# COGNITIVE RESPONSE OF OCCUPANTS TO INDOOR ENVIRONMENTAL INFORMATION AND ITS IMPACT ON SIMULATION

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## ABSTRACT

For better building system controls and occupant's comfort, a number of sensors and network technologies have been developed and installed in central HVAC systems. In most modern buildings, however, indoor environmental information (specifically, room temperature, CO2 concentration, illumination level, etc.) is not well provided for occupants even though it has been well acknowledged that such information can impact occupant's behavior and satisfaction. As reported in many studies (IBPSA proceedings 1989-2011), understanding occupant's behavior is very essential for better application of simulation tools. This study reports the impact of environmental information on occupant's response and its relevance to building energy simulation. A series of experiments were conducted in a university laboratory (floor area: 54m2, the maximum number of occupants: 11) with sensing CO2 concentration of the lab. The following is addressed in this paper: (1) when occupants are informed of indoor environment, they can behave as an intelligent agent, far surpassing sophisticated mechanical systems, (2) it is significantly important to take into account cognitive response of occupants for better building energy simulation.

## INTRODUCTION

Building's thermal characteristics, environmental systems (e.g., air conditioning/heating ventilation, and lighting systems), climate, and occupants' behavior affect energy consumption of the building. For the past several decades, modeling, numerical methods, controls, etc. have enormously improved in area of building simulation (IBPSA 1987-2011).

It has been recently acknowledged that occupants are one of the most significant uncertainty factors in building simulation (IBPSA 2005-2011). However, we still lack understanding and modeling of occupants' behavior and its impact on building energy simulation. It is indeed difficult to make a mathematical modeling of human beings either in a statistical manner or in an analytical manner since human beings make independent judgment and decisions based on their unique experiences, knowledge, habits, and recognition (Page et al, 2007). Therefore, most of the research on occupants merely deals with relatively a simple set of measured data and derive occupation schedule with a statistical manner (e.g. Markov Chain, regression model) (Bourgeois et al, 2006; Kim et al, 2009; Mahdavi and Proglhof, 2009; Zhun et al, 2011).

There have been three approaches to deal with building occupants as follows: (1) deterministic approach (e.g. schedule of occupants in ASHRAE energy standard 90.1, 2004), (2) stochastic approach (.e.g, Markov chain; Kim et al, 2009), and (3) cognitive approach. The cognitive approach uses human's sensation, perception, cognition, and psychomotor. This approach is realized with agent simulation (Fujii and Tanimoto 2004; Clinton et al 2011; Kashif et al, 2011). Kashif et al (2011) developed the casual model by using the agent simulation in order to estimate the behavioral patterns of occupants who use equipment. Agents were formed with that the agents would be able to independently operate the air conditioning equipment (air conditioner), windows (opening and closing), and lights (turning on and off) in the given indoor environment. Brahms Language (Sierhuis et al 2007) developed by National Aeronautics and Space Administration (NASA) was used. Kashif et al (2011) showed the diversity of occupants' behavior and was proven to be close to reality. However, Kashif et al (2011) concentrated only upon the behavioral changes of occupants and did not consider the impact of occupants' behavior on the building's energy and environment changes.

This study approaches from a different angle. Modern buildings are now equipped with cutting-edge smart devices (e.g., controls, sensors, wall-pad) and tightly interwoven with network technologies. A variety of more indoor environmental information are provided for occupants such as temperature and humidity. This study aims to investigate how 'provision of such information' affects occupants' behavior and its impact on building energy simulation. The goals of this study were as follows: (1) to identify the impact of 'providing indoor environmental information' to occupants upon their behavioral changes; (2) to investigate the importance of cognition and responsive behavior of the occupants; (3) to quantify how building's energy use can be influenced by such occupants' cognitive behavior.

## EXPERIMENT

Four experiments were conducted at a laboratory of S University in June 2012 (Figures 1 and 2). The maximum number of occupants was 11. Since occupants (graduate students) were not major in building environment and not knowledgeable about environmental information. The indoor temperature of the lab was controlled by two wall-attached air conditioners. There is no installed ventilation system. Outdoor air is supplied either 'passively' by infiltration or 'actively' by opening/closing of windows/doors. There are two windows and one exit door.

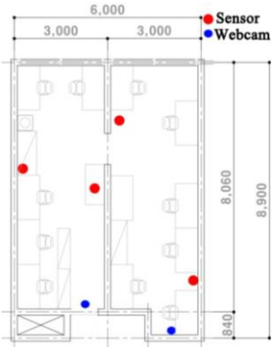


*Figure 1. Floor plan of the lab*

*Figure 2. Scenes of the lab*

CO2 concentration was chosen as a criterion of the indoor air quality as well as indoor environmental information. CO2 is a typical contaminant generated primarily by occupants and, in addition, measurement of CO2 in occupied spaces has been used widely to evaluate the sufficiency of outdoor air supplied to indoor spaces (ASHRAE 2009). In CO2 concentration is easy and cheap to measure. In this study, IBIT's IS-320 (temperature, humidity, CO2) was used (Figure 3).

*Figure 3. CO2, temperature, humidity sensors*

The sensors were located at four spots 1.5m above the floor suggested by KECO (2010) (Figure 1). However, positioning the sensor at human face altitude (e.g., 110cm) would be preferable. The measured data were transferred on a real time basis to a server computer via a wireless network. The database has been made by MySQL (Figures 4 and 5).

To observe of the number of occupants and their behaviors (open or close doors/windows), web cameras were installed in two spots (Figure 1). If a web camera records per a predetermined interval (e.g. one shot per every minute), the recorded images would be too much and it would take a long time to analyze. Therefore, secure cams were used which record images when a movement is detected. The recorded images were also saved at the server computer on a real time basis (Figures 4 and 5).

*Figure 4. IP-USN router interlocking server program*

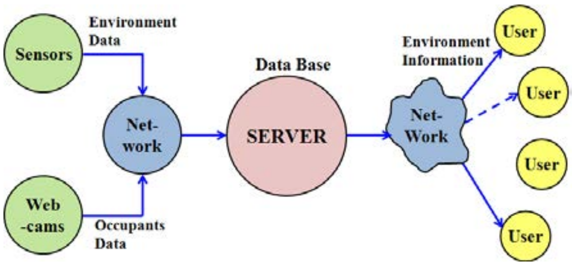


*Figure 5. network diagram*

Four experiments (Table 1) were conducted with a sampling time of one minute. The duration of Experiment #1-#4 was two days long. The details of the experiments are as follows:

- Experiment #1: CO2 information was not provided for occupants.
- Experiment #2: CO2 information was provided for occupants on a real time basis (Figure 6).
- Experiment #3 (CO2 information and its meaning provided): Prior to Experiment #3, a short guide (10 minutes) and 1-page note were delivered with regard to meaning of CO2 concentration. In addition, when CO2 concentration is higher than 1,000ppm and 1,500 ppm respectively, first and second alarms appear in the pop-up window.
- Experiment #4 (fake CO2 information provided): Manipulated CO2 information, i.e., measured CO2 concentration plus 500ppm, was provided and occupants' behavior was observed.

*Table 1. Start date and end date of each experiment (each started at 00:00:00 and ended 23:59:59)*

| **EXP.** | **START** | **END** | **AVR. TEMP. (℃)** | |
|---|---|---|---|---|
| | | | **OUTDOOR** | **INDOOR** |
| Exp.1 | 2012/06/04 | 2012/06/05 | 22.8 | 23.5 |
| Exp.2 | 2012/06/11 | 2012/06/12 | 23.1 | 23.4 |
| Exp.3 | 2012/06/14 | 2012/06/15 | 24.0 | 23.9 |
| Exp.4 | 2012/06/27 | 2012/06/28 | 24.6 | 24.0 |

By comparing Exp. #1 to #2, the impact of environmental information provision can be understood. By comparing Exp. #2 to #3, the impact of occupants' cognition is better understood. Exp. #3 can be easily practiced in Korea since a wall pad (a small digital pad attached to a wall of a living room) is very popular. By comparing Exp. #3 to #4, it can be studied that which is more influential to occupants' response between environmental information or environment itself. Since the profiles of outdoor mean temperature was similar to those of indoor mean temperature during each experiment (Table 1, Figure 6), it was assumed that the relation within the people response and internal/external temperature is negligible (Table 1, Figure 6).

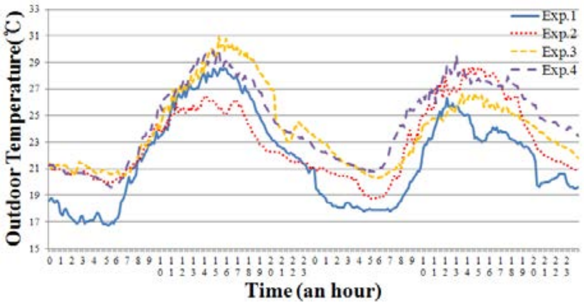
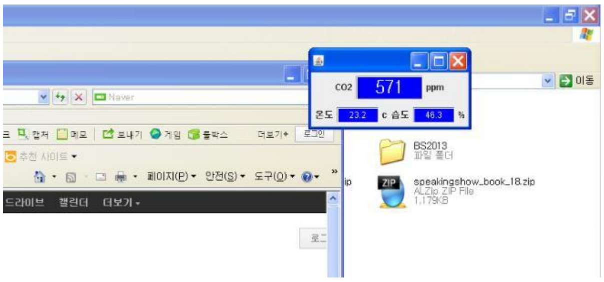


*Figure 6. Outdoor Temp. of each experiment*

Figure 7 shows a pop-up window that provides indoor environmental information (CO2 concentration) in real time for each occupant. The pop-up was programmed with the JAVA language and interlocked with MySQL Database in real time. The authors can monitor whether the pop-ups are active in occupants' monitors via the server on a real time basis and relevant log-on data were archived during the experiments. The pop-up application was installed to each PC with occupants' agreement. The application can be off if he/she wants. Based on the post surveys aim at occupants, it was found that the 9 out of 10 occupants were not aware of the meaning of the CO2 concentration during the EXP. #1-2.


CO2 571 ppm
온도 23.2 c 습도 48.3 %

*(a) pop-up window in an occupant's monitor*


CO2 799 ppm
온도 23.4 c 습도 41.0 %

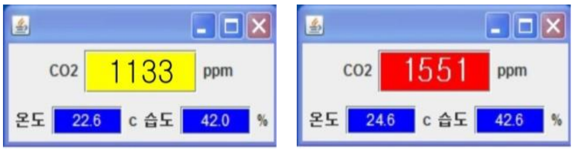
*(b)Pop-up window*

*Figure 7. Information provided to occupants*

Before Exp. #3, Table 2 was distributed and explained to all occupants for a short period (about 5-10 minutes). Some occupant attached Table 2 to his partition surface. While in Exp. #2 there was no alarm greater than 1,000ppm, the pop-up turned yellow and red when CO2 concentration becomes greater than 1,000ppm and 1,500ppm respectively in Exp. #3 (Figure 8).

*Table 2. Information provided to the occupants*

| **CO2(PPM)** | **REMARK** | |
|---|---|---|
| 350-450 | concentration level of outdoor air | |
| 1,000 | Acceptable level for ventilation and air quality | |
| 1,500 | Light disorder of metabolism, declined learning & concentration ability, light headache, drowsiness | |
| 4,000 | Pressure on the chest, respiration difficulty, headache | Oxygen shortage and abnormal balance of oxygen in blood |
| More than 7,000 | Difficult to survive | |

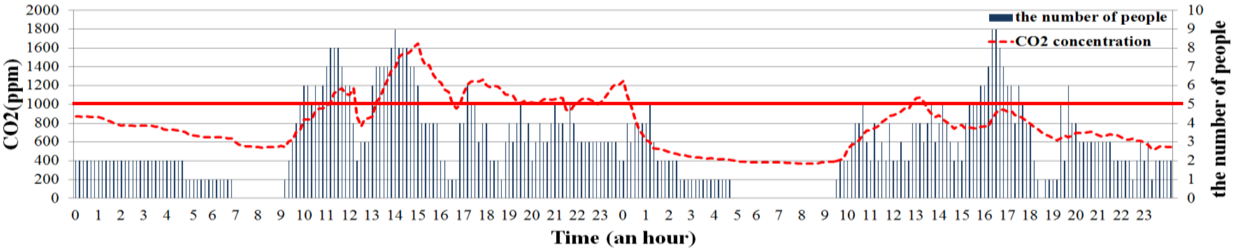

CO2 1133 ppm
온도 22.6 c 습도 42.0 %
CO2 1551 ppm
온도 24.6 c 습도 42.6 %

*(a) yellow alarm greater than 1,000ppm (Left)*
*(b) red alarm greater than 1,500ppm (Right)*
*Figure 8. Pop-up in Exp. #3*

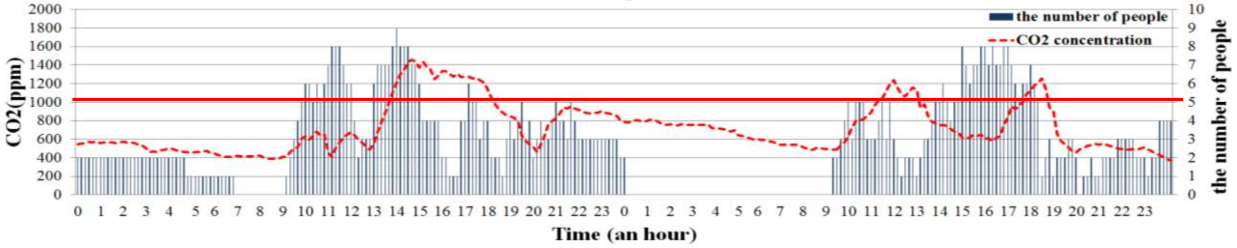
## RESULTS

Figure 9 illustrates the measured indoor CO2 concentration and the number of occupants during the experiments for 48 hours (sampling time: 1 minute). Though the number of occupants from Experiments #1-#4 remained similar, the CO2 concentration is significantly different from one another.

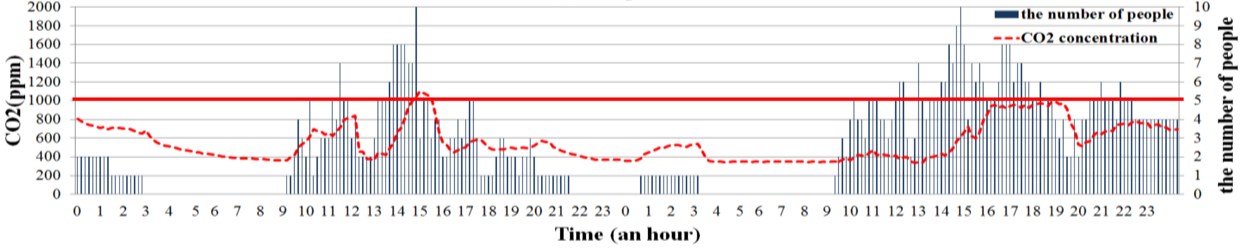
- Experiment #1: On the first day of the experiment, the CO2 concentration largely exceeded 1,000ppm and reached 1,600ppm. On the second day, it remained under 1,000ppm (Figure 9(a)). According to the webcam images, the occupants kept the exit door open most of the time during the second day, for which the reason is not discernible to the authors.
- Experiment #2: Although the CO2 concentration was informed to the occupants, the concentration sometimes reached 1,000ppm with the increased number of occupants. In



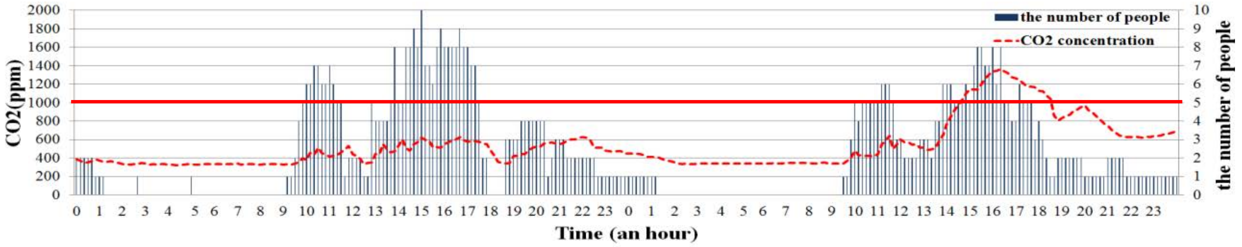
*(a) Experiment # 1*



*(b) Experiment # 2*



*(c) Experiment # 3*



*(d) Experiment # 4*

*Figure 9. Results of experiments*

general, lower CO2 concentration was measured, compared to Experiment #1 (Figure 9(b)).

- Experiment #3: After the 5-10 minutes short guide and 1-page note was distributed, occupants' reactions significantly changed. They took active actions in order to keep the indoor CO2 concentration under 1,000ppm (e.g., they kept the windows and the exit door open). As a result, the CO2 concentration remained under 1,000ppm most of the time. Although the number of occupants was greater than 6 on the second day, the CO2 concentration was still remained under 1,000ppm. (Figure 9(c)).
- Experiment #4: False information of CO2 concentration, 500 ppm plus the actual one, was provided. The occupants took much more active actions for ventilation than Exp. #3. As a consequence, the CO2 concentration on the first day was kept under 600ppm (Figure 9(d)). On the second day, however, the CO2 concentration exceeded 1,200ppm. It is interesting that the occupants stopped their ventilation efforts on the second day because they couldn't lower the indoor CO2 concentration less than 1,000 ppm. On the second day, they concluded that sensors are out of order.

Based on what has been mentioned above, what follows can be inferred:

- It is important that occupants are accurately informed of the indoor environmental information in real time. Providing indoor environmental information such as temperature, humidity, and CO2 is as beneficial as cutting-edge automatic control systems for comfort and satisfaction.
- For healthy environment, providing CO2 information, which is affordable with $50-$100, and enabling occupants to act as intelligent agents may be more responsive and effective than depending on expensive automatic ventilation systems. In Korea, installation of ventilation systems in residential buildings has become mandatory since 2006 (KMOCT 2006) Rather than resorting to mechanical ventilation

systems for indoor air quality, it might be better to leave occupants to be capable of maintaining good air quality as they wish.

- If appropriate guide and knowledge are delivered along with environmental information, the benefit will be multiplied.

### Stochastic analysis

The indoor CO2 concentration is affected by the respiration of the occupants. Table 3 shows the frequency of the number of occupants. The data with the least standard deviation, which is pertaining to ‘equal to or more than five occupants,’ was used for the following analysis.

*Table 3. Frequency of the number of occupants (The value measured every one minute was aggregated for the interval of ten minutes. Therefore, the number of samples for each experiment is 6 times/hour * 48 hours = 288)*

| NO. OF OCCUPANTS | EXP. #1 | EXP. #2 | EXP. #3 | EXP. #4 | AVR. | STD. |
|---|---|---|---|---|---|---|
| More than or equal to 4 | 93 | 93 | 104 | 86 | 94.0 | 5.76 |
| More than or equal to 5 | 73 | 66 | 71 | 68 | 69.5 | 2.32 |
| More than or equal to 6 | 36 | 45 | 35 | 44 | 40.0 | 4.04 |

Figure 10 shows the results in a probability density function. A Lognormal function in MATLAB was used for generating probability distribution curve since the P value of K-S (Kolmogorov-Smirnov) from the lognormal function is finest.

As shown in Figure 10, the CO2 concentration in Exp. #2 is lower than that in Experiment #1 in general. The averages of CO2 concentration are 1,131ppm (Exp. #1) and 844ppm (Exp. #2), and the probabilities exceeding 1,000ppm are 76.4% (Exp. #1) and 27.3% (Exp. #2) respectively. It can be inferred that occupants take active ventilation actions with environmental information provided.

During Exp. #2, the indoor CO2 concentration became higher than 1,000ppm due to the occupant’s lack of knowledge on the appropriate CO2 level. It is intriguing that a majority of the occupants wanted to know what the appropriate CO2 level is after the pop-up application had been installed (Figure 7).

Four out of eleven occupants curiously asked the authors the appropriate CO2 level but no answers were provided during Exp. #2. Although the occupants were not aware of the appropriate CO2 level, they showed their interests in CO2 level and accordingly took actions to decrease the CO2 level.

Before Exp. #3 the brief guide and 1-page note were provided (Table 2). The occupants being aware of CO2 level took ventilation actions with the pop-up alarms. Therefore, the frequency exceeding 1,000ppm was only three times, which was surprisingly as low as 4.2%. The maximum and average CO2 concentrations are 1,080ppm and 688ppm. This is contrary to Exp. #2 where the maximum and average CO2 concentrations are 1,458ppm and 844ppm (Table 4). It can be inferred that occupants took more ‘effective and intelligent’ actions during Exp. #3 than during Exp. #2 when comparison is made in terms of CO2 concentration standard deviations and the probabilities exceeding 1,000 ppm (Table 4).

It is interesting that the most frequent level of Exp. #2 is 600-699ppm, while that of Exp. #3 is 900-999ppm. This provides meaningful implication that when appropriate information and knowledge are provided, the occupants turn into intelligent agents in terms of healthy environment. In case of a mechanical ventilation system installed at a residential building, occupants frequently find it difficult to determine when to turn on or turn off the ventilation system. It is very likely to bring excessive outdoor air if current indoor CO2 concentration and a guide like Table 2 are not provided.

On the first day of Exp. #4, occupants continuously took ventilation actions (e.g., opening the exit door or windows). Based on the authors’ observation (e.g., frequent visit to the lab, interviews), more ventilation actions were taken in Exp. #4 than in Exp. #3. Therefore, the actual CO2 concentration was continuously kept between 500 and 700 ppm on the first day of the experiment, and the most frequent level is between 500 and 599ppm (Table 4). However, on the second day, the occupants concluded that the pop-up or the sensors might be malfunctioning since the CO2 concentration did not fall under 1,000ppm despite the opening of the windows and the door. As a result, they turned off the pop-up or stopped taking ventilation actions on the second day. The probability exceeding 1,000ppm increased from 4.2% (Exp. #3) to 25.0% (Exp. #4) accordingly (Table 4). The indoor CO2 concentration even reached a maximum of

*Table4. Comparison between experiments( Average number of occupants during ordinary office hours (from 9 to 22), and probability that CO2 concentration exceeds 1,000 when occupants are more than 5)*

| | EXP. #1 | EXP. #2 | EXP. #3 | EXP. #4 |
|---|---|---|---|---|
| AVERAGE NUMBER OF OCCUPANTS | 3.99 | 4.19 | 4.05 | 4.02 |
| MININUM (PPM) | 700 | 508 | 440 | 455 |
| AVRERAGE (PPM) | 1,131 | 844 | 688 | 716 |
| MAXIMUM (PPM) | 1,646 | 1,458 | 1,080 | 1,363 |
| STANDARD DEVIATION (PPM) | 208 | 275 | 217 | 317 |
| MOST FREQUENT LEVEL (PPM) | 1,000-1,099 | 600-699 | 900-999 | 500-599 |
| PROBABILITY EXCEEDING 1,000PPM | 76.4% | 27.3% | 4.2% | 25.0% |

1,363ppm. Due to such phenomenon on the second day, the standard deviation increased from 217ppm (Exp. #3) to 317ppm (Table 4). As the experiments were made in order, the occupants more or less learned the relationship between their ventilation actions and the CO2 concentration. As such relationship changed, they stopped the actions. This clearly shows that occupants are not 'static' but 'intelligently dynamic' and calls significant attention to how to account for cognitive response of human beings in building performance simulation.

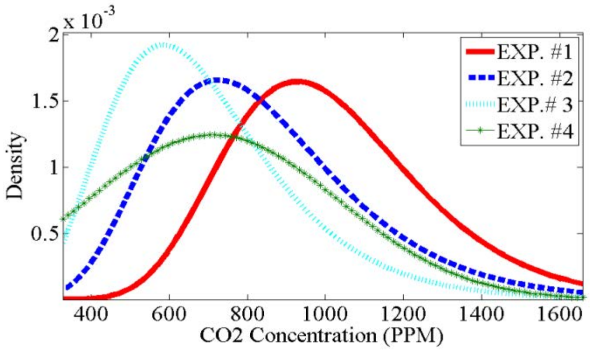


*Figure 10 . CO2 concetraion analysis*

## SIMULATION

One of the main themes in this paper is to address urgent need to reflect the aforementioned cognitive response of occupants for better building performance simulation. In this section, the authors want to demonstrate importance of occupants' response.

After the four experiments, the simulation run were made. The geometric thermal information of the laboratory was modeled in EnergyPlus 7.0. The measured occupant's schedule and meteorological data (KMA 2012) were used for the following simulation study. Occupants' ventilation actions (opening/closing the windows and door) and their influence on outdoor air rate entering the lab were modeled using infiltration schedule. The infiltration rate at each time step was determined so that 'Zone Air Carbon Dioxide Concentration,' one of the simulation results in EnergyPlus, would match the actual measured CO2 concentration. Be noted that Exp. #0 was added to Table 5 for comparison of cognitive agent simulation (Exp. #1-#4) to a traditional simulation approach. Exp. #0 represents a tranditional approach: schedules of occupants, equipment and lighting follow ASHRAE (2004). The indoor ventilation rate was set to 0.7 Air Changes per Hour (KMOCT 2006). Two different modeling approaches (traditional approach [Exp. #0] vs. occpuant based approach [Exp. #1-4]) were shown in Figure 11.

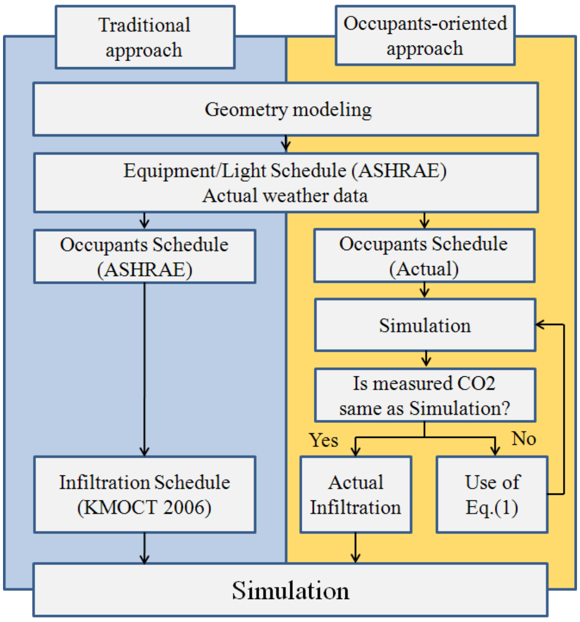


*Figure 11 . Simulation process*

The following simple optimization formulation was used for estimate infiltration model:

$$J = \min[(M - I)^T (M - I)] \quad (1)$$

Where

$J$: cost function,
M: vector of measured CO2 concentration,
I: vector of simulated CO2 concentration,
T: transpose

The following infiltration model in EnergyPlus was selected for this study. Due to lack of information on A, B, C, and D, FMINCON, one of the optimization routines in MATLAB was used.

$$I = \left(I_{design}\right) \times \left(F_{sch}\right) \times \left[A + B \times \left|\left(T_{zone} - T_{out}\right)\right| + C(Wind) + D(Wind^2)\right] \quad (2)$$

Figure 12 shows the simulation results of CO2 concentration. There was a significant difference between the measured, simulated (denoted by 'without Eq. (1)') and calibrated (denoted by 'with Eq. (1)').

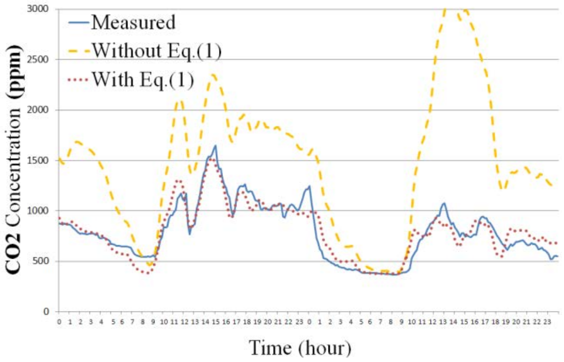


*Figure 12. Simulation result of CO2*

With the aforementioned calibration process as depicted in Figure 12, the simulated CO2 were made close to measured data for each experiment. Occupant behavior during each experiment were simulated for two days as shown in Table 5.

- Exp. #1: The energy use for Exp. #1 27.4kwh and 32.0kwh (Table 5). Compared to other experiments, Exp. #1 represents the least energy consumption due to lowest infiltration/ventilation rate and is similar to the results of Exp. #0.
- Exp. #2: Since more ventilation actions were taken compared to Exp. #1, the average of cooling energy consumption during days increased from 29.7 to 32.2kwh (Table 5).
- Exp. #3: Due to occupants' being aware of CO2 concentration and its impact, ventilation actions were taken actively to keep the indoor CO2 concentration less than 1,000ppm. As a result, the average energy consumption is as much as 35.4kwh. Since the occupants took ventilation actions more actively and regularly on the second day of the Experiment, the energy consumption on the second day was higher by 6.4kwh than on that on the first day (Table 5). This means that even with the same cognitive agent energy simulation model, such significant difference (about 7kwh) may exist.
- Exp. #4: Since occupants were informed of the manipulated CO2 concentration information, the energy consumption increased to 47.2kwh on the first day. As the occupants stopped ventilation actions on the second day, the energy consumption drastically dropped to 22.7kwh (Table 5). This means twofold: (1) occupants are a very dominant and intelligent agent in building energy use. (2) mal-functioning sensors/systems/equipment can significantly change the landscape we view by lens of building simulation.

Based on the discussion above, the following can be inferred:

- The traditional (conventional) approach (Exp. #0) significantly differs from those that consider cognitive agents in building. For the next decade, simulating such agent is very urgent for better prediction and performance assessment.
- When indoor CO2 information and its meaning were provided, energy consumption was increased, contrary to our expectation. However, please be noted that the experiments were conducted in the small and densely populated laboratory. The energy use could be reverse if it had been done in a large and sparsely populated or randomly occupied space.
- Smart devices are widely adopted in Architecture / Engineering / Construction (AEC) industry and sooner or later occupants will be able to check the indoor environment ubiquitously, anywhere anytime. It means that occupants will act as not static but dynamic and intelligent agents in buildings. Future building simulation must challenge to represent such agents' behavior and response in building simulation.

## CONCLUSIONS

This paper examined the impact of providing indoor environmental information and knowledge upon the occupants' behaviors and response. It also aimed to discover the influence of occupants' behaviors and response on the building energy simulation. Therefore, a total of four experiments were performed and their results were analyzed. Based on the experiments, simulation runs were made.

As a result, occupants' awareness and behavior have changed through the provision of indoor environmental information and knowledge. In particular, their cognitive response to keep the CO2 concentration under 1,000ppm shows that occupants can become intelligent agents when richer information ("the information with knowledge") is provided. Such cognitive response and actions of the occupants greatly influence the building's energy consumption, which must be reflected in traditional building simulation.

## ACKNOWLEDGEMENT

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*Table5. Simulation results (weather data between 2012/06/04 00:00:00 ~ 2012/06/05 23:59:59 were used)*

| | **EXP. #0** | | **EXP. #1** | | **EXP. #2** | | **EXP. #3** | | **EXP. #4** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Day1 | Day2 | Day1 | Day2 | Day1 | Day2 | Day1 | Day2 | Day1 | Day2 |
| Energy Use(Kwh) | 28.6 | 31.4 | 27.4 | 32.0 | 30.9 | 33.4 | 32.2 | 38.6 | 47.2 | 22.7 |
| Compare Exp. #0 (%) | - | - | 95.8 | 102.0 | 108.0 | 106.4 | 112.6 | 122.9 | 165.0 | 72.3 |
| Daily Average | 30.0 | | 29.7 | | 32.2 | | 35.4 | | 35.0 | |
| Air Change /hour | 0.70 | | 0.97 | | 1.13 | | 1.89 | | 2.13 | |

## REFERENCES

ASHRAE / ANSI / ASHRAE Standard 90.1 (2004), Energy standard for building except low-rise residential buildings. USA: Atlanta

ASHRAE (2007), ASHRAE Standard 62.1, Ventilation for Acceptable Indoor Air Quality, American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc., Atlanta, USA

ASHRAE (2009), ASHRAE Handbook — fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc., Atlanta, USA

Bourgeois D., Reinhart C. and Macdonald I. (2006), Adding advanced behavioural models in whole building energy simulation: a study on the total energy impact of manual and automated lighting control, Energy and Buildings Vol.38, No.7, pp.814-823

Clinton J.A., Daniel Y., Uta K., Jennifer A.S. and Richard E.W. (2011), Designing buildings for real occupants: An agent-based approach, IEEE Transactions on systems, man, and cybernetics-part A: systems and humans, pp.1-15

Fujii H. and Tanimoto J. (2004), Integration of building simulation and agent simulation for exploration to environmentally symbiotic architecture, Building and Environment Vol.39, No.8, pp. 885-893

IBPSA (2005-2011), Proceedings of the IBPSA (International Building Performance Simulation Association) conference ('05, '07, '09, '11)

Kashif A.X.H., Binh L., Dugdale J. and Ploix S. (2011), Agent based framework to simulate inhabitants' behaviour in domestic settings for energy management, ICAART 2011 (International Conference on Agents and Artficial Intelligence), Italy.

KECO (2010), Indoor air quality test standards process 2010.10. Seoul, Korea: Korea Environment Corporation.

Kim, J.H., Park, S.L., Kim, D.W. and Park, C.S. (2011), Agent-based Building Energy Simulation, Journal of Architectural Institute of Korea, Vol.27 No.12 pp.315-324

Kim, Y.J. and Park, C.S. (2009), Probabilistic Prediction of Occupants' Presence in Residential Dwellings, Proceedings of the 11th ROOMVENT Conference, May 24-27, Busan, South Korea, pp.105-112

KMA (2012), Observed meteorological data, Suwon, Korea: Korea Meteorological Administration(http://www.kma.go.kr/weather/observation).

KMOCT (2006), Ventilation Standard for Residential Buildings 2006-11-512. Seoul, Korea: Korean Ministry Of Construction and Transportation (in Korean).

Mahdavi A. and Proglhof C. (2009), Toward empirically-based models of people's presence and actions in buildings, Proceedings of Building Simulation, Scotland 9, pp.537-544

Page J., Robinson D., Morel N. and Scartezzini J.L., (2007), A generalised stochastic model for the prediction of occupant presence, Energy and Buildings, Vol.40, No.2, pp.83-98

Park, Sang-Lin, Kim, J.H., Kim, D.W and Park, C.S. (2012), Stochastic and Cognitive Agent-based Building Energy Simulation, Journal of Architectural Institute of Korea Vol.28 No.1 pp.293-301

Sierhuis M., Clancey W.J. and Hoof V.R. (2007), BRAHMS A multi-agent modelling environment for simulating work processes and practices, International Journal of Simulation and Process Modelling

Zhun Y., Benjamin C.M.F., Fariborz H., Hiroshi Y. and Edward M. (2011), A systematic procedure to study the influence of occupant behavior on building energy consumption, Energy and Buildings Vol.43, No.6, pp.1409-1417