Method for Estimating Smoke Leakage through Small Openings Using Tracer Gas

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ABSTRACT

Smoke leakage through openings concealed behind ceilings and/or walls can create confusion and therefore a hazard which threatens occupants in case of a building fire. This kind of small opening, which is the result of defective construction work and/or aging, can not be found easily after the completion of the building.

This paper presents a method for estimating the effective areas of these openings as well as smoke leakage rates trough application of methods for measuring air infiltration rates of buildings with SF_6 tracer gas.

Two test series consisting of a total of eleven full-scale experiments were conducted to determine the degree of accuracy of this prediction method. Smoke leakage rates estimated from tracer gas concentrations and ventilation rates agree well with experimental data measured by an orifice flow meter. The maximum error is about 20%. However, rapid concentration change and its unhomogeneousness in the fire room immediately after purging tracer gas increases the degree of error.

1. INTRODUCTION

In building fires in Japan, a little less than half of the deaths are reported to be the result of smoke inhalation [1]. However, many victims seem to be trapped by thinner smoke in the early stage of a fire, spend much time struggling to escape before dying. As Dr.Jin has pointed out [2], evacuees lost visibility and mobility in relatively thin smoke ($Cs<=1.0$) before CO concentration reached a dangerous level.

Many smoke problems are the result of smoke infiltration through unexpected openings, unused air ducts, unplugged piping shaft etc, as well as stair cases in Japan. Small openings, which are consequences of defective construction work and/or aging, can not be found easily after the completion of the building. Unanticipated smoke leakage through these openings creates confusion among evacuees. In addition these openings constitute an even greater danger when they permit the spread fire into other parts in a building.

Many efforts to predict fire smoke movement have been made in the past and are now continuing. However, no mathematical model can predict smoke spread without knowing the size and locations of such openings. Mathematical models--

zone models for example--- are powerful prediction tools for designers and engineers involved in the planning of new buildings, but they do not always adequately address the problem of smoke propagation in existing buildings. For this reason we need some other experimental methods to get the boundary conditions for predicting smoke propagation in more practical situations.

One Study concerned with this problem was conducted by Fung C.W. and R.H.Zile [3] in '75. They tried to predict the possibility of smoke propagation in an existing building using SF_6 tracer gas. However the results are limited to the qualitative character of the building they studied, and are not expandable to a general prediction method. This paper presents an method for estimating such smoke leakage rates and opening areas which applies a method for measuring the rate of air infiltration of building using SF_6 tracer gas and provides a basis for the practical inspection of existing buildings now and in the future.

2.ESTIMATION METHOD OF SMOKE LEAKAGE AND OPENING AREA.

Estimation of infiltration through openings has been investigated within the research field of building physics [4][5][6]. The principle interest of those studies was the ventilation rate between the inside and outside of the building from the view point of energy saving. However, nearly the same method is applicable to smoke leakage between rooms inside a building .

When effective areas of openings are known between rooms, the smoke leakage rate can be obtained by the next simple equation. For simplification, locations of openings, especially their heights, are not considered.

$$\dot{Q} = \alpha A \left[\frac{2\Delta P}{\rho} \right]^{1/n} \quad \text{----------(1)}$$

where $\dot{Q}$: Volumetric leak rate [m^3/sec]
- n : nondimensional value varies from 1.6 to 2.0 depending upon the opening character and passing flow rate. 2.0 is commonly used when the pressure difference is relatively large (≥45 pa [6]) and/or the opening area is large.
- α : opening coefficient.
- A : area of opening [m^2]
- ΔP : pressure difference across the opening (between rooms) [pa].

The difference between normal ventilation and smoke leakage is the magnitude of the pressure difference. Compared with normal ventilation, the pressure difference in the case of fire is larger, so even a small opening can not be neglected.

To obtain the αA value, the values of both Q and ΔP are required. Once the αA is known, the smoke leakage rate through the opening under certain fire conditions can be predicted with mathematical models. To get the smaller αA, we had to produce more pressure difference or take much time to measure Q under a lower pressure difference condition. However, the latter is not practical, since the surrounding conditions vary, especially wind, and long time exclusive possession for testing is inconvenient for the tenants of the building.

To simplify the situation, we consider the case shown in **Fig.1**. Smoke leaks through openings from the lower fire room to room directly above and gradually contaminates the air in the upper room. (Here we express these rooms as FIRE-room and UPPER-room.) The smoke leakage can be estimated easily with the mass conservation equation (2) given the concentration of smoke and ventilation rate, provided that the following quasi-steady conditions are satisfied:

(1) Smoke concentration distribution in the upper room is uniform.
(2) Change of density due to temperature rise is negligible.
(3) Smoke leaks only from assumed FIRE room to UPPER room, and does not turn back and/or and comes from other routes,i.e. corridor, stair well, etc.

and as a preferable condition for accessing the experimental prediction method

(4) Leak and ventilation rate are in quasi-steady.

The conditions mentioned above are not the same as occur in a real fire, even in the early stage. However it is not necessary to duplicate the fire condition to determine αA for the opening.

(Mass conservation equation in the UPPER-room.)

$$\bar{g}_1(t) = \frac{\{ Co(t) - Co(t_0)\} V_o + \int_{t_0}^{t} Co(t)\, Go(t)\, dt}{\int_{t_0}^{t} Co(t)\, dt} \quad \text{----------(2)}$$

where $\bar{g}_1(t)$: mean leak rate during time t_0 to t. [m^3/min.]
C (t) : smoke or tracer gas conch. at time t. [volumetric conch.]
G (t) : ventilation rate at time t. [m^3/min.]
V : room volume [m^3]
(*cf. weight unit is also available for above g_1,C,G instead of volumetric unit.)

subscript o : observation UPPER-room (2FL)
f : FIRE-room (1FL)
0 : basic time point

In practical estimation methods for leakage, certain tracer gases (SF_6 in this study) can be used instead of smoke and the αA can be obtained from Eqs.(1) and (2) when the pressure difference between rooms is measured. In this paper the first priority is to assess the degree of accuracy of smoke leakage rate estimated with Eq.(2). However, αA is also estimated in one series of experiments.

There are two methods for producing the required pressure difference between rooms. One utilizes the buoyant effect,i.e. warm the FIRE-room to an adequate temperature level, and the other uses mechanical venting, i.e. pressurize the FIRE-room and/or exhaust from the UPPER-room. The latter is a useful and powerful method when a VHA system and other ventilation fan are available.

3. EXPERIMENTS

3.1. INSTALLATION

Two series of experiments are conducted to assess the degree of accuracy of the estimation method for the leak rate from a small opening and its effective area.

Each experiment has one FIRE-room, and one upper observation room directly above as shown in **Fig.2** and **Fig.3**. An orifice flow meter (ID.50-40 mmϕ) is installed at a slab between two rooms and serves as an "unknown" small opening. The leakage through this opening is measured directly with this orifice flow meter, and also estimated by tracer gas concentration and ventilation rate as indicated by **Eq.(2)**. Thus comparisons between estimations and experiments are possible.

The difference between the two series of experiments is the method used to produce the pressure difference. Natural ventilation force due to buoyancy effect is adopted in the six runs in the first series of experiments, and mechanical exhausting with a ventilation fan is used to produce the pressure difference in the five runs of the second series of experiments.

3.2. Producing Pressure Difference

3.2.1. Series-I

In this experimental series, the electrical fan heater is used to warm the FIRE-room. Two operating conditions of the fan are examined ; Run-No.1 to 3 the condition is higher temperature and more wind volume (12 kW, 7.3 m^3/min.) and the other is a lower condition (8 kW, 10.2 m^3/min.). About ten minutes prior to releasing the SF_6 tracer gas, warm wind is blown into the FIRE-room. The FIRE-room temperature rises to a level from 8 to 20 deg.C above ambient temperature, and a steady state temperature is achieved and maintained in each run. Under such conditions, the estimated maximum pressure difference due to buoyant effects is about 2.8 pa. Some difference of temperature rise between runs is caused by changes in the opening condition of the FIRE-room.

3.2.2. Series-II

Two levels of pressure difference are produced by mechanical exhausting with the ventilation fan in the UPPER-room with all windows and a door of the room is closed, values of about 3 pa. and 2.3 pa. pressure differences are obtained. In this series of experiments, the ventilation rate is directly measured with an orifice flow meter connected to the fan.

3.3. Description of Measurements

3.3.1. Tracer Gas

To estimate the leak rate, the gas concentration in each room and the ventilation rate of the UPPER-room are required. SF_6 gas, which is ordinarily

used for measurement of building ventilation or investigation of atmospheric dispersion mechanism, was selected as the tracer gas for these experiments.

Charging Gas ; 99.9 vol.% pure SF_6 gas is charged into the FIRE-room at a constant rate of 400 cm^3/min. in series-I and about 80 cm^3/min. in series-II to reach some ten ppm after 20 min. In these experiments, time=0 occurs at the initiation of charging.

SAMPLING & ANALYSIS ; In each series of experiments, air is sampled with automated gas sampling equipment as shown in **Fig.4** on the time schedules indicated in **Fig.5** and **Fig.6**. In both series the sampling rate is one sample/4 minutes. Differences between the series are the time interval during which the sample is accumulated (sampling time), sample volume, and sampling location. In series-I, the sampling time is two minutes and the samples are taken at three different levels at the center of the UPPER-room using three independent sampling lines. In series-II, the sampling time is one minutes and samples are drawn through two independent lines; one line is connected to eight sampling ports and the other to two sampling ports as shown in **Fig.4**

The air in the FIRE-room is sampled from a line having four sampling ports located 50cm below the ceiling. These test specimens are accumulated in a 5000 cm^3 teflon sampling bag at a rate of 1000 cm^3/min. in series-I and 4000 cm^3/min.in series-II.
The specimen are quantitatively analyzed by a gas chromatograph with a Flame Photometric Detector within 24 hours after each experiment. Details of the gas chromatograph and its operating conditions are shown in **Tab.1**. With this method, the analysis error is found empirically to be within five percent.

Tab.1. Condition of Chromatographic Analysis

Column	porapack Q, SUS.col. , I.D. 3ϕ x 2 m
Temperature	Col.230 °C, Inj.240 °C, Det.230 °C
Detector	FPD (Flame Photometric Detector)
	H_2 flow rate 0.4 cm^3/min., applied Voltage 800 V O_2 flow rate 0.2 cm^3/min. N_2 flow rate 0.2 cm^3/min.
Carrier gas	N_2 flow rate 70 cm^3/min.
Working Curve	concentration $\propto$ ln(peak height)

3.3.2. Ventilation Rate

The ventilation rate is measured with a CO^2 decay method. Prior to each run, CO_2 gas is released to attain some thousands ppm level in the UPPER-room. The depletion of the CO_2 concentration is then measured during the experiment. Since the ventilation rate seems to be quasi-steady, an average ventilation rate (number of exchanges) is obtained from a tangent of the regression line of $-\ln\{Cco_2(t_i)/Cco_2(t_0)\}$ against time lapse $t_i - t_0$, where t_i is the i-th time increment. In these experiments, data obtained every one minute with the infrared analyzer are used to get a mean average between t_i and t_0. In series-II, the ventilation rate is measured directly by an orifice flow meter as mentioned above as well as the decay method.

3.3.3. Leak Rate & Pressure Difference.

The leak rate through an orifice ($\alpha A = 11.3\ cm^2$) is measured with a pressure transducer. In series-II, the pressure difference between the rooms --- i.e., between the ceiling level of FIRE-room and floor level of the UPPER-floor --- is measured at the center of the room as shown in **Fig.3** with a high resolution pressure transducer. These data are recorded with a pen recorder (in series-I and-II) and digital recorder of one second interval in series-II.

3.3.4. Other Equipments

Gas temperatures in each room and ambient temperature are measured with CA-thermocouples. The room temperature profiles are measured at 15 points in a vertical line at every 15 seconds. With the above mentioned equipments, the experimental runs are conducted on the time schedules shown in **Fig.5** and **Fig.6**.

4. RESULTS AND CONSIDERATIONS

4.1. Experimental Conditions and Results.

Six runs in experimental series I and five in series II were conducted under quasi steady state conditions. The experimental conditions (ventilation rate in UPPER-room, SF_6 concentration level in FIRE-room and temperature), and the results consisting of the leakage rate from the orifice, SF_6 concentration in the UPPER-room and the pressure difference are indicated in **Tab.2** and **Tab.3**.

In spite of efforts to establish the same experimental conditions in some runs, the experimental conditions and leakage rates are slightly different between those runs. For example, the conditions of the outer wind appears to effect the ventilation rate and leak rate.

In series-I, a principle parameter of the experimental condition is the temperature rise in the FIRE-room. For example, runs No.1 to 3 show more heat and mass flow to the FIRE-room than the other three runs as explained in 3.2.1. The SF_6 concentrations in FIRE room were intentionally changed slightly to determine the effect on estimation accuracy.

In series-II, runs No.1 to 3 were conducted under almost the same conditions, however No.4 was conducted with two orifice opening, and No.5 was done under smaller pressure difference. Other conditions were the same.

The dilution listed in **Tab.2** and **Tab.3** is the ratio of SF_6 concentration in the UPPER-room to that in the FIRE-room. These results indicate how easily the air in the UPPER-room is contaminated through relatively small openings even under lesser pressure-difference conditions than occur in a real fire.

4.2. Comparisons between Estimation and Experiment.

4.2.1. Estimation of Leak Rate.

The leak rate is estimated with a numerical approximation of Eq.(2); that is,

Tab.2. Conditions, Leak Rate & SF_6 Conc. ; (Series I)

Exp. Run No.	Temperature [deg.C] Ra. temp. 2FL	rise 1FL	Ambient temp.	Vent. rate [turn /hour]	Leak rate [$x10^{-3}$ $m^3/m.$]	SF_6 CONC. [ppm] 2FL. (UPPER)	1FL (FIRE)	dilution [%]
1	+5.9	18.9	19.8 C	1.9	100.1	0.931	38.3	2.4
2	0.9	18.2	17.8	2.7	79.0	0.477	20.7	2.3
3	0.1	14.4	26.6	2.1	82.3	0.485	17.0	2.9
4	2.4	11.1	20.4	1.9	80.1	0.597	27.5	2.2
5	2.3	9.2	21.5	3.1	87.9	0.781	47.7	1.6
6	0.6	7.9	25.3	2.4	61.9	0.471	24.5	1.9

cf. *1) temp. rise of 1FL:2FL is an average temperature difference of 15 vertical measuring points from ambient temperature.
*2) Vent. rate is presented here as number of room air exchange between five to 20 min.
*3) SF6 conc.is the average of three vertical sample points at 20 to 22 min. period.(exp.5, 18 to 20). dilution is the diluted conc.of 2FL. against the 1FL.Conc.

Tab.3. Conditions, Leak Rate & SF_6 Conc.; (Series II)

Exp. Run No.	Vent rate [T/H] by orifice (SD/M)	by CO_2 decay	Leak rate [$m^3/m.$] (SD/M)	pressure differ. ΔP [pa] (SD/M)	SF6 CONC. [ppm] 2FL. UPPER	1FL. FIRE	dilution [%]
1	4.58 (.01)	4.6	0.173 (.04)	2.99 (.08)	1.07	35.5	3.0
2	4.57 (.05)	4.7	0.181 (.05)	2.84 (.11)	1.22	38.2	3.2
3	4.45 (.11)	4.6	0.175 (.11)	3.21 (.29)	0.59	26.2	2.2
4	4.43 (.07)	4.6	0.340 (.07)	2.89 (.17)	1.87	39.0	4.8
5	3.22 (.16)	3.6	0.158 (.16)	2.32 (.47)	0.82	28.2	2.9

cf. *1) Vent. rate is presented here as a number of room air exchange during 29 min. after starting of SF6 injection.
*2) vent rate ,leak rate and pressure are mean value during 29 min. the value in parenthesis is standard deviation/mean.
*3) SF6 conc.is the average of 8 sample points at 23 to 24 one min. period.(exp.1, 24 to 25, exp.2, 20 to 21). dilution is the diluted conc.of 2FL. against the 1FL.conc.
*4) exp.1 to 3 are almost the same exp.condition except SF6 purge rate and weather, mainly wind conditions.

$$g_{1\,i_0 \to i} = \frac{(Co_i - Co_{i_0})\,Vo + G_{i_0 \to i} \sum_{i=i_0}^{i-1} (Co_i + Co_{i+1})/2\,\Delta T}{\sum_{i=i_0}^{i-1} (C_{f\,i} + C_{f\,i+1})/2\,\Delta T} \quad \text{-------(2')}$$

where $g_{1\,i_0 \to i}$: mean estimation of leak rate during Ti_0 and Ti time duration.
$G_{i_0 \to i}$: mean ventilation rate during Ti_0 and Ti time duration.
C_i : mean SF_6 conch. of the i-th sampling duration.
Ti : mid time of the i-th sampling duration.
ΔT : $T_{i+1} - T_i$
i0 : basic time point

Thus the mean leak rate through a small opening (orifice in this experiments) are obtained by the above simple procedure. In this analysis, a base point Ti_0 and accumulated time duration ($i_0 \to i$) are varied to determine their effects on the accuracy of this prediction method.

4.2.2. Comparisons between Estimation and Experiment.

Tab.4 and **Tab.5** show the ratio of estimation against to experiment.

Basic Time and Sampling Interval; As shown in **Tab.4**, the error is larger when the starting time of the SF_6 charge is chosen as the basic time (Ti_0) and an averaging time duration($Ti_0 \to i$) is shorter. These results show that the rapid concentration change immediately after starting the SF_6 charge is not desirable for this prediction method for the reason as mentioned in section.2 condition (1).

When the basic time is set to be seven or nine minutes and the averaging time duration is longer than eight min. the prediction agrees with experimental results fairy well. (see **Tab.4** and **Tab.5**) The averaging procedure is required for this method and shorter time interval for sampling can be used when the basic time is set to be later from the beginning of SF_6 purging.

In these experiments, the errors are found to be within 20 %. For example, an average value of error is about 8 %, when the Ti_0 = 9 min. and Ti = 17 min. are chosen in series-I. More accurate estimations are obtained in Series-II within a few percent when later basic time is adopted.

Ventilation Term ; Compared with the series-II experimental results, a tendency of depletion of accuracy at the longer durations is found in series-I. This difference appears to be caused by the ventilation term in Eq.(2'). In series-II , the mechanically ventilated rate was stable and the measurement error was less than that for the natural vent in series-I. In this estimation methods, the effect of the ventilation term becomes larger when the SF_6 conc.level is higher as time goes by. So although the averaging effect improves the estimation, the error of ventilation measurements seems to offset this improvement.

Tab.4. Comparison of Experiment and Estimation Leak Rate under Different Basic Time(Ti_0) and Duration($Ti_0 \rightarrow i$) ; (series I)

[ratio = estimation/experiment]

Exp. Run No.	Basic Time (Ti_0) = beginning of SF_6 inj.					Ti_0 = 9 min.		
	to 5 min.	9.	13.	17.	21.	to 13 min.	17.	21.
1	1.57	1.21	1.10	1.17	1.17	0.85	1.08	1.07
2	1.89	1.32	1.22	1.25	1.31	1.05	1.16	1.27
3	1.51	1.30	1.25	1.23	1.22	1.16	1.16	1.19
4	1.65	1.21	1.16	1.22	1.18	0.92	1.04	1.02
5	0.76	0.61	0.65	0.77	0.84	0.69	0.87	0.91
6	1.16	1.02	1.07	1.09	1.23	1.17	1.15	1.30

cf. *1) the values in table are estimation/experiment of leak rate calculated through the each duration from basic time Ti_0 a certain time.)

*2) estimation value are calculated with eq.(3). Steady state of ventilation rate is assumed as shown in Tab.1.

*3) the SF6 conc. of two minutes sampling time is assumed to be the conc. of mid time in each sampling period, and linear approximation between each data is assumed.

*4) the time shown in Tab. is a mid time of each two minute sampling period. (in Run No.5, deduct two minutes from each time including basic time = 9 in right side)

Tab.5. Comparison of Experiment and Estimation Leak Rate under Different Basic Time(Ti_0) and Duration($Ti_0 \rightarrow i$) ; (series II)

[ratio = estimation/experiment]

Exp. Run No.	Basic Time (Ti_0)=8.5 min. after SF_6 inj.					Ti_0 = 16.5 min.		
	to 12.5	16.5	20.5	24.5	28.5	to 20.5	24.5	28.5
1	0.90	0.90	0.90	0.98	1.09	0.88	1.01	1.13
2	0.95	0.98	0.97	1.00	1.05	0.94	1.00	1.03
3	0.98	0.91	0.92	0.94	0.98	0.91	0.95	1.00
4	0.82	0.84	0.85	0.89	0.96	0.87	0.92	1.01
5	0.70	0.91	0.95	0.97	1.07	0.99	0.99	1.15

cf. *1) the values in table are estimation/experiment of leak rate calculated through the each duration from basic time Ti_0 a certain time.)

*2) estimation value are calculated with eq.(3). Steady state of ventilation rate is assumed as shown in Tab.1.

*3) the SF6 conc. of one minutes sampling time is assumed to be the conc. of mid time in each sampling period, and linear approximation between each data is assumed.

*4) the time shown in Tab. is a mid time of each one minute sampling period. (in Run No.1, deduct two minutes from each time point, and add one minute for Run No.4 & 5)

Tab.6. Comparison of estimated effective area with orifice opening;
(series II)

Exp. Run No.	Leak rate estimation [m^3/min]	Pressure difference [pa]	Estimated effective area [cm2]	Description of orifice opening.
1	0.174	2.97	12.9 (1.14)	effective area of
2	0.173	2.83	13.2 (1.17)	40-50 mmϕ orifice
3	0.167	3.22	11.9 (1.05)	is 11.3cm^2
4	0.312	2.82	23.6 (1.04)	(α=0.89,
5	0.167	2.74	12.9 (1.14)	A=12.6 cm^2)

cf *1) the value inside the parenthesis indicates the ratio against the effective area of orifice. run No.4 is two orifice of the same area are used.

*2) The values are obtained from measured data of Ti_0=16.5 to Ti=24.5.

4.2.3. Estimation of Effective Opening Area (αA).

The effective area of the opening can be estimated from Eq.(1). **Tab.6.** shows the estimated effective area for each run in series-II. The estimation error is about 20 % and is sufficiently accurate for estimating these area for practical use. The measured pressure difference is under estimated in the experiments and more improvement is needed for the measurement of pressure difference between rooms of different floor.

5.CONCLUSIONS and FUTURE DIRECTIONS

A simple experimental method for estimating the smoke leakage through small openings and the effective areas of the openings is presented. Two series of experiments were conducted to determine the degree of accuracy of the method by measuring tracer gas density, ventilation rate and the pressure difference. Comparisons of estimation and experimental leak rates show agreement within 20 %. When the exhaust system is used to produce the pressure difference between rooms, the accuracy is fairly well within a few percent. These results indicate that this estimation method is favorable as a practical estimation method.

However this experimental study was limited to only one type of opening between relatively small volume rooms. Uniformity inside the room and quasi-steady state are very important for this method. Further experimental studies are desirable for verifying its appropriateness in larger volume rooms. The size of opening that can be distinguished with this method is determined by room volume, charged tracer gas concentration, produced pressure difference, and mostly depends on the resolution of the tracer-gas analyzer. Future work will formulate relationships between distinguishable opening size and these other parameters for practical building configurations.

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Fig.3. Installation of full scale test (series-II)

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Fig.6. Time schedule of experiment (series-II)

Tab.1. Condition of chromatographic analysis.

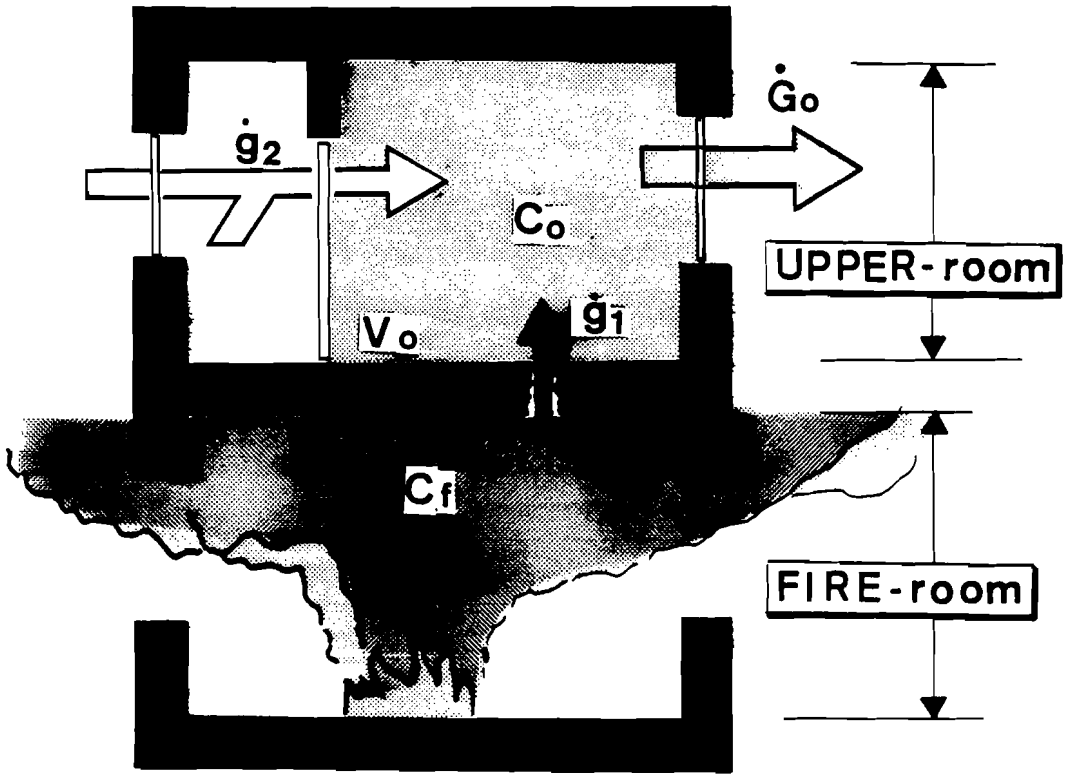
Tab.2. Conditions, leak rate & SF_6 conc. ; (Series-I)

Tab.3. Conditions, leak rate & SF_6 conc. ; (Series-II)

Tab.4. Comparison of experiment and estimation leak rate with different basic time(Ti_0) and interval($Ti_0 \rightarrow i$) ; (series-I)

Tab.5. Comparison of experiment and estimation leak rate with different basic time(Ti_0) and duration($Ti_0 \rightarrow i$) ; (series-II)

Tab.6. Comparison of estimated effective area with orifice opening ; (series II)



$$\overline{\dot{g}_1(t)} = \frac{\{C_o(t) - C_o(t_a)\} V_o + \int_{t_a}^{t} C_o(t)\, \dot{G}_o(t)\, dt}{\int_{t_a}^{t} C_f(t)\, dt}$$

NOMENCLATURE

C ····· smoke concentration
$\dot{G}_o$ ··· ventilation outflow
$\dot{g}_1$ ··· smoke leakage
$\dot{g}_2$ ··· fresh air inflow $(=G - g_1)$
V_o ··· room volume

suffix
o ····· UPPER room
f ····· FIRE room
—— ····· $t - t_a$ time average

Fig.1. Schema of smoke leakage model ; Buoyant fire smoke leaks out from a FIRE room to an UPPER room through small openings, and air in the UPPER-room is contaminated by the smoke gradually with fresh air ventilation. Instant diffusion is assumed in this model.

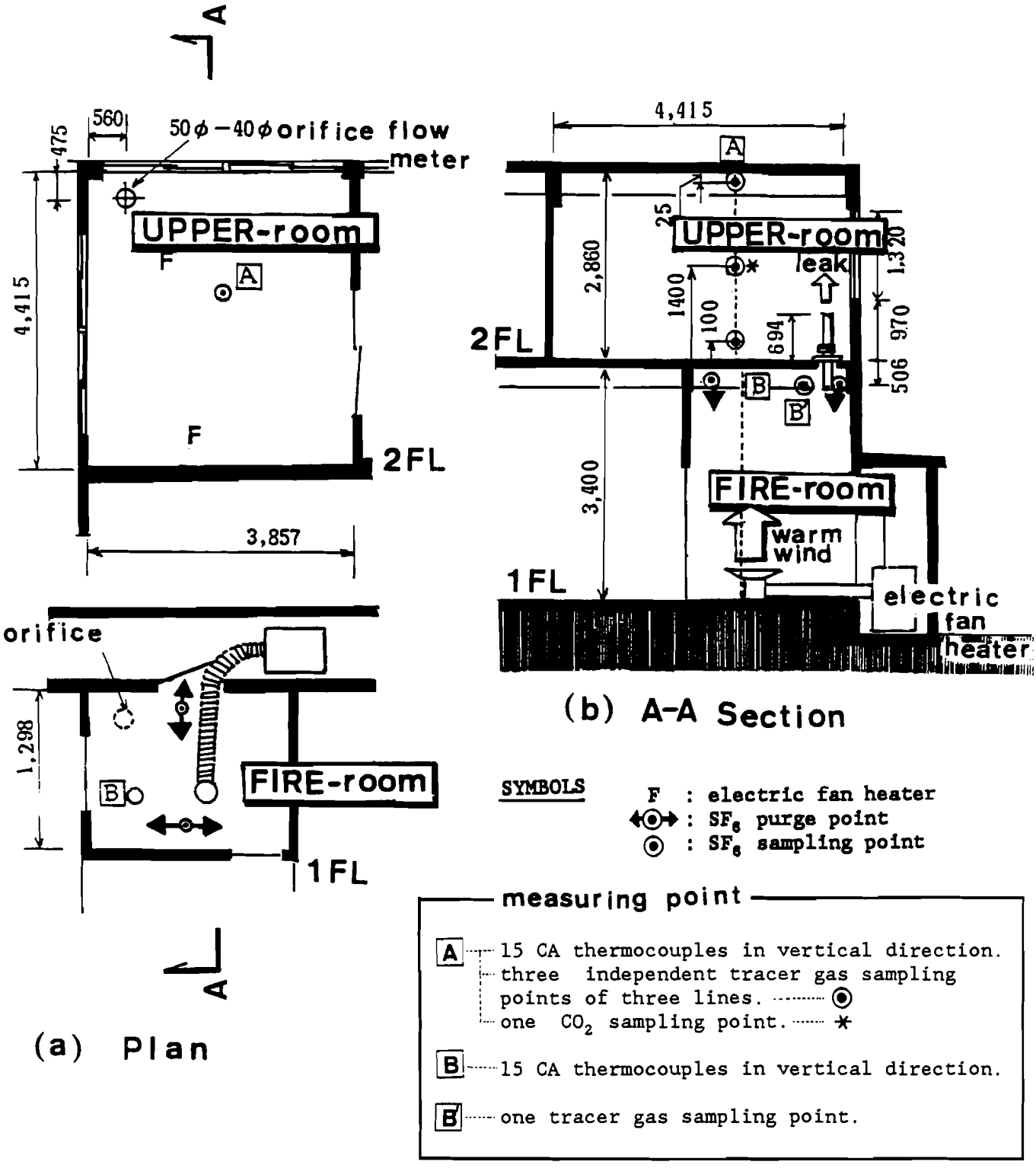
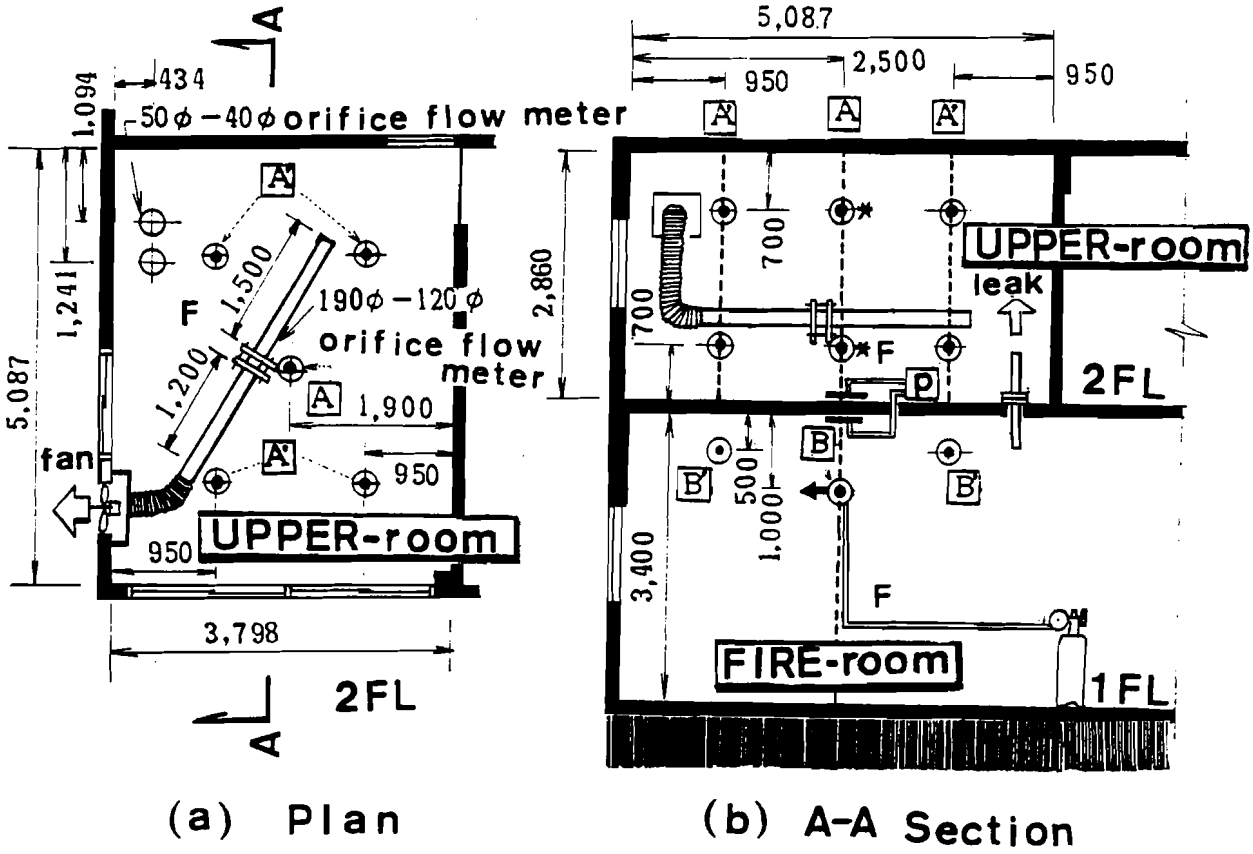


Fig.2. Instalation of full scale test (series I) ; A room on the 1st floor and another room directly above are supposed to be FIRE room and UPPER room respectively. Tracer gas is used instead of fire smoke to estimate leakage from FIRE-room to UPPER-room, while the leakage is measured by an orifice flow meter installed at a slab. pressure differnce is produced by natural ventilation due to buoyant effect.



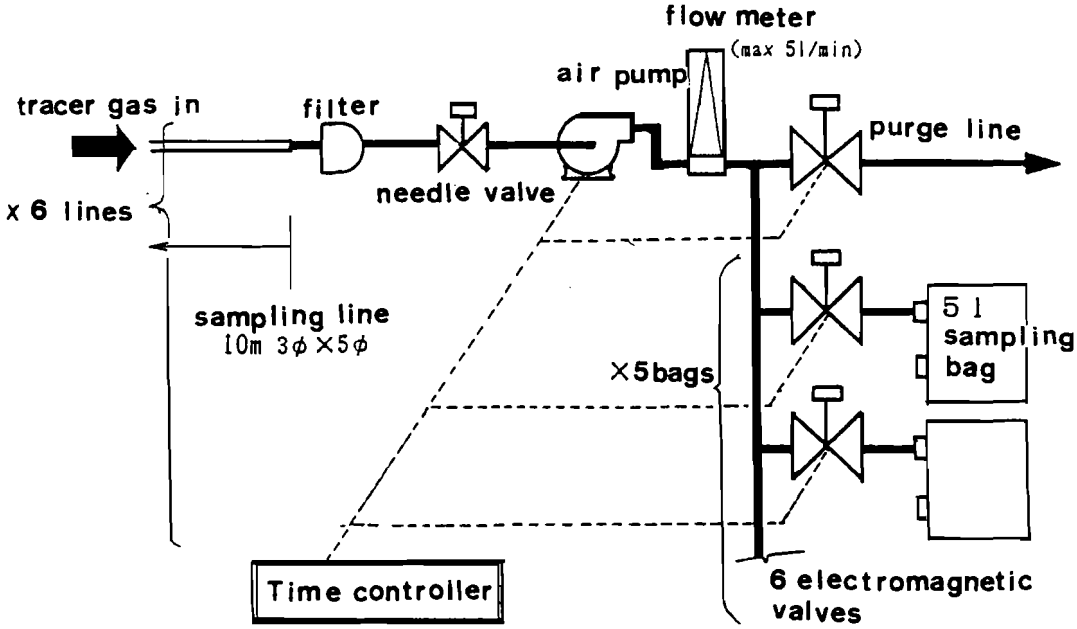
SYMBOLS

- **F : electric fan heater**
- **P : pressure differnce measuring point**
- **: SF_6 purge point**
- **: SF_6 sampling point**

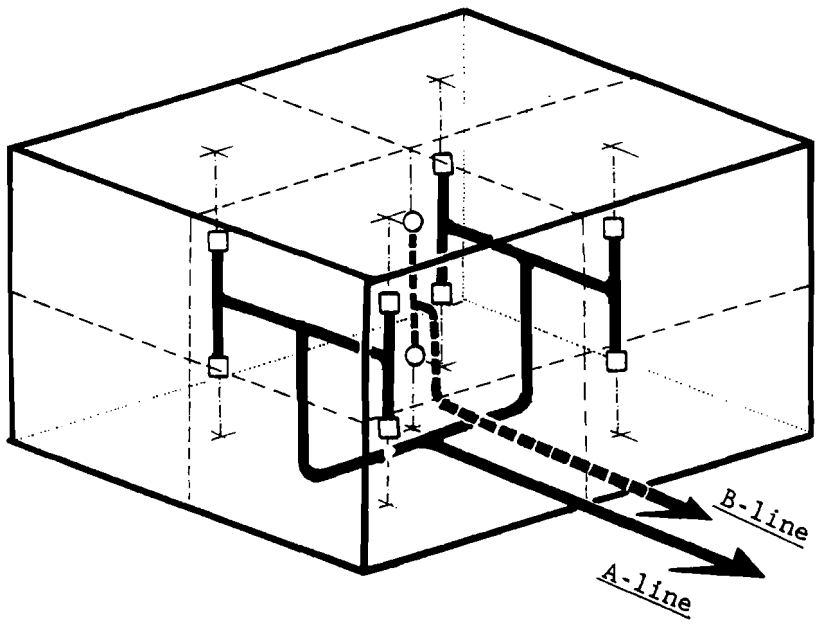
measuring point

- A — 15 CA thermocouples in vertical direction.
  - two tracer gas sampling points of one line.
  - two CO_2 sampling points of one line.
- A' — two sampling points of one line, which line has total eight sampling points.
- B — 15 CA thermocouples in vertical direction.
- B' — one tracer gas sampling point of one line, which line has total four sampling points.

Fig.3. Instalation of full scale test (series II) ; Mechanical ventilation is used to produce pressure differnce between rooms. Ventilation rate is measured with orifice flow meter directly besides by CO2 decay method.



(a) Schema of auto gas sampling equipment.



A-line : Upper room is devevided into eight parts of same volume, and samplings are made at the center point of each parts.
B-line : UPPER room is devided into two upper and lower parts, then samplings are made at the center points of each parts.
Two kinds of sampling are conducted under same time schedule.

(b) Schema of sampling points in UPPER room (series-II)

Fig.4. Schema of tracer gas sampling equipment

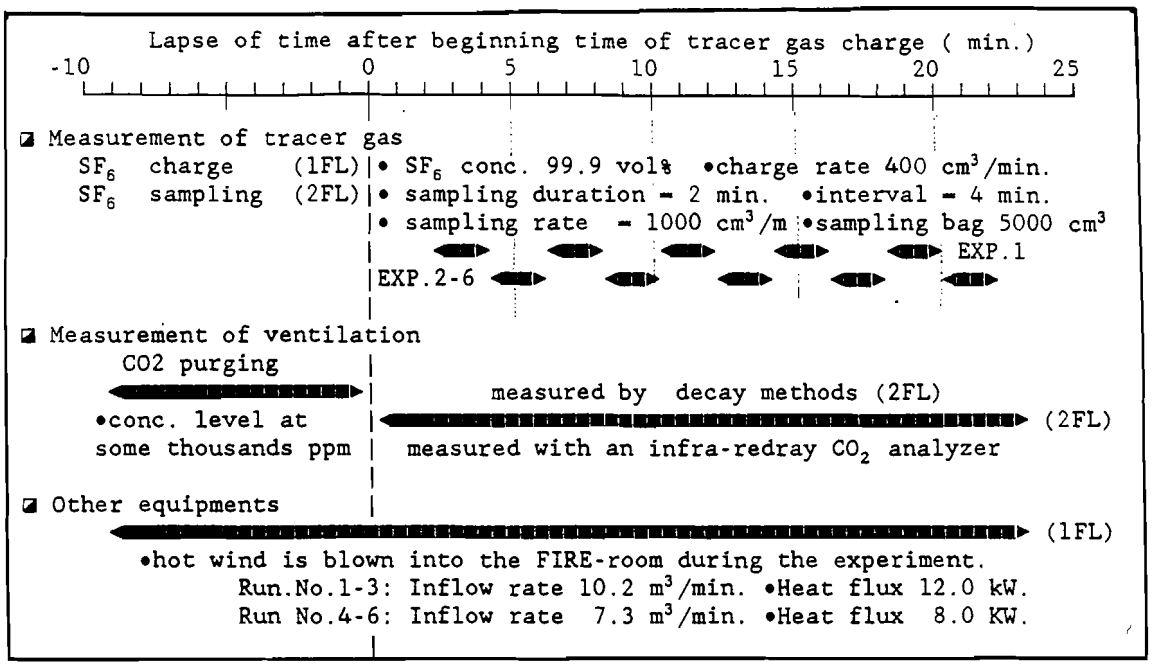


Fig.5 Time Schedule of Experiments (series I) ; A starting time of experiments is defined as the beginning time of point when tracer gas is charged in FIRE-room.

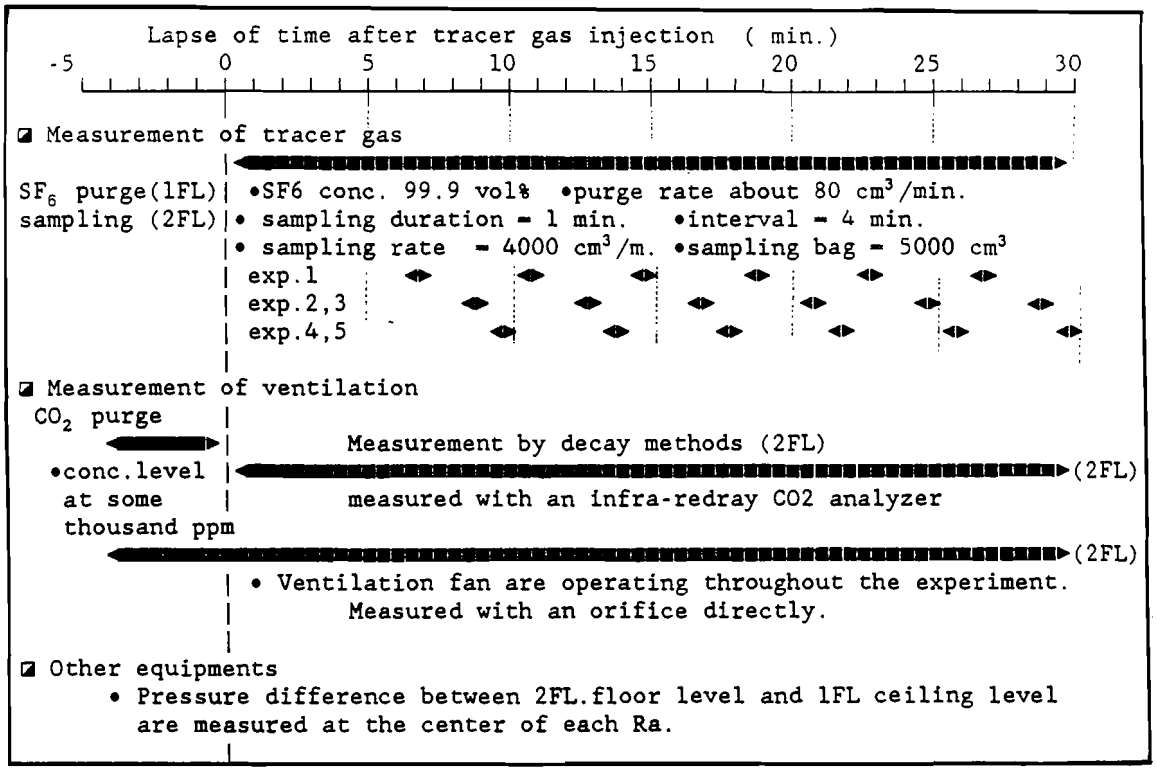


Fig.6 Time Schedule of Experiments (series II) ; A starting time of experiments is defined as the beginning time of point when tracer gas is charged in FIRE-room.