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Calculation of Carbon Stocks on Korean Traditional House (Hanoks) in Korea

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Abstract: This study analyzes the contribution of hanok that construction in reducing greenhouse gas (GHG) emissions in Korea by calculating the carbon storage of hanoks and comparing it to different housing types in Korea. The hanok is a traditional Korean house. And it were first designed and built in the 14th century during thd Joseon Dynasty. According to our results, the number of hanoks in 2016 was approximately 547,085 which was accounting for 7.8% of the total construction market, This study found Gyeongbuk with 95,083, Jeonnam with 88,981, Gyeongnam with 76,388 and Seoul with 43,519 hanoks. According to the GHG Inventory Report for 2016, Korea's total annual GHG emissions amounted to 650 million tCO_2, with the carbon stocks in hanoks amounting to 19.2 million tCO_2. This accounts for 2.8% of Korea's total GHG emissions and 46.1% of the carbon absorbed by forests. Our results show that hanoks store four times more carbon than light-frame-wood-houses, and 15 times more carbon than concrete-reinforced and steel-frame houses. The main factors causing the hanok industry slowdown are the high construction costs, lack of government support, and insufficient knowledge of hanok architecture. Therefore, to further increase the carbon stock of hanok, more research is needed to improve the technical use of wood and reduce construction of the hanok and prepare legal and institutional arrangements related to hanok industry.

Keywords: *greenhouse gas (GHG), wood carbon stock, hanok architecture*

1. Introduction

The role of forest and wood to absorbing and storing greenhouse gases (GHGs) has expanded considerably in accordance with Article 5 of the 2015 United Nations Climate Change Conference (COP 21), which was held in Paris, France. In addition, at the 2009 COP 15 conference in Copenhagen, Korea announced that it would reduce its GHG emissions by 30% compared to the business-as-usual (BAU) baseline by 2020. Wood, which is a basic product of forests, is used in the construction of houses and furniture, and stores carbon for a long period of time (Pregitzer et al., 2004; Lippke et al., 2010) In addition, wood manufacturing produces fewer GHG emissions compared to the manufacturing processes of other materials. For example, Greenhouse gas emissions from wood processing are 1/350 of steel and 1/1,500 of aluminum (Korea Forestry Service, Wood industry promotion comprehensive plan, 2012- 2016.). Thus, wood has an important role not only in reducing GHG emissions but also in carbon fixation. That's why several approaches have been proposed to estimate the amount of carbon

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in harvested wood products (HWPs), (Dakar, Senegal, 1998) including large stock- change approaches, production approaches, and atmospheric-flow approaches.

However, to use wood carbon models, currently has many problems due to competing interests between the producers and importers of wood. The General Assembly COP 17, held in Durban, South Africa, in November 2011, employed the stock change approach for domestic wood products only, paving the way for government policies promoting the use of domestic timber.

Except for paper and pulp, the most common use of wood is housing. Therefore, wood can play a considerable role in reducing GHG emissions if substantially more material is used in construction. Traditionally, Korea uses the hanok housing style, but it began to disappear in favor of apartments and reinforced concrete buildings since the 1970s. However, due to the healing effects of disease such as atopic dermatitis and asthma, more and more people live in hanok. As a hanok is constructed with processed lumber, building more hanoks will increase wood production. Therefore, the purpose of this study is to quantify the contribution of hanoks to reducing GHG emissions in Korea, by estimating and analyzing carbon stocks in hanoks. Furthermore, we evaluate the reasons for the slowdown in hanok building in Korea.

2. Method of Research

2.1. Method of Calculation CO_2 stored in hankos

In order to estimate the carbon stocks of Korean hanoks, data on the amount of wood consumption were required. The total number of hanok buildings was sourced from a statistical survey of the construction industry from 2012 to 2016 (Ministry of Land, Infrastructure and Transport, 2016). We determined the contribution of hanoks to GHG emissions in Korea by calculating carbon stocks based on the 2006 IPCC Guidelines Volume 4 (AFOLU 12.18). To estimate the carbon stocks of wood products used in hanoks, we first obtained the total amount of wood used in the hanoks from the statistical data, and we multiplied the total floor area of a typical hanok by the amount of timber used in the hanok (m^3/m^2). Then, we multiplied the density of the wood and the carbon content of the wood (dry weight). According to the 2006 IPCC Guidelines, the density of wood is not uniform and depends on its category (wood, lumber, or wood chips). The density of wood (oven-dry) residue is 0.45 t/m^3, and that of plywood, PB, and MDF is 0.628 t/m^3. Because the exact amount of wood used in the hanoks is not known, we used a uniform (oven-dry)density of 0.5 t/m^3. That is, we did not differentiate the wood by type.

2.2. Types of wood used in hanok architecture

Traditional hanoks predominantly used pine trees. The parts of a hanok are mainly divided into column, beams, jangyeo, and dori, depending on the location (Fig. 1.). The column receives the load of the roof and transmits it to the ground. The horizontal beam is located in front of the unit, and is the largest element in hanok architecture. The dori is installed at right angles to the beam and supports the rafter. The jangyeo supports the dori in the same direction as the beam, but is located underneath the dori. The force applied to the house can differ depending on the part of the Hanoks may be made of pine, larch, spruce pine fir, Douglas

(a) (b)

Fig. 1. (a) Photograph of Eum-pyeong hanok in Korea, (b) Close-up view of part of a hanok and its elements.

(a) (b)

Fig. 2. Sketches of hanok structures showing (a) a Mat-bae roof and (b) a Pal-Jak.

fir, Radiata pine, or Western Hemlock. Wood imported for the hanok market is cheaper than domestic wood; however, hanok construction volumes using only domestic wood is expected to increase as the needed equipment is available and the supply chain to the domestic region has not only expanded but has also remained stable in recent years. Therefore, this study calculated the amount of carbon storage in a hanok, assuming, that all hanoks are made with domestic wood.

2.3. Wood consumption by hanok type

To calculate the amount of wood used in a hanok, it is important to know how the wood was shaped; therefore, we determine wood usage by hanok type. The shape of the hanok depends on four criteria. First, the structure can be a 3-beam frame or a 5-beam frame. The 3-beam frame is the most basic hanok structure, and results in three thin sloping roofs. Second, structures can be divided into the '—', 'ㄱ', and 'ㄷ' shapes, depending on the layout of the land. Third, depending on the shape of the roof, it can be categorized as either Mat-bae or Pal-Jak (Fig. 2.). Fourth, recently built hanoks can be divided into mini-sized hanoks, small-sized hanoks, and medium-sized hanoks. For each case, the amount of wood used will vary. In this study, we determined wood usage based on hanok type, using data from the Korea Hanok Center (2014).

3. Results and Discussion

3.1. Wood usage in hanoks

Table 1 shows wood usage by hanok type. Mini-sized hanoks use the largest amount of wood per 1 m^2 (0.68 m^3/m^2), the average being 0.59 m^3/m^2. Small-sized hanoks use an average of 0.59 m^3/m^2 of wood and medium-sized hanoks use an average of 0.56 m^3/m^2. The proportion of wood to all the other materials used in hanok construction is more than 30%, and the quantity of wood varies according to the size of the structure, the shape of the plane, and the type of roof. A 3-beam frame uses 0.52 m^3/m^2 of timber, whereas a 5-beam frame uses 0.57 m^3/m^2. Wood usage for a Pal-Jak roof is 1.3 to 1.5 times higher than that of a Mat-Bae roof. The total average wood used in a hanok is 0.58 m^3/m^2.

3.2. Carbon stock estimation in hanoks

Table 2 shows that the most recent hanok construction which consisted of 547,085 hanoks in 2016, accounting for 7.8% of the total construction cost 7,054,733 buildings. Among the 17 cities and provinces, Gyeongbuk province has the largest number of hanoks (95,083), followed by Jeonnam, Gyeongnam, and Seoul.

Table 1. Amount of Wood Use by Hanok Type

Scale	Shape	Area (m^2)	Roof	Total wood usage (m^3)	wood usage/m^2 (m^3/m^2)	Average (m^3/m^2)
Miniature hanok (about 40 m^2)	ㅡ (3beam 4part)	36	Mat-bae	17.38	0.48	0.58
			Pal-jak	22.72	0.63	
	ㄱ (3beam 4part)	36	Mat-bae	19.19	0.53	
			Pal-jak	24.53	0.68	
	ㄷ (5beam 3part)	40.5	Mat-bae	22.19	0.55	
			Pal-jak	27.48	0.68	
Small hanok (about 50 m^2)	ㅡ (5beam 3part)	49.5	Mat-bae	27.37	0.55	
			Pal-jak	32.69	0.66	
	ㄱ (5beam 4part)	54	Mat-bae	28.33	0.52	
			Pal-jak	33.63	0.62	
	ㄷ (3beam 6part)	54	Mat-bae	28.52	0.53	
			Pal-jak	33.87	0.63	
Medium sized hanok (about 70 m^2)	ㅡ (5beam 5part)	67.5	Mat-bae	34.48	0.51	
			Pal-jak	39.77	0.59	
	ㄱ (5beam 4part)	72	Mat-bae	37.28	0.52	
			Pal-jak	42.60	0.59	
	ㄷ (5beam 4part)	72	Mat-bae	38.71	0.54	
			Pal-jak	44.05	0.61	

Source : Korea Hanok Center. A study on the calculation of the cost of wood according to the size and shape of Hanok. (2013).

Table 2. Amount of Wood Use by Hanok Type

(unit : house, 1,000 m^2)

Division		2012		2013		2014		2015		2016	
		numbers	floor area	numbers	floor area	numbers	floor area	numbers	floor area	numbers	floor area
Total		577,243	37,968	569,557	37,493	5561,834	37,017	544,540	36,589	547,085	36,129
metro area	Sum	91,558	6,058	89,316	5,992	87,476	5,816	85,944	5,733	84,112	5,611
	Seoul	48,288	3,006	46,983	2,918	45,585	2,840	44,656	2,781	43,519	2,708
	Incheon	10,553	572	10,343	563	10,211	558	10,043	553	9,899	545
	Kyungki	32,717	2,479	31,990	2,440	31,680	2,418	31,245	2,398	30,694	2,357
metro city	Sum	81,993	4,790	80,081	4,676	78,291	4,573	746,056	4,448	74,013	4,321
	Pusan	25,804	1,345	25,316	1,317	24,725	1,286	23,751	1,237	22,960	1,194
	Daegu	25,915	1,486	25,113	1,440	24,541	1,405	23,904	1,367	23,244	1,326
	Kwang ju	14,272	955	13,919	932	13,503	907	13,230	889	12,964	869
	Dae jeon	4,865	328	4,760	320	4,693	315	4,624	311	4,455	301
	Wool san	8,250	459	8,131	453	8,021	449	7,891	443	7,788	435
	Se jong	2,887	215	2,842	211	2,808	208	2,656	198	2,602	195

To be continued

Table 2. Continued

(unit : house, 1,000 m^2)

Division		2012		2013		2014		2015		2016	
		numbers	floor area	numbers	floor area	numbers	floor area	numbers	floor area	numbers	floor area
Province	Sum	403,692	27,119	400,154	26,895	396,067	26,628	392,540	26,407	388,960	26,197
	Kang won	31,423	2,003	31,063	1,982	30,612	1,960	30,369	1,944	30,014	1,928
	Chung buk	20,506	1,648	20,324	1,634	20,110	1,616	19,920	1,598	19,748	1,582
	Chung nam	36,337	2,449	36,085	2,438	35,719	2,415	35,452	2,400	35,167	2,384
	Jeon buk	44,048	3,146	43,542	3,100	43,135	3,068	42,718	3,040	42,277	3,010
	Jeon nam	91,356	6,711	90,861	6,683	90,064	6,621	89,617	6,586	88,981	6,538
	Kyung buk	99,327	6,036	98,299	5,976	97,236	5,912	96,151	5,853	95,083	5,801
	Kyung nam	79,419	5,019	78,716	4,978	77,917	4,928	77,020	4,875	76,388	4,840
	Jeju	1,276	102	1,264	101	1,274	104	1,293	107	1,302	110

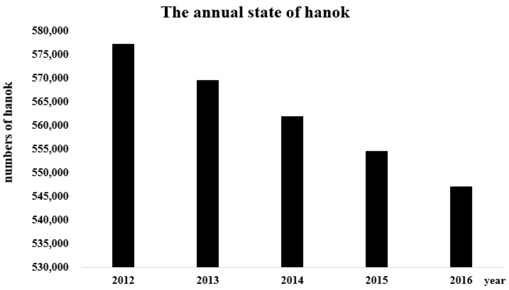


Fig. 3. Annual trend of hanok construction in Korea between 2012 and 2016.

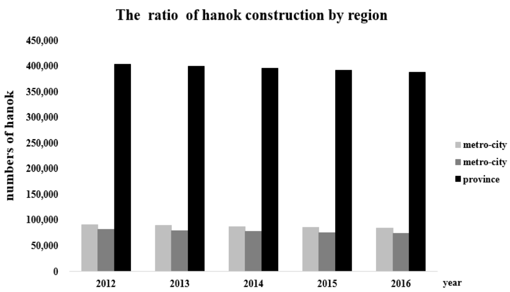


Fig. 4. Ratio of hanok construction by region between 2012 and 2016 in Korea.

Figs. 3 and 4 shows that annual hanok construction is gradually decreasing. Reasons for the decline in hanok construction are discussed in the conclusions.

Next, the carbon stocks in hanoks were estimated using the total number and total floor area of Korean traditional hanoks from Table 2. Table 3 shows the calculation of the fraction of carbon in the dry weight of wood and the total amount of carbon in wood products. Table 4 shows the CO_2 estimation procedure. The carbon fraction in drywood was determined as 0.5 t/oven-dry t, and the carbon stock in hanoks was converted to CO_2 by multiplying it by 44/12. The estimated wood carbon stocks of Korean hanoks for 2016 is 19.2 million tCO_2. About 18% of this amount (3.4 million tCO_2) is stored in hanoks in Jeonnam province, and a further 16.0% (3 million tCO_2) and 13.4% (2.5 million tCO_2) is stored in hanoks in Gyeongbuk province and Kyongnam province, respectively. Although Kyungbuk province boasted having the largest number of hanoks in 2016, Jeonnam province accounts for the largest CO_2 stock because the total floor area of hanoks is larger in this province than in Kyungbuk.

Figs. 5 and 6 show that the annual carbon stocks of hanoks have been continuously decreasing from 2012 to 2016. This is because hanoks are expensive to build compared to oth-

Table 3. Factors Used to Convert Wood Product Units to Amount of Carbon

	Roundwood, industrial roundwood, sawn wood, other industrial roundwood, pulpwood, chips, particles, wood fuel, wood residue		Charcoal	Average for wood panels	Paper and paperboard, pulp, recovered fiber pulp, recovered paper
	Temperate species	Tropical species			
1. Density (oven dry t/m^3 of solid wood product or oven dry ton per air dry ton of pulp or paper product)	0.45 oven-dry t/m^3	0.59 oven-dry t/m^3	0.9 oven-dry t/air dry t	0.628 oven-dry t/m^3	0.9 oven-dry t/air dry t
2. Carbon fraction (tons of carbon per oven dry ton of wood material)	0.5	0.5	0.85	0.468	0.5
3. Carbon factor (t/m^3 of product or ton per airdry ton of product) (row 1) × (row 2)	A = 0.225 t/m^3		A = 0.295 t/m^3	B = 0.765 t/air dry t	C = 0.294 t/air dry t

Table 4. Process for Calculating the Amount of CO_2 in Wood

Total amount of wood in hanoks	Annual hanok total area (m^2) × amount of wood in hanok unit (m^3/m^2)
	↓
Carbon stock in hanok	Wood density (0.5 oven-dry t/m^3) × carbon fraction (0.5 t/oven-dryt)
	↓
CO_2 stock in hanok	Carbon stock in hanok × 44/12
	↓
ex) 2016 carbon stocks in hanoks	36,129,000 (m^2) × 0.58 (m^3/m^2) × 0.5 (t/m^3) × 0.5 f (t/oven-dryt) × 44/12 = 19,208,585 tCO_2

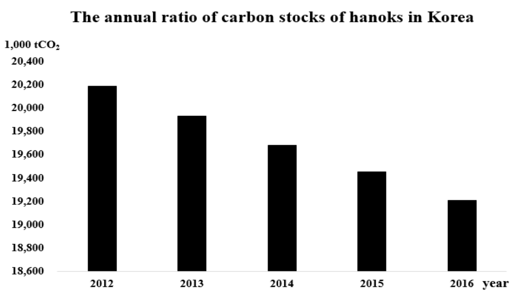


Fig. 5. Annual carbon stocks of hanoks in Korea.

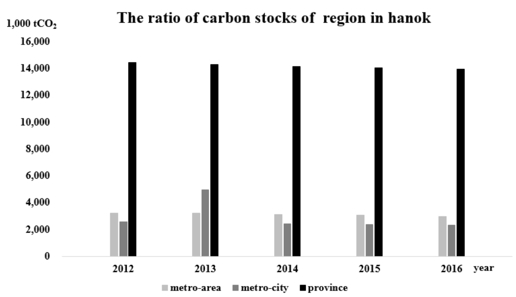


Fig. 6. The ratio of carbon stocks of region in hanok.

er types of construction. Furthermore, the government has predominantly supported apartment-based housing projects since the 1970s. The hanok industry have suffered from a lack of government support. Finally, specialist hanok builders have gradually decreased in number.

Table 5. CO_2 Stocks in Hanoks in Korea (1,000 tCO_2)

Division		2012	2013	2014	2015	2016	Percentage (2016)(%)
Total		20,186	19,934	19,681	19,453	19,209	100
metro area	Sum	3,221	3,186	3,092	3,048	2,983	15.5
	Seoul	1,598	1,551	1,510	1,479	1,440	7.5
	Incheon	304	299	297	294	290	1.5
	Kyungki	1,318	1,297	1,286	1,275	1,253	6.5
metro city	Sum	2,547	2,486	2,431	2,365	2,297	11.9
	Pusan	715	700	684	658	635	3.3
	Daegu	790	766	747	727	705	3.6
	Kwang ju	508	496	482	473	462	2.4
	Dae jeon	174	170	167	165	160	0.8
	Wool san	244	241	239	236	231	1.2
	Se jong	114	112	111	105	104	0.5
Pro vince	Sum	14,418	14,299	14,157	14,040	13,928	72.5
	Kang won	1,065	1,054	1,042	1,034	1,025	5.3
	Chung buk	876	869	859	850	841	4.3
	Chung nam	1,302	1,296	1,284	1,276	1,267	6.6
	Jeon buk	1,673	1,648	1,631	1,616	1,600	8.3
	Jeon nam	3,568	3,553	3,520	3,502	3,476	18.1
	Kyung buk	3,209	3,177	3,143	3,112	3,084	16.0
	Kyung nam	2,668	2,647	2,620	2,592	2,573	13.4
	Jeju	54	54	55	57	58	0.3

According to the 2016 World Environment Performance Index Report (yale university, 2016), Korea ranked the lowest in the world in terms of carbon dioxide emission reductions (CO_2/kWh). This is because of rapid economic and industrial growth since the 1970s, which has contributed to the extensive use of coal-based fuels and GHG emissions in the country. As a result, Korea's GHG emissions amounted to 690 million tCO_2 in 2014. Please note that since GHS inventory report in 2016 were available until 2014, we were compared the data in 2014. Table 5 shows that the total amount of carbon stock in hanoks in 2014 was 19.7 million tCO_2, which accounts for 2.8% of the annual CO_2 emissions. This also represents 46% of the amount of CO_2 absorbed by forests (landuse, landusechange, and forestry, or LULUCF; Table 6), indicating that hanok wood CO_2 stocks play an important role in reducing GHG emissions. Fig. 7 compares the carbon stocks of hanoks with those of other house types. Hanoks store 4 times more carbon than other light frame wood construction, and 15 times more than concrete-reinforced houses and steel-framed houses.

4. Conclusion

Wood is a carbon-neutral material that stores carbon for many years. It can also replace fossil fuels as an energy source. Although Korea has traditionally used hanok houses, the demand for

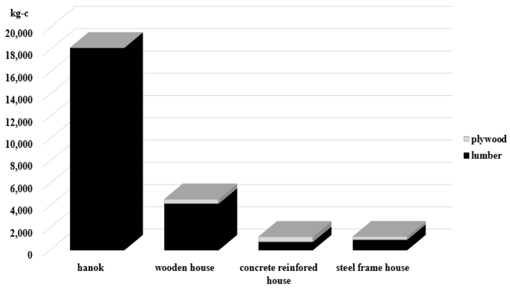
Table 6. Greenhouse Gas Emissions by Sector in Korea (Million tCO_2)

Sector	1990	2000	2010	2012	2013	2014
Energy	241.4	410.4	565.2	597.7	606.7	599.3
Industry	19.7	49.6	54.0	51.7	52.0	54.6
Agriculture	21.6	21.8	22.4	21.9	21.9	21.3
LULUCF	- 34.1	- 58.8	- 54.3	- 44.7	- 42.8	- 42.5
Waste	10.4	18.9	15.1	15.8	16.0	15.4
Total emissions (except for LULUCF)	293.1	500.6	656.6	687.1	696.6	690.6
Total emissions (including LULUCF	259.0	441.8	602.3	642.4	653.8	648.1

Source : Greenhouse Gas Inventory Center : National Greenhouse Gas Inventory Reoprt, 2016.

hanoks has gradually decreased since the 1970s, as concrete buildings have been built to cater to the high housing demand caused by urbanization. However, people have recently begun to live in hanoks again, primarily for health concerns. According to The General Assembly conference COP 17, the stock change approach is to be used for domestic wood products only. Therefore, the Korean Forest Service is trying to raise the rate of domestic wood self-sufficiency in multiple ways. In this study, we estimated the amount of carbon used in Korean hanoks and its contribution to reduce greenhouse gas emissions, assuming, that only domestic wood is used in building hanoks.

Our results show that the number of hanoks in Korea was 547,085 in 2016. Carbon stocks for wood use were estimated at 19.7 million tCO_2 (2014), accounting for approximately 2.8% of the total annual greenhouse gas emissions that year (650 million tCO_2), and approximately 46% of carbon absorption by forests (LULUCF). Thus, the use of wood in hanok buildings account for a small percentage of the reduction in greenhouse gas emissions. Furthermore, hanoks store four times more carbon than light frame wood houses and 15 times more carbon than concrete-reinforced and steel-framed houses.



Source : National Institute of Forest Science (2012).

Fig. 7. Carbon stock by house type (per 125 m^2).

However, the number of hanok residents has decreased steadily from 2012 to 2016, the reasons being higher construction costs for hanoks than other buildings, a lack of infrastructural support from the government, and fewer hanok building experts. Therefore, it is important to research ways to reactivate the hanok industry in Korea.

Our results show that wood use in the hanok industry has contributed to a reduction of GHG emissions. However, this is based, on the assumption, that only domestic wood was used to build hanoks. In fact, the domestic wood self-sufficiency rate in 2016 was only 16.2% (Forest Supply and Demand Plan 2016). Therefore, most of the carbon stocks in hanoks involved imported timber, which accounts for approximately 80% of the domestic timber market. Thus, it is vital to harvest domestic timber and use it as a material for hanok construction to increase carbon storage.

In conclusion, to expand the hanok industry in Korea, it is important to conduct research on methods of reducing construction costs for hanoks compared with other housing types, improvement of technical wood using, and the government should also train and appoint more people with expertise in building hanoks as well as the legal and institutional arrangements related the hanok industry

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