DEVELOPMENT OF VALIDATION OF AC-PRESSURIZATION MEASURING OF LEAKAGE AREA OF HOUSES

Yuko WATANABE*[1], Hiroshi KOBAYASHI*[1] and Yasuo UTSUMI*[1]

*[1]Miyagi National College of Technology

Miyagi, 981-1239, Japan

ABSTRACT

This paper is focused on the development of measuring equipment of Effective Leakage Area (ELA) by AC-pressurization method. The formula to design the measuring system is derived according to the governing equation of the leakage, e.g. in terms of flow rate through the leakage, volume changing, sinusoidal pressurization, etc. Considering the constraints, such as available equipment performance, the size to be transported by hand, etc., the simulation with 180 cases is executed and the configuration is designed.

After constructing the equipment, the field experiment is carried out to validate the equipment performance, particularly the peak pressure difference ΔP between inside and outside should be over 4[Pa]. The result shows that the equipment generates expected ΔP and that the measured ELA is slightly over the one by DC-press. (de-pressurization) method.

INTRODUCTION

Recently Indoor Air Quality (IAQ) in room is one of topics with air-tightened houses. To achieve acceptable IAQ in room, adequate ventilation design is necessary and effective leakage area (ELA) of houses is the primary data to calculate ventilation rates. For measuring ELA, DC-press. method and AC-press. method are known. DC-press. method is divided into pressurization method and depressurization method, and the latter is common and many measurements have been executed with this, as well as there is ISO code.

On the other hand AC-press. method has less number of measurements[1,2)] than the one of DC-press, and measurement method is not established to be incorporated in the standard[3,4)]. The characteristics of this method is; 1) measurement is possible under high wind speed, 2) the system can be small, etc.

This paper describes design and development of the measuring system which deals with the actual house. The numerical simulation is executed to figure out the dimensions considering the experience of preliminary trial equipment. Finally ELA of real size house is measured.

PRINCIPLE OF THE SYSTEM

(1)MODELING

Leakage model is shown in Figure 1. AC-press. method applies the sinusoidal room volume changing at the room to be measured and calculates ELA. In effect the equipment is attached to the room across the wall and the piston is driven to provide the room volume changing where ΔP(t), pressure difference between indoor and outdoor, is measured. The relationship between room volume changing $_d$, air flow across the wall q and ΔP(t) is shown by eq.(1).

$$<A> = \frac{1}{t}\int_0^t A(t)dt = \frac{1}{t}\sum_{t=1}^{m} A(t_i) \qquad (2)$$

Then it yields eq. (3).

$$<q\cdot\Delta p> + <\dot{v}_d\cdot\Delta p> + c <\Delta\dot{p} \ \cdot\Delta p> = 0 \quad (3)$$

The first term is written in the following form.

$$q=q_0|\Delta p|^n \mathrm{sign}(\Delta p) \qquad (4)$$

where q_0 is the constant. Here the time averaged third term of eq.(3) is equal to zero when integrated within the wave lengths, therefore, eq.(3) results in;

$$<A_0\sqrt{\frac{2\Delta p_{ref}}{\rho}}\ \left|\frac{\Delta p}{\Delta p_{ref}}\right|^{1/n} \mathrm{sing}(\Delta p \ \cdot\Delta p>$$

$$+<\dot{v}_d\cdot\Delta p>=0 \qquad (5)$$

where Δp_{ref} is reference pressure and it is 9.8Pa in Japan and 4Pa in some countries. Then Ao, ELA, can be expressed without c as;

$$A_0=-\sqrt{\frac{\rho}{2\Delta p_{ref}}}\cdot\frac{\dot{v}_d\frac{\Delta p}{\Delta p_{ref}}}{\left|\frac{\Delta p}{\Delta p_{ref}}\right|^{\frac{n+1}{n}}}$$

Where n must be provided in advance to calculate Ao with above equation.

(2)REMARKS FOR APPLICATING

The characteristics of AC-press are; 1) less disturbance to indoor environment, 2) executable under high wind speed, 3) measurement possible without duct penetrating building envelope, and 4) can be portable because it can be compact.

The preliminary experiment also reveals that it is essential to maintain smooth sinusoidal pressure varying in order to estimate ELA, so that the leakage and friction between piston and cylinder is designed to be smaller by the adjustment of driving part.

DESIGN OF MEASUREMENT SYSTEM

(1)INSTRUMENTATION

Structure of equipment including the model room is shown in Figure 2. It consists of control part, data acquisition part, and data analysis part. Control part has the computer and regulated actuator. A movable bar attached to actuator is connected directly to the piston, where actuator has the precision of 2/100mm for the minimum adjustment. Data acquisition part is of a manometer and a counter to check the location of the piston. The third part has the computer for data analysis.

(2) DESIGN METHOD WITH THE NUMERICAL SIMULATION

Numerical simulation is carried out to design the equipment which measures actual size of houses with generating certain reference pressure. Changing the cylinder volume and moving frequency, i.e. the dimension of equipment, the pressure varying against time is calculated.

To provide the equations for the simulation, substituting eq.(4) to the first term of eq.(1) yields;

$$-q_0|\Delta p|^n \mathrm{sign}\Delta p(t)+\omega v_s\cos\omega t+c\Delta\dot{p}=0 \qquad (7)$$

where ω is angular velocity and v_s is the cylinder volume. Finite difference method is applied to eq.(7) as following forward equation of one order for time marching.

$$\Delta\dot{p}=\frac{\Delta p(t+\Delta t)-\Delta p(t)}{\Delta t} \qquad (8)$$

From above both equations, it yields;

$$-q_0|\Delta p|^n \mathrm{sign}\Delta p(t)+\omega v_s\cos\omega t+c\,\frac{\Delta p(t+\Delta t)-\Delta p(t)}{\Delta t}=0 \qquad (9)$$

and results in;

$$\Delta p(t+\Delta t)=\Delta p(t)+\frac{\gamma p_0}{v_0}\Delta t\{-q_0|\Delta p|^n \mathrm{sign}(\Delta p(t))+\omega v_s\cos\omega t\} \qquad (10)$$

This equation is calculated under initial condition $\Delta P(t)=0$ at $t=0$ and time increment $\Delta t=0.001$, while c is derived from eq.(11).

$$c=\frac{v_0}{\gamma\, p_0} \qquad (11)$$

where γ is specific heat ratio, p_0 is atmospheric pressure and v_0 is the room volume.

The house to be dealt with is assumed as; 1)floor area 150[m^2], and 2) ELA per unit floor area 1.5[cm^2/m^2].

Considering the constraints from available equipment configuration, the conditions are; 1) piston stroke, 0.1/0.15/0.2[m], 2) piston moving frequency, 0.1/0.2/0.3/0.4[Hz], 3) section area of piston, 0.09/0.16/0.25/0.36/0.49[m^2], and 4) flow exponent n 1.0/1.5/2.0 and the total is 180 cases.

(3) RESULT AND DISCUSSION

The relationships between peak ΔP and cylinder volume with n=1.0, 1.5 and 2.0 are indicated in figure 3, 4 and 5. In all cases larger piston volume and frequency provide larger ΔP as expected. Also smaller n has smaller ΔP. For measuring air-tightened house of smaller n it may allow less ΔP than leaky house, i.e. more piston volume is necessary while ΔP can easily increase with the house of less ELA.

To maintain ΔP over 4Pa as reference pressure in all cases, the section area of 0.25(0.5x0.5)[m] is chosen with a case of piston stroke 0.1[m], frequency 0.4[Hz] and n=1.0. This size of section area may be the maximum for transporting by hand.

VALIDATION BY FIELD EXPERIMENT

(1) METHOD AND A HOUSE

The equipment designed by the simulation is attached in a model house in Gunma Prefecture, Japan. The measurement by DC-press. and AC-press are done and the ELA of them is compared where the pressure varying is checked if it is smooth. Also The influence of ΔP and outdoor wind speed is examined.

The house is so called highly insulated and air-tightened house and has the floor area of 139[m^2] and the volume of 360[m^3]. The plan is shown in figure 6.

(2) RESULTS AND DISCUSSIONS

The measurement executed on 1998/10/3 by DC-press, depressurization, results in as shown in table 1. The house has ELA of 188.2 to 260.2[cm^2] and n is 1.51 to 1.62.

The measurement by AC-press. was carried out under 5 conditions of 25 cases, 1-1 to 5-5, shown in table 2. The frequency is 0.2/0.4[Hz], piston stroke is 100/200[mm] and supply and exhaust duct are open/closed, where indoor-outdoor temperature difference varies from 0.1 to 3.6 degree, and wind speed is from 0.9 to 2.2[m].

The pressure changing is shown in figure 7 and 8 for case 2-4 and case4-4 respectively as examples. The peak pressure ΔP is over 4[Pa] as designed, as well as in other cases. In case 2-4 under wind speed of 0.9[m/s] the curve shape seems to be smooth, on the other hand case 4-4 with wind speed of 2.2[m/s] is likely to be rugged and to have a component of longer frequency around 1/18[Hz].

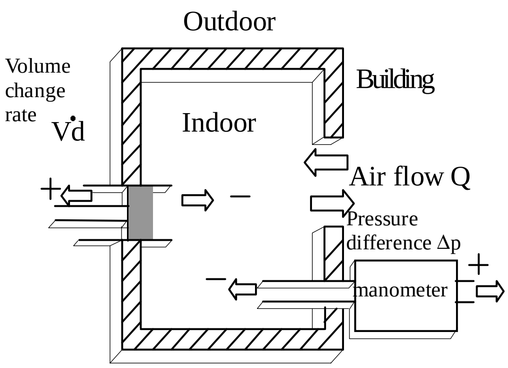


Figure 1 LEAKAGE MODEL

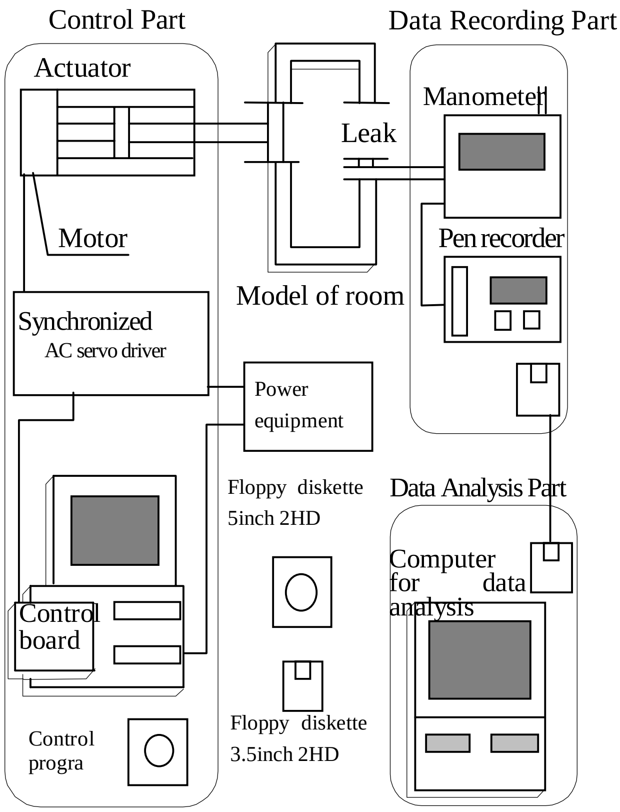


Figure 2 SYSTEM CONFIGURATION

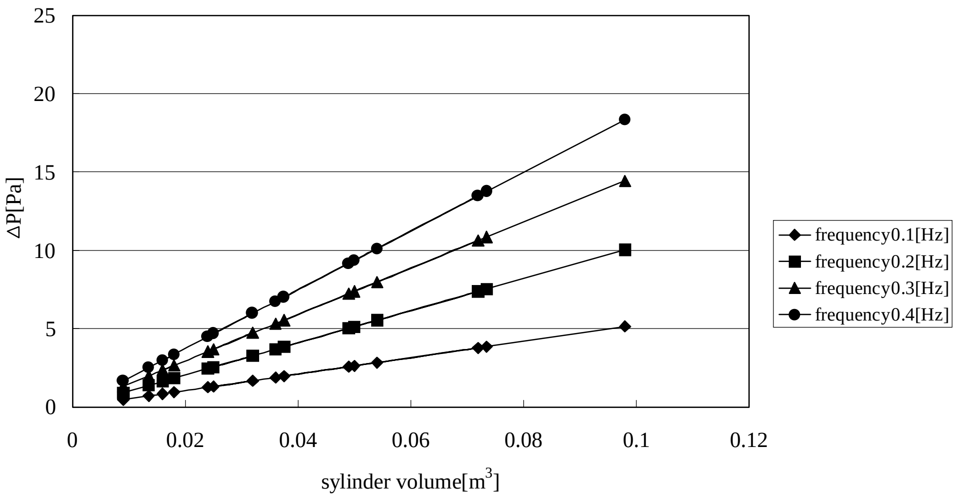


Figure3 RELATION SHIP BETWEEN ΔP PEAK AND SYLINDER VOLUME(n=1)

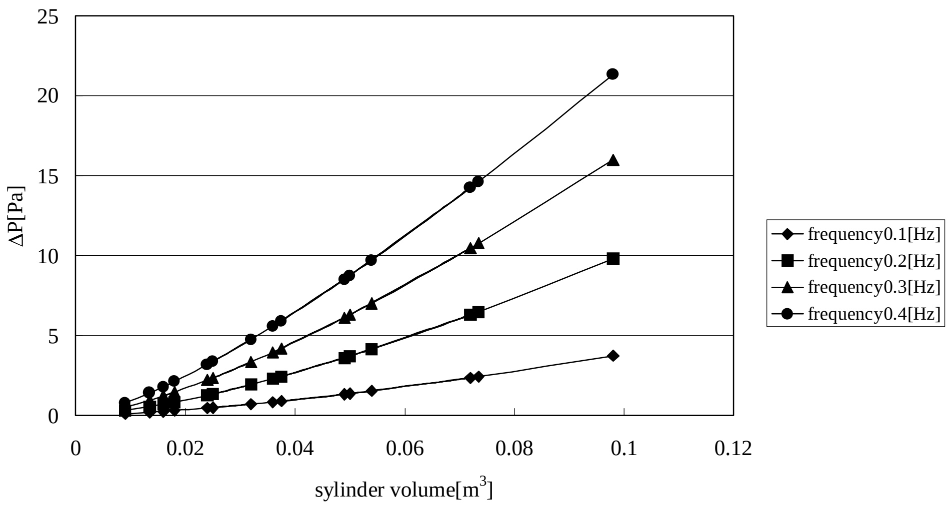


Figure4 RELATION SHIP BETWEEN ΔP PEAK AND SYLINDER VOLUME(n=1.5)

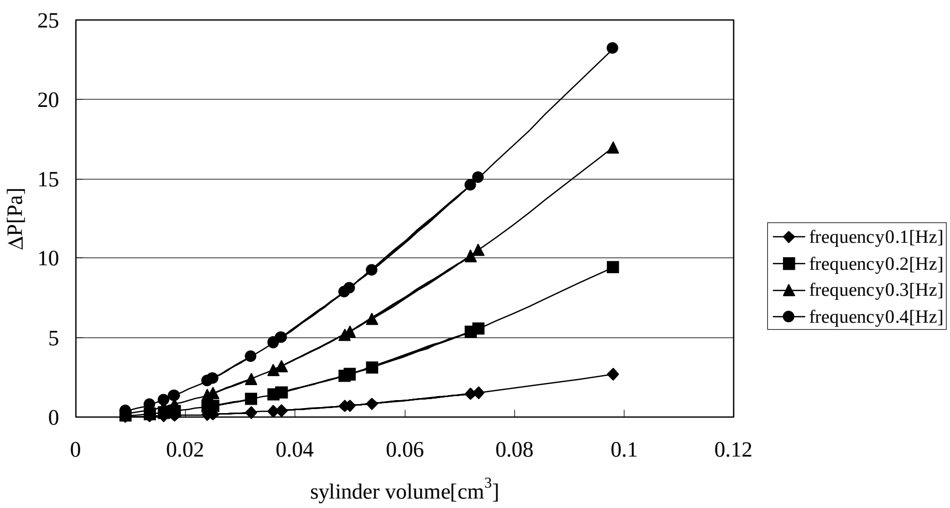


Figure5 RELATION SHIP BETWEEN ΔP PEAK AND SYLINDER VOLUME(n=2.0)

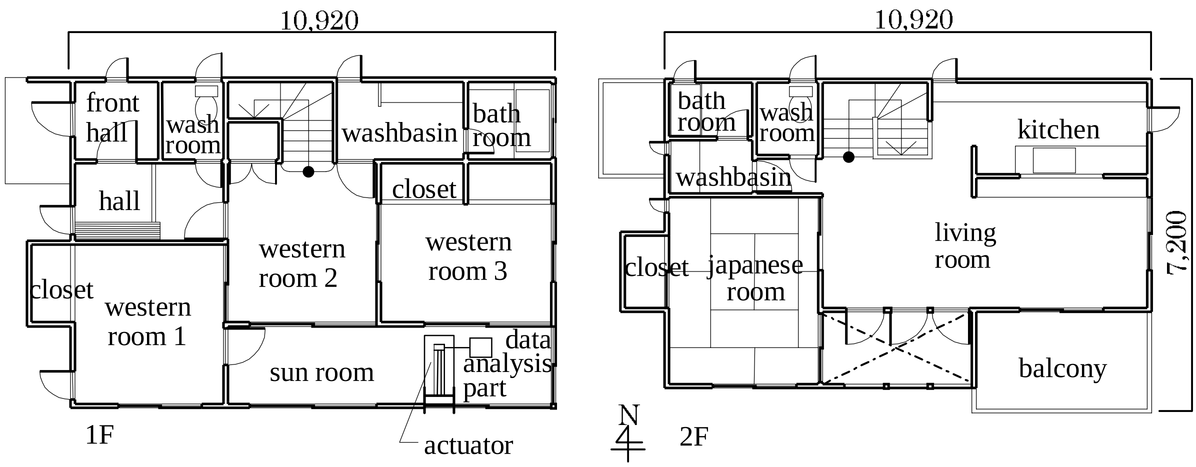


Figure6 PLAN OF THE HOUSE

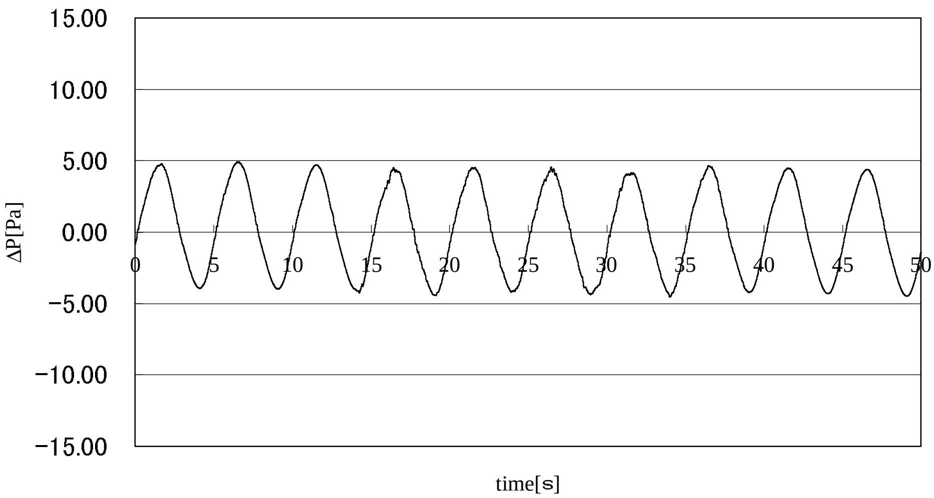


Figure7 MEASURED ΔP case2-4

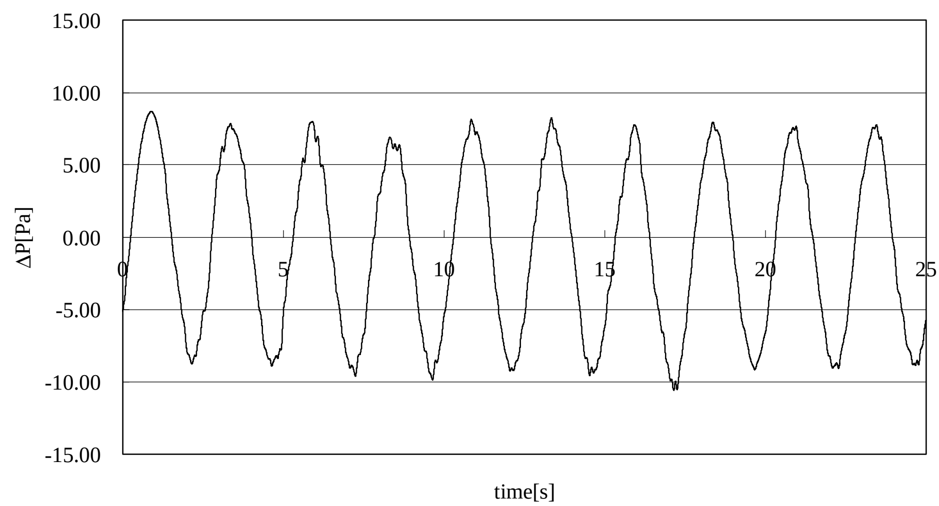
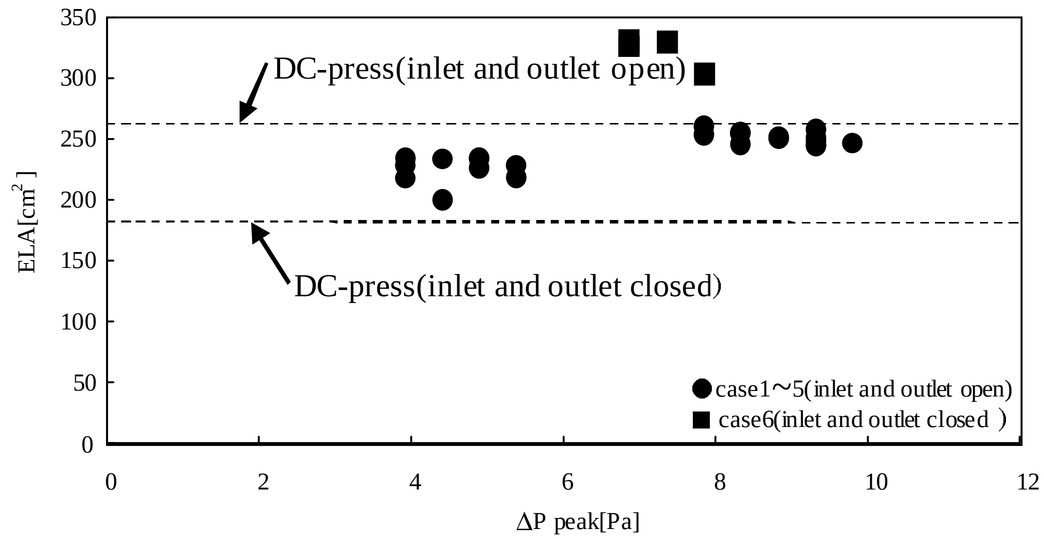


Figure8 MEASURED ΔP case4-4



Fiure9 RELATION SHIP BETWEEN ΔP PAEK AND ELA

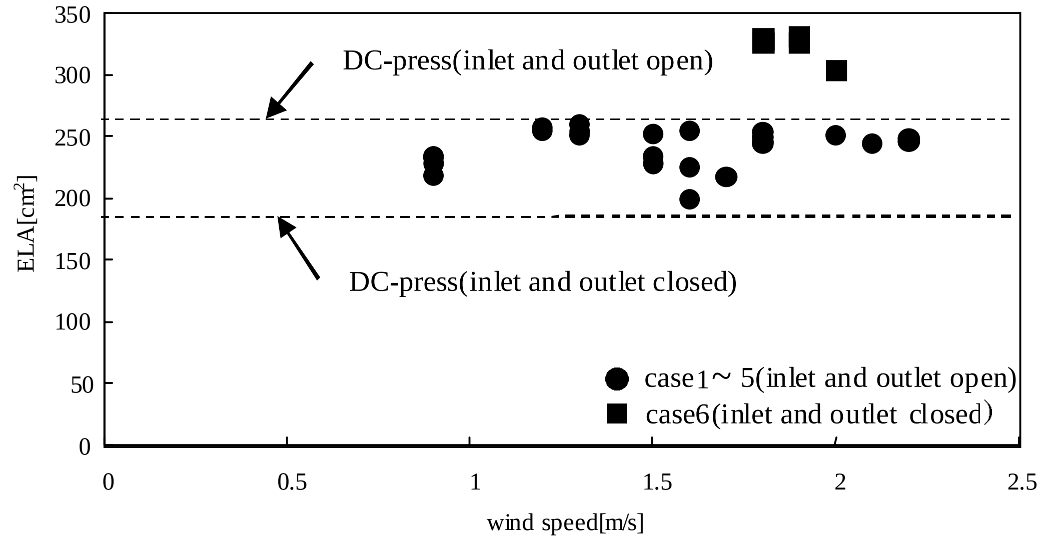


Figure10 RELATION SHIP BETWEEN WIND SPEED AND ELA

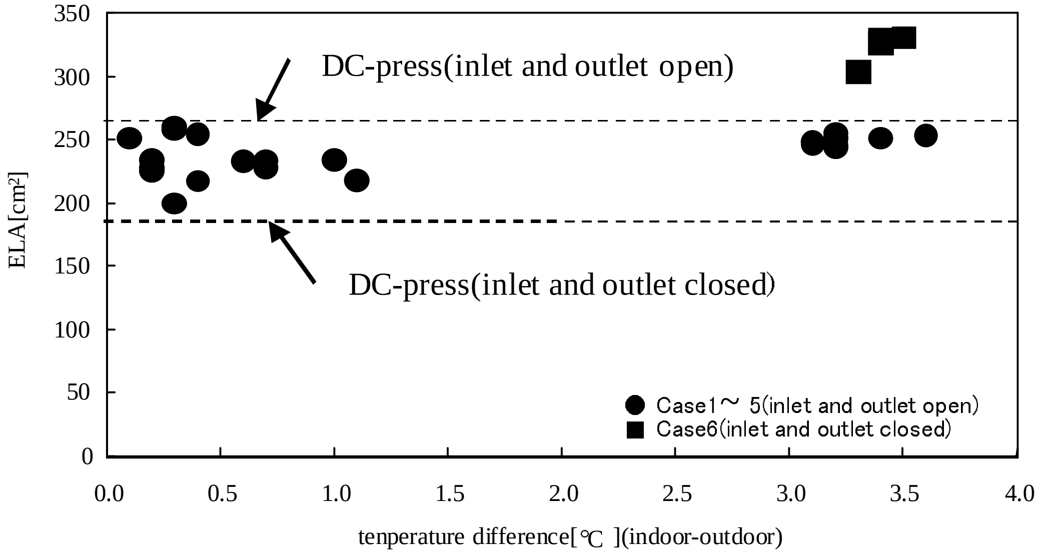


Figure11 LELATION SHIP BETWEEN INDOOR-OUTDOOR TEMPERATURE DIFFERENCE AND EL

Derived ELA is plotted in figure 9, 10 and 11. Figure 9 reveals the relationship between ΔP and ELA by both methods. AC-press may give larger ELA than DC-press, however, the values may be close considering the depressurization method provides larger ELA than pressurization by around 10-20% in general. Also larger ΔP provides larger ELA.

Figure 10 indicates the relation between wind speed and ELA. ELA seems not scattered by different wind speed though they are under 2.5[m/s]. Figure 11 shows the relation between temperature difference and ELA. ELA is not likely to vary within the difference of 3.6 degree. Basically AC-press should be robust with the wind speed and temperature difference and the integral interval can be longer to avoid the other longer frequency disturbance and the air across the envelope flows forward and backward to averaging the air temperature in the crack, therefore, it may be reasonable though the difference of them is moderate.

CONCLUSIONS

The configuration of ELA measuring equipment by AC-pressurization method is designed by the simulation which satisfies the many constraints with available equipment and the size for transportation. A constructed equipment is examined by the field experiment with real size model house. The result shows that the equipment provides the pressure of 4[Pa] as reference and that measured ELA is close to the one of DC-press.

ACKNOWLEDGEMENTS

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RFERENCES

1) Yuko Watanabe et al., “Leakage Measurement of Test House by AC-pressurization Method”, Proceedings of annual meeting if AIJ, 1998.9

2) Yasuo Utsumi et al., “Measuring Technique of Leakage Area of Houses by AC-Pressurization Method”, 5th International Conference on Air Distribution in Room ROOMVENT’96, July 17-19,1996

3) J. Dewsbury “AC pressurization :Analysis by non-linear optimization” “AC pressurization : Fourier analysis and the effect of compressibility of air” Proc. CIBSEA:Buil12ding serv. Eng. Res., Technol.17(2)65-17 1996

Table1 ENVIRONMENTAL CONDITIONS ANDRESULT

Case	Outdoor temp. [degrees]	Indoor temp. [degrees]	Indoor-outdoor temp. [degrees]	Wind velocity [m/s]	ELA [cm^2]	Frequency [Hz]	Stroke [mm]	Supply and exhaust air duct
1-1	24	25	0.4	1.3	254.3	0.4	200	Close
1-2	24	25	0.3	1.3	260.4			
1-3	25	25	0.1	1.3	251.3			
1-4	24	25	0.3	1.2	257.7			
1-5	24	25	0.4	1.2	254.9			
Ave.	24	25	0.3	1.3	255.7			
2-1	24	25	1.1	0.9	218.1	0.2	200	Close
2-2	24	25	1.0	0.9	234.1			
2-3	24	25	0.7	0.9	228.3			
2-4	24	25	0.7	0.9	233.7			
2-5	24	25	0.6	0.9	233.0			
Ave.	24	25	0.8	0.9	229.4			
3-1	25	25	0.2	1.5	234.2	0.4	100	Close
3-2	25	26	0.2	1.5	228.2			
3-3	25	26	0.2	1.6	225.7			
3-4	25	26	0.3	1.6	199.6			
3-5	26	26	0.4	1.7	217.2			
Ave.	25	26	0.3	1.6	220.9			
4-1	21	24	3.6	1.8	253.6	0.4	200	Close
4-2	21	24	3.4	2.0	251.4			
4-3	21	24	3.2	2.1	244.6			
4-4	21	24	3.1	2.2	246.4			
4-5	21	24	3.1	2.2	248.5			
Ave.	21	24	3.3	2.1	248.9			
5-1	21	24	3.2	1.8	250.4	0.4	200	Close
5-2	21	24	3.2	1.8	245.7			
5-3	21	24	3.2	1.8	244.4			
5-4	21	24	3.2	1.6	255.2			
5-5	21	24	3.2	1.5	252.0			
Ave.	21	24	3.2	1.7	249.5			
6-1	21	24	3.3	2.0	304.0	0.4	200	Open
6-2	21	24	3.4	1.9	326.6			
6-3	21	24	3.5	1.9	331.1			
6-4	21	24	3.4	1.8	326.4			
6-5	21	24	3.4	1.8	329.7			
Ave.	21	24	3.4	1.9	323.6			
Total Ave.	23	25	1.9	1.6	254.7			

Table 2 CONDITIONS AND MEASURED ELA BY DC-PRESS(DERESSURIZATION)

Case	1	2	3
inlet	○*1	○	×
outlet	○	×	×
Living room	○	○	○
Windows of san room	×	×	×
Outdoor temp.[℃]	30.0	27.6	28.0
Indoor temp.[℃]	27.4	27.2	27.3
n	1.62	1.59	1.51
ELA[cm^2]	260.2	245.5	188.2

*1 ：○ open、× close