

SIMPLE VERIFICATION METHOD OF BUILDING FIRE SAFETY PERFORMANCE

-- Required width of opening at corridors of condominium --

KADOYA Mitsuo and TANAKA Takeyoshi
Disaster Prevention Research Institute, Kyoto University,
Gokasho, Uji, Kyoto 611-0011, JAPAN
kadoya@drs.dpri.kyoto-u.ac.jp, takey@drs.dpri.kyoto-u.ac.jp

KUJIME Mamiko
Nikken Sekkei, Osaka Office,
4-6-2 Koraibashi Chuo-ku, Osaka 541-8528, JAPAN, kujime@nikken.co.jp

NAKAMICHI Akiko
General Building Reserch Corporation,
1-2-10 Minami-Shinmachi, Chuo-ku,Osaka 540-0024,JAPN, nakamichi@gbrc.or.jp

ABSTRACT

Performance-based regulations have developed gradually in the field of fire safety design of buildings. Yet there are not a few prescriptive provisions in the Building Standards Law of Japan. Many of them are based on empirical knowledge and their effectiveness is not well ensured. In some cases, they cause controversy between designers and building officials in an actual fire safety design.

Here some fundamental and simple methods are introduced to examine the problems that are focused on the outdoor corridor of condominium and some results of the investigations are shown. From these results the followings are known.

In order to ensure safety from smoke for evacuees or fire brigades in an outdoor corridor, approximately 4.5[m] wide opening to the air is necessary in usual conditions of a condominium. But this requirement changes depending on various conditions. It is influenced a little by fire room temperature, but is influenced largely by vertical sections and dimensions of the corridor.

KEYWORDS: simple verification method, performance-based fire safety of building, smoke exhaust from corridor, condominium,

1. Introduction

It is not rare that the provisions in the Building Standard Law or the Fire Service Law are reinforced by Ministries' notifications or the local bylaws to secure fire safety of a

building. In such notifications or bylaws, there are some specific standards that seem to be based on empirical knowledge, and in not a few cases, their effectiveness is suspicious when applied to a practical building. It is desirable for such a standard to be improved based on performance. But only if there are methods to verify the safety on such a case quantitatively and simply, it might be easier for designers or building officials to decide their safety assessments in many cases.

This paper aims to introduce such simple methods as to be used easily by designers or reviewers of building fire safety design. And some example results examined by these methods, focusing the objects on problems to be often brought up concerning with "outdoor corridors of condominium" are demonstrated.

The authors have proposed the basic predicting methods for fire safety design under this concept¹⁾, but they can be applied mostly under relatively simple conditions. This paper introduces a method integrating several fundamental methods and able to be applied to a more realistic condition often encountered in the practice.

2. Problems related to the outdoor corridor of condominiums

Problems often raised relating with fire safety of outdoor corridor of condominium are such as follows;

i.) Safety from smoke in an outdoor corridor opened to the air.

Even in an outdoor corridor opened to the air it is rare that it is entirely opened to the air, and so it is difficult to say whether such a corridor is outdoor or indoor. When smoke leaks out from a dwelling unit of fire origin into such a corridor, it is often to be a question whether the corridor's safety from smoke can be secured, in other words whether necessary width of opening are ensured to exhaust smoke effectively from it.

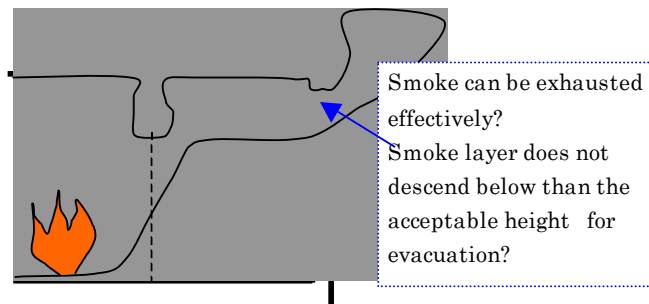


Fig.1 Safety from smoke in an outdoor corridor

ii.) Necessity of a lobby to a special escape stairs linked to an outdoor corridor.

An escape stairs linked to an outdoor corridor is to be a special escape stairs and a lobby is required if the building is classified as a high-rise one by the Building Standard Law.

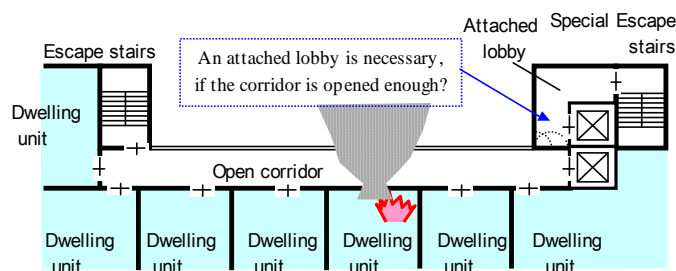


Fig.2 Necessity of a lobby to escape stairs

The potential hazard of smoke invasion into a lobby or special escape stairs itself will be decreased if a sufficient opening exists in the outdoor corridor. However, whether an attached lobby is necessary or not is occasionally disputed under practical conditions of the corridor.

iii.) Necessity of smoke prevention curtains between stairs and outdoor corridor.

If an opening of an outdoor corridor is insufficient, it will be possible that smoke invades into a stairs linked to it, so there are some cases that a certain depth of smoke curtain is required between a stairs and outdoor corridor. But in these cases, the quantitative requirement of the depth of smoke curtains in the prescriptive provisions becomes often to be a question.

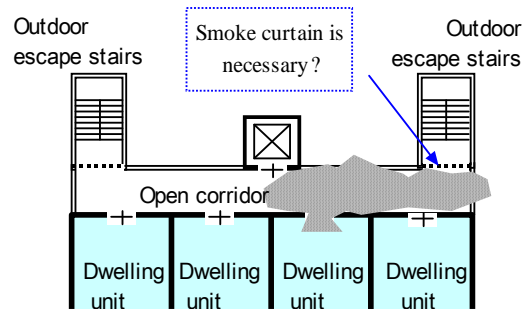


Fig.3 Necessity of smoke proof curtains between outdoor corridor and stairs

iv.) Openness of void space in a high-rise condominium

In a case of a high-rise condominium that has a void space in it, if the void space is assumed to be equivalent to the outdoor space, the corridors in the void space may be similar the ordinary outdoor corridors in conjunction with smoke hazard. Assuming that smoke flows out into void space from the dwelling unit of fire origin, what is the quantitative conditions that provide severer dangers to upper floor corridors than ordinary open corridors? This subject often becomes to be a question too.

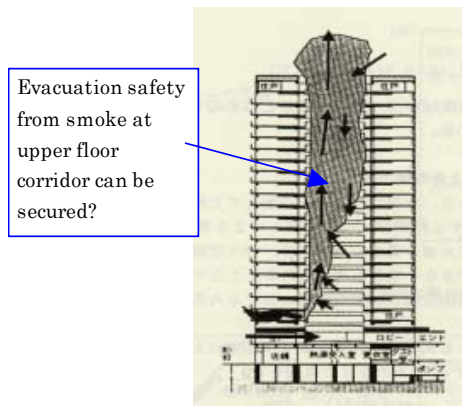


Fig.4 Safety from smoke in a void space

Methods for examining such problems as mentioned above based on performance and some examined results by the method are introduced in the following.

However, notice that the performances examined here is focused on "safety from smoke". So performances such as preventing fire spread or easiness of a fire brigade intervention by fire ladder etc. are not addressed here. Nevertheless such performances will be able to be examined once their requirements are defined.

3. Problems related to the openness of outdoor corridors

The problems from 'i.)' to 'iii.)' of those mentioned above can be reduced to the same

question of whether a smoke layer may descend to an untenable height when smoke flows into an outdoor corridor from the dwelling unit of fire origin. In other words, how wide the opening of corridor needs to be to keep smoke layer interface higher than the critical height.

Concerning these problems there is a standard^{note1)} by a notification, but here their validity will be investigated based on the fire safety performance from the basics.

3-1. Examining method of the necessary opening width of outdoor corridors

The methods for estimating the necessary opening width to keep smoke layer interface at an acceptable height in an outdoor corridor by the fundamental and simple formulas are firstly investigated and described.

i.) Heat release rate Q in a corridor

a.) Mass flow rate into the corridor

Heat release rate of fire source is the essential conditions to predict the behavior of smoke in a corridor. The amount of heat brought by opening jet from the dwelling unit of fire origin into the corridor corresponds to the heat release rate for a fire source.

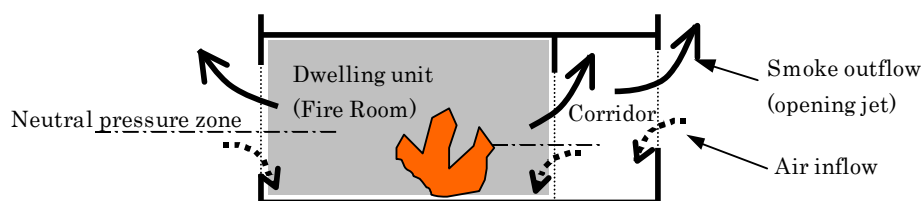


Fig.5 Opening jet from a fire room

The mass flow rate of hot gas through an opening of fire room such as doors or windows is given by following equations, indifferent to the fire room temperature if the fire is at a fully-developed stage²⁾.

$$m_d = 0.5A\sqrt{H} \quad (1)$$

Where, m_d : Mass flow rate of opening jet into a corridor [kg/s]

A : Area of opening [m²]

H : Height of opening [m]

b.) Heat release rate

The heat release rate, which is brought into the corridors via the opening jet from the dwelling unit, is given as follows as a function of the fire room temperature.

$$Q_d = c_p m_d \Delta T = c_p m_d (T_f - T_\infty) \quad (2)$$

Where, Q_d : Heat release rate brought into a corridors from an opening [kW]

c_p : Specific heat of air at constant pressure [kJ/kgK]

T_f : Fire room temperature at a fully-developed stage [K]

T_∞ : Ambient air temperature [K]

And, a method to calculate the fire room temperature at fully-developed stage have been proposed ^{note 2)}, but a fire is not always fully-developed in actual cases and the temperature will vary according to its stages.

ii.) Plume flow rate from fire source.

a.) Estimating formula of plume flow rate

If the fire source is assumed individually in the corridor, the most important condition to investigate the smoke behaviors is to determine an equivalent plume flow rate to that of the opening jet flow rate. Plume flow rate of opening jet varies by the height. According to the existing research^{2),3)}, plume flow rate of opening jet is not much dependent on the aspect ratio of an opening, and can be estimated by following equation.

$$m_p = 0.072Q^{1/3}(z_e + z_d + z_0)^{5/3} \quad (3)$$

Where, m_p : Mass flow rate of opening jet plume [kg/s]

z_e : Distance from the upper end of an opening [m]

z_d : Distance from the upper end of an opening to the position where m_p becomes to be equal to the flow out rate from the opening (call this position as "reference height") [m].

z_0 : Distance from "reference height" to the virtual point fire source [m].

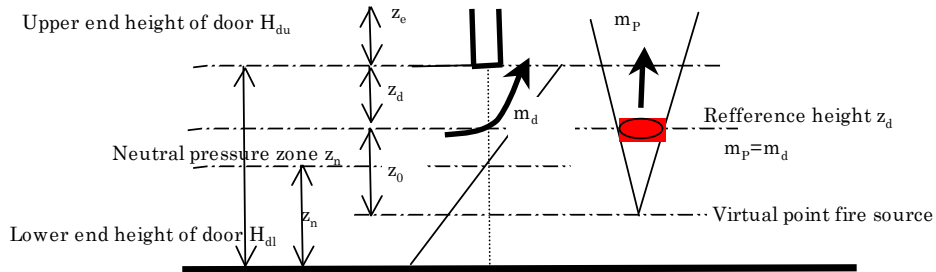


Fig.6 Vertical dimensions about opening jet

b.) Distance from the upper end of the opening to the reference height

$$z_d = (2/3)(H_{du} - z_n) \quad (4)$$

Where, H_{du} : Height of the opening [m]

z_n : Height of the neutral zone from the bottom of the opening [m]

The height of the neutral zone z_n in Eq. (4) is given as follows.

$$z_n \approx 0.36 \cdot (H_{du} - H_{dl}) \quad (5)$$

Since in a single opening of a fire room at fully-developed stage, the neutral zone height at the opening is almost constant as $H''/H \approx 0.64$, not much influenced by the temperature²⁾. Adopting this relation gives safer side estimations even if a fire has not reached the fully-developed stages.

- c.) Distance z_0 from "reference height" to the virtual point fire source
 This distance is expressed as follows from the relations in Eq. (3).

$$z_0 = \left(\frac{m_d}{0.072Q^{1/3}} \right)^{3/5} \quad (6)$$

Hence, the height z_0' [m] from floor to the virtual point fire source is expressed as follows, and the plume flow rate can be obtained assuming the height of the virtual point fire source to be there.

$$z_0' = H_{du} - z_d - z_0 \quad (7)$$

- iii.) Necessary width of corridor's opening and other related factors.

The width of opening of a corridor required to keep the smoke layer higher than the critical level can be obtained as follows.

- a.) Critical smoke layer height z_c

Critical smoke layer height z_c [m] according to the corresponding purpose is necessary to be defined.

- b.) Plume flow rate

Assuming that the smoke layer is kept at the critical height z_c , the plume flow rate penetrating into the smoke layer is obtained as follows.

$$m_{z_c} = 0.072Q_d^{1/3} (z_c - z_0')^{5/3} \quad (8)$$

- c.) Smoke layer temperature

$$T_s = T_\infty + Q_d / (c_p m_z + hA_w) \quad (9)$$

Where, A_w : Area of the corridor surface contacting with the smoke layer [m²]

h : Effective heat transfer coefficient ^{note 3)} [kW/m²K]

- d.) Density of smoke and air

$$\rho_s = 353/T_s \quad (10a)$$

$$\rho_\infty = 353/T_a \quad (10b)$$

Where, ρ_s : Densities of smoke [kg/m³]

ρ_∞ : Densities of ambient air [kg/m³]

- e.) Height of neutral zone at opening of corridor

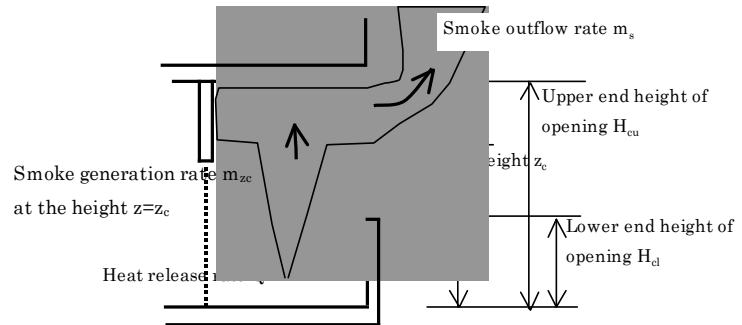


Fig.7 Discharge of smoke from corridor

The neutral zone height z_n at the opening of the corridor is difficult to obtain analytically. It can be obtained only numerically as follows:

Letting m_s' be the smoke outflow rate per a unit width, and m_a' be the air inflow rate from the outdoor to the corridor per unit width,

smoke outflow rate per a unit width is expressed as the following,

$$m_s' = (2/3) \cdot \alpha \sqrt{2g\rho_s \Delta\rho} (H_{cu} - z_n)^{3/2} \quad (11)$$

air inflow rate per a unit width (in the case of $H_l > z_c$) is expressed as the following,

$$m_a' = (2/3) \cdot \alpha \sqrt{2g\rho_a \Delta\rho} (z_n - H_{cl})^{3/2} \quad (12a)$$

air inflow rate per a unit width (in the case of $H_l < z_c$) is expressed as the following.

$$m_a' = (2/3) \cdot \alpha \sqrt{2g\rho_a \Delta\rho} (z_n - z_c)^{3/2} + \alpha (z_c - H_{cl}) \sqrt{2g\rho_a \Delta\rho} (z_n - z_c) \quad (12b)$$

Where, H_l : Height of the lower end of opening part of corridor from floor level [m]

$$\Delta\rho = |\rho_\infty - \rho_a| \quad [\text{kg/m}^3]$$

Equating Eq.(11) and Eq.(12), i.e. $m_s' = m_a'$, we have a non-linear algebraic equation.

Solving the equation by a trial and error method for the neutral zone height z_n , we obtain the mass outflow rate of smoke and inflow rate of air which satisfy the mass continuity of the corridor.

f.) Necessary width of the opening of corridor.

$$B = m_{zc} / m_s' \quad (13)$$

3-2. An example examined the required opening width of an outdoor corridor

An example in which the smoke behavior and the required opening width of a building is examined using the above mentioned methods is explained in the following.

a. The problem

This is the problem mentioned in 'i.)' of section 2. Often the opening area of the outdoor corridor of a relatively small condominium is restricted by a staircases and an elevator shaft. In case of such a plan, it becomes a question how much width of opening is necessary to ensure the safety from smoke in the corridor during the evacuations.

b. The objective building to be examined.

Fig.8 shows quite a popular plan and dimension of a standard floor of a small condominium in Japan, which is investigated in this section.

c. Fire scenario, conditions and criteria for investigations

When the fire safety design of a building is investigated, it always induce a dispute that under what kind of situations the fire safety should be secured, and these situations are often called fire scenarios. On these fire scenarios, a standard design fire source has been established to an extent, but it is hard to say that the rules for other conditions have been well established currently.

The following investigations are made under the scenarios, respective conditions and acceptable criteria mentioned below.

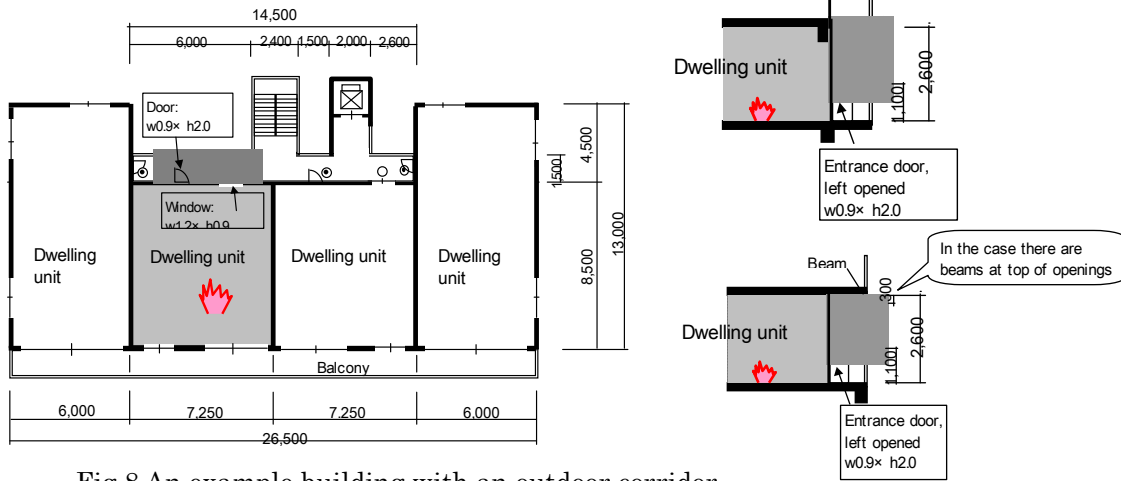


Fig.8 An example building with an outdoor corridor

c-1. Fire scenario

A fire occurred in a dwelling unit in a condominium with outdoor corridor (one side corridor type). The residents of the unit of fire origin failed to put out the fire at its initial stage and escaped from the room. In that occasion some objects were got jammed at the entrance door to hinder its closure, though it had a door closer. Considering that in such buildings like the condominium the time for occupants to perceive a fire out-break tends to be delayed, it is assumed that the fire has grown to its fully-developed stage when the residents in other dwelling units start to escape.

Two types of the cases regarding to the openings of the fire room are assumed. The first is the case that the entrance door and the window of room facing the corridor are both left opened (Case1 & 3) and the other is that only the entrance door is left opened (Case2 & 4). Also two types of the cases regarding to the shape of corridor's opening are assumed. The first is the case that there is no beam, which serve as a smoke barrier, at the top of the corridor's opening (Case1 & 2), and the other is that there is such a beam there (Case3 & 4).

The investigations are concerned with the stage that non-fire room residents are evacuating and that fire brigades are engaging with fire fighting in the corridor.

c-2. Respective conditions.

- Fire room temperature : Temperature is assumed widely as from 400 to 1200 [C]
- Entrance door of the fire room : 0.9 (width), 2.0 (height, 0 - 2.0 from floor level) [m]
- Window facing the corridor : 1.2 (width), 0.9 (height, 1.1 - 2.0 from floor level) [m]
- Area of the corridor : 1.5 (width)x14.5 (length)=21.8 [m²]
- Ceiling of corridor : 2.6 (height) [m]
- Opening of the corridor

in the case without a beam : 1.5 (height, 1.1 - 2.6 from floor level)[m]
in the case with a beam : 1.2 (height, 1.1 - 2.3 from floor level)[m]

Smoke control facilities : No mechanical facilities in the corridor.

c-3. Acceptable criteria.

Fire safety in this problem is evaluated by the height of the smoke layer in the corridor. The critical smoke layer height is set to be $z_c=1.8[m]$, rounding up the criteria values⁴⁾ for the safety from smoke for evacuees and also for the fire brigades. Though fire brigades are thought to be able to reach the fire room with low postures, it may be necessary to ensure the same height of smoke layer as that for evacuees after all, since their operations⁵⁾ such as rescuing and carrying refugees or fire fighting with heavy equipments.

The key question is what is the necessary width of the opening of outdoor corridor to keep the smoke layer above this critical height during the time of evacuation and fire fighting activities.

d. Results of examination.

The main results of Case 1-4, which are assessed based on the procedures mentioned at previous section, are shown in the Table 1.

From these results, it can be known that the necessary width of opening of corridors is only slightly influenced by the fire room temperature conditions. (Tab.1, Fig. 9)

In the cases that there is no beam at the top of the corridor's opening, the necessary width of the opening is known to be about 4.5[m] when hot gases are ejected from two openings (Case1.) and about 3.5[m] when ejected from one opening (Case2.).

In the cases that there is a beam at the top of the corridor's opening, the necessary width of the opening is known to be about 8.3[m] when hot gases are ejected from two openings (Case3.) and about 6.5[m] when ejected from one opening (Case4.).

Tab.1 Necessary width of the opening to ensure safety from smoke in the corridor (Case 1-4)

Case	Building conditions		Fire conditins		Criteria	Results of estimation					
	Opening of a corridor Upper end H_u [m]	Lower end H_l [m]	Opening spout hot gas	Temperature of fire room T_f [°C]	Smoke layer height Z_c [m]	Heat release rate Q [kW]	Mass rate of opening jet \dot{m}_p [kg/ s]	Temperature of smoke layer T_s [°C]	Height of neutral pressu Z_{nc} [m]	Smoke discha per unit width [kg/ s/ m]	Needed width of opening B [m]
1-1	2.6	1.1	Entrance door +window	400	1.80	678	2.89	190	1.934	0.653	4.43
1-2				600		1035	3.00	273	1.922	0.693	4.33
1-3				800		1392	3.08	354	1.913	0.709	4.35
1-4				1000		1749	3.15	433	1.905	0.712	4.43
1-5				1200		2106	3.21	510	1.898	0.708	4.53
2-1	2.6	1.1	Entrance door	400	1.80	484	2.23	166	1.938	0.632	3.53
2-2				600		738	2.33	236	1.927	0.680	3.43
2-3				800		993	2.40	305	1.918	0.701	3.43
2-4				1000		1247	2.46	372	1.911	0.710	3.47
2-5				1200		1502	2.51	437	1.904	0.711	3.53
3-1	2.3	1.1	Entrance door +window	400	1.80	678	2.89	190	1.848	0.364	7.95
3-2				600		1035	3.00	273	1.843	0.384	7.82
3-3				800		1392	3.08	354	1.839	0.388	7.95
3-4				1000		1749	3.15	433	1.835	0.389	8.10
3-5				1200		2106	3.21	510	1.832	0.384	8.36
4-1	2.3	1.1	Entrance door	400	1.80	484	2.34	166	1.850	0.353	6.63
4-2				600		738	2.33	236	1.845	0.377	6.18
4-3				800		993	2.40	305	1.841	0.386	6.22
4-4				1000		1247	2.46	372	1.838	0.390	6.31
4-5				1200		1502	2.51	437	1.835	0.388	6.47

(Note) Gray colored part is under the same condition as Case1

e. Summary

As the results, the position and dimension in vertical section of corridor's opening is recognized to be very important for the necessary opening width. So in the case to express the required openness specifically, it is crucial to clarify the conditions of the vertical dimension. When a windbreak screen is attached to the opening of corridors, it is necessary to ensure that the upper end of screen is to be opened.

The estimated results of the necessary width of opening of corridors are shown in Fig. 9 together.

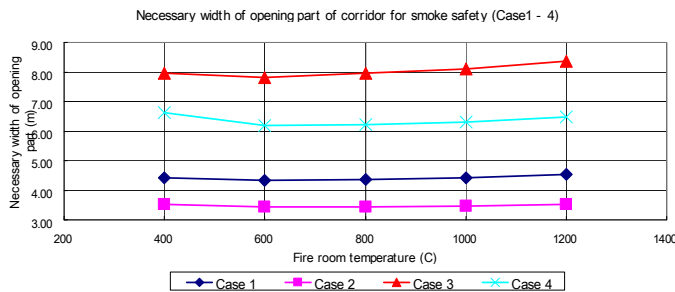


Fig. 9 Fire room temperature and the necessary opening width (Case1-4)

The reason why the necessary width of the opening does not vary significantly even if the fire room temperature changes widely is thought to be as follows. As the fire room temperature rises, spouting rates of the heat and smoke into a corridor increase, and the temperature of the smoke layer becomes higher. If the smoke layer temperature becomes higher, the pressure difference between smoke layer and outside air increases, so the exhaust rate of smoke from the corridor increases too. If smoke layer temperature becomes still higher, the effect of the density decrease of the smoke layer becomes larger, and then mass exhaust rate of smoke is rather depressed. The result shown above is the consequence of a combination of such phenomena (Fig.10).

So, the fire room temperature around 800 degrees centigrade is a practically good assumption in this aspect, if a normal building fire is presumed.

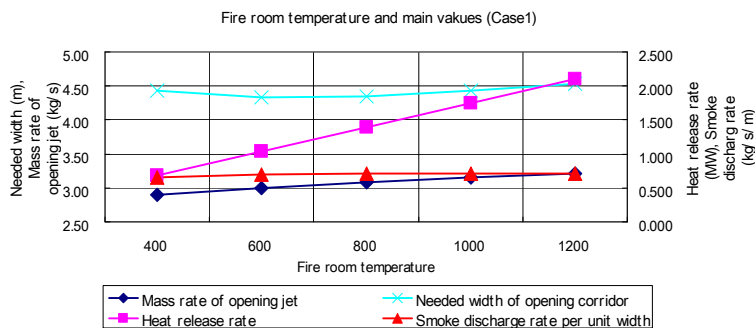


Fig. 10 Fire room temperature and main calculated values (Case1)

4. Conclusion

About several problems on fire safety from smoke concerning with "outdoor corridors of condominium", some fundamental and simple methods are introduced to examine building designs based on fire safety performances and some example results examined by these methods are shown in order to be helpful for actual designs.

There are still many other problems on fire safety provisions concerning condominium and also supposed to be more problems concerning buildings of other use. For those problems, it is beneficial to establish the simple methods for examining fire safety performances similar to that mentioned in this paper.

[Explanatory notes]

1) A standard to evaluate the openness of open type corridor (notification by Fire Defense Agency, Abstract, necessary to be referred to the original document in detail.)

The open type corridor is defined as such conditions as follows.

- i. Opening area > 1/3 of the corridor facade area
- ii. Opening height upper the handrail > 1[m]
- iii. Hanging wall height up to the corridor ceiling < 30[cm]
- iv. When windbreak screen is established
Screen width < 2[m] and mutual interval distance of then > 1[m]
- v. When there are staircases
L < 8W and L < 12[m]
Where, L: Length of corridor of the part not opened,
W: Depth of corridor of the part not opened.

2) A method to predict temperature in a fire room at fully-developed stage
(Abstract, necessary to be referred to the reference document 1), 2) in detail.)

i. In the case of combustion type ruled by fuel

$$\Delta T_F = 20Q^{2/3} \left(\frac{1}{A_R A \sqrt{H}} \right)^{1/3}$$

ii. In the case of combustion type ruled by ventilation

$$\Delta T_F = 2450 \left(\frac{A \sqrt{H}}{A_R} \right)^{1/3} -$$

Where, A : Area of an opening [m²]
A_R : Area of heat transferring surface [m²]
H : Height of an opening [m]
Q : Heat release rate [kW]
ΔT_F : Temperature rise [K]

3) Effective coefficient of heat transfer

A method suggested by McCaffrey and others.

(Abstract, necessary to be referred to the reference document 1), 2) in detail.)

$$h_k = \begin{cases} \frac{k}{\delta} \cdot \cdot \cdot \cdot \cdot \left(t > \frac{\delta^2}{4\alpha} \text{の時} \right) \\ \left(\frac{k\rho c}{t} \right)^{1/2} \cdot \cdot \cdot \cdot \cdot \left(t \leq \frac{\delta^2}{4\alpha} \text{の時} \right) \end{cases}$$

Where, k : thermal conductivity [kW/mK]

δ : thickness [m]

ρ : density [kg/m³]

c : specific heat capacity [kJ/kgK]

α : thermal diffusivity [m²/s]

t : duration time [sec]

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