and no action) based on their perceptions, beliefs, and inferences. If there is a conflict between agents, then intention of one agent that has a greater utility value (Eq. 1) is chosen. During simulation run, the agents move stochastically between rooms with a given probability P at every hour (Eq. 2). The outputs of NetLogo are (1) location of the agents and (2) status of the air conditioner, windows, doors, and luminaires. These are fed into EnergyPlus simulation at every time step.

The building energy model (Figure 5) was developed using EnergyPlus (Crawley et al., 2001). The construction layers and properties were made as medium construction defined in ASHRAE (2009). The air conditioner was modeled using

AirLoopHVAC:Unitary:Furnace:HeatCool object with DX cooling coil (COP of 3.0) and electric heating coil (efficiency=1.0). With regard to infiltration and airflows between zones, *AirflowNetwork* was applied with the use of Effective Leakage Area method (ASHRAE, 2001). Table 2 shows settings of four agents used in this study.

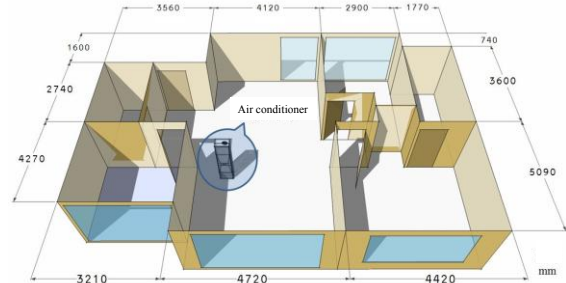


Figure 5. Screenshot of EnergyPlus building model

In this study, BCVTB (Wetter, 2010) was used for external coupling. The BCVTB, a middleware program, synchronizes data exchange between the inputs/outputs of NetLogo and EnergyPlus during run-time (Figure 6). For smooth data exchange, NetLogo was executed in MATLAB platform and the coupling sequence is as follows:

- (1) Agent locations are calculated with a given P (Eq. 2) and MATLAB saves the location of each agent as a text file (.txt).
- (2) Information on initial room air temperatures and outdoor air temperature, and the location of the agent, which are saved in a text file, is passed by MATLAB to NetLogo.
- (3) NetLogo conducts ABS and the results (location of the agents, and status of the air conditioner, the windows, the doors, and the luminaires) are

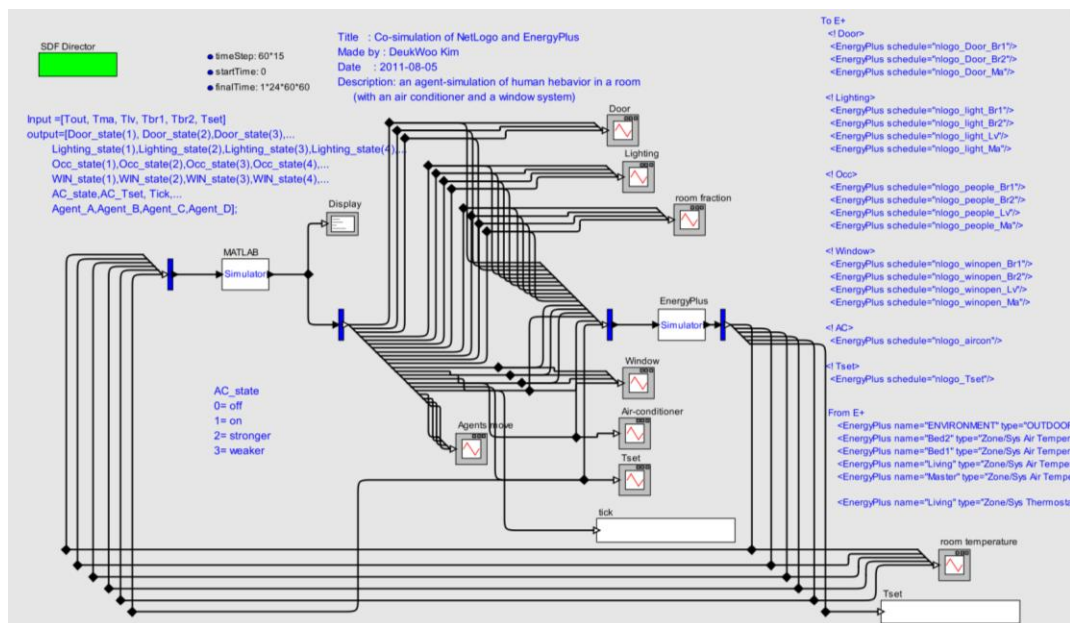


Figure 6. Co-simulation of EnergyPlus and NetLogo in BCVTB environment

saved as a text file.

- (4) MATLAB reads the text file, and passes the results to EnergyPlus via BCVTB. Then EnergyPlus conducts energy simulation for a current time step.
- (5) Outputs from EnergyPlus (room air temperatures, outdoor air temperature) are passed to the NetLogo via BCVTB.

The steps from 1 to 5 are iterated at every time step (15 minutes). The co-simulation was conducted under clear sky condition using the EPW file (location: Seoul, Korea, summer: Jul. 26th).

RESULTS

Due to lack of space, part of simulation results is addressed in this paper (Table 3). In addition, the results between 09:00 and 15:00 are excluded because most of the agents were not in a building. Energy consumption in Table 3 is calculated by the summing up cooling and lighting energy consumption. The following is a detailed description of the results (Table 3).

- At 17:00, Agent B (an adult woman) is located in the master bedroom and agent A, C and D (an adult man, two students) are located in outdoor (refer to MOVEMENT in Table 3). At that time, there is neither movement nor behavior of the A, C and D (windows, lighting, and Air Conditioner (A.C.)). Agent B felt the room air temperature too hot (refer to PERCEPTION in Table 3) and acts to close the window and turn on the A.C. (refer to INTENTION in Table 3). The energy consumption is 1,168W, which is the sum of the lighting energy (30W) in the master bedroom and the cooling energy (1,138 W) of the A.C. (refer to ENERGY USE in Table 3).
- At 17:15, Agent B moves from the master bedroom to the living room. Now she feels neutral because the living room is cool compared to the master bedroom (master bedroom: 29.9°C, living room: 27°C). Agent D arrives at home (at room 2) from school. Agent D feels too hot because the room air temperature is 30.4°C hence, has intention to turn on the A.C. strongly. At that time, Agent B is in conflict with Agent D (weakly vs. strongly for AC), but the intention of Agent B is chosen because its utility is higher (UTILITY: U_B of 57 > U_D of 36).
- At 17:30, Agent B feels warm and intends to open windows though outdoor temperature is even higher than the living room (Agent B does not know outdoor air temperature is higher than the living room temperature until Agent B recognizes it). Meanwhile, Agent D wants to turn on the A.C., but agrees to Agent B due to the utility (U_B of 84 > U_D of 57). Finally, they

Table 3. Agent-based simulation results

POINT #	TIME	AGENT	MOVEMENT*		TEMP. (°C)		PERCEPTION	INTENTION		UTILITY	STATUS OF SYSTEM		ENERGY USE (W)
			FROM	TO	RM	OUT		A.C.	WINDOWS		A.C.	WINDOWS	
1	17:00	A	Outdoor	Outdoor	-	29.6	-	-	-	-	On	All closed	1,168
		B	mr	mr	29.9		Hot	On	Closed	84			
		C	Outdoor	Outdoor	-		-	-	-	-			
		D	Outdoor	Outdoor	-		-	-	-	-			
2	17:15	A	Outdoor	Outdoor	-	29.5	-	-	-	-	Weakly	All closed	1,107
		B	<u>mr</u>	<u>lv</u>	27		Neutral	Weakly	Closed	57			
		C	Outdoor	Outdoor	-		-	-	-	-			
		D	<u>Outdoor</u>	<u>rm2</u>	30.4		Hot	Strongly	Closed	36			
3	17:30	A	Outdoor	Outdoor	-	29.4	-	-	-	-	Off	Open (lv, rm2)	80
		B	lv	lv	27.8		Warm	Off	Open	84			
		C	Outdoor	Outdoor	-		-	-	-	-			
		D	rm2	rm2	28.1		Hot	Strongly	Closed	57			
4	22:00	A	Outdoor	Outdoor	-	25.7	-	-	-	-	Off	Open (lv, rm1)	80
		B	lv	lv	26.0		Neutral	Off	Open	84			
		C	rm1	rm1	26.5		Neutral	Off	Open	27			
		D	lv	lv	26.0		Neutral	Off	Open	87			
5	22:15	A	<u>Outdoor</u>	<u>mr</u>	30.5	25.7	Hot	On	Closed	57	Off	Open (lv, mr, rm1)	110
		B	lv	lv	25.9		Neutral	Off	Open	84			
		C	rm1	rm1	26.4		Neutral	Off	Open	36			
		D	lv	lv	25.9		Neutral	Off	Open	87			
6	22:30	A	mr	mr	28.7	25.7	Hot	On	Closed	57	Off	Open (lv, mr, rm1)	110
		B	lv	lv	25.9		Neutral	Off	Open	84			
		C	rm1	rm1	26.3		Neutral	Off	Open	36			
		D	lv	lv	25.9		Neutral	Off	Open	87			

* The words in underlined italic mean occurrence of the agent's movement

** lv=living room, rm=bed room, mr= master bedroom, A.C.: Air-Conditioner

open the window in the living room and room 2. They do not use A.C., so the energy consumption is 80W, which is the sum of lighting energy in the living room and room 2.

- At 22:00, Agents B and D in the living room feel neutral thermal sensation (living room: 26°C). They choose to turn off the A.C. and opening the window. Agent C in room 1 has the same thermal sensation and intension. Therefore, they behave in a similar way.
- At 22:15, Agent A arrives from outdoor to the master bedroom and feels hot (30.5°C). Therefore, Agent A wants to turn on the A.C. However, Agents B, C and D want to maintain the previous status (with the A.C. off and the windows open) due to their neutral perception. As a result, Agent A is in conflict with Agents B, C and D. Although Agent A wants to turn on the A.C., Agent A has to agree with Agent D who has the highest utility (U_D of 87 > U_A of 57). Finally, they decide to open the window.
- At 22:30, the master bedroom air temperature is decreased (30.5°C → 28.7°C) due to the windows open (Refer to at 22:15). Agent A still feels hot, but there is no option but acting same as at 22:15.

Figure 7 shows a comparison of ABS with three deterministic simulation results during the day. The deterministic simulation means following a traditional simulation approach (using a fixed schedule, having a constant room air temperature of 26.0°C when occupants are present.) With regard to the schedule, three households out of 30 households were randomly selected (Hyun et al., 2008).

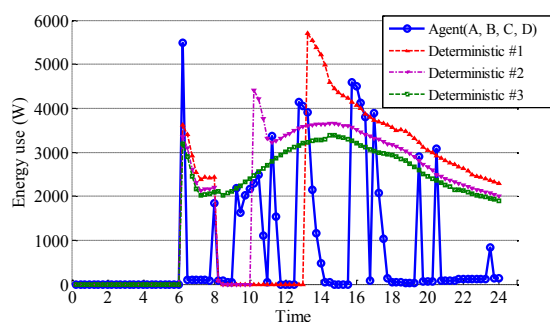


Figure 7. Result comparison between agent and deterministic simulation

In the deterministic simulation, the energy use over the day is in a smooth pattern, which is unrealistic. In the ABS approach, occupants' cognitive responses are reflected based on their perception, desire and belief. In addition, they can make rational optimal decision (finding a maximum utility) at every time step. Hence, the pattern of the energy use fluctuates at every time step. As shown in Table 4, there is significant difference between traditional (deterministic) and agent approaches.

Table 4. Energy consumption comparison between agent and deterministic simulation

APPROACH	ENERGY CONSUMPTION (KWH/DAY)	DIFFERENCE (%)
Agent approach	18.96	-
Deterministic approach #1	44.34	57.2
Deterministic approach #2	48.04	60.5
Deterministic approach #3	47.52	60.1

CONCLUSION

In this simulation study, the agents are capable of mimicking human behavior and are reflected in a general whole building energy simulation tool, EnergyPlus. The agents can open/close a window or turn on/off an air conditioner based on their thermal sensation. In addition, a simple Multi-Attribute Utility Function was utilized for interactions between agents.

It has been shown that there is a not negligible difference between a traditional simulation approach and agent simulation approach. It can be inferred that by adopting agent simulation approach, the current simulation tools could predict the reality in a more accurate and realistic fashion. It is expected that the role of building performance simulation will be much further expanded with the adoption of ABS.

ACKNOWLEDGEMENT

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