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A Study on Cost-Performance of Fire Door in a MOT Viewpoint

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ABSTRACT

Fire door would be one of the most important factors for securing building fire safety, which are generally made of thick wood or heavy metal, causing they are subject to be put aside on account of inconvenience to Japanese daily life in spite of cutting down fire performance. The size of fire door in Japan has been enlarging for the attainment of convenience and amenity. From Japanese legal point of view, the area of doors is not included in that of interior finishing, which indicates another increment of fire-growth risk because of decorative finishing of doors. In addition, Japanese approved steel door with plastic surface finishing allows easy ignition and spread of fire to an ambient compartment by its high rate of heat transfer. This paper deals with some legal issues and cost/performance of Japanese fire doors in a MOT (Management of Technology) viewpoint, through several investigations and analyses on commercial products made of wood and/or steel. An operation break-through aimed at innovating cost-performance of a wood fire door is now making its completion mainly focused at cost reduction under considerations of some innovative technologies, which might survive Japanese wood culture or woody daily life and also effective as an example of cost/performance analysis on fire risk.

Key Words: *wood fire door, building fire safety, fire risk, legal issues, cost /performance, Japanese wood culture*

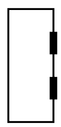
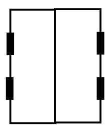
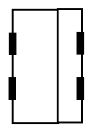
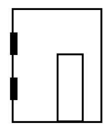
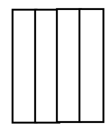
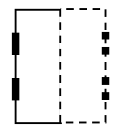
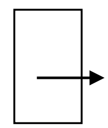
INTRODUCTION

Generally speaking, main factors for fire safety are composed of passive protection such as fire resistive compartment and evacuation corridor or staircase, and active one represented by fire management and fighting. A tremendous number of fire tragedies have been derived from the lack of late awareness of fire occurrence and smoke control. Recently, building fire safety field had experienced two fatal fires, those were multi-occupied small building fires occurred in Incheon, Korea and Tokyo, Japan. Both fire were started by intentional flame-touching to volatile materials and emerged dense smoke quickly dispersed through open or low-grade fire doors into upper floors occupied by amused people, most of whom lost their lives within a few minutes. The former case was estimated the cause of tragedy would be derived from fixed veneer-clad and thick window-glass on the second floor together with opened entrance fire door, and the later caused by curtain-concealed windows, only one open-away fire door at the entrance. A great number of house-fires have been also occurring accompanied by multi-deaths, which would be derived from the structural or systematic weakness of fire door. The authors would like to discuss several innovative issues on fire door in this paper, based on various aspects concerning risk and cost/performance from a MOT point of view.

Performance Requirements of Fire Door

Passive fire protection is mainly attained by wall or floor compartment, which indicates openings such as door, shutter and partition-curtain should have fire enclosing function just equal with immovable compartments, and walk- or transfer-through function for human and products at the same time. Some solutions for conquering these contradictive functions have been submitted to fire protection field. For example, self-closing systems are available by using metal spring, oil pressurizing or a certain explosive substances, some of which are remote controlled from fire command center, and fixing systems by using electric magnet, metal hook or dropping latch. The movable types of fire door are generally classified like the following **[1];** single swing type appropriate to about 910 – 1365 mm width, double swing (called Kannonn Biraki in Japan) to 1365-1820 mm, double swing with parent and child size to 1365-1820 mm, single swing included child size to 1365 - 2275 mm, folded pieces to 1365 – 2275 mm, two way double swing to 1365-2275 mm, and sliding to 910-1820 mm (3 x 6 Shaku in Japanese unit) as shown in **Table-1**. These types and sizes affect the rate of smoke or fire barriers. Fire protection performances are arranging in heat insulation and flame or smoke shutting. Fire door with no decorative finishing for evacuation rout would be expected to posses the later functions, because there exists a few combustible obstacles in corridor or staircase, which would show a slight burden for evacuees who escape in an early stage of fire.

Table-1 The size and O/C type of doors

o/c type	single	double swing	double swing (parent & child)	single (included child)	joint folded pieces	double swing (two way)	sliding
figure							
Size(mm)	910-1365	1365-1820	1365-1820	1365-2275	1365-2275	1365-2275	910-1820

For multi-storied buildings, however, there need heat insulated fire doors, because in some cases, upper-floor people have to evacuate downwards through stairwell ambient to a fully developed fire area. Steel door has high rate of heat-transfer, expansion or deformation on the contrary to its strong resistance of heat deterioration, causing it would be useful to prevent fire spread between rooms with an appropriate clearance from combustible commodities or goods and earthquake vibration. Thick wood door, on the other hand, is effective to protect heat or smoke-attach into ambient rooms, on condition that there exist no aperture or gaps between door and surrounding frame. **Figure-1** shows the main requirements of fire door.

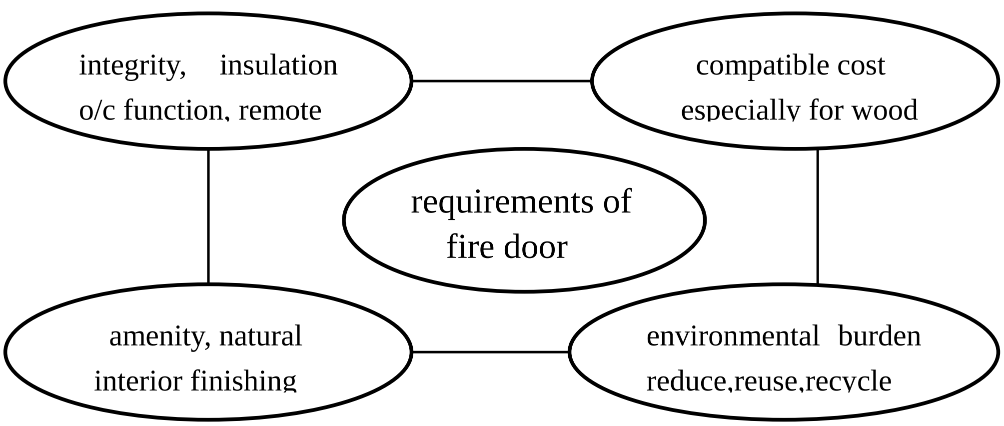


Figure-1 Requirements of fire doors

Detailed Requirements of Self-Closing System

Self-closing system of fire door would be quite important for securing life safety of evacuees, who consist of handicapped, elderly, child, youth, man, or woman. In general, door opening force (Fm) by man is measured as approximately 40% of his weight (Wm), and (Fw) by woman as about 30% of her weight (Ww), and (Fec) by elderly or child as 20 - 50 N (the max. value of Fec is reported about 100N) **[2].** Increasing pressure at an early stage of fire (⊿ Pf) , draft pressure in vertical void (⊿ Pv), and wind pressure (⊿ Pw) are expressed as follows.

$$\triangle Pf = 5x10^{-6}(Q/Ad)^2 \quad Pa \qquad (1)$$

where, Q is heat release in fire room (kW), which is given $0.2t^2$ (kW) for dwelling occupancy, and Ad is the broken or leakage area of fire room openings (m^2)

The value of ⊿ Pv during winter season would be generally larger than that of in summer, and if the temperature indoor was 293 K and outdoor was 273 K, the difference of air density ⊿γ would be about 0.1, then

$$\triangle Pv = 10x10^{-1}((Hd/2)-H) \quad Pa \qquad (2)$$

where, Hd is the height of vertical void (m), H is the height from ground (m)

Wind velocity at H (Vh) is expressed in the following,

$$Vh/Vo=(H/Ho)^{1/4} \quad m/s \qquad (3)$$

where, Ho is standard height (normally 10m), Vh is wind velocity at H

Wind pressure is given as

$$\triangle Pw = C(\gamma\ Vh^2)/2g=C(\gamma\ / 2g)Vo^2(H/Ho)^{1/2} \qquad (4)$$

If C=1 and γ = 1.3(273/T)=1.3(273/293)=1.2, then

$$\triangle Pw = 1.0(1.2/2x9.8)Vh^2=0.61Vo^2 (H/10)^{1/2} \quad Pa \qquad (4')$$

The value of pressure to fire door (⊿Pd) is expressed as follows.

$$⊿Pd= ⊿Pf+ ⊿Pv+ ⊿Pw \quad (5)$$

here, each ⊿P is the value of pressure devided by the number of related openings.

If the size of fire door is a in height and b in width, opening force ab⊿Pd(b/2) should be more than door torque Td. As before-mentioned, actual opening forces are measured around 20 – 240 N, and we decided here the value 50N, minimum of elderly. As for draft pressure at 6m for the second story, ⊿Pv is –10 Pa. As for wind pressure, we take 4.5 m/s at 10 m in height based on the data by Japanese meteorological Agency. Then, at 6m, ⊿Pw is 10 Pa.

As for fire pressure, if heat release Q in a fire room, at lapse time 1, 3, 5, 7,10 minutes, Qavg=0.4, 3.3, 9.0, 17.7,36.0 MW reported by the MOC project **[3],** and a fire room has 4 openings of $2m^2$ with 0.5, 6.3, 20.3, 44.0, 100% broken area per each Qavg respectively resulted by some experimental studies **[4],** and $2m^2$ fire door with $100cm^2$ bottom shoe-chafing leakage, and also if the opening ratio decreased to 1/2, 1/4 of the above-mentioned percentage, then, ⊿Pf is given in the following **Table-1**.

Table-1 Relationship between Q and ⊿Pf

Lapse time (min)	1	3	5	7	10
Opening ratio (%)	0.5	6.3	20.3	44.0	100
⊿Pf (Pa)	77	39	31	26	21

Some discussions on the function of fire door

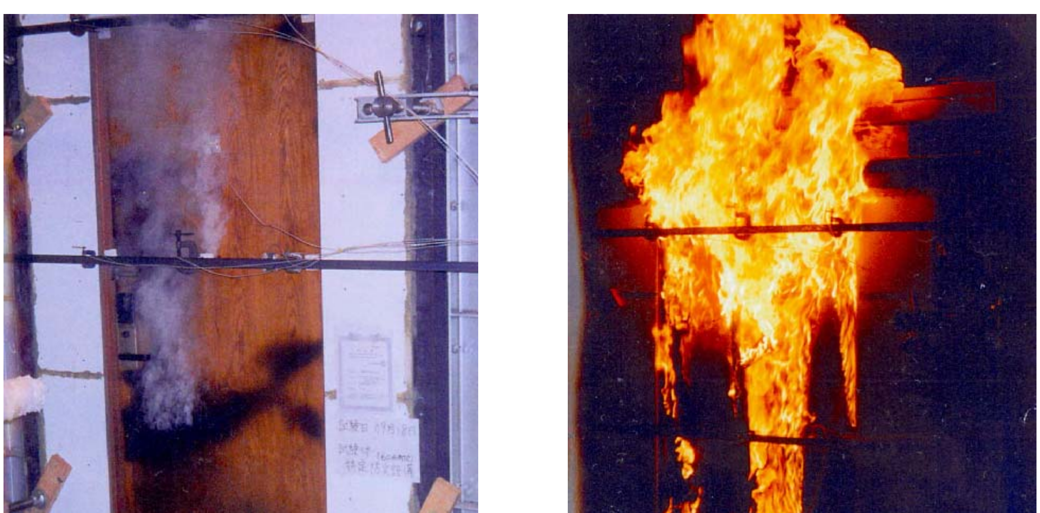
As before-mentioned, ⊿Pd is given by the sum of ⊿Pf, ⊿Pv, and ⊿Pw, and the maximum value which press a fire door would be estimated around 80 Pa under the condition of ⊿Pf =77, ⊿Pv =0, and ⊿Pw =10/5, which indicates that the torque of a fire door should be more than 160 N and also might be hard to open the door for daily use, despite of the easiness of evacuation. On the contrary, when the openings on a fire room had broken down, the value of pressure on the fire door ⊿Pd is approximately 31 Pa which is derived from (21+10/1), and this would be possible to make door torque more than the pressing force 62 N, which also less than opening force of evacuees.

According to the Japanese Building Standard Law, the fire performance of door for enclosing fire should protect the penetration of flame by using steel plate. However, steel itself would be easily deformed by intensive heating, and if it would be decorated by combustible finishing materials, severe flaming might be occurred on the back side of door as shown in **Figure-2,** which warns the necessity of heat integrity and insulation **[5]**. Recently, the Law had been revised aiming at the induction of performance-based design, where the requirements of fire enclosing door are provided in the management document of the designated testing organizations, which are as follows**[6].**

1) No occurrence of pass-through cracks in any specimen during 20,45,or 60 minutes for the provided testing time.
2) No emerging flame from heat-exposed side for over 10 seconds
3) No flaming on unexposed side for over 10 seconds

[note] If there exists shoe-chafing leakage less than 10 cm in height beneath the bottom of a door, any phenomena here should leave out of consideration.

In accordance with this provision, if a decorative steel or aluminium door with no core insulation would be installed between room and corridor, the door might be difficult to clear the fire test as shown in Figure-2. And if the door would be set on a room higher than neutral zone, smoke or gasses emerged from a lower fire origin would invade the room through the door.



A. Lapse time 6 min (unexposed surface temperature 250 K)

B. Lapse time 8 min (just after ignited, flame sustained over 3 min)

This specimen door is composed of steel covering with 0.2mm plastic sheet, paper-honeycomb core, and 3mm wood side covering, which indicates the easiness of heat transfer to an exposed side, and the ignition of surface finishing.

Opening/closing function against deformation force are measured, resulting that the deformation following performance of wood doors with wood frame is relevant for evacuees to open and escape through the door after earthquake vibration, because the wood door can be opened by 500 N under 8mm deformation at 1/120 radian according to JIS A 1414 " performance test of a building panel", and in addition, this wood door has Paulownia core, which is low density enough to absorb compressive force and insulate severe heating.

Analysis on The Cost/Performance of Fire Door

Various sorts of steel doors have been on sale in all over Japan, because of their lower prices than those of wood ones. In spite of their higher prices, they possess excellent performances composed of temperature or sound insulation, low rate of expansion, fire integrity, image of humanity or amenity derived from natural or healing properties. However, the difference of cost itself has been quite large between steel and wood products, which estimated a price of wood is three or four times higher than that of steel. The reason of the market-robustness of single steel door would be focused in its low price and generally authorized provision, which reads a steel door more than 1.5mm thickness for single use or for double more than 0.5mm each thickness should be approved as specific fire door according to Notification by MLIT. This provision might be aimed at preventing the emergence of flame to pass through the unexposed side of door **[6].** From performance-based point of view, paulownia wood has lower density around 300 kg/m^3, heat transfer coefficient about 0.16 W/mK, ignition temperature about 430 K, and rather sticky cell structure, which produces the excellence of fire performance as the ancestor used this wood for wardrobe or interior finishing of metal safe **[7]**. In addition, paulownia has ability of little warping, humidity control by low density and specific cellulation, durability from sesamin, and tannin. Then, if this wood could be served with low price, an innovative fire protection by using a new paulownia –cored door would be able to make another stride into the future fire market. **Table-2** shows the rate of cost components of a developed door, whose cost would be 1.1 times in comparison with steel door enough competitive to a price-cutting war.

Table-2 cost percentage of a newly developed door

item	core	Finish-ing	Intumes-cence	stile	adhe-sive	paint-ing	dip-ping	conceal closer	hinge heavy	guard	R&D	expense
point	11.6	8.0	4.0	5.0	6.0	8.0	6.0	4.0	4.6	1.6	4.0	5.6

Conclusion

Doors would be one of the most important and complicated functions for enclosing fire, because they should stop heat and smoke together with passing through evacuees. Generally, heavy and massive wood doors have been applied for building fire compartmentation. However, in Japan, a single steel door have been regally approved as fire enclosing openings, causing its expansion or bending deformation by fire would be dangerous to evacuation and ineffective to stop emergence of smoke. Several investigations were carried out for clarifying the cost/performance of approved steel fire doors, which resulted almost all were inappropriate to fire integrity, insulation and amenity in spite of possessing high rate of market-sharing. Nevertheless, wood doors have been out of consideration caused by their high prices, which led to promote the cost reduction project reported here. The paulownia and quake-resistive hinge were allocated at the most inevitable factors as the results of cost/performance analysis, which born this quite innovative fire door superior to steel one.

References

(1) Dept. of Technology Management: Classification of the opening types of doors, The Curtain-wall and Fire Protective Openings Association, Mar 2002

(2) Housing Bureau: Performance-based project for building, BCJ report,Apr, 1989

(3) MOC Secretariat: Development on performance-based building fire design, Mar 1990

(4) Sugahara S. et al.: Experimental studies on one-room fire behavior by using ordinary wood houses with various interior finishing, Japan House & Wood Technology Center,1981

(5) Sugahara S. and Kuroiwa Y.: A report on evidence by ISO standard fire test of on-sale products, Sep 2002

(6) Building Bureau : Notification No. 1369 (24th Dec,2002), MLIT, 19th Jul,2004

(7) Miura I. and Nishida K.: Wood chemistry, Maruzen Publishing Co., Jan 1948