Fire Risk Analysis of Wood-Based Base Buildings - For joint development of wood-based open building system between Japan and Austria

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Fire Risk Analysis of Wood-Based Base Buildings

- For joint development of wood-based open building system between Japan and Austria

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1. INTRODUCTION - AWARENESS OF THE ISSUES

1.1. WOOD BASED BUILDINGS IN URBAN CONTEXT

Wood is expected to be used for urban buildings as a sustainable material, and there are potential global demands for wood-based[1] buildings. On the other hand, individual have to hold additional risk on the combustibility of wood structure, when they use / own these buildings.

Middle raised wood-based structures tend to be expensive due to additional fireproof layers on the surface.[2] Also the primary structural cost of the Skelton-Infill system (SI system) is more than normal structures because of investments in potential flexibility. [3]

If the flexibility works for both positive and negative changes, the flexible system can be invested as a kind of insurance. I expect that the combination of wood-based and open building can be a reasonable solution for harmonization of primary investment and potential flexibility.

1.2. JAPAN AND AUSTRIA

Japan and Austria are two of the countries, which building codes have strict technical requirements for wood-based buildings in urban areas; even both countries are rich in forest resources. Thus, two countries hold common / mutual interest in technical solutions for large and multi-story wood-based structures in urban contexts and these backgrounds.

Since 1990's, many countries have revised their former prescriptive building codes to performance-based codes. After 2000's, several multi-story wood-based buildings have been built with the performance-based codes. Japanese and Austrian performance based codes requires "equivalent" fire resistance in burning engineering between wood and non-combustible structures.

KEYWORDS: fire, wood, risk, frequency, comparison, and classification

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[1] As word definitions of this paper, "wood (or wooden)" means material or traditional (solid wood or pure wood) products or structure, and "wood-based" includes contemporary (hybrid or chemical treated) products or building elements.

[2] (WINTER 2012)

[3] (IGARASHI 2003)

1.3. WOOD AND FIRE

1.3.1. *Tradition and Prejudice*

Wood had been used as a workable material in various domestic areas from ancient days. We had used wooden structures for limited size or parts of the buildings and had not used in large and multi-story urban buildings.

As wood is a traditional material, each individual knows a lot about the character and has common sense and a silent understanding connected to the domestic way of use. Sometimes the knowledge tends to cause certain prejudice about use of this material, even with contemporary solutions.

Also, we have used fire with wood since primitive age and have kept the fear for danger of fire.

1.3.2. *Combustibility and Sustainability*

Actually the requirements of "equivalence" are not adequate for wood construction. Non-combustible materials are already burnt by fossil fuels and wood can be used as fuel in the future because of its combustibility. This is why wood is recognized as a sustainable material. Usually fire resistance of wood-based structures is realized by coverage of non-combustible materials or chemical treatments. The solutions are technically reasonable, but these are not the best for sustainability or cost efficiency.

1.3.3. *Engineering and Design*

The main difference between burning science and structural mechanics in the building codes is whether external forces are classified by frequency or not. Building codes treat reduction and control based on burning engineering after ignition of fires, but do not treat classification, type, and frequency of fires as external forces. These causes are related to rather design than burning science because the cause of fire and frequency are social scientific problem.

1.4. CONTRADICTION AND HARMONIZATION

1.4.1. *Social and Individual Demands*

Currently, it is difficult to offer the cost benefit of wood-based buildings for individual building owners, especially for multi-story buildings in urban areas of Japanese and Austria. Nevertheless, if the use of sustainable material is social demand, the risk of material should be bared by social system.

1.4.2. *Positive and Negative Interventions*

We need to review countermeasures and technical requirements against fires not only as a part of burning science, but also as a part of design method.

SI system is a common design method for accommodations and offices in the field of Open-Building-System. Usually, SI system covers interventions caused by changes of lifestyle but does not consider changes accidents. We should discuss how to count negative intervention by accidents into design method.

2. OVERVIEW OF RESEARCH

2.1. THE WHOLE RESEARCH

I think that various professionals should discuss wood-based buildings in urban contexts from comprehensive viewpoints and intend to show viewpoints for discussions to review fire risk management on wood-based buildings in the urban contexts of Japan and Austria as a goal of my doctoral research. This paper is a part of the doctoral research, and a goal of this paper is to illustrate a draft proposal for further discussions about harmonization between risk management and design.

2.2. APPROACH

The doctoral research analyzes several issues in comparison for following two aspects:

- To obtain objective viewpoints to recognize our blind spots due to our common sense and a silent understanding; and
- To define the key of common and mutual developments in the future.

2.3. MAP OF DISCUSSION

This paper uses two diagrams as maps of discussions. Figure 1a is drawn based on a diagram by J.N. Habraken, and that tells as the structure of hierarchy and relationship of designers / levels.[4] Figure 2a is drawn based on "Level of Damage / Frequency of Occurrence and Fire Risk Management[5]", and that tells us types of countermeasures depend on combination of frequency.

Both Figure 1a and 2a include "individual-social" and "human-physical" factors, and base-buildings' responsible parts are highlighted in dark gray. Figure 1b and 2b summarize common axes (frequency, scale, and target) and factors (physical or human) in Figure 1a and 2b.

2.4. STRUCTURE OF THE WHOLE RESEARCH AND AREA OF THIS PAPER

The whole research is composed by four topics:

1. Basic technical requirements on wood-based base-building and sub-systems (structural elements and materials)[6];
2. Influence of upper structure (=historical urban developments) to current regulations[7];
3. Character and distribution of cause and damage of fire; and
4. Social countermeasures.

Topic 3 is analyzed in this paper with following points:

A. To break down physical and human factors of fires to fit to design method, and;
B. To show situations of current wooden base-building buildings and relations to companion problems.

Each of the factors in "A" correlates to probability of risk, and degree of the each factor in "A" seems influenced from companion problems in "B".

[4] (Open Building Workshop 2004)

[5] (Architectural Institute Japan 2009)

[6] (TANI, Comparison of Fire-Proof Regulations for Multi-Storey Wood-Based Buildings in Japan and Austria 2011)

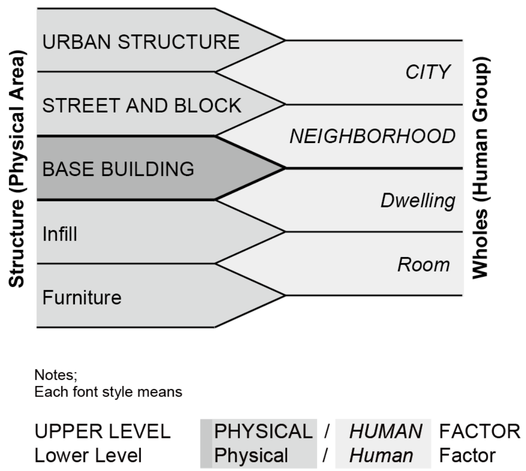
[7] (TANI, Wood Buildings and Fire in Historical Urban Context in Edo (Former Tokyo) and Vienna 2014)

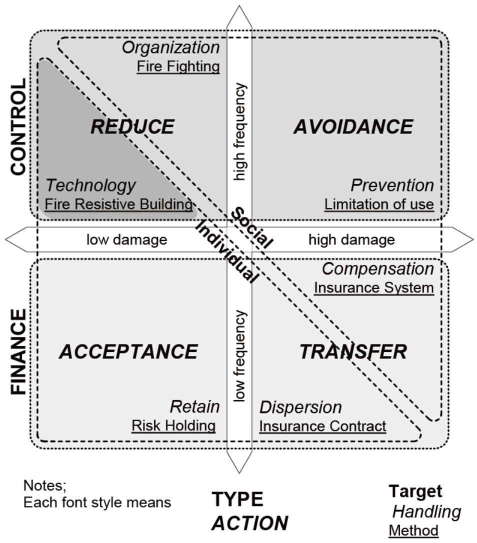
2.5. WORD DEFINITION

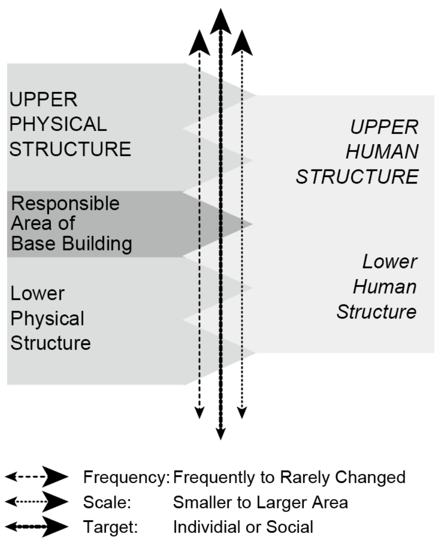
Following words in Table 1 are defined as a part of the main- and the sub-system of construction in this paper. Causes and damages of fires are analyzed along word definitions in Figure 1a/1b and 2a/2b.

Table 1: Word Definitions

Words for Parts of Constructions (Examples)	The Part Composed by…
Building (Office, housing, shop, etc.)	Base-building (= Skelton) and full out (= Infill)
Base-building	Structural elements as a sub-system of the building (= Structural parts with fire proof requirements)
Structural elements (Floor, wall, roof, etc.)	Materials (combustible / non-combustible)







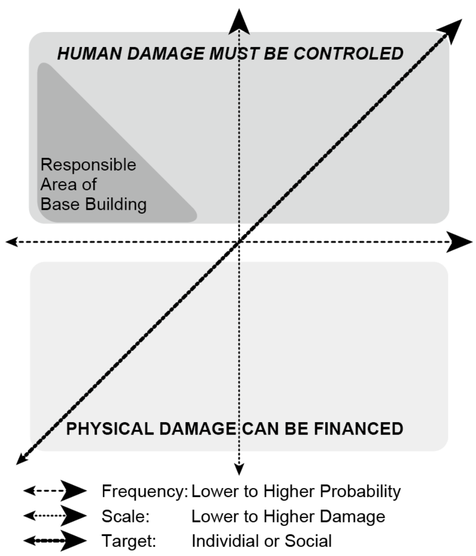


Figure 1a: A Map of Discussions (Based on “Hierarchy of Dominance”) (Upper Left)
Figure 1b: Axes of Discussions in Figure 1a (Lower Left)
Figure 2a: Risk Management by Frequency and Damage (Upper Right)
Figure 2b: Axes of Discussions in Figure 2a (Lower Right)

3. FORMER STUDIES AND PRECONDITIONS OF ANALYSES

3.1. TYPE OF DATA

3.1.1. International Statistics

WHO (World Health Organization) reports international statistics about fire death rates collected based on death certifications at hospitals in the same conditions. Austrian death rate per 100 thousand is 0.42 and Japanese one is 1.67.[8] Nevertheless the reports do not include details of causes. Just a few countries collect fire statistics for both physical and human-damages by fire. Thus, there are pretty few researches about international comparison about fire damages.

3.1.2. National Statistics

Austrian population is less than 10 million, and the number is not sufficient for analysis especially for the fire death rate. Association of insurance company had reported annual fire statistics from 1950 to 1984[9], but between 1985 to 2006 fire statistics did not report. The lack of statistical data causes hesitation of relaxation of fire regulations.

Japan is one of the few countries, which has sufficient quantity and quality of fire statistics for analysis. The Japanese population is more than 100 million, and public fire fighters report census and detailed fire statistics.

3.2. PRECONDITIONS AND FORMER RESEARCHES

3.2.1. Selection and Adjustment of Data

This paper analyses statistics by international associations, and public statistics by Japanese government and gives discussions about adjustment of results to Austria.

3.2.2. Frame of Discussions – Responsibility of Base Building against Cause of Fire

In this paper, fire means building fire[10] occurred in the interior of the buildings. (See bold figures in Table 2.)

I recognize that the limitation covers a necessary and sufficient condition of base-building buildings' responsibility. For example, crimes like arson should be treated by criminal law.

Table 2: Type of Cause of Fire

Place	Type of Factor	Type of Cause	Example of Cause
Exterior	Human	Crime, Conflict	Arson, War, etc.
Interior		**Human Error**	**Smoking, etc.**
	Mixed	**Unsuitable Use**	**Cooking Heater, Heating Device, etc.**
	Physical	**Mechanical Trouble**	**Electric Lines, Phone Lines, etc.**
Exterior		Natural Disaster	Earthquake, Typhoon, etc.

[8] (The Geneva Association 2010) The Geneva Assosiation reports the death rates based on research by WHO with their own adjustment.

[9] (Zentralstelle für Brandverhütung 1950 - 1984)

[10] E.g. Excluding automobile fires, forest fires, and etc.

3.2.3. Cause and Damage – Human- / Physical-Factors and Distributions

According to former researches, frequency and damage by fire correlate to several human- physical-factors; gender of user, age group of user, use of space, the size of the compartment, and material of the structure.[11] [12] [13]

Table 3 summarizes the relations between factors and phase of fire. Penetration of human- and physical-factors are different depends on the uses of buildings. Human-damages tend to happen earlier phase of fire.

We need to consider that frequency of cause of fire influenced by companion problems, which are related to penetration of factors of causes. (E.g. population pyramids, age of buildings, scale effect of buildings (related to the type of fire equipment), and ownership of buildings (related to frequency of restoration).

3.2.4. Frequency of Occasion and Damage – Acceptable Risk

If both frequency and damage are enough small, it is better to accept risks. (See lower left square of Figure 2a.) In this paper, following damages are treated as acceptable risks:

- Death rate (human-damage) less than once one million years and
- Occasion (physical-damage) less than 500 to 1,000 years.

Concerning human-damage, one one-millionth will be a rough standard of acceptable risks of this paper, which Émile Borel, a French mathematician, wrote in his book.[14] According former research in Japan, death rate per person by car accident, fire, and natural disaster are approximate once 10 thousand years, once 100 thousand years, and once one million years. [15]

In case of physical-damage on Base-building by pretty rare and severe earthquakes (less than once 500 to 1,000 years), codes allow plastic deformation of structure, if the structure keeps stability during the escape of the user. In the same sense, if the probability of fires is once less than 500 to 1,000 years per building, the object of technical requirements can be same as against pretty rare earthquakes.

Table 3: Parameter of Fire and Relative Phase of Fire

Type of Factor		Factor	Character	Relative Phase of Fire (Earlier to Later)				
				Cause	Human-Damage		Physical-Damage	
				Ignition	Perception	Escape	Spread	Destruction
User (Human-Factor)		Gender	Penetration of Activity	✓				
		Age Group	Ability	✓	✓	✓		
		Use of Space	Activity (Ability)	✓	✓	✓		
Building (Physical-Factor)	Infill		Accident / Failure	✓	✓	✓		
		Shape of Space	Fire Load 1 [16] / Air Supply		✓	✓	✓	✓
		Size of Compartment	Fire Prevention Equipment		✓	✓	✓	✓
	Skelton	Material of Structure	Fire Load 2 [17]			✓	✓	✓

[11] (SEKIZAWA 1995)

[12] (MIZUNO 2003)

[13] (SUZUKI 2007)

[14] (Borel 1962)

[15] (HARADA 2007)

[16] Fire Load 1 means colorific value of furniture and finishes, which are burnt in early phase of fire.

[17] Fire Load 2 means colorific value of structural parts, which are burnt in later phase of fire.

4. ANALYSES ON FIRE DAMAGES – Japanese Fire Statistics

This chapter deals with both: breaking down the causes and damages of fires in physical and human factors; and companion problems related to fire factors.

4.1. FIRE DAMAGE BY USE AND CAUSE

As Table 2 and 3 show, use of the building influence to combination of human- and physical-factors of fire. This paper picks up office and housing as target use of buildings. These two uses are typical for both multi-story and SI systems-buildings.

4.1.1. Proportion of Physical- and Human-Damages by Use

According to Figure 3, sum of fire victim by housing fire makes up 90%, even the number of fires occupies only 60%. Proportion of number of victims by office fire is far less than housing fire. The difference comes from human-activity ability of the user. Office users do not sleep in the building and are able to escape soon after breaking out of fire.

Figure 4 illustrates the proportion between physical- and human-damages. Physical damages are influenced by shape of buildings (multi-story / wide span), and human-damages are influenced activity related to use (residential / non-residential).

4.1.2. Probability of Break Out of Fire and Damages

Table 4 summarizes probability of damages by fires in office and housing. Concerning human-damage per one million users, death rates are 8.30 people per year in housing and 0.13 people per year in office. If we take a comment of Borel (See section 3.2.4.), human-damage of office fire is negligible, but the damage in housings is not negligible. Frequency of breaking out of fire is less than once per 500 years both in one average sized office or housing. (See Table 4, C2.) Probability of serious physical-damage, burn down[18] of buildings, is one digit less than breaking out.

On the basis of rough tendency toward probability of damages, I will concentrate on human-damages in housings and physical-damages in office in section 4.2 and 4.3.

4.1.3. Proportion of Physical- and Human-Damages by Cause

Proportion between average human and physical-damages by cause show different tendency depend on use. (See Figure 5 and 6) Unevenness of human-damage by cause is larger than physical-damage, and degree of damages by causes do not correlate to each other.

Perception of fire is influence to degree of damages. Concerning physical-damages, electric lines cause larger damage compare to cooking heaters in both uses. In housing, cooking heaters cause less human-damage than heating devices. Reason of difference is situation of activity of the user; cooking heater is used when user awake, and users can aware as soon as fire occurs.

[18] “Burn down” means more than 70% of total floor area of building is damaged by fire and does not mean destruction.

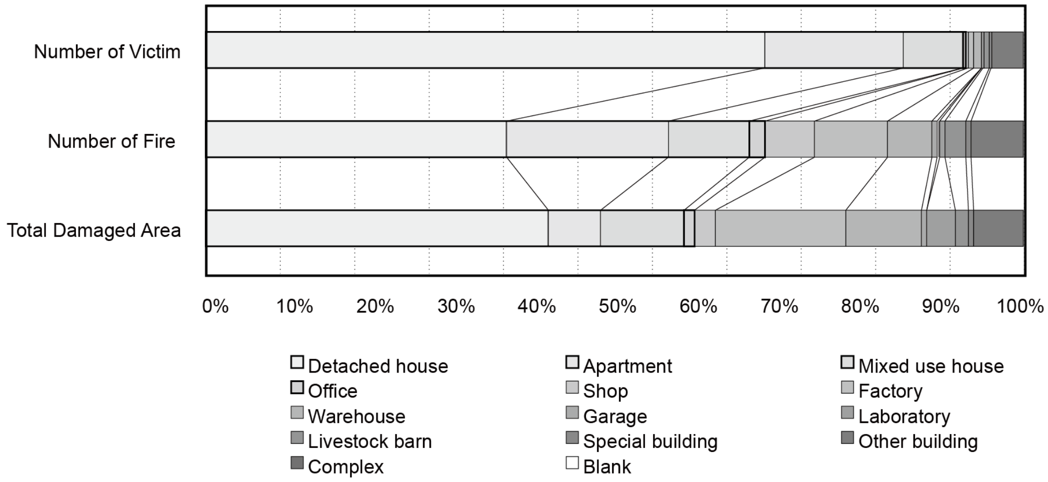


Figure 3: Proportion of Number of Fire Death / Number of Fire / The Cost of Damage (2006-2010, Japan) [19] [20]

Table 4: Frequency and Damage of Fire (Average of 2006-2010, Japan) [21]

		[22]Housing	Office
A. Number of Fire[23]		15,744	416
B. Human Damage	B1. Number of Death	1,060.8	2.6
	B2. Total Number of User	[24]127,759,400	[25]20,000,000
	B3. Death / Person * Year (A/B2)	**8.30^{-6}**	**0.13^{-6}**
C. Physical Damage	C1. Number of Burn Down	3,375.4	71.8
	C2. Fire / Building * Year (A/C6)	**0.317^{-3}**	**1.912^{-3}**
	C3. Burn Down[26] / Building * Year (C1/C6)	**0.068^{-3}**	**0.330^{-3}**
	C4. Fire / 1000m^2 (A/(C7*1000))	3.37^{-9}	1.37^{-9}
	C5. Ave. Floor Area (m^2) (C7/C6)	94.13	[27]1,363
	C6. Number of Building	[28]49,598,300	[29]217,490
	C7. Total Floor Area of Stock	[30]4,668,687,979	[31]301,457,000

[19] (Fire and Disaster Management Agency 2006-2010)

[20] (Research Institution for Disaster Prevention Administration (Bousai Gyousei Kenkyukai) 2011)

[21] (Fire and Disaster Management Agency 2006-2010)

[22] "Housing" includes "Detached house", "Apartment", and "Mixed used house" in Figure 3

[23] (Fire and Disaster Management Agency 2006-2010)

Data was narrowed as: All fire in 2006-2010 (258,065=173.9%) > Building fire (148,328=100.0%) > Internal cause in Table 2 (119,273=80.4%) > In housing (78,720=65.9%) / In office (2,080=1.4%)

[24] (Statistics Bureau, Ministry of Internal Aware and Communications 2006-2010)

[25] Calculated as 15m^2 per person

[26] (Research Institution for Disaster Prevention Administration (Bousai Gyousei Kenkyukai) 2011)

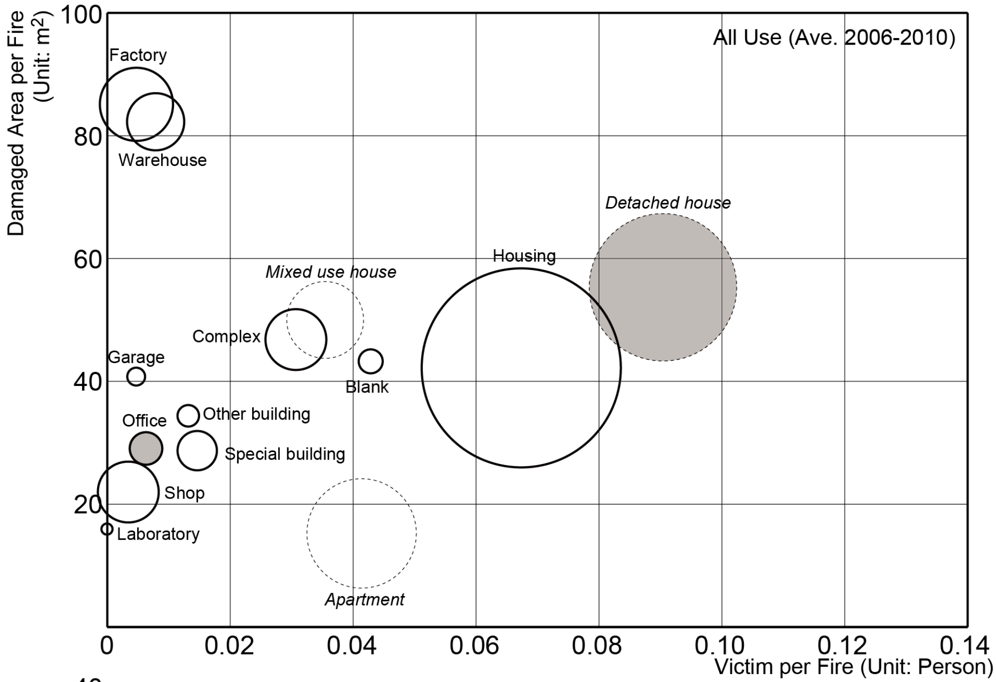
[27] (Ministry of Land, Infrastructure, Transport and Tourism, Japan 2008)

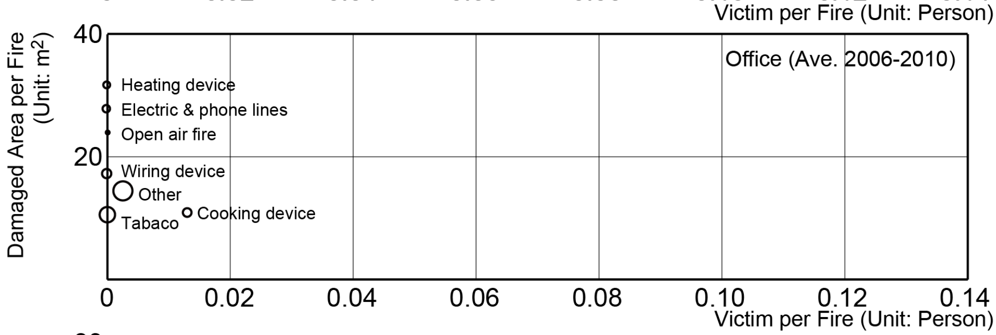
[28] (Statistics Bureau, Ministry of Internal Aware and Communications 2008)

[29] Calculated by C5 and C7 in Table 4

[30] (Statistics Bureau, Ministry of Internal Aware and Communications 2008)

[31] (Ministry of Land, Infrastructure, Transport and Tourism, Japan 2008)





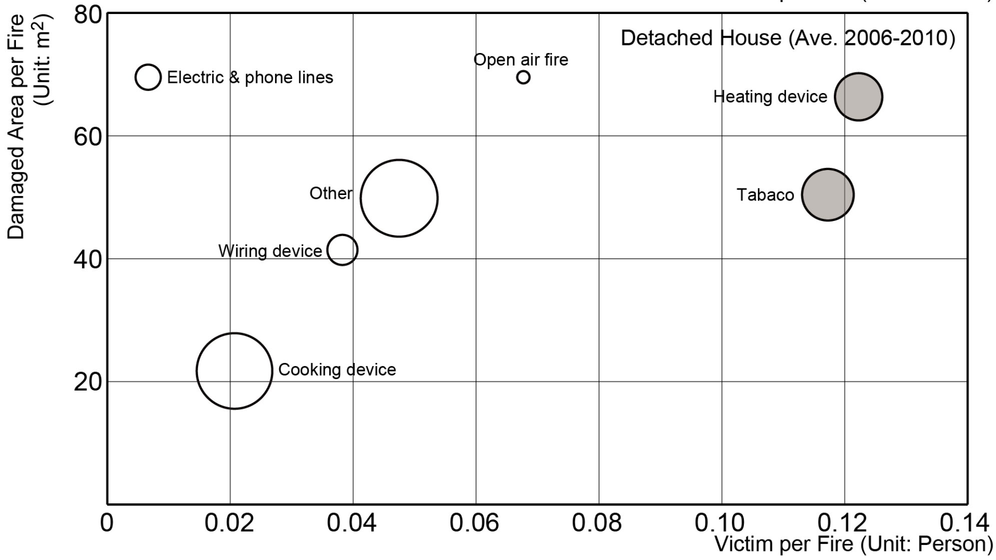


Figure 4: Proportion between Average Human- and Physical-Damage by Use (Upper)
Figure 5: Proportion between Average Human- and Physical-Damage by Cause in Housing (Middle)
Figure 6: Proportion between Average Human- and Physical-Damage by Cause in Office (Lower)
(Areas of bubbles in Figure 4 to 8 proportion to number of fires.)

4.2. FIRE DEATH IN HOUSING

4.2.1. Tendency of Failure Curve of Damage

Reliability engineering deals with not only physical-damages, but also human death rates as a kind of probability of failure. Graphs for the probability of failure is called bathtub curve composed of three curves, early failures (EF), constant failures (CF), and wear out failures (WF). Fire death rates correlate to age of users and draw a similar curve as WF. (E.g. Figure 7.)

4.2.2. Analysis of Fire in Detached House

Figure 7 indicates correlation between age group and the fire death rates by major 8 causes[32] of fire in detached houses. Tobacco fire makes a higher curve in the middle age due to higher smoking rate.

Death rate by tobacco fire per smoking population is given in Figure 8. Concerning gender, male and female draws similar WE curve, but the WF curve for wooden housing shows higher rate than non-combustible housings. If we discuss from the proposition that smokers live with equal distribution in each structure, the figure means older people live in wooden housings than non-wooden housings.

Figure 10 is distribution of age group of the main earner of housings and displays same tendency with Figure 9. More old people seem to live in wooden housings compare to non-wooden ones.

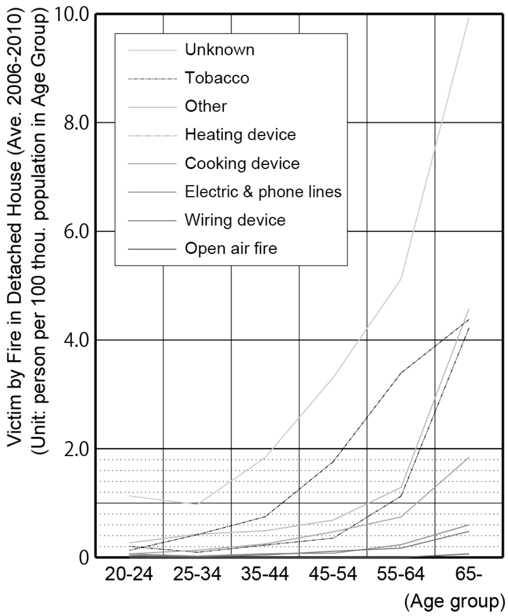
4.2.3. Discussions on Companion Problems

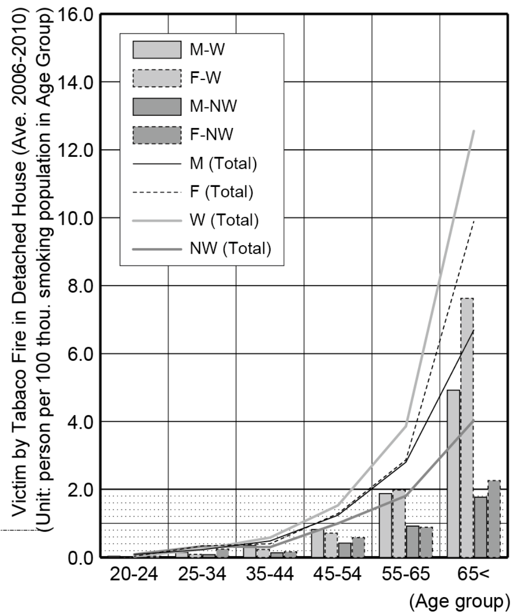
In Japan, many people buy own house with a long bank loan[33], and same people live in one house for a long period. Thus, older people tend to live in older houses without appropriate restoration. Housing policy seems an important companion problem of higher fire death rate in housings.

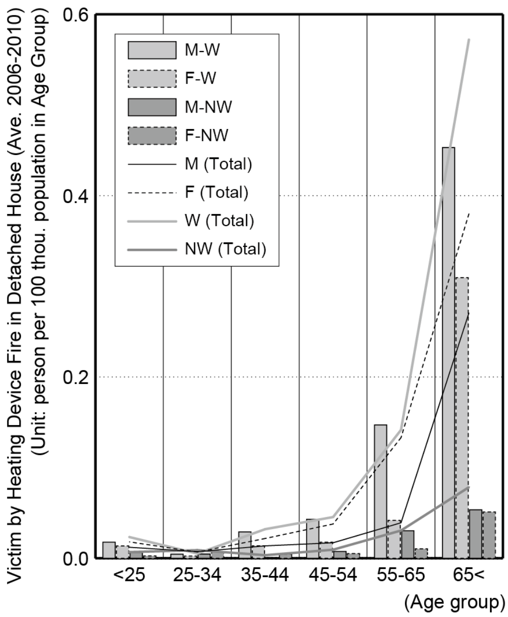
The fire death rate by heating device fires shows the same tendency in wooden- and non-wooden structures as tobacco fire. (See Figure 9.) I guess that oil- or gas-heating devices tend to be used old wooden houses due to insufficient thermal insulations, and these cause higher death rate.

[32] (Fire and Disaster Management Agency 2011) Arson and suspected arson are omitted from 10 major causes.

[33] Maximum 35 years with fixed interest rate for private houses.







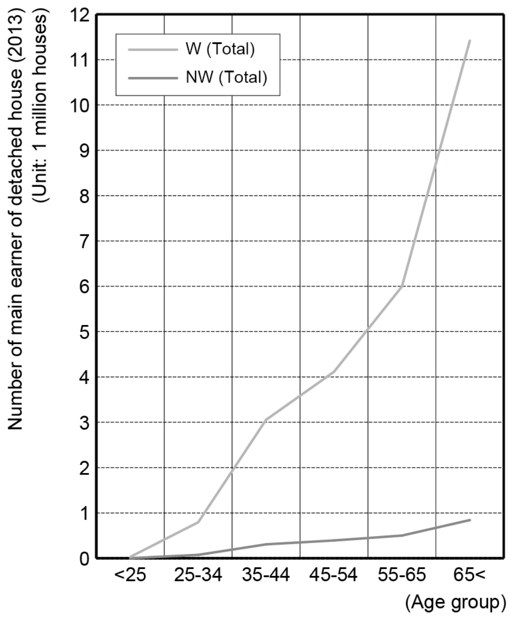


Figure 7: Fire Victim by Major Causes in Detached House (Upper Left)
Figure 8: Victim by Tobacco Fire in Detached House by Gender / Structure (Upper Right)
Figure 9: Victim by Heating Device Fire in Detached House by Gender / Structure (Lower Left)
Figure 10: Main Earner of Detached House in Age Group by Structure (Lower Right)
[34] [35] [36] [37]

Abblibiations: M - Male, F-Female, W- Wood, and NW - Non-Wood.

[34] (Statistics Bureau, Ministry of Internal Aware and Communications 2006-2010)

[35] (Ministry of Health 2006-2010)

[36] (Fire and Disaster Management Agency 2006-2010)

[37] (Ministry of Land, Infrastructure, Transport and Tourism, Japan 2008)

4.3. PHYSICAL DAMAGE IN OFFICE

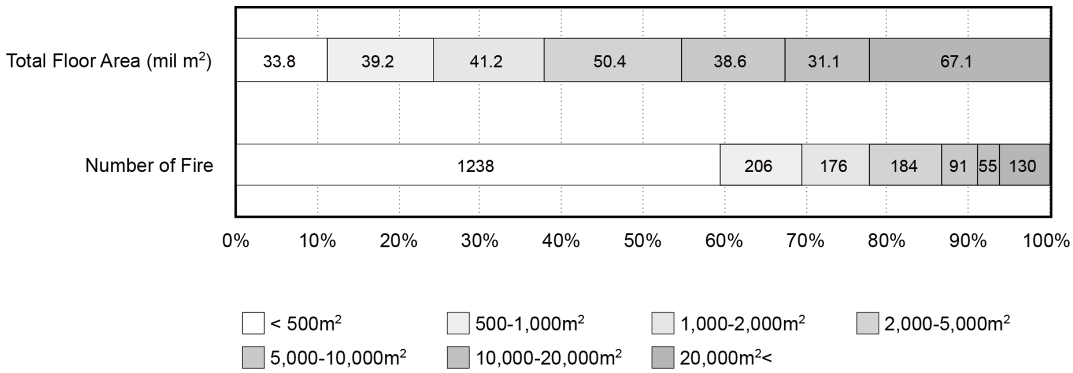
4.3.1. General Tendency of Scale Effect of Buildings

The scale effect of building against fire is reported in former research. In case of office in larger buildings (more than 500m^2) catch lesser fires per same total floor area.[38] The author concludes that the decline of outbreak of fires is due to requirements on fire equipment for large-scale buildings.

A former research about hospitals deals with probability of outbreak of fire with long-term observation[39] and concluded that fire-equipments decreased probability of outbreak of fire in these buildings.

4.3.2. Scale Effect of Buildings

Figure 11 indicates the proportion of the total floor area to the number of fires in offices. Figure 12 to 15 illustrate comparisons of wood and non-wood offices about the number of fires, area of fire damages (total and average), and distance to the nearest fire stations.



Large numbers of fires occur in small offices (= up to 500m^2). This tendency is same for both wood and non-wood offices. (See Figure 12.) One reason of high fire rate in the small offices seems tolerance of legal requirements for fire-equipment. In case of office, the size of the building is an important factor of frequency of fire.

Figure 11: Proportion of Total Floor Area and Number of Fire[40 41]

4.3.3. Discussions on Companion Problems

According to a comparison between Figure 12 and 15, average damage in small wood offices is larger than non-wood small ones. Cause of larger damage of small wood offices seems to correlate with an average distance to the nearest fire stations. (See Figure 17.)

Especially in Figure 16 and 17, higher numbers about wood offices appear at same floor area. That means that large damaged wood offices situated at farther distances from the nearest fire stations.

Differences of geographical conditions of wood and non-wood offices seem to affect to average damage of buildings.

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[38] (MIZUNO 2003)

[39] (TSUJIMOTO 2003)

[40] (Ministry of Land, Infrastructure, Transport and Tourism, Japan 2008)

[41] (Fire and Disaster Management Agency 2006-2010)

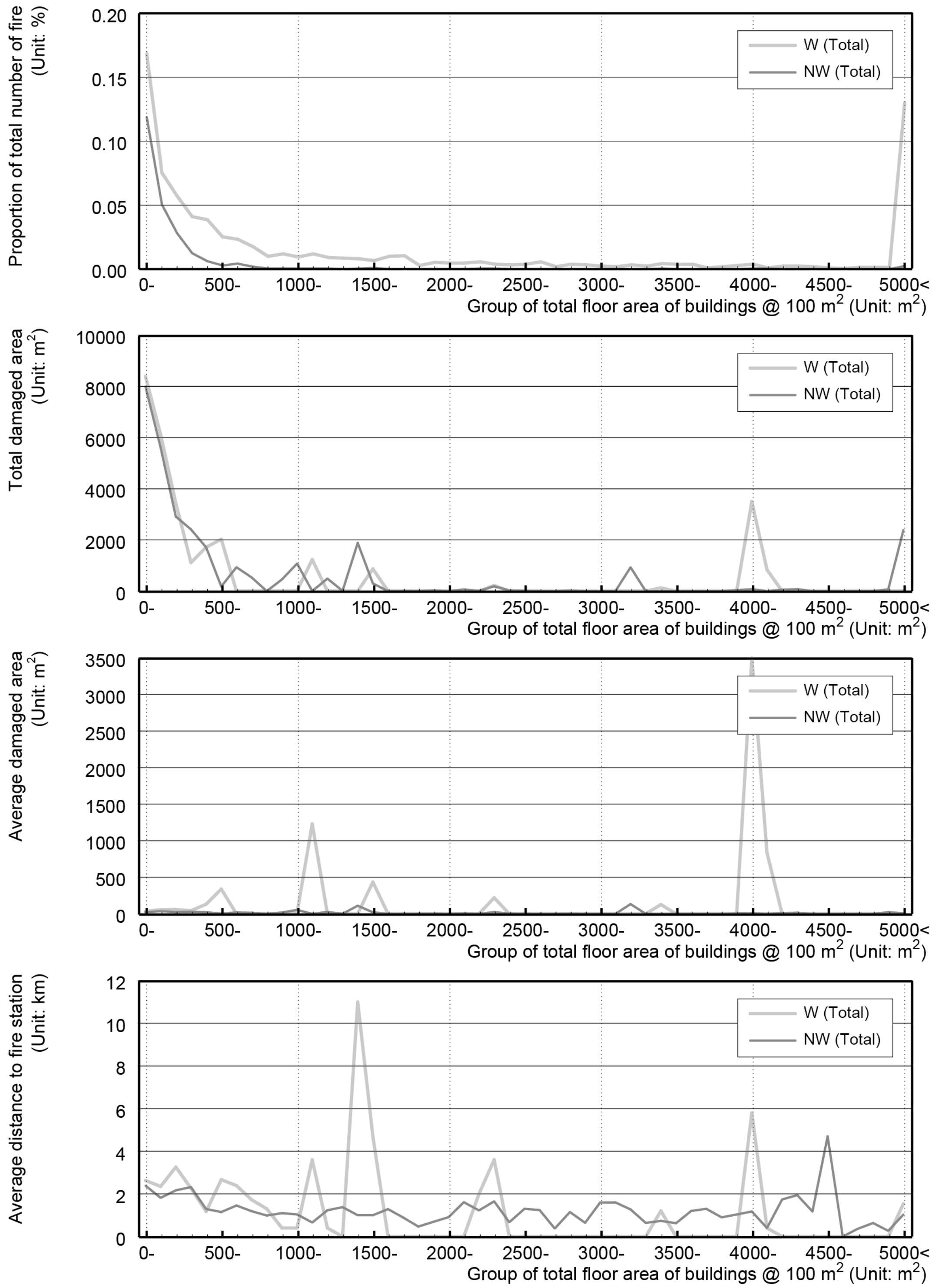

Figure 12: Size Effect of Office Buildings on Number of Fire (Upper)
Figure 13: Size Effect of Office Buildings on Total Damaged Area (Upper Middle)
Figure 14: Size Effect of Office Buildings on Average Damaged Area (Lower Middle)
Figure 15: Size Effect of Office Buildings on Average Distance to Fire Station (Lower) [42]

[42] (Fire and Disaster Management Agency 2006-2010)

5. CONCLUSIONS

5.1. RESULTS

Human and physical fire damages in offices and detached houses are analyzed by Japanese fire statistics. Frequency of outbreak of fire in average sized detached houses or offices are less than 500 to 1,000 years. Degrees of average physical- and human-damages do not correlate to each other in case these are sorted by use or cause. Compare to the average physical-damages, difference of probability of the human-damages are larger.

Human damages in detached houses seems influenced by proper ability factors related to age of users and buildings, especially in case of fire victims by tobacco and heating devices.

Concerning tendency of damages in offices, human-damages in offices can be negligible, and a majority of fires occurs in small sized offices less than $500m^2$.

5.2. DISCUSSIONS

In Japan, age groups of user and age groups of wooden detached houses themselves seem to influence on amount of human-damage. Especially human-damages in wooden detached houses are related to housing policy rather than materials of base buildings.

In Austria, there are less companion problems, and following points seem influence to lower fire death rate:

- Higher proportion of middle-aged group and lesser proportion of old-aged group by social increase;
- Lower smoking rate of old-aged group;
- Higher proportion of social housings with periodical restoration for low- and middle-income groups; and
- Higher penetration of central heating systems.

The detailed analyses about the distribution of companion problems will be discussed in another paper.

5.3. CONCLUSION

Wood based structural elements have been used for small sized detached houses, and wooden detached houses have been recognized as higher risk factor against fire. Nevertheless, the companion problems influence to degree of human-damages rather than type of material of structural elements. If we mainly use wood for detached houses, we need to discuss about companion problems to reduce human-damages.

From the viewpoint of factor and companion problem of fire, it seems rational to use wood for large office buildings. Development of building elements can be shared both countries because these fire risks are independent from domestic companion problems.

Technical requirements on wood-based base-building buildings are avoidance of destruction during safe escape, and appropriate restoration or maintenance of infill system will reduce the risk of fire. These basic perspectives will fit to former technical solutions on SI system.

5.4. DISCUSSIONS IN THE FUTURE

Lightweight and workability are two superiors, and it is better to discuss how to make advantages of these.

In case we use wood for large office buildings, lightweight-building elements can reduce cost of temporary works (e.g. cranes for construction) or substructures (e.g. seismically isolated basements, which costs correlate to weights of superstructures).

In case we count risk factors into design, it is necessary review priorities. For example, electric and phone lines cause a certain amount of fire with larger average physical-damage than cooking devices, we should be careful about the installation of these lines even these are light parts of the SI system. Higher workability of wood-based base-building buildings can allow joints for sub-systems without detailed modular coordination.

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