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Performance-based fire safety evacuation in high-rise building flats in Indonesia – a case study in Bandung

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Abstract

This paper presented assessment of performance-based fire safety evacuation in RUSUNAMI (Prosperous Ownership Flats) with case studies BB RUSUNAMI Bandung (21 floors), which rely on natural ventilation. This concept is incompatible with the smoke-tight as stated in the life safety standard. The method used was a field study of evacuation experiment with 33 occupants and compare them with the results of the computer simulation model that compare the ASET(the available safe egress time) and RSET(the required safe egress time). The finding showed that to fulfill of life safety, the building needs additional appropriate fire protection systems.

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Keywords; *High-rise building flats, fire safety, evacuation, performance-based, simulation, fire stairwell natural ventilation*

1. Introduction

RUSUNAMI (Prosperous Ownership Flats) is high-rise flat (8 to around 20 floors height) that grows rapidly in Indone-sia. This program is supported by a government policy known as the '1000 Tower Development Program', which started in 2007 with guided by the Ministry of Public Works technical guidelines[1] and now supported by the Multi stories Building Law[2]. Problems arose on fire safety, since the related technical guidelines were not written in

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details and interpreted variously in practice. Therefore it needs a study to produce a single provision of fire safety in RUSUNAMI.

In this paper it will be presented the study results of the BB RUSUNAMI building in Bandung as shown on Fig. 1. It has two exit stairwell open type with natural ventilation. The concept of an open exit stair well is not in accordance with a smoke-tight and fire safety concept, which is required by relevant regulations and standards, both SNI (Indonesian National Standard) and NFPA (National Fire Protection Association, USA)[3,4]. According toNFPA101LifeSafetyCode standard, which is the main reference of the SNI of mean of egress, the BB RUSUNAMI with 21 floors is categorized as a high-rise building. Those exit stair wells that are not smoke-tight and no fire door can result in a longer occupant evacuation distance and increase vulnerability due to potential exposure to fire before occupants reach a safe place outside the building.

Assessment methods used in this study is a performance-based approach. The concept of performance by NFPA requires building designers to consider the possible range of fires that may occur in the building, how the fire un-tenability impact on building occupants, and how long it takes for the occupants can evacuate safely out of the building. The analysis compares the performance of the base time available for evacuation (ASET) and the danger of growth time (RSET). It is expected the results can be used as recommendations for fire protection improvement in residential high rise building.

Nomenclature

RSET	the required safe egress time
ASET	the available safe egress time
M	man
W	woman
SD	standard deviation
SE	standard error
N	number
Q_{fo}	flashover energy
MJ	mega Joule
sec	second

2. Literatures

Evacuation time is a relatively complex matter. It consists of two main components, i.e. the time before the move (pre-movement) and travel time (movement). ASET of the occupants in case of a fire is the time from fire ignition to the time untenable conditions along the evacuation route. RSET is the time required for occupants to reach the safety area. After fulfilling a safety standard, the calculated ASET needs to exceed RSET to make sure safety of the occupants. Time prediction of occupant movement is an essential component of performance-based fire safety analysis[3]. Components of RSET are: detection phase (time from fire ignition until be able to be detected), notification phase (time from detection until fire notification), pre-evacuation phase (time from notification until starting evacuation), and evacuation phase (time from start of evacuation until safe condition is reached)[5,6].

Evacuation phase can be predicted by using FDS-EVACsoftware[7,8] and then validated by field experiments. The software assumed the speed of occupant is (1.25 ± 0.30) m/s. The evacuation experiment was carried out by the available occupants in the BB RUSUNAMI.

Calculating ASET needs to predict the fire development. Before doing fire simulation, fire load of the tested unit must be determined. Based on Suprapto et.al[9] it shows that for a low income multi story building has a fire load of around 12.1 kg/m^2(“21Type”) and 14.8 kg/m^2(“36 Type”). Based on observation in recent years, there is a change in people life style and plastic materials are commonly used. It brings consequences to apply a safety factor, i.e. 1.5 which results a fire load of 21.2 kg/m^2 (“21Type”) and 25.9 kg/m^2 (“36 Type”). Fire simulation was carried out by using FIRM[10] and CFAST[11]softwares and flashover prediction[12].

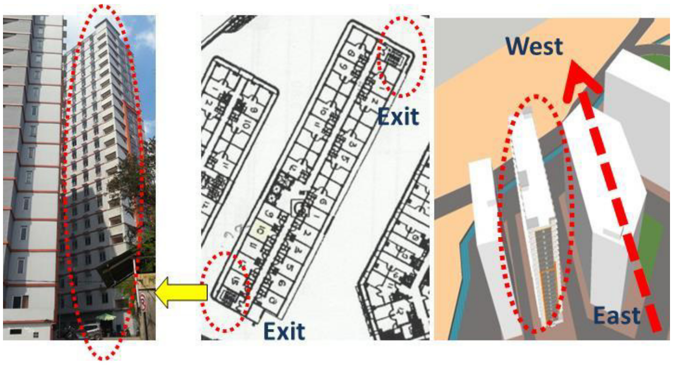

Fig. 1. The exit stairwell position and lay out of the BB RUSUNAMI.

3. Methods

Performance-based method was used to find out recommendation for safety features after comparing RSET to ASET. Steps of the method are:

- Evacuation of BB RUSUNAMI occupants. This experiment consists of 33 occupants which representing half of all occupants on each floor. The occupants were grouped into the trained persons (security officer) and non-trained persons. The building has 21 floors with 10 units of "36 Type-5 persons" and 11 units of "21 Type-2 persons" on each floor (total of 72 persons per floor). There are two evacuation routes on each floor, and the experiment was intended to find evacuation speed along the corridor (50 m, horizontally) and exit stairwell (20 floors, vertically). A medical doctor assisted to convince the state of health of all occupants.
- Evacuation simulation, it is intended to compare the calculated and actual evacuation speed of the occupants. The result is then extrapolated for various floors, and finally RSET can be obtained.
- ASET determination, it is calculated based on fire development prediction which may occur at the building. For this, the indoor and outdoor wind conditions were measured. Besides that, observation on available active and passive fire protection was carried out.
- Recommendation development for fire safety protection based on the obtained RSET and ASET.

4. Results and Discussions

4.1. Evacuation Experiments

The results of the trained and non-trained persons were listed in Tables 1 and 2 respectively. Each group was asked to run one by one (personal) and in group along the horizontal corridor. It looks that the personal travel time was higher than that in group. The width of the existing corridor was only fit for personal running instead of in group. For trained persons in group, the average personal travel time horizontally was 2.5 m/s whereas that in group was 1.9 m/s. The travel time in vertical direction (through stairwell) was 0.97 m/s (60 m high or 148.2 m distance). For non-trained persons in group, the average personal travel times horizontally were 2.68 m/s and 1.45 m/s in group, with 0.79 m/s vertically through the stairwell. In those two cases, personal evacuation speed was higher than that in group and this is due to crowd factor.

Table 1. Experiment results for trained person.

No	Gender	Age (year)	Height (cm)	Weight (kg)	Travel time (s)		
					Horizontal corridor – Personal(A1)	Horizontal corridor - Group (A2)	Vertical stairwell (A3)
1	M	34	171	75	26.1	19.0	140.0
2	M	18	171	71	20.8	20.0	141.5
3	M	40	172	50	19.7	21.0	142.7
4	M	23	168	70	17.8	22.2	144.8
5	M	37	72	170	17.5	23.5	146.6
6	M	25	90	170	17.77	25.7	148.4
7	M	43	160	55	20.7	29.0	150.3
8	M	22	171	74	24.2	27.0	160.2
9	M	36	170	95	17.2	28.4	165.5
10	M	40	169	55	17.1	29.4	166.2
11	M	34	169	73	18.9	29.5	166.7
12	M	28	177	85	20.2	30.2	167.4
		Averages			19.8	25.4	153.3

4.2. Evacuation simulation

FDS-EVAC evacuation models were illustrated in Fig.2 (a) and (b) for vertical and horizontal evacuation respectively. For vertical evacuation, five variation modes were made during simulation, namely:

- Mode A, representing the number of person involved in field experiment which run down from the 20th floor through the stairwell.
- Mode B, representing half of the number of floor occupants which run down from the 20th floor.
- Mode C, representing the evacuation from 10th and 20th floors. This assumed the crowd factor can be neglected.
- Mode D, representing the evacuation from 5th, 10th, 15th and 20th floors. It was also assumed half of the numbers of floor occupants are involved.
- Mode E, representing the evacuation of all floors (from 1st to 21st floor) simultaneously.

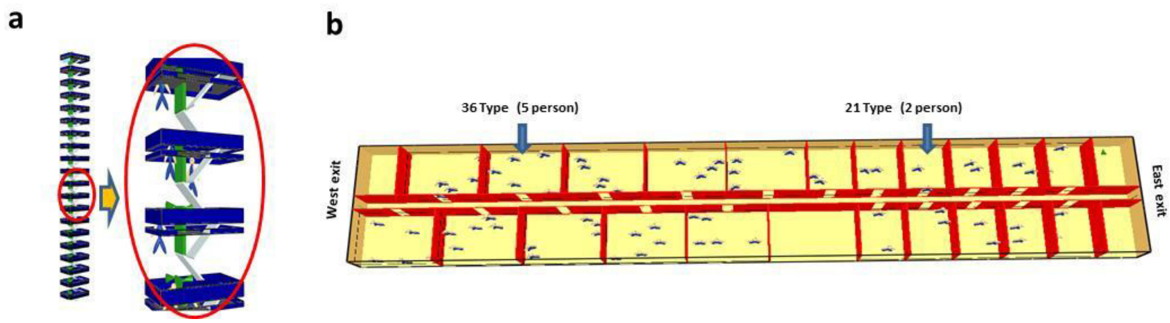

Fig. 2.(a). FDS-EVAC vertical evacuation model through exit stairwell; (b) and horizontal evacuation along the floor.

Table 2. Experiment results for non-trained person.

No	Gender	Age (year)	Height (cm)	Weight (kg)	Travel time (s)		
					Horizontal corridor-Personal(A4)	Horizontal corridor-Group(A5)	Vertical stairwell(A6)
13	W	43	168	60	19.4	29.8	163.5
14	M	21	160	50	20.3	30.0	167.4
15	W	45	169	60	18.4	30.1	172.2
16	M	53	172	53	18.4	30.3	174.5
17	M	26	165	45	18.2	31.3	176.1
18	M	-	120	46	18.6	31.5	177.3
19	M	38	170	74	17.5	32.5	178.7
20	M	53	170	65	20.3	32.7	181.5
21	M	31	165	48	17.9	33.5	182.9
22	M	20	168	64	17.3	34.4	184.5
23	M	50	162	65	17.8	34.5	188.8
24	M	51	165	65	16.9	35.0	189.4
25	M	35	165	48	21.3	35.4	194.5
26	M	22	162	56	19.5	35.7	196.2
27	M	16	170	98	16.8	36.0	197.8
28	M	19	165	52	17.6	36.1	199.5
29	M	58	171	62	18.3	37.0	200.1
30	W	27	160	50	17.3	38.0	200.5
31	M	56	156	60	19.4	39.7	201.1
32	W	41	160	65	23.0	39.7	203.5
33	M	42	154	75	17.0	39.9	203.9
		Averages			18.6	34.4	187.3

Results at Table 1 and 2 above were experiments with spontaneous actions, where occupants with their various interpretations want to run as fast as possible. Then, after the three experiment modes were conducted (involving 12 trained respondents), then the following results were obtained as in Table 3.

Table 3. Experiment results of the three evacuation modes.

Mode	Horizontal evacuation		Vertical evacuation	
	Time (s)	Speed (m/s)	Time (s)	Speed (m/s)
Normal walk	46.9	1.1	218.8	0.7
Fast walk	32.9	1.5	180	0.8
Half running	22	2.5	67	2.2

Table 4. Evacuation simulation result at the stairwell

No	Mode A		Mode B		Mode C		Mode D		Mode E	
	Person	Time (s)	Person	Time (s)	Person	Time (s)	Person	Time (s)	Person	Time (s)
1	10	188	26	235	54	235	110	284	375	725
2	10	193	27	238	54	236	111	277	375	730
3	11	192	28	242	55	230	111	273	376	725
4	11	183	28	233	56	252	111	275	376	732
5	11	199	28	254	57	247	111	284	376	745
6	11	186	28	231	57	258	111	273	377	747
7	11	179	29	236	58	240	112	293	377	737
8	12	192	29	245	58	241	112	272	377	738
9	12	193	29	237	58	238	112	302	378	733
10	12	187	29	245	58	245	112	289	378	766
11	12	215	29	241	58	250	112	292	379	740
12	12	209	29	246	58	245	113	285	379	745
13	12	191	29	245	59	242	113	275	379	730
14	12	209	29	236	59	253	113	285	379	731
15	12	197	29	245	59	259	113	274	379	727
16	12	208	30	240	60	252	113	264	379	747
17	12	191	30	233	60	244	114	283	380	781
18	12	203	30	248	60	245	115	282	380	750
19	12	183	30	236	60	242	115	283	381	748
20	12	196	30	238	60	234	115	283	381	755
21	12	191	30	244	60	249	116	291	381	748
22	12	197	31	246	60	236	116	293	382	743
23	12	196	31	238	60	232	116	292	383	770
24	12	196	31	244	60	235	117	279	383	765
25	12	191	31	247	61	248	117	269	383	744
26	12	208	31	251	61	238	117	274	383	750
27	12	191	31	256	61	246	120	292	384	777
28	13	200	31	246	61	236	120	299	384	750
29	13	211	31	238	62	239	120	280	384	766
30	13	198	31	233	62	240	120	295	385	760
31	13	191	32	246	62	242	120	282	386	758
32	13	194	32	251	62	271	121	300	386	793
33	13	193	32	243	62	239	121	308	386	759
34	13	199	32	254	63	244	121	295	386	785
35	13	186	32	251	64	248	121	291	387	764
36	13	195	33	241	64	237	122	293	389	773
37	13	197	33	234	65	245	122	293	389	791
38	14	190	33	243	66	248	122	293	389	761

Each simulation mode was executed 38 times and then averaged. This was carried out several times due to stochastic approach which is used by FDS-EVAC. Therefore, average values will then be used for analysis. Data is listed in Table 4.In mode A, the travel time is 195 sec (12 person involved). If it is compared to the initial experiment results (Table 1 & 2), it looks that simulation results was slower than that for trained and non-trained person. It was also noted that some person did half running during the experiments. Initial experiments were spontaneous actions, where occupants with their various interpretations want to run as fast as possible. Whereas when the three evacuation mode were conducted, it looks all travel time is close to that of normal walk mode (see Table 3). Therefore it is clear that the time required to evacuate the FDS models is comply with the experiments evacuation, as long as the occupants walk normally.

In mode B, it was found the travel time is 242.37 sec (averaged for 30 person involved). Compared to mode A, it looks that increase the number of person 2.5 times results in a longer evacuation time (1.2 times). In mode C, the travel time is 243.71 sec (60 person involved). This is very close to the results of mode B, and this means the evacuation from 20th floor is not affected by that from 10th floor. It should be noted that the evacuation should be determined based on the travel time from the highest floor. In mode D, the average time is 285.45 sec (116 person involved). Compared to the mode C, it looks a shorter floor distance will result in increasing evacuation time. In mode E, the average time is 753.08 sec (381 person involved). This could be considered as the total evacuation time if all occupants must be evacuated through the two exit stairwells available.

For horizontal evacuation simulation, this was assumed all persons are ready near the edge of the stairwell. 72 persons were involved and the calculated travel times are: (39.45, 45.25, 40.65, 40.5, 40.65, 38.5, 39.25, 39.9, 39.2, 40.25, and 41.45) sec with statistic mean of 40.45 sec.

4.3. Existing building condition

Possibility for arousing flashover is determined by the amount of fire load and burning rate. After doing some calculations (by looking at the available fire load, openings and room geometry), it was found that the energy produced in "21 Type" and "36 Type" is greater than the minimum energy required for flashover. In short, flashover is very likely to occur at the BB RUSUNAMI.

Initial studies related the passive protection system at BB RUSUNAMI has been conducted by Sujatmiko et. al[13]. The other susceptibility at the passive system of that building which may spread of the fire are:

- Rectangular openings with high ventilation factor ($A_o\sqrt{H_o}$).
- Canopies between openings are not optimal (the existing canopies fit only for AC installation and not sufficient for fire protection).The minimum length of thecanopyforreducingexternalfirespreadis100cm[14], while the existing condition is only 50cm.
- doors are made from combustible wood without fire retardant coating, and opening doors may spread the smoke to corridors.
- Position of the openings, both vertical and horizontal utility shaft, which could spread the fire and smoke. Vertical shaft located near the corridor utility which integrates with horizontal shaft as shown in Fig.3 needs considering the potential dangers of the spread of fire smoke in the corridor and its impact on life safety.
- wind condition at the exit stairwell and corridors affect to evacuation process. Referring early result[15], in Fig 4.(a)shows that the wind at the stairwell could reach almost 2 m/s, and Fig. 4.(b) shows that wind direction in corridor reaches 0.526 m/s and 1.615 m/s at outdoor, parallel to the building mass.
- detector and alarm system have not fully installed, it requires additional protection.
- sprinkler system is available only at the corridors, and not inside the units.

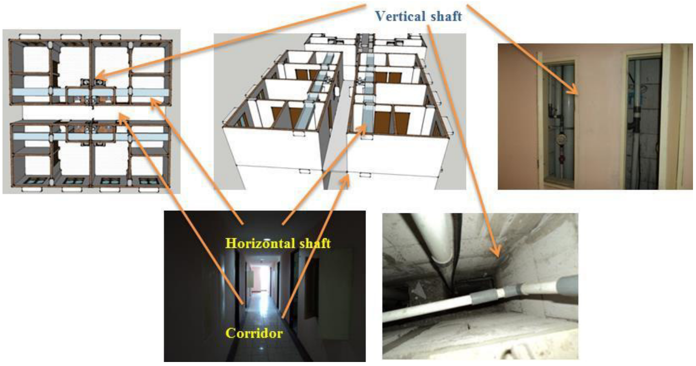

Fig. 3. The typical arrangement of corridors, vertical and horizontal shaft of the BB RUSUNAMI.

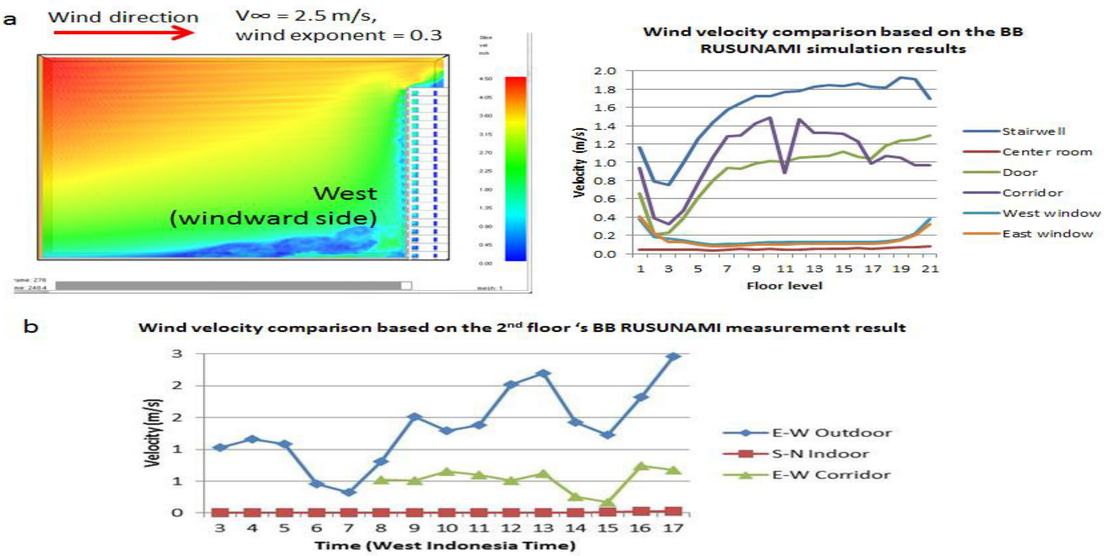

Fig. 4. (a). CFD-FDS results, which show air movement surround the building. It looks high wind speed at the stairwell, at west side.(b).Measurement results of indoor and outdoor wind velocity.

4.4. Fire development prediction

Prediction of fire development is needed to calculate ASET. At the beginning zone models was used with neglecting wind condition. As listed at Table 5 it shows that flashover may occur at “21 Type” and “36 Type” units. Simulation results by using FIRM (Fig 5.(b)) shows that temperature of 113 ^{o}C reached in 40 sec (“21 Type”) and 112 ^{o}C in 35 sec (“36 Type”). This illustrates unsafe condition and starts being dangerous. Then CFAST zone model was used to see the spread of the fire at the room test unit, corridors, and exit spaces (see Fig. 5.(c)).The fire load consists of 2 mattresses, TV, 2 cupboards and sofa. Fire starts from mattresses and goes to others when the temperature reaches 100 ^{o}C. The other scenario is if all fire load burns simultaneously. The results are:

- Burns in steps: it was found the air temperature under 1.6 m reached over 100 ^{o}C at 785 sec, while corridor temperature of 65 ^{o}C reached at 1210 sec. Exit stairwell is relatively safe with only 28 ^{o}C.

- Burns simultaneously: the unit burns in 125 sec at temperature of 124 ^{o}C, and it is beyond the safety zone. Corridor temperature reached of 65 ^{o}C in 295 sec, and exit stairwell temperature of 48 ^{o}C. This illustrated the unsafe condition and can be dangerous.

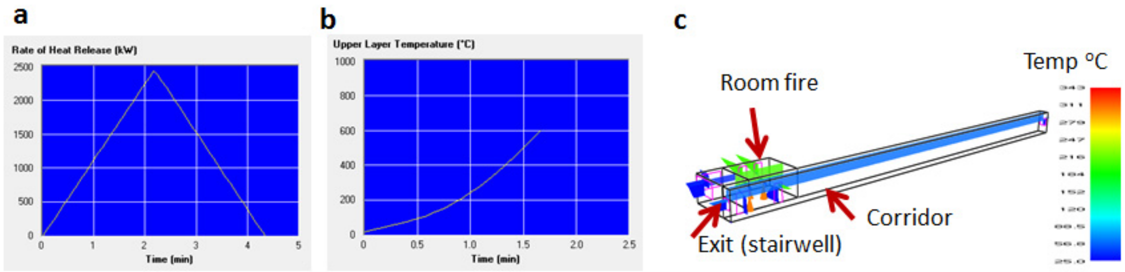

Fig. 5. (a) Rate of heat release curve and (b) upper layer temperature by FIRM calculation; (c). Room model with exit and corridor using CFAST

Table 5. Flashover calculation.

Unit	Opening	Opening area A_v (m^2)	Ventilation factor $A^*\sqrt{H}$	Burning rate (kg/s)	Flashover energy Q_{fo} (MW)	Fire energy (MW)	Results
"21 Type" (floor area 17,05 m^2)	Door and window	3.45	4.98	27.38	2.53	10.50	Flashover
	Window (all glass area)	2.04	2.81	15.43	1.71	5.92	Flashover
	Window (one openable area)	1.09	1.49	8.22	1.21	3.15	Flashover
"36 Type"– main room (floor area 9 m^2)	Door and window	3.54	4.98	27.38	2.29	10.50	Flashover
	Window (all glass area)	2.04	2.81	15.43	1.47	5.92	Flashover
	Window (one openable area)	1.01	1.51	8.29	0.98	3.18	Flashover

4.5. RSET and ASET analysis

RSET results are as follows:

- Travel time at the experiment are 157 sec (personal) and 159 sec (in group) for trained person, while for non-trained person are 180.3 sec(personal) and 193.3 sec (in group).
- Travel times based on simulation are235.5 sec (Mode A), 282.87 sec (Mode B), 284.16 sec (Mode C), 325.9 sec (Mode D) and 793.53 sec (Mode E).

ASET results are as follows:

- FIRM results show that the available time within safety zone are 40 sec ("21 Type") and 35 sec ("36 Type"). Looking back to experiment results, it looks the actual travel time is much longer than the FIRM results on each type. Therefore to avoid occurring flashover, the units require installing additional fire protection such as sprinkler, fire detection and alarm.

- CFAST results show that by making fire load arrangement, it could significantly increase ASET. It is shown that the ASET 785 sec (burn in steps) is much longer than 125 sec (burn simultaneously). By this arrangement it is clear the spread of the fire at the corridor and exit stairwell can be reduced.

5. Conclusions

Some conclusions from this case study are:

- Evacuation speed during experiment is complying with the simulation prediction if occupants walk normally. This mode could be considered to determine real evacuation time since it covers any health condition of occupants.
- With simulation, various evacuation modes can be easily and efficiently carried out instead of conducting real experiments.
- High wind speed at the exit stairwell could affect spread of the smoke and evacuation process. It needs further CFD (Computational Fluid Dynamic) studies on the spread of smoke during evacuation
- Additional fire protection should be installed such as sprinkler, detection and alarm, and fire load arrangement. Need to study more about the minimum protection requirements of the RUSUNAMI buildings, primarily associated with the response time and the capacity of the city fires institution.

6. Acknowledgements

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