

Energy and Filtration Performance Verification Study of a Dynamic Breathing Building System in KIER

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ABSTRACT: Power consumption in the building thermal load could be the sum of the building fabric conduction load, building ventilation convection load and other such as radiation loss load. Dynamic Breathing Building (DBB) is the state-of-the-art to improve the wall insulation and indoor air quality (IAQ) performance as making air flow through the wall. This heat recovery type DBB contributes the power consumption saving due to the improved dynamic U-value. The key principle comes from the nano scaled breathing wall technique and thus could apply to the real building to improve the energy and health performance toward a future low carbon green building. KIER (Korea Institute of Energy Research) twin test cell with static insulation (SI) and dynamic insulation (DI) at KIER was developed to test building power consumption at the real outside conditions. Then, the actual results were compared with the theory to predict the power consumption at the KIER twin test cell and introduced the building new radiation loss factor α to explain the difference between the both the theory and the actual case. Filtration performance was also evaluated about breathing DI wall building. The energy performance results indicated that the power consumption at the breathing DI wall building could be saved 10.8% at the 2ACH compared with conventional insulation. The building radiation loss factor α for this test condition to calibrate the actual test was 0.55 in the test condition. And the filtration performance test indicated that the breathing DI wall building at the 0.7ACH could reduce the dust particles by 80%.

Keywords: dynamic breathing building (DBB), static insulation (SI), dynamic insulation (DI), building radiation loss factor, energy filtration performance

1. INTRODUCTION

The need of energy conservation and indoor air quality improvement has been becoming more evident issue in new building science. Recent drastic decrease in indoor air quality due to more required air tightness of modern building puts emphasis to make changes in building designs to bring

in more fresh outdoor air in order to make more pleasant air quality inside. This air exchange has brought forth couple of undesirable issues of excess energy expenditure in the usage of a ventilation system in a building to maintain relatively constant air quality and temperature. The excess energy consumption from buildings inevitably produces more harmful GHG

gases that will make the environmental condition even worse.

The problem that needs to be addressed is to find a dynamic insulation (DI) methodology for dynamic breathing building (DBB) to save energy and improve the indoor air quality simultaneously. DBB is a building with DI material envelope. The DI increases the insulation with the nano scale air insulator and could reduce the conduction heat loss as the air velocity increases through the DI. A fresh air could penetrate through the DI so that it could also reduce the indoor air quality problem as well. DBB could reduce heat loss from building envelope and building ventilation. Therefore, DBB could be a part of the architectural solution for the future global warming problems.

The purpose of this paper is to investigate the theory of DBB so that the degree of heat transmission rate depending upon the air velocity through a DI will be explained. Second, the theoretical prediction over energy performance will be verified with the twin test cell which has dynamic insulation (DI) and static insulation (SI) set up for this purpose in KIER. Third, the filtration performance is also verified with actual test data under a spring yellow dust conditions in Korea. The predicted and experimented results will be compared to develop a better theoretical model and support the model validation and the future DBB dissemination.

2. STATIC INSULATION AND DYNAMIC INSULATION FOR DYNAMIC BREATHING BUILDING

Dynamic breathing building (DBB) technique provides high insulation, ventilation and filtration as making air flow through the wall. Therefore, this technology enables provision of high quality indoor environments, uses less energy, and combats urban air pollution. Because air flow through the wall is very slow (under

$v=0.01\text{m/s}$), as well residents rarely be aware of it. The DBB breathing wall heat loss coefficient reduces dynamically as a function of inward airflow rate can significantly reduce conduction heat loss through the wall. The DI breathing wall also acts as a heat exchanger and heat recovery device, pre-heat fresh air used to ventilate the building. A dust and pollution particles are filtered and indoor air quality (IAQ) was satisfied. In order to understand the basic process of heat transfer in a breathing wall, a single layer conventional versus breathing wall are compared in Figure 1 below for heating mode. For a conventional SI wall in winter, the heat loss is governed solely by the temperature difference ($T_i - T_o$) and the static heat loss coefficient of the wall. A DI could reduce ΔT with the heat recovery principle; which the cool outside air is drawn into the wall and it causes the outer layers of the wall to cool down as forcing the temperature profile downwards as shown in the Figure 1.

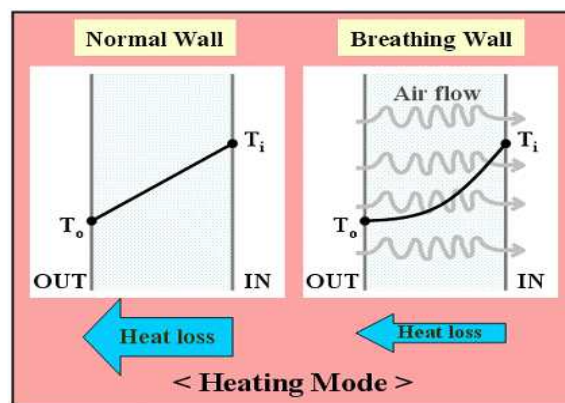


Figure 1: Concept of dynamic insulation breathing wall.

2.1 A DI Energyflo cell was considered to verify its predicted behaviour

The Energyflo cell is a modular DI product that consists of porous filter inside and styrofoam outside and this directly replaces conventional thermal insulation in buildings. Porous filter, inside the Energyflo cell, improves indoor air quality by intercepting or filtering a dust and pollution

particles. The module's heat loss coefficient changed according to airflow rate. This module insulation called by dynamic insulation.

The cell is available in thickness of 95, 135 and 175 mm. The U-value of Energyflo cells varies dynamically with inward air flow through the cells. A plot of elemental U-values using different cell thickness is shown in Figure 2 below. In the Figure, the U-value at the 0 airflow rate is 0.36W/m².K in 95mm, as well 0.28W/m².K in 135mm, 0.20W/m².K in 175mm. The airflow rate to be 0 U-value is 0.005m/s in 95mm cell, 0.02m/s in 135mm, 0.0015m/s in 175mm.

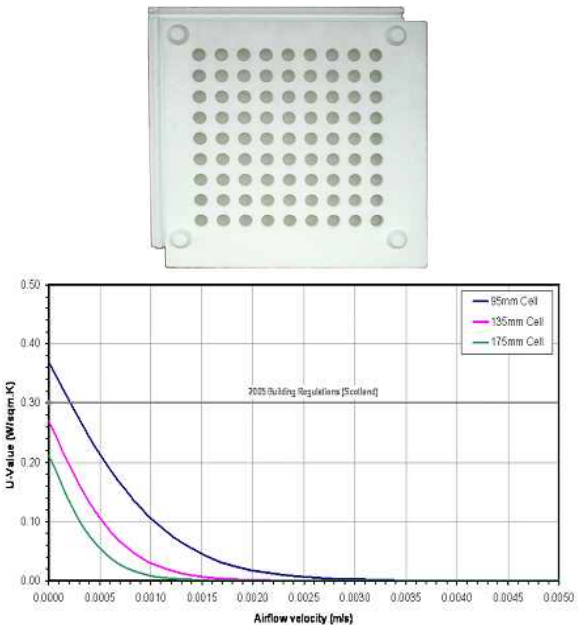


Figure 2: Tested dynamic insulation energyflo cell (above) and dynamic U-value (below)[1].

3. KIER TWIN TEST CELL

3.1 Twin test cell specifications

Two identical cells with SI and DI have been set up to test the energy performance in a heating season. The picture and the schematic of the test cells are shown in Figure 3. The dimension and thermal data are also shown in Table 1. The main concept of the cell has been referenced and supported from the international labs, which had the

similar test such as European Passive Solar Component Test project PASSYS to test several passive solar components.

Two identical cells of 2.0*3.8*2.4m in width*depth*height have all the same panels except the southern face wall component: one with SI(Styrofoam) and the other with DI(Energyflo).

Table 1: KIER twin test cell specification.

Type	Area (m ²)	Material	Conductivity (W/m.K)	Thickness (m)	U-value (W/m ² . °C)
Wall (East, West)	9.12	Steel panel	194.000	0.001	0.291
		Urethane foam	0.023	0.075	
Wall (North)	4.80	Steel panel	194.000	0.001	0.291
		Urethane foam	0.023	0.075	
Wall (South)	RW	Air	0.170	0.040	0.273
		Plywood	0.140	0.012	
		Wood panel	0.075	0.015	
		Insulation(Styrofoam)	0.032	0.095	
		Steel panel	194.000	0.001	
	BW	Air	0.170	0.040	0.293 (zero flow)
		Plywood	0.140	0.012	
		Wood panel	0.075	0.015	
		Insulation(Energyflo cell)	0.035	0.095	
		Steel panel	194.000	0.001	
Floor	7.60	Steel panel	194.000	0.001	0.291
		Urethane foam	0.023	0.075	
		Urethane foam	0.023	0.100	
Roof	7.60	Gypsum board	0.180	0.010	0.194
		Air	0.170	0.100	
		Steel panel	194.000	0.001	

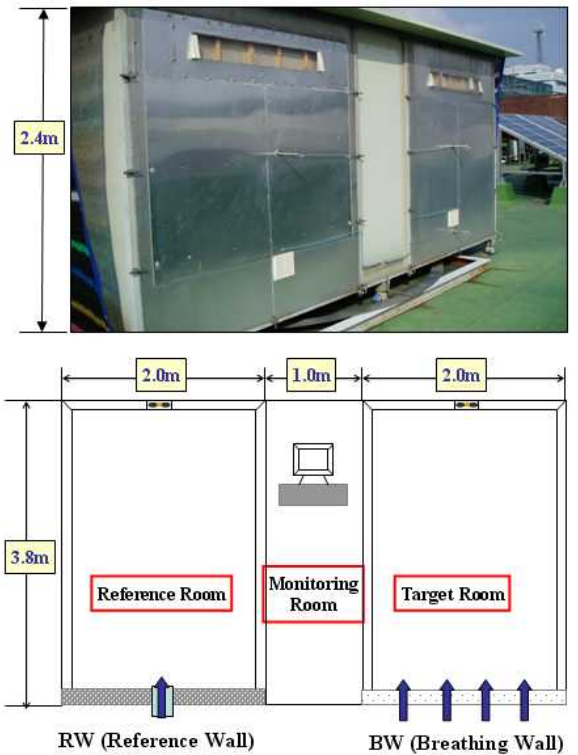


Figure 3: KIER twin test cell picture.

Monitoring systems to measure the heating and cooling power for each cell

have been set up as in Figure 4(Right for the SI and left for the DI). The cell could control the indoor set temperature and the monitoring system could obtain the temperatures of the outdoor, outer face and the inner face of the insulation and the inner surface and the outer surface of the cell. RTD temperature sensors were used for temperature logging. The power for the heat pump has been measured with power transducer located inside the cell. The duct of 100mm diameter and 1,000mm length hole duct simulated the expected ventilation for the SI case. The total outward ventilation, for instance, could sum of the inward ventilation and the infiltration; which was measured by a turbine flow meter up to about 7ACH at the DI case.

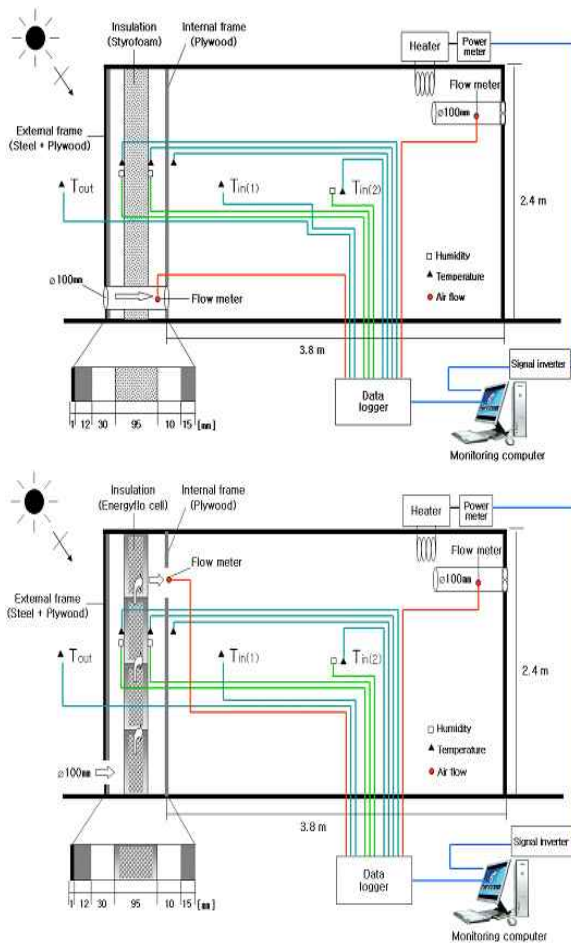


Figure 4: Monitoring system for RW with SI(above) and BW with DI(below).

Agilent 34970A data acquisition system with RS232 and RS485 data communication

protocol were used for data logging at the remote office from the cell. Key measured parameters were temperatures, humidity, air flow rates and power consumption. The data has been collected every one minute and stored in computer and also the data could be monitored from the remote office through the internet web and the data communication process.

Test has been conducted in two steps: the first passive step is to check it the initial conditions of the two cells and the second active step is to compare the power from the cells for the different ventilation rate and out door temperatures. The indoor temperature was set to 22°C and the air flow rate varied from 0 to 7 ACH (0.0074 m/s). Test data during the night time was used to avoid the impact of solar radiation during the day time. And the heating power in winter days was measured for the cells.

3.2 Dynamic Insulation (DI) Theory

A building thermal conduction load is generally estimated by the building wall U-value. The reference conventional building envelope static U-value U_s is obtained by equation (1).

$$U_s = \frac{1}{\frac{1}{\alpha_o} + \sum_{i=1}^n \frac{l}{\lambda} + \gamma_a + \frac{1}{\alpha_i}} \quad (1)$$

Where:

α_o = Wall outside surface heat transmission value [kcal/m²·h·°C]

α_i = Wall inside surface heat transmission value [kcal/m²·h·°C]

λ = Thermal conductivity [kcal/m·h·°C]

l = Thickness [m]

γ_a = Air heat resistance [m²·h·°C/kcal]

U-value of a dynamic breathing building (DBB) is not possible to get by equation (1) due to the changed U-value as an air velocity variety through the wall. U-value of a DI is obtained using the expression derived by Taylor *et al* [3]. Therefore,

dynamic U-value U_d to get the building insulation effect of the DBB is obtained by equation (2).

$$U_d = \frac{v_a \rho_a c_a}{\exp(v_a \rho_a c_a R) - 1} \quad (2)$$

Where;

v_a = Air flow velocity through DI [m/h]

ρ_a = Density of air [kg/m³]

c_a = Specific heat of air [kcal/kg·°C]

R = Resistivity of the dynamic insulation [m²·h·°C/kcal]

3.3 Building thermal load power prediction model

Power consumption in the building thermal load is the sum of the building fabric conduction load, building ventilation convection load and other such as radiation loss load. Building fabric conduction load comes into the difference of indoor and outdoor temperature. Building ventilation convection load comes into the air flow from outdoor to indoor. Power consumption in the building is given by equation (3). Here, U_T is total heat transmission rate and A_T is a total wall area of the building.

$$POWER = U_T A_T \Delta T + M_T C_p \Delta T \quad (3)$$

$$U_T = \frac{1}{A_T} [U_r A_r + U_{wE} A_{wE} + U_d A_{wS} + U_{wW} A_{wW} + U_{wN} A_{wN} + U_f A_f] \quad (4)$$

$$A_T = A_r + A_{wE} + A_{wS} + A_{wW} + A_{wN} + A_f \quad (5)$$

Where;

$U_T A_T \Delta T$ = Building fabric conduction load [kcal/h]

$M_T C_p \Delta T$ = Building ventilation convection load [kcal/h]

Subscript r is a roof, wE is an east wall, wS is a south wall, wW is a west wall, wN is a north wall and f is a floor.

Building ventilation convection loads are the sum of the building ventilation load and infiltration load as in equation (6). The building ventilation load is directly occurred when outdoor air is guided inside building

by natural ventilation and mechanical ventilation.

$$(M_T C_p \Delta T)_{out} = (m_v C_{pv} \Delta T_v + m_i C_{pi} \Delta T_i)_{in} \quad (6)$$

Where;

$(M_T C_p \Delta T)_{out}$ = Ventilation convection loads from inside to outside [kcal/h]

$m_v C_{pv} \Delta T_v$ = Ventilation load from outside to inside [kcal/h]

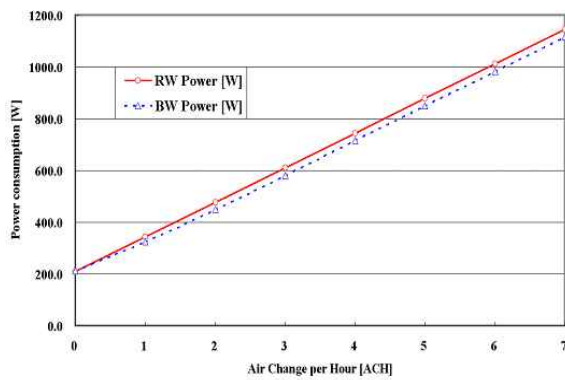
$m_i C_{pi} \Delta T_i$ = Infiltration load form outside to inside [kcal/h]

3.4 KIER twin test cell power model results

Table 2 shows the test conditions for the theoretical model heating power prediction. Table 2 has the out door 0°C and indoor temperature 22°C conditions for a typical winter design condition in Korea. The air flow rate varies from 0 to 7 ACH in one ACH change step by step. Figure 5 shows the power consumption from two cells for the different air flow rates and the relative saving from DI cell, which could be up to 5.7% at 2ACH in this case.

Table 2: Twin test cell pre-test condition

Outdoor temperature		0 [°C]	
Indoor temperature		22 [°C]	
Monitoring room temperature		18 [°C]	
A_T		43.04 [m ²]	
Volume		18.24 [m ³]	
ACH	M_T [m ³ /hr]	U_T [W/m ² k]	
		RW	BW
0	0	0.272	0.274
1	18.24	0.272	0.252
2	36.48	0.272	0.243
3	54.72	0.272	0.241
4	72.96	0.272	0.241
5	91.20	0.272	0.241
6	109.44	0.272	0.241
7	127.68	0.272	0.241



ACH	Pre-test power consumption [W]		
	RW	BW	Saving [%]
0	209.6	211.7	-1.0
1	343.3	324.9	5.4
2	477.1	449.8	5.7
3	610.9	582.2	4.7
4	744.6	715.9	3.9
5	878.4	849.7	3.3
6	1,012.0	983.4	2.8
7	1,145.9	1,117.2	2.5

Figure 5: Twin test cell power consumption pre-test results graph (above), data(below)

3.5 KIER twin test cell power actual test results

KIER twin test cell experiment has been conducted from 7 December 2007. The indoor set temperature was 22°C and the night time test of total nine hours from 22:00 PM to 07:00 in the next day morning used to provide the following data: indoor set temperature of each cell, outdoor temperature and the room temperature and the power consumption of each cell.

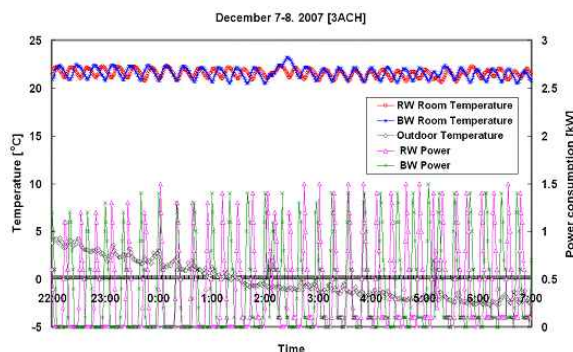
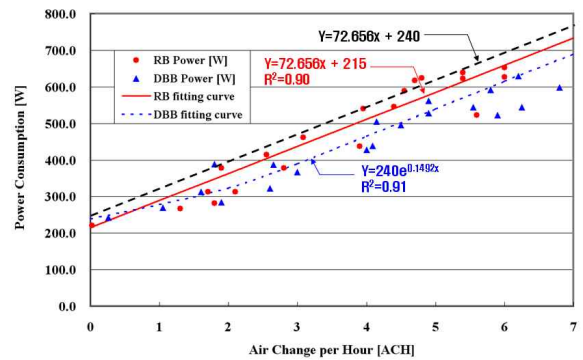


Figure 6: Twin test cell temperature and power consumption data graph.

Table 3: Twin test cell power consumption actual data.

Date (2007-2008)	Average Tout [°C]	RW		BW	
		ACH	Power [kWh]	ACH	Power [kWh]
12/02-12/03	0.14	0.02	1.98	0.26	2.19
12/03-12/04	0.46	3.08	4.15	4.09	3.95
12/06-12/07	3.16	2.10	2.81	312.2	2.60
12/07-12/08	-0.13	2.80	3.40	377.8	3.00
12/09-12/10	-1.70	4.55	5.30	588.9	5.55
12/13-12/14	0.13	1.30	2.40	266.7	1.05
12/14-12/15	-1.30	1.90	3.40	377.8	1.80
12/15-12/16	-0.90	5.60	4.70	522.2	4.70
12/17-12/18	-1.70	3.95	4.86	540.0	4.15
12/22-12/23	0.45	1.70	2.81	312.2	1.60
12/23-12/24	-1.40	4.40	4.91	545.6	4.50
12/24-12/25	-0.50	2.55	3.73	414.4	2.65
12/25-12/26	1.60	3.90	3.94	437.8	4.00
12/26-12/27	1.30	1.80	2.54	282.2	1.90
01/02-01/03	-0.68	6.00	5.87	652.2	6.20
01/03-01/04	-2.25	5.40	5.75	638.9	5.80
01/04-01/05	-1.50	4.70	5.56	617.8	4.90
01/05-01/06	-0.90	4.80	5.62	624.4	4.90
01/07-01/08	1.65	5.40	5.60	622.2	6.25
01/08-01/09	1.49	6.00	5.64	626.7	6.80
Average	-0.13				

Figure 6 shows the temperature variations and the power consumption variations of the cells at the air flow rates of 3 ACH. The average outdoor temperature was -0.13°C. Table 3 shows the power(W) for the cells at the different average outdoor temperature and the air flow rates starting from 2 December 2007 to 9 January 2008.



ACH	RW [W]	BW [W]	Saving (%)
0	240.0	215.0	-11.6
1	278.8	289.1	3.6
2	323.8	363.1	10.8
3	390.1	437.2	10.8
4	465.2	511.2	9.0
5	540.4	585.5	7.7
6	615.5	659.3	6.7
7	690.6	733.4	5.8

Figure 7: Twin test cell power consumption actual test results graph(above), data(below).

Figure 7 shows the test results and curve fitted line. And the table shows the summary and compare the power of the cells of the winter test indicating the maximum 10.8% saving at 2-3ACH but -11.6% saving at zero flow condition due to the DI's lower values of static U-value at zero velocity.

4. COMPARASON BETWEEN PRE-TEST AND ACTUAL TEST RESULTS

Figure 8 shows the power consumption comparisons between SI and DI at theoretical and actual test conditions. Main discrepancy occurs at higher ventilation rates due to the lack of the sky radiation loss model in theory, which could not consider the additional possible heat loss from the actual case. The theory only considered the fabric conduction and the ventilation convection loss. Therefore, this study introduced a factor to include the additional possible power loss due to the building radiation loss factor so called alpha(α).

$$POWER = U_T A_T \Delta T + \alpha M_T C_p \Delta T \tag{7}$$

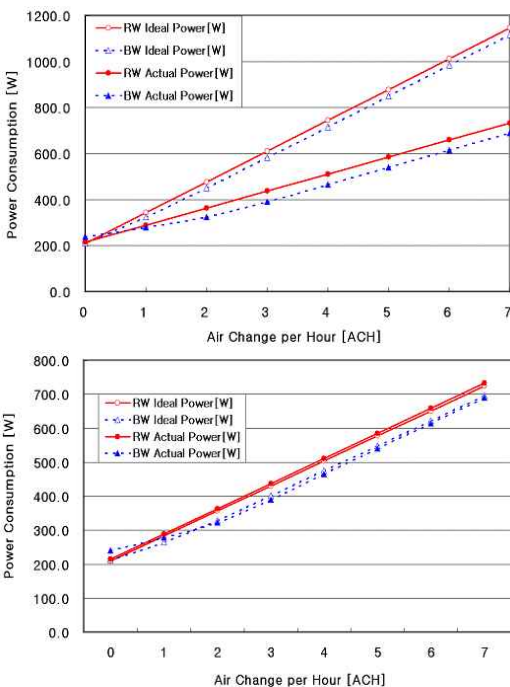


Figure 8: Power consumption comparison results (above, $\alpha=1.00$, below, $\alpha=0.55$)

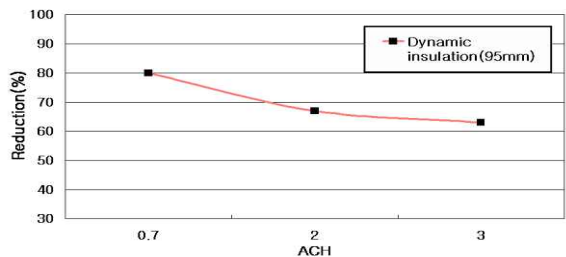
So, the modified theory with alpha could fit better to the actual test result as in Figure 8(right). The sky radiation loss factor for this test case was about 0.55, which is one of the key findings from this actual twin test cell study.

5. FILTRATION TEST RESULTS

Filtration performance was also evaluated at KIER twin test cell in 2008. The dust particle data have been carried out using a TSi p-trak nano-particle measurement device during yellow sand season in 2008. Figure 9 shows the filtration performance test condition and results for the test period every 30minute. The average value was reduced by 80% compared to outdoor dust particles at 0.7ACH and 67% reduced at the 2ACH and 63% reduced at the 3ACH.

Test condition									
Test day	2008, 03, 20			2008, 04, 18			2008, 03, 18		
Outdoor temperature	15.5℃			23℃			16℃		
Indoor temperature	17℃			22℃			17℃		
Wind speed	0.8-2m/s			0.5-2.5m/s			0.8-2m/s		
ACH	0.7			2 ACH			3 ACH		
Test results									
Time	Outdoor (PT/CC)	DBB (PT/CC)	Reduction (%)	Outdoor (PT/CC)	DBB (PT/CC)	Reduction (%)	Outdoor (PT/CC)	DBB (PT/CC)	Reduction (%)
1:00	15300	2950	81	10836	3252	70	13100	5010	62
1:30	21100	3010	86	11804	3905	67	11500	4860	58
2:00	20300	3580	82	13755	4371	68	10800	4680	57
2:30	20600	3930	81	16248	4619	72	10100	4550	55
3:00	20100	4280	79	18883	5121	73	10700	4190	61
3:30	17600	3860	78	19614	5919	70	12500	3920	69
4:00	17100	3710	78	17760	6604	63	13300	4210	68
4:30	16500	3760	77	14484	6576	55	11600	4390	62
5:00	14500	2940	80	15048	5839	61	12200	3830	69
average	18122	3558	80	15403	5134	67	11756	4404	63

Figure 9: Filtration test condition.



ACH	Outdoor [PT/CC]	DBB [PT/CC]	Reduction (%)
0.7	18,122	3,558	80
2	15,403	5,134	67
3	11,756	4,404	63

Figure 10: Filtration test results.

6. CONCLUSION

This study first investigated the theory and the mechanism of DBB and DI so that the power could be expressed by the sum of the building fabric conduction loss and the ventilation convection loss and finally the sky radiation loss with the factor-alpha(α). Second, the theoretical prediction over energy performance was verified with the actual twin test cell with DI and SI in KIER.

The actual test results indicated the need of the theory modification to include the additional radiation loss to the sky. The alpha factor of 0.55 for the test cell and the test condition could properly predict the test results from the modified equation. The verified model study indicated that it could save up to 10.8% at the 2-3ACH condition. Third, the dust particle reduction effect at the breathing DI wall building was analyzed quantitatively. The filtration performance test indicated that the breathing DI wall building at the 0.7ACH could reduce the dust particles by 80%.

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