7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient Buildings and Urban Environments

ibpc2018.org | #ibpc2018

Periodic alternation between intake and exhaust of air in dynamic insulation

Masaru Abuku[1,*], Akira Fukushima[2], Tsukasa Tsukidate[3], Sayaka Murata[3], Akinori Hosoi[4], Hideo Ichiboji[5], Daisuke Kitagawa[5] and Kanako Makita[5]

[1]Kindai University, Japan
[2]Hokkaido University of Science, Japan
[3]Northern Regional Building Research Institute, Hokkaido Research Organization, Japan
[4]Japan Woman's University, Japan
[5]Asahi Kasei Construction Materials Corporation, Japan

[*]*Corresponding email: abuku@arch.kindai.ac.jp*

ABSTRACT
Dynamic insulation (DI) can recover heat lost in conduction by drawing cold outdoor air into indoor through an insulation wall in winter. A "breathing DI" system we proposed in the past has functions both as an insulated envelope and as a highly efficient heat exchanger for ventilation. It is alternated periodically that the outdoor air is drawn through half of walls made of breathable inorganic concrete (BIC) and the indoor air is exhausted through the other half of the BIC walls. In order to put the breathing DI system into practice in housing construction, this paper presents some studies from various points of view in addition to the past studies on heat and moisture transport based on laboratory experiments and numerical simulations. We first experimentally studied the filtering efficiency and clogging of a BIC panel. This showed that approximately 30 % of the atmospheric dust can be captured by a BIC panel and no clogging would occur for at least 10 years. We also measured the sorption and desorption of formaldehyde by a BIC panel to confirm the effectiveness of a BIC wall to sorb gaseous state formaldehyde. We furthermore constructed a new test house at Ibaraki, Japan, to confirm the thermal performance of the breathing DI system based on full scale experiments.

KEYWORDS
Insulation, ventilation, heat recovery, indoor air quality,

1. INTRODUCTION
Dynamic insulation (DI) can recover heat lost in conduction by drawing cold outdoor air into indoor through an insulation wall in winter (Jensen, 1993; Taylor and Imbabi, 1997; Taylor et al. 1997; Dimoudi et al. 2004). A "breathing dynamic insulation" system (Abuku et al. 2012; Murata et al. 2015) we proposed in the past has functions both as an insulated envelope and as a highly efficient heat exchanger for ventilation. It is alternated periodically with a certain time interval that the outdoor air is drawn through half of walls made of breathable inorganic concrete (BIC) and the indoor air is exhausted through the other half of the BIC walls. After the heat in the exhaust air is stored inside the BIC walls, the stored heat in addition to the heat lost in conduction through the BIC walls is recovered by the supply air.

Our past numerical study (Abuku et al. 2012) showed that the inside surface temperature of the BIC walls can be kept the same as that of conventional "static" insulation walls and the recovery efficiency of the heat in the exhaust air can be improved to up to more than 90%. It was also experimentally shown that the BIC wall under study has recovery efficiencies of almost 90% of the heat in the exhaust air, 18 to 35 % of the heat lost in conduction, and approximately 80% of the moisture lost through the BIC wall (Murata et al. 2015).

In order to put the breathing DI system into practice in housing construction, this paper addresses some other aspects of the system. We first experimentally studied the filtering efficiency and clogging of a BIC panel. We also measured the sorption and desorption of formaldehyde by a BIC panel to confirm the effectiveness of a BIC wall to sorb gaseous state formaldehyde. We furthermore constructed a new test house at Ibaraki, Japan, to perform full scale measurements of the hygorthermal performance, ventilation, energy consumption, and indoor air quality.

2. BREATHING DYNAMIC INSULATION SYSTEM

The breathing DI system consists of two distinct spaces that are enclosed by BIC walls and fans between the two spaces as illustrated in Fig.1. BIC has a high air permeability, a high insulation performance and a relatively large thermal storage. In this system, the outdoor air is drawn through half of the BIC wall, while the indoor air is exhausted through the other half. Intake and exhaust of air through the two halves of the wall are periodically alternated. An airflow from one space to the other is controlled by fans. After the heat in the exhaust air is stored inside the BIC walls, the stored heat in addition to the heat lost in conduction through the BIC walls is recovered by the supply air. Consequently, the “Breathing DI” system has functions both as an insulated envelope and as a highly efficient heat exchanger for ventilation.

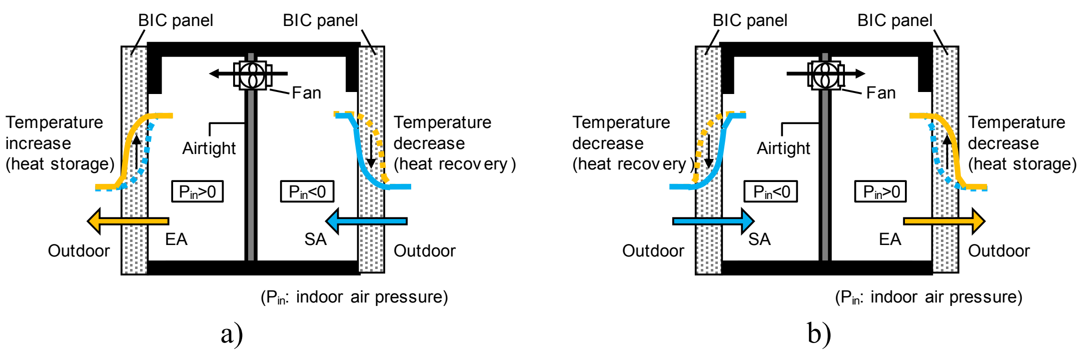


Figure 1. Schematic of the breathing DI system (slightly modified based on Murata et al. 2015). a) One operation mode with airflow in one direction, b) the other operation mode with airflow in the opposite direction.

3. FILTERING EFFICIENCY AND CLOGGING

The filtering efficiency of BIC panels for dust was measured outdoor. The measurement was conducted on the flat roof of building #34, Higashi-Osaka campus, Kindai University, Japan during October 24, 2016 – January 31, 2017. The building is located near busy roads and highways. The schematic of the experimental set-up is given in Fig. 2. The set-up is composed of wooden panels and frames, an electronic fan, a BIC panel (30 cm x 30 cm x 8 cm) with an air filter as well as a hygro-thermometer and a digital dust monitor both in and outside the box. The air filter was attached to the inner surface of the BIC panel to diminish the influence of powder remaining in the BIC panel on the dust concentration in the box. Note that it was confirmed that this air filter does not influence the dust concentration measured by the dust monitors. The difference between the outside dust concentration C_o (mg/m^3) and the inside dust concentration C_i (mg/m^3) is considered to be due to the BIC panel. In the current paper, the filtering efficiency E_f (%) is defined by

$$E_f = \frac{C_o - C_i}{C_o} \times 100 . \tag{1}$$

In the breathing DI system, the direction of airflow though BIC panels changes with a certain interval of time (e.g. 10 minutes). However, in this experiment, the direction of airflow through a BIC panel was not changed to accelerate the decrease of the filtering efficiency of the BIC panel.

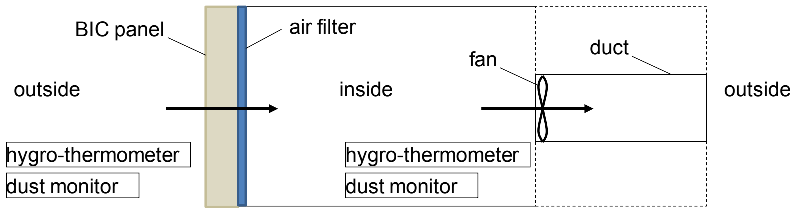


Figure 2. Schematic of the experimental set-up to measure the filtering efficiency of a BIC panel.

The inside and outside dust concentrations as well as the temperature and relative humidity (RH) values were measured and averaged over every 10 minutes. For each parameter, 211 data were successively obtained. The average outside dust concentration for all the data was 0.0135 mg/m^3 with a standard deviation of 0.0084 mg/m^3 and the maximum is 0.0350 mg/m^3. E_f was 29.7 % on average with a standard deviation of 11.8 % and 61.5 % at the maximum. The relation between E_f and the number of measurement is given in Fig. 3a; the dependency of E_f on C_o is shown in Fig. 3b. Note that although in Fig. 3b there seems to be less number of data points, this means that some data show the same relation between E_f and C_o. The results show that the filtering efficiency did not decrease with time at least under the current study, although this is also supported by discussion on clogging in the last part of this section. It was also shown that the filtering efficiency is stably high when the outside dust concentration is high. This is probably because when the dust concentration is high, particles in the dust are large and thus easily captured by the BIC panel.

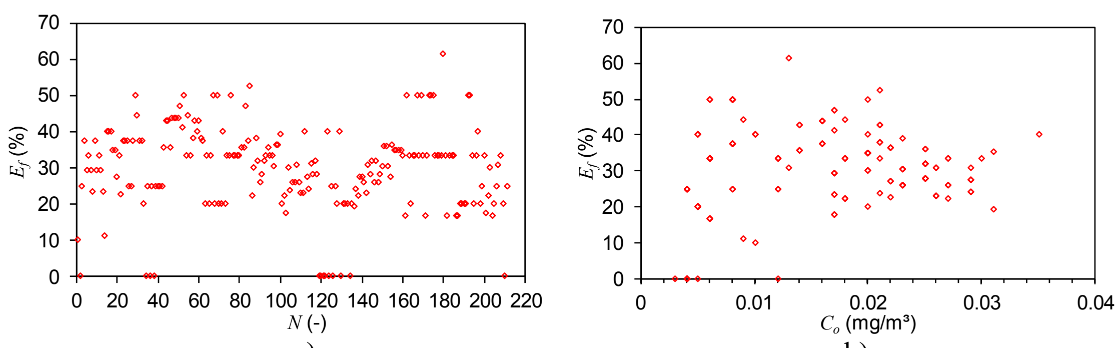


Figure 3. The dependency of the filtering efficiency E_f of the BIC panel on a) the number of measurement N and b) the outside dust concentration C_o.

In general, various factors affects the dust concentration (e.g. Csavina et al. 2014) that would eventually influence the filtering efficiency. In the current study, the relationships of E_f with the outside RH and humidity ratio are discussed as they would be considered to be one of the most important factors. Fig. 4. There is no correlation between E_f and the RH. However, only when the humidity ratio is high, E_f became stably high and there seems to be a positive correlation between E_f and the humidity ratio. This is because particles in dust can swell when they absorb moisture and can be then captured by the pore structure of the panel more easily and because a wet surface of the pore structure can capture more dust.

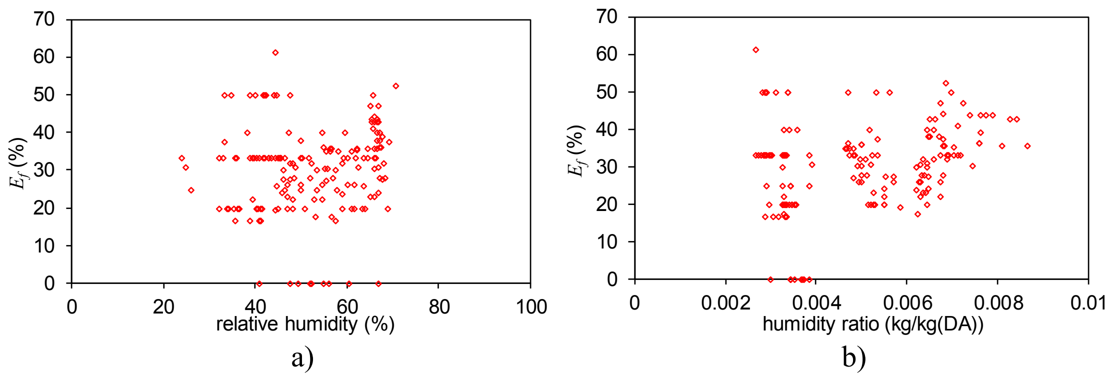


Figure 4. The dependency of the filtering efficiency E_f of the BIC panel on a) the outside relative humidity and b) the outside humidity ratio.

Apart from air filtering, when a large amount of atmospheric dust accumulates in the BIC panel, the air permeability might be reduced which affects the performance of the DI system. The possibility of clogging of a BIC panel due to atmospheric dust was also estimated here tentatively assuming some input values and summarised in Table 1. The air permeability value of the BIC panel was taken from our own measurements. The result show that as the dust mass captured by the panel is very small, almost no clogging of the BIC panel would occur at least for 10 years. It should be noted that in the breathing DI system, the intake and exhaust of air through the panel are alternated periodically and thus the dust mass captured by the panel should be the half of the one given in Table 1 if the indoor air is clean.

Table 1. Estimate of the possibility of clogging of the BIC panel due to atmospheric dust

Input/Output	Parameter	Value	Unit
	Atmospheric dust concentration	0.02	mg/m^3
	Air permeability	1.07	m/(h·Pa)
Input	Pressure difference between indoor and outdoor	20	Pa
	Service life	10	year
	Filtering efficiency	30	%
	Airflow rate	1.92	m^3/h
Output	Airflow speed	5.93	m/s
	Dust mass captured by the panel	11.2	g/m^2

4. SORPTION AND DESORPTION OF FORMALDEHYDE

As one of drawbacks of the breathing DI system, a BIC panel can also sorb volatile organic compounds when the indoor air is exhausted through the BIC panel and then desorption of them to the inside might occur. According to Curling et al. (2012), the sorption and desorption of water and those of water plus formaldehyde were measured using the dynamic vapour sorption technique with a RH interval of 5 %. The results are given in Fig. 5a. The measured mass content of water plus formaldehyde was then subtracted by the measured water content to obtain the content of formaldehyde (Fig. 5b). Furthermore, the absorption/desorption rate was obtained by dividing the mass content increment/decrement for each RH step by the time used to obtain the equilibrium (Fig. 5c). The result means that after one cycle of absorption and desorption, most formaldehyde captured in the material is not desorbed. It was also shown that the desorption rate is lower than the absorption rate.

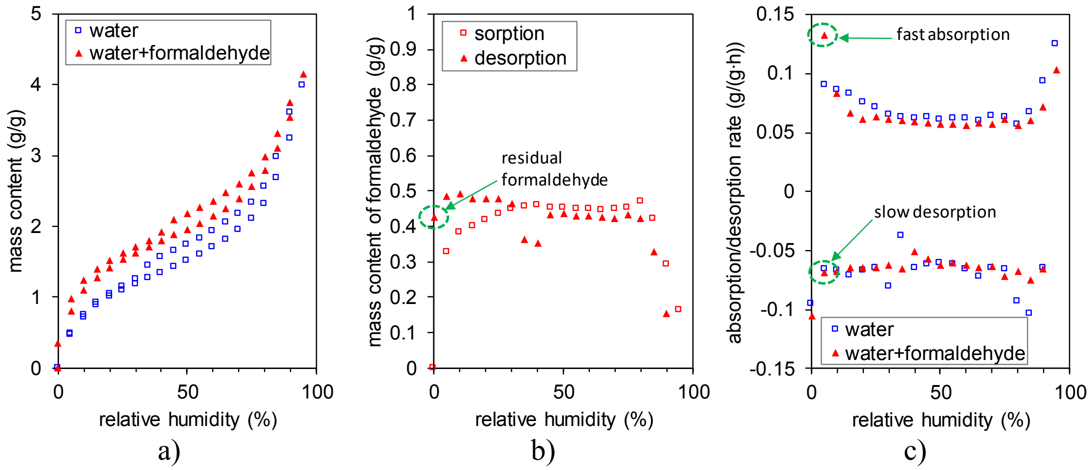


Figure 5. Measured sorption and desorption of water and formaldehyde by the BIC panel. a) sorption and desorption isotherm of water and water plus formaldehyde, b) the mass content of formaldehyde in the material, c) sorption and desorption rate of water and water plus formaldehyde.

5. FULL SCALE MEASUREMENTS AT A TEST HOUSE

Full scale measurements to confirm the thermal effectiveness of the breathing DI system were carried out at a two-storey test house (Fig. 6) located at Ibaraki prefecture, Japan. The test house has a gross floor area of 103 m^2 (1F: 52 m^2; 2F: 51 m^2), a total volume of approximately 300 m^3 and a high insulation performance with the area-weighted average U-value of 0.25 $W/(m^2K)$. At this test house, we measured the vertical temperature distribution (Fig. 6b) in an atrium space of the house with or without the breathing DI system. For three days (January 13-15, 2017) when the breathing DI system was operated with a time interval of 15 minutes for alternation of intake and exhaust of air, the ventilation rate was kept at 150 m^3/h. For other three days (February 3-5, 2017) without the breathing DI system, three mechanical ventilation fans were always operated in two rest rooms and an undressing room to obtain a total ventilation rate of ~ 200 m^3/h. Fig. 7 plots the indoor temperatures measured at different heights as well as the outdoor temperature measured near the test house. The results confirm the effectiveness of the breathing DI system, showing that with the breathing DI system, the indoor temperatures can be kept both higher and more uniform. Note that there

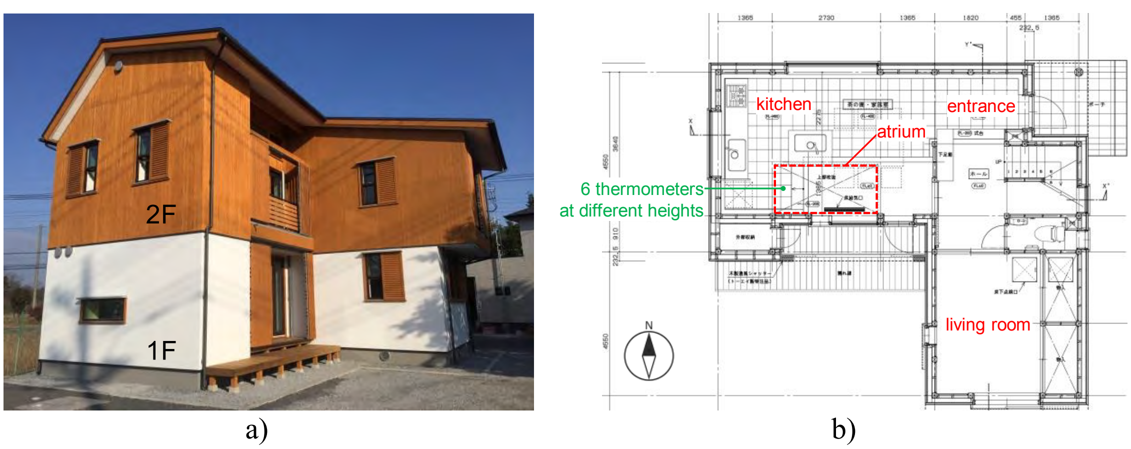
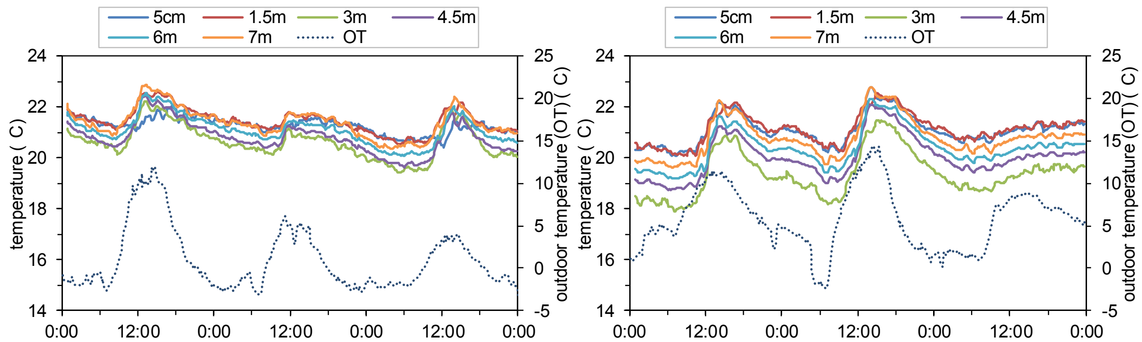


Figure 6. A two-storey test house equipped with the breathing DI system at Ibaraki prefecture, Japan. a) A photograph, b) Plan (1st floor).



a) b)

Figure 6. Indoor temperatures measured at different heights in an atrium of the test house compared to the outdoor temperature. a) Breathing DI system, b) Normal mechanical ventilation.

was a heat source under the floor of the 1st floor, so the temperatures measured at 5 cm and 1.5 m were higher than those at ≥ 3m.

6. CONCLUSIONS

In order to put the breathing DI system into practice in housing construction, we first experimentally studied the filtering efficiency and clogging of a BIC panel. This showed that approximately 30 % of the atmospheric dust can be captured by a BIC panel and no clogging would occur for at least 10 years. By measuring the sorption and desorption of formaldehyde by a BIC panel, we also showed that a BIC wall is effective to reduce gaseous state formaldehyde. Lastly, full scale experiments at the test house demonstrated that the breathing DI system can keep the indoor temperature higher and more uniform in winter.

REFERENCES

Abuku M, Fukushima A, Tsukidate T, Murata S, Iba C, Watanabe H, Ogawa A. 2012. Periodic alternation between intake and exhaust of air in dynamic insulation: A preliminary study. In: *Proceedings of the 5th International Building Physics Conference (IBPC)*, Kyoto, Japan, May 28-31, 2012, pp.303-307

Csavina J, Field J, Félix m, Corral-Avitia AY, Eduardo Sáez A, Betterton EA. 2014. Effect of wind speed and relative humidity on atmospheric dust concentrations in semi-arid climates, *Sci Total Environ*, 487, 82–90.

Curling SF, Loxton C, Ormondroyd GA. 2012. A rapid method for investigating the absorption of formaldehyde from air by wool. *Journal of Materials Science*, 47(7), 3248-3251

Dimoudi A, Androutsopoulos A, Lykoudis S. 2004. Experimental work on a linked, dynamic and ventilated wall component, *Energy and Buildings*, 36, 443-453

Jensen L. 1993. Energy impact of ventilation and dynamic insulation. In: *Proceeding of the 14th AIVC conference*, pp.251-260

Murata S, Tsukidate T, Fukushima A, Abuku M, Watanabe H, Ogawa A. 2015. Periodic Alternation between Intake and Exhaust of Air in Dynamic Insulation: Measurements of Heat and Moisture Recovery Efficiency. *Energy Procedia*, 78, 531-536

Taylor BJ, Imbabi MS. 1997. The effect of air film thermal resistance on the behaviour of dynamic insulation. *Building and Environment*, 32(5), 397-404

Taylor BJ, Webster R, Imbabi MS. 1997. The use of dynamic and diffusive insulation for combined heat recovery and ventilation in buildings. In: *Proceedings of BEPAC/EPSRC Sustainable Building Conference 1997*, pp.168-174