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The Impact of Building Types on Fire Damage by Month

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Abstract

Statistics show that while the number of fires has decreased over the last decade, losses of human life and economic property due to fire have increased. Moreover, the number of large-scale fires that have occurred in recent years has resulted in heightened public anxiety. This study aims to identify a specific period of the year most vulnerable to fire, and fire trends, such as damage of fire to humans, to the economy, and different building types. For this purpose, we analyzed human and economic damages using statistics related to fire from 2007 to 2017 and provided a monthly distribution of fire damages both to humans and to the economy by building type. We also identified the relationship between the human damage and the economy damage, and compared the economic losses per casualty by building type. The human damage in residential buildings occupied the highest portion, whereas the economic damage of industrial buildings represented more than a half of all economic damage due to fire. The economic damage per casualty was shown highest for industrial buildings and has also increased rapidly in recent years.

Keywords : fire, fire forecasting, fire damage, building fire, fire statistics

1. Introduction

As a nation's economy grows and its society develops, public expectations of social safety are also increasing. In the last several decades, South Korea has seen improvements in many of its social safety indexes, but it is difficult to say that fire incidents are decreasing. According to the statistics over the last decade, while the number of fire incidents appears to be declining, the loss of human life and property damage are still on the rise. What is worse, large-scale fires have become more prevalent in recent years, escalating public anxiety. For instance, fire accidents at Jechon Sports Centre in December 2017 and Milyang Sejong Hospital in January 2018 are still vivid in the public memory.

The large scale fire incidents seem to commonly occur in winter. It is a generally accepted truism that "fire is more common in winter." At this point, several questions might come to one's mind: Firstly, "is it true that fire really occurs more often in winter? If so, how much more does it occur in winter compared to in summer? In other words, in which month of the year does fire occur the most? Secondly, does it have something to do with the building type? And finally, is there any relationship between human damage and economic damage?

Regarding the truism that "fire damage is larger in winter than in summer," it seems to be quite logical as more fuel are consumed for heating in winter. However, this "common sense" belief needs to be statistically verified. To do this, monthly distribution of fire damage needs to be verified. Fossil fuels are still generally used for cooking and

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heating in residential buildings, while recently more electricity has been used for cooking and heating in commercial and industrial buildings. For this reason, the "common sense" belief needs to be also analysed in terms of building type, as an increasing use of electricity may influence a reduction in fire accidents. A building type may also affect a pattern of human and economic damages. For instance, as industrial buildings have become more automated, economic damage may become larger while human damage may decrease in an event of fire.

Although many researchers have been dealing with these topics, few have tried to analyse the relationship between fire damage and building type, and very few have compared fire incidents with regard to a specific period of the year and the type of fire damage. Lin[1] analysed the relation between the number of fire occurrences and the time of fire occurrences. Hanea and Ale[2] presented a model for human damage produced by fire in a public building. Hasofer and Thomas[3] performed a statistical analysis that determined the characteristics of fire incidents that resulted in the risk of casualties, using Generalized Linear Models together with Analysis of Deviance, and identified and quantified the effect of the most significant fire-related factors and personal factors. Heo et al.[4] performed fire risk assessment based on fire damage characteristics by building type in central commercial areas, while also presenting yearly and regional distributions of fire occurrences. Lee[5] compared the occurrence of casualties caused due to fire, analysing the casualty occurrence trend by fire type, place of occurrence, cause of fire, age, month, and hour. Lee et al.[6] identified the fire load by building type, using basic data provided through case studies.

The studies aforementioned are partially related to the topics of this research, as they do not answer the questions mentioned above: (1) The most vulnerable period to fire of the year, and the monthly profile for fires in the year; (2) The relationship between fire and building type; (3) Comparison of human damage and economic damage caused by fire.

On this background, this study aims to statistically identify the month of the year with the highest human and economic damages due to fire, and to provide a monthly profile of human and economic damages by building type. For these purposes, this study is conducted through the following steps. Firstly, this study estimates the total sum of human and property damages of each month from the fire statistics over the 11 years (from 2007 to 2017)[7,8]. While many different types of facilities are included in these statistics, this study includes only public, industrial, commercial, residential, office, and medical facilities in the analysis. In terms of the commercial facility, this study includes the facilities for food, amusement, entertainment and others with similar purposes. In this study, human damage refers to deaths and bodily injuries, while economic damage refers to monetary losses to property values. Secondly, the human and economic damage is reclassified by building type. The month with the highest damage to human and property are then identified for each building type. As most of major fire accidents occur in building environments, the patterns of fire incidents may differ in various types of building. Let alone the building types, the fire damage profile may be also affected by human and economic factors. For this reason, both factors are separately analysed, and their monthly distributions are compared. In order to compare the monthly fire damage distribution of each building type, this study conducted a regression analysis and a hypothesis test, and classifies the building types into two categories: one that has high fire frequency in winter and the other that does not. This study analyses the relationship of monthly fire damage pattern between the total fire incidents and each building type. Coefficients of correlation are used for this analysis. Finally, this study conducts the comparison of economic damage per capita among building types.

2. Annual Fire Statistics

According to National Fire Agency[7,8], annual human and economic damages caused by fire do not appear decreasing. Table 1 shows the fire statistics from 2007 to 2017. It shows slight decreasing tendency in the human damage, yet rapidly increasing trend of economic damage.

Table 1. Annual fire statistics from 2007 to 2017

Year	Human (casualties)	Economic (₩billion)
2007	4155	248
2008	4588	383
2009	4077	252
2010	3108	267
2011	2914	257
2012	3291	289
2013	3412	434
2014	3481	405
2015	3102	433
2016	3248	421
2017	3577	507
Total	38953	3897

Figure 1 shows the result of economic damage divided by casualties. In this study, this value is hereinafter referred to as the EPH (economic damage per human damage). Looking at the annual trend of EPH shown in Figure 1, it has apparently increased quite rapidly in recent years. Although there has been no notable increase in residential and commercial buildings, a remarkable increase may be found in industrial buildings. For example, the EPH in the industrial sector was just 262 in 2007, but it was 1084 in 2015, meaning it more than quadrupled.

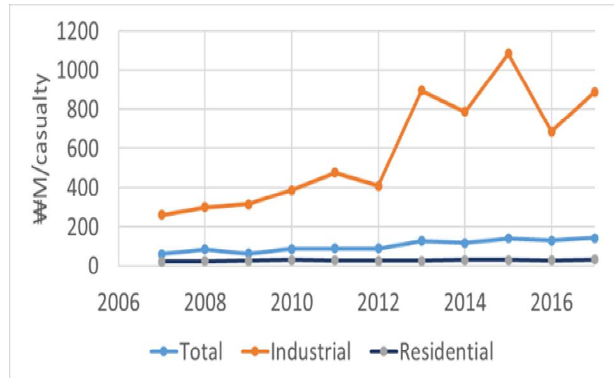

Figure 1. Economic damage per human damage from 2007 to 2017

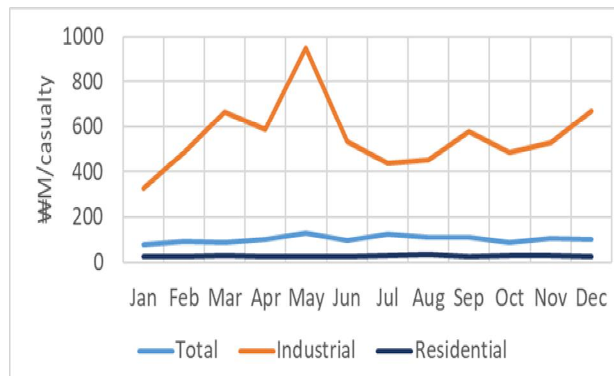

Figure 2. Economic damage per human damage

Figure 2 shows EPH values on a monthly basis. Here, we can see high EPH values in summer months but relatively low EPH values in winter months. As expected, the EPH value was highest in industrial buildings but lowest in residential buildings. These values explain the different characteristics of fire damage between residential and industrial buildings. The high economic damage in industrial buildings can be explained with the loss of valuable machines and commodities during a fire.

3. Monthly fire profile by building type

Figures 3 through 6 show the different forms of annual fire statistics, which are reclassified by month and building type. For example, statistics on fires that occurred in every January from 2007 and

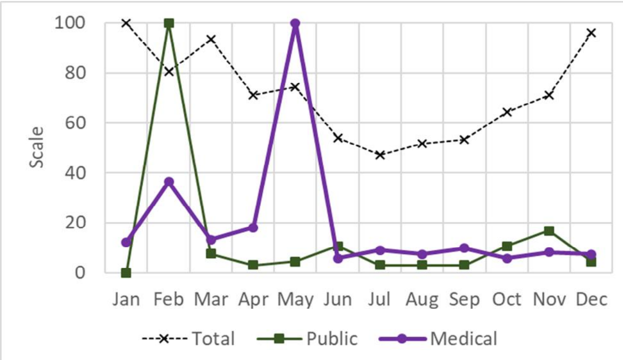

Figure 3. Sum of human damage by month (Pattern I)

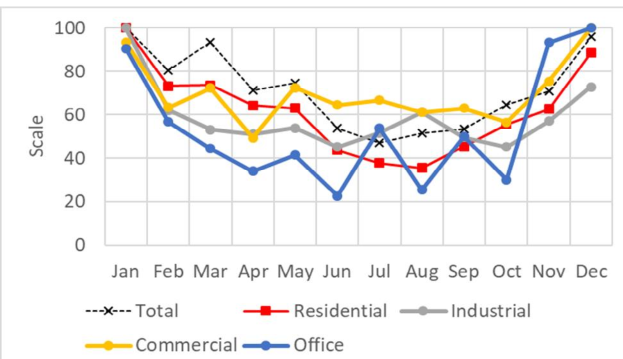

Figure 4. Sum of human damage by month (Pattern II)

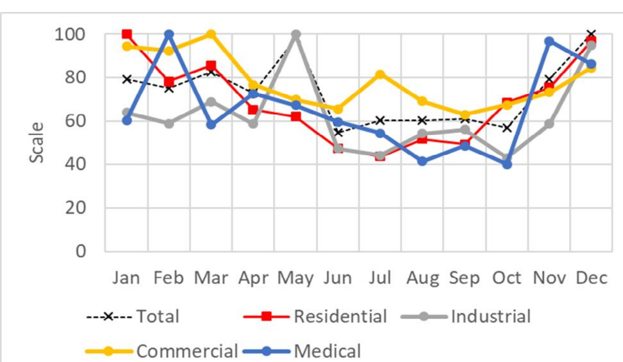

Figure 5. Sum of economic damage by month (Pattern I)

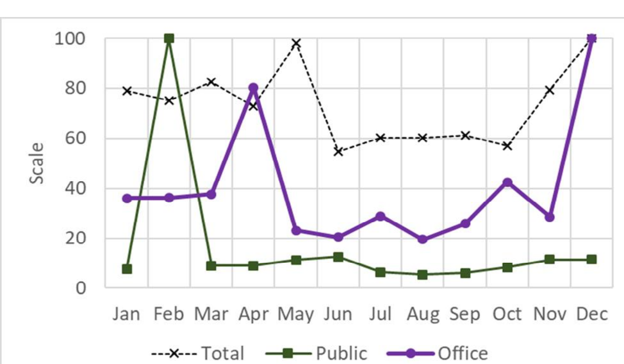

Figure 6. Sum of economic damage by month (Pattern II)

2017 are summed up and displayed in the January column of the figures. To make the comparison easier, damage values of each building type were scaled to a maximum of 100. By examining these values, it is possible to identify the month with the highest fire damage. In other words, the "common sense" belief of whether or not fire occurs more in winter than in summer is verified.

To verify the month with the highest fire human damage, the sum of each month is plotted by building type as shown in Figures 3 and 4. There are two different patterns of monthly distribution: pattern I with high values in winter while low values in summer, and pattern II that has no distinct tendency. Figure 3 shows pattern I. In pattern I are residential, industrial, commercial, and office buildings. The curves of these types of building are similar the curves of the total human damage. It tells us that the truism that "more fire damage occurs in winter," applies to these building types with regard to human damage.

On the contrary, some building types do not follow "that truism." The figures for public and medical buildings show a somewhat arbitrary pattern. The two building types do not seem related, but it is interesting that the two building types have extraordinary peaks. For medical buildings, this occurs in May, and for public buildings it occurs in February.

Although human damage data implies that "the common perception regarding winter fires" may be true in most cases, economic damage does not seem to follow the same pattern (Figures 5 and 6). As with human damage, residential buildings show a pattern of high damage in winter and low damage in summer. In industrial buildings, in terms of total fire, it is true that economic loss is highest in December, which is almost as high in May.

It is unlikely that we will find any tendencies in the figures for public, commercial, and office buildings

(Figure 6). Their patterns all look rather arbitrary, and do not always show high figures in winter.

4. Regression analysis and monthly trend

The previous chapter illustrated that there are various aspects of monthly fire distributions by damage type and by building type. For instance, some of them have a parabolic shape or V-shape, while the others do not. To verify this, this study conducted a regression analysis for each building type, and the results are shown in Tables 2 and 3.

Table 2. Regression results of human damage charts

	Jan to Jun	Jul to Dec
Building Type	Slope (R square)	Slope (R square)
Total	-7.76 (0.77) ↘	8.95 (0.86) ↗
Public	-6.77 (0.11) ↘	1.63 (0.28) ↗
Industrial	-8.59 (0.65) ↘	2.52 (0.23) ↗
(Manufacturing)	-2.37 (0.28) ↘	0.34 (0) ↗
Commercial	-4.02 (0.27) ↘	5.78 (0.47) ↗
Residential	-9.18 (0.87) ↘	9.88 (0.87) ↗
Office	-11.29 (0.8) ↘	11.86 (0.5) ↗
Medical	4.65 (0.06) ↗	-0.28 (0.13) ↘

Table 3. Regression results of economic damage charts

	Jan to Jun	Jul to Dec
Building Type	Slope (R square)	Slope (R square)
Total	-1.77 (0.06) ↘	7.15 (0.63) ↗
Public	-6.91 (0.12) ↘	1.28 (0.81) ↗
Industrial	0.86 (0.01) ↗	7.28 (0.52) ↗
(Manufacturing)	-2.43 (0.16) ↘	3.76 (0.21) ↗
Commercial	-6.68 (0.77) ↘	0.9 (0.04) ↗
Residential	-9.46 (0.9) ↘	10.18 (0.9) ↗
Office	-2.15 (0.03) ↘	11.42 (0.51) ↗
Medical	-2.5 (0.09) ↘	9.03 (0.48) ↗

If a chart shows either a V-shape or a parabolic shape with both ends rising, it should have a downward trend from January to June and an upward trend from July to August. This trend can be found in the human damage charts of residential, office, and industrial buildings. According to Table 4, most buildings show a downward trend from January to June and an upward trend from July to December. These cases can be considered as "more human damage due to fire occurring in winter" type. In particular, residential buildings show a high coefficient of determination, confirming that the truism of "more vulnerable to fire in winter than in summer" is more accurate for these buildings than for other building types. Only medical buildings do not comply with the "more fire damage in winter" theory, with a very small R-squared value, which implies a rather irregular tendency. The remaining building types seem to follow the aforementioned truism, but with a low accuracy, as they have a low coefficient of determination.

With regard to economic damage, the results are shown slightly different(Table 3). Most buildings fit the truism, but only the industrial buildings do not. These show an upward trend both from January to June and from July to December, contradicting to the "more fire damage in winter" theory. Again, residential buildings show a high coefficient of determination, but others do not.

In summary, only residential buildings verify the premise of "more fire damage in winter than in summer" with high accuracy, both in terms of human damage and in economic damage. Human damage of medical buildings and economic damage of industrial buildings show exceptional figures. Other building types verify the truism but with low accuracy

5. Month by month comparison of fire occurrence

The previous chapter discussed the monthly distribution pattern of fire damages by building type and by damage type. This chapter is going to compare fire statistics of each month. To do this,

Table 4. Probability that the damage of a specific month is higher than the average by building type

Damage type	Building types	Jan	Feb,	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Human damage	Total	0.94	0.69	0.89	0.49	0.56	0.17	0.09	0.14	0.16	0.35	0.49	0.91
	Public	0.31	1.00	0.41	0.35	0.37	0.45	0.35	0.35	0.35	0.45	0.54	0.37
	Industrial	1.00	0.59	0.36	0.31	0.38	0.19	0.32	0.57	0.28	0.19	0.46	0.82
	(Manufacturing)	0.34	0.72	0.37	0.10	0.19	0.28	0.49	0.99	0.33	0.23	0.81	0.85
	Commercial	0.95	0.33	0.56	0.08	0.57	0.36	0.42	0.27	0.32	0.18	0.65	0.98
	Residential	0.97	0.71	0.72	0.55	0.52	0.18	0.11	0.09	0.20	0.38	0.51	0.91
	Office	0.91	0.55	0.37	0.23	0.33	0.13	0.50	0.15	0.45	0.19	0.93	0.96
	Medical	0.40	0.74	0.41	0.48	1.00	0.30	0.35	0.33	0.36	0.30	0.34	0.33
Economic damage	Total	0.65	0.55	0.73	0.48	0.95	0.11	0.20	0.20	0.21	0.14	0.65	0.96
	Public	0.37	1.00	0.39	0.39	0.42	0.44	0.35	0.34	0.35	0.38	0.42	0.42
	Industrial	0.53	0.42	0.64	0.42	0.98	0.20	0.16	0.33	0.36	0.14	0.42	0.96
	(Manufacturing)	0.55	0.44	0.94	0.73	0.51	0.14	0.07	0.62	0.75	0.04	0.55	0.86
	Commercial	0.91	0.88	0.96	0.45	0.25	0.16	0.61	0.23	0.11	0.19	0.34	0.70
	Residential	0.95	0.69	0.81	0.43	0.37	0.13	0.09	0.19	0.15	0.50	0.64	0.93
	Office	0.44	0.44	0.46	0.95	0.25	0.22	0.33	0.20	0.29	0.54	0.32	0.99
	Medical	0.40	0.96	0.36	0.64	0.53	0.39	0.29	0.11	0.20	0.10	0.94	0.85

hypothesis tests are conducted to examine which month has the highest fire damage. Table 4 shows the probability that the damage of a specific month is higher than the average of all months. For instance, 0.97 is the probability that the human damage of public buildings due to fire in January is higher than the monthly average human damage of the building type. Taking the figures into account, a fire incident is more likely to occur in winter since the values of November, December, and January are higher than those of Jun, July, and August. However, at the significance level of 5%, we cannot conclude that more human damage occurs in November, February, January or December compared to the average. In other words, it cannot be concluded, at the significance level of 5%, that a fire incident is more likely to take place in winter. It is highly likely that in January and December, human damage is higher in public (0.97), industrial (1.00), residential (0.97), and office (0.96) buildings than in other types of buildings. However, it is found that there are three cases where human damage is higher in summer: in medical (1.00) and commercial (0.99) buildings in May and in manufacturing (0.99) buildings in August.

With regard to economic damage, it shows the highest probability in December at the significance level of 5%, but it also shows almost as high in May. In January, it is not as high as in December. In most cases, the values for economic damage are shown slightly different compared to those of human damage. In February, the values in public (1.00) and medical (0.96) buildings have higher probabilities, while in December, industrial (0.96) and office (0.99) buildings have higher probabilities. The values of industrial buildings in May (0.98) and of commercial buildings in July (0.98) are the examples that contradict the the “more fire damage in winter” theory.

For the next step, this study carried out a hypothesis test between every month. While in the previous the value of a specific month was compared with the average, the purpose of this test is to compare the value of a specific month with the values of all the other months. The results for the total fire incidents are shown in Table 5. For instance, Pr(Jan>Jun)=1.00 means the probability that human damage in January is higher than in

June is 1.00 and that in December than in August is 0.99. These results explain that, at the significance level of 5%, more human damage definitely occurs in January and December than in June, July, August, and September. On the other hand, with regard to economic damage, it is hard to conclude that January and December have a higher probability compared to other months at a significance level of 5% (Table 6).

Table 5. Probability that the human damage of a specific month is higher than that of each month

A>B		A											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Jan		0.14	0.32	0.06	0.21	0.00	0.00	0.02	0.01	0.04	0.08	0.45
	Feb	0.86		0.72	0.30	0.43	0.10	0.01	0.08	0.06	0.19	0.24	0.70
	Mar	0.68	0.28		0.06	0.26	0.00	0.00	0.02	0.01	0.09	0.13	0.54
	Apr	0.94	0.70	0.94		0.56	0.05	0.02	0.11	0.19	0.31	0.50	0.82
	May	0.79	0.57	0.74	0.44		0.17	0.14	0.16	0.25	0.33	0.45	0.73
B`	Jun	1.00	0.90	1.00	0.95	0.83		0.31	0.42	0.49	0.76	0.89	0.97
	Jul	1.00	0.99	1.00	0.98	0.86	0.69		0.61	0.69	0.94	0.96	0.97
	Aug	0.98	0.92	0.98	0.89	0.84	0.58	0.39		0.54	0.82	0.90	0.99
	Sep	0.99	0.94	0.99	0.81	0.75	0.51	0.31	0.46		0.72	0.86	0.98
	Oct	0.96	0.81	0.91	0.69	0.67	0.24	0.06	0.18	0.28		0.67	0.86
	Nov	0.92	0.76	0.87	0.50	0.55	0.11	0.04	0.10	0.14	0.33		0.88
	Dec	0.55	0.30	0.46	0.18	0.27	0.03	0.03	0.01	0.02	0.14	0.12	

Table 6. Probability that the economic damage of a specific month is higher than that of each month

A>B		A											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Jan		0.39	0.54	0.39	0.60	0.03	0.28	0.26	0.24	0.09	0.50	0.66
	Feb	0.61		0.59	0.46	0.62	0.09	0.25	0.32	0.29	0.20	0.55	0.72
	Mar	0.46	0.41		0.28	0.58	0.22	0.31	0.29	0.15	0.24	0.47	0.62
	Apr	0.61	0.54	0.72		0.63	0.24	0.37	0.36	0.14	0.27	0.57	0.70
	May	0.40	0.38	0.42	0.37		0.28	0.33	0.29	0.32	0.29	0.41	0.51
B	Jun	0.97	0.91	0.78	0.76	0.72		0.57	0.59	0.61	0.57	0.81	0.81
	Jul	0.72	0.75	0.69	0.63	0.67	0.43		0.50	0.51	0.46	0.66	0.94
	Aug	0.74	0.68	0.71	0.64	0.71	0.41	0.50		0.51	0.44	0.68	0.73
	Sep	0.76	0.71	0.85	0.86	0.68	0.39	0.49	0.49		0.43	0.67	0.77
	Oct	0.91	0.80	0.76	0.73	0.71	0.43	0.54	0.56	0.57		0.76	0.78
	Nov	0.50	0.45	0.53	0.43	0.59	0.19	0.34	0.32	0.33	0.24		0.64
	Dec	0.34	0.28	0.38	0.30	0.49	0.19	0.06	0.27	0.23	0.22	0.36	

The same analysis was performed for all building types, but only the residential building type shows a clear result. With regard to human damage, it is more likely to occur in January, December, February, March, April, and November than in June, July, and August. Similar results are acquired for economic damage. In summary, the theory of "more fire damage in winter" is true for residential buildings at a significance level of 5%. With regard to human damage, the same is statistically true as for total fire, but it is because more than a half of fire casualties occur in residential buildings, which affects the total figure for human damage. In terms of economic damage, one cannot conclude that more fire occurs in winter.

6. Correlation between each building types

Correlation coefficients are derived to identify the relationship between each building type and the total fire (Table 7). The purpose of this is to identify how each building type affects total fire damage. Since the economic damage of industrial buildings represents the largest part of the total economic damage, it also has the greatest impact on the distribution of the total fire damage over the year. Likewise, casualties in residential buildings, as they take the highest portion, affect the distribution of total human damage.

Table 7. Correlation between total fire damage and fire damage of each building type

Building types	Human	Economic
Total	1.000	1.000
Public	0.136	0.078
Industrial	0.669	0.939
(Factories)	-0.058	0.598
Commercial	0.681	0.444
Residential	0.971	0.672
Office	0.608	0.462
Medical	0.142	0.573

We also conducted a correlation analysis among

Table 8. Correlation among building types

	Building type	Public	Industrial	(Factories)	Commercial	Residential	Office	Medical
Human damage	Public	1.00						
	Industrial	−0.01	1.00					
	(Factories)	0.19	0.25	1.00				
	Commercial	−0.16	0.75	0.26	1.00			
	Residential	0.15	0.75	−0.11	0.70	1.00		
	Office	0.04	0.68	0.27	0.83	0.68	1.00	
	Medical	0.17	−0.05	−0.28	−0.01	0.11	−0.12	1.00
Economic damage	Public	1.00						
	Industrial	−0.02	1.00					
	(Factories)	−0.04	0.58	1.00				
	Commercial	0.36	0.22	0.39	1.00			
	Residential	0.18	0.48	0.48	0.71	1.00		
	Office	−0.02	0.39	0.38	0.28	0.52	1.00	
	Medical	0.59	0.38	0.28	0.36	0.46	0.36	1.00

building types. The analysis results are shown in Table 8. For human damage, the correlation coefficient exceeds 0.5 in five cases, which are indicated in bold. Office and commercial buildings are more strongly related (0.83) compared to any other combination of two building types. For economic damage, the correlation factor that exceeds 0.5 is shown only in three cases as shown in Table 8. Significantly, the correlation factor between commercial and residential buildings exceeds 0.7.

7. Conclusions

To verify the period most vulnerable to fire and to examine it by damage type and by building type, this study compares the monthly fire damage profile and classifies the patterns of monthly fire profile of each building type. In addition, it verified the relationship among each building type and the influence between human and economic damages. Fire statistics from 2007 to 2017 are used for the analysis.

Comparing the values of 2007 and 2017, economic damage has more than doubled. In particular, the economic damage in industrial buildings has almost tripled. Although casualties in industrial buildings account for less than 10% of the total human damage, their economic damage reaches more than half of the total economic damage from fires(53.6%). Of this, more than a half of the total casualties come from manufacturing plants. Residential buildings, in contrast, take up a half of the human damage, while causing only 14% of total economic damage. In short, fire causes low economic damage and relatively high human damage in residential buildings, whereas relatively small human damage occurs with quite significant economic damage in industrial buildings.

The results of the hypothesis test show that the human damage due to fire is higher than the average in in December and in January, whereas the economic damage is higher than the average in May and in December. This implies that human damage does not always correspond to economic damage. For instance, although human damage was mostly high in winter months, economic damage was high not only in December but also in May.

Looking into each building type, human and economic damage showed a similar pattern only in residential buildings. With regard to human damage, residential and industrial buildings showed the highest figure in January, while for economic damage, industrial buildings are the most vulnerable to fire in December. In general, the human damage in residential buildings occupies the highest portion, 50.9% of the total, and the economic damage of industrial buildings shares more than a half of the total. Some other types of buildings, on the other hand, showed diverse patterns. For instance, the human damage in manufacturing buildings is highest in August, whereas the human damage in medical buildings is highest in May. The economic damage of industrial buildings peaked both in May and in December, and the economic damage of commercial buildings is shown highest in March. As the fire damage of these building types shares a small portion of the total fire, its impact is quite limited.

High economic damage in May resulted in the highest economic damage per human damage (EPH) in the same month. The highest and the lowest EPHs are shown in industrial and residential buildings, respectively. Overall, an EPH is higher in summer than in winter. The annual EPH figure has been rapidly increasing in recent years. This may be because a remarkable increase of the EPH in industrial buildings.

The results of this study are expected to contribute to forecasting fire damage and to aiding budget allocation by period, by damage type, and by building type.

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