

A New Apartment Construction Technology with effective CO₂ Emission Reduction Capabilities

***Won-Kee Hong¹, Jin-Min Kim², Seon-Chee Park², Seung-Geun Lee³,
Seung-Il Kim³, Hee-Cheul Kim⁴, Ki-Joon Yoon³, and Ho-Chan Lee²**

¹Associate Professor, P.E., Ph.D., Department of Architecture and Civil Engineering, KyungHee University, Yongin, 449-701, Korea,
hongwk@khu.ac.kr

²Ph.D. Candidate, Department of Architecture and Civil Engineering, KyungHee University, Yongin, 449-701, Korea, kimjm@khu.ac.kr,
pscgogo@khu.ac.kr, lhc@mcs-tech.co.kr

³Master's Student, Department of Architecture and Civil Engineering, KyungHee University, Yongin, 449-701, Korea, lsg08@khu.ac.kr,
seungilkim@khu.ac.kr, ynb101@hanmail.net

⁴Professor, Ph.D., Department of Architecture and Civil Engineering, KyungHee University, Yongin, 449-701, Korea, kimhc@khu.ac.kr

ABSTRACT: As global warming persists under the influence of greenhouse gas, many nations are actively studying alternatives to reduce the emission of the most significant greenhouse gas - CO₂. The U.S. plans to reduce CO₂ emission by 20% between 2008 and 2018. The EU is developing technologies to ensure a 20% reduction in CO₂ emission by 2020 as well. As a developing nation, Korea is exempt from the obligation to reduce CO₂ emission during the first commitment period of the Kyoto Protocol, from 2008 to 2012. However, this obligation will also become applicable to Korea in 2013. This research has been prompted by the understanding that the construction industry accounts for over 30% of the total industrial CO₂ emission in Korea and, thus, the construction industry's efforts to cut CO₂ emission will contribute significantly to the nationwide drive to reduce CO₂ emission.

This study is intended to estimate the CO₂ emission of bearing wall apartment housing, which accounts for more than 50% of all housing in Korea, and propose a new type of apartment that can deliver advantages not only in terms of construction cost and schedule but also in terms of CO₂ emission.

Keywords: Composite beam, Pre-cast concrete, CO₂, Apartments, Remodeling

1. INTRODUCTION

1.1 Responses and Reduction Strategies from the Global Community

2008 marks the beginning of the first commitment period (2008~2012) of the Kyoto Protocol that entered into force in February, 2005. 39 countries, including 26 industrialized countries such as the U.K., Japan, and Germany, are obligated by the Protocol to reduce greenhouse gas emission by 5% in comparison with 1995 levels. CO₂ is the primary greenhouse gas, accounting for 88.6% of the total greenhouse gas emission and 55% of the global warming phenomenon. The reduction of CO₂ emission is now vital for the protection of the environment, for our survival, and for the safeguarding our national interest. According to statistics released by the Korean Energy Economics Institute (KEEI), CO₂ emission in Korea totaled approximately 523.6 million tons in 2005 alone, ranking Korea 6th among OECD members and 9th in the world. In addition, Korea's CO₂ emission growth rate between 1990 and 2005 is ranked 2nd at 98.7%, exposing Korea to potentially stronger pressure from the global community for a reduction in CO₂ emission. However, Korea has yet to define any mid or long-term reduction target.

This research is intended to propose new construction approach for a reduction in the amount of concrete and re-bar use, as

well as an increase in the use of prefabrication, as a way to drastically cut the CO₂ emission of the construction industry. A migration to the Rahmen structure, which is more efficient than conventional construction methods, in combination with the removal of CO₂ emission during fabrication would greatly reduce the CO₂ emission coming from construction sites.

1.2 CO₂ Emission Reduction Strategy for Apartment Housing in Korea

In order to effectively reduce CO₂ emission attributable to the construction industry, notably, the construction of apartment housing in Korea, primary causes of CO₂ emission from each construction process and material need to be analyzed.^[1]

An analysis of CO₂ emission sources in bearing-wall type apartments revealed that materials used in large quantities resulted in high CO₂ emission volumes.^[2] Therefore, focus was placed on suggesting methods to address the sources of the CO₂.

This research is intended to present an approach to reduce the CO₂ emission at a construction site as much as possible by employing MHS construction technology.^{[3][4]}

2. ANALYSIS OF CO₂ EMISSION VOLUME BY PRIMARY SOURCE

Table 1 contains statistics regarding the CO₂ emission by component from “An Assessment of the Energy Consumption & CO₂ Emission during the Construction Stage of Apartments (2005)” written by “Kim, JY”. The data presented is for CO₂ emission volume by component in the architectural stage of bearing-wall type apartment construction. Cement, ready-mix concrete, concrete products and re-bar account for approximately 60% of total CO₂ emission.

The top 20 materials in Table 1 account for 89% (5122.3t-CO₂) of the total CO₂ emission of a conventional bearing-wall type apartment.

Table 1: CO₂ emission by component for a conventional bearing-wall type apartment. (Bd. 103 reference gross coverage: 8685.4 m²)^[5]

Architectural Components	Total CO ₂ Emission (t-CO ₂)	CO ₂ Emission Original Unit (kg-CO ₂ /m ²)	Ratio (%)
High strength re-bar	1834.7	211.2	31.86
Ready-mix concrete	1130.7	130.2	19.64
Gypsum board	373.7	43	6.49
PHC pile	304.4	35.1	5.29
Cement	289.5	33.3	5.03
Gang form	193	22.2	3.35
Tile	145.4	16.7	2.53
PP glass door	125	14.4	2.17
Glass	112.8	13.0	1.96
Panel	97.9	11.3	1.7
ALC	68	7.8	1.18
Concrete products	66.6	7.7	1.16
Foothold	62.5	7.2	1.09
Steel section	53	6.1	0.92
WD+WD	53	6.1	0.92
Room carpet	51.6	5.9	0.9
Powder-coated railing	46.2	5.3	0.8
White cement	40.8	4.7	0.71
Entrance door	38.1	4.4	0.66
Balcony cage	35.3	4.1	0.61
Total for Key Materials	5122.3	589.8	89
Total for All Materials	5755.4	662.7	100

CO₂ emission occurs in the cement manufacturing process because a lot of fossil fuel combustion is required to

maintain the firing temperature (800~1450 °C) and the decarbonation of limestone at 800 °C.

Cement, a major raw material for concrete, was classified as one of the major CO₂ emission sources in the world in the '90s. The impact of cement use on the total CO₂ emission in the 2000s is expected to increase, as the use of cement has increased. In a conventional bearing-wall type apartment, space is partitioned using a one-piece concrete wall. However, in a MHS-built apartment, a detachable lightweight partitioning wall is used. As a result, CO₂ emission attributable to the lightweight partitioning wall must be compared to that of the concrete wall.

Additional analysis of the CO₂ emission of the lightweight partitioning wall as compared to the concrete wall is provided below.

3. THE BEARING-WALL TYPE APARTMENT: CO₂ EMISSION SOURCES AND IMPROVEMENTS

Since the bearing-wall type of apartment uses the bearing walls to support vertical load, it is bound to use a large amount of concrete and re-bar. The resulting amount of concrete used per unit area leads to massive CO₂ emission.

A switchover to pre-cast concrete and the adoption of a new apartment structure that allows for minimal use concrete is deemed essential for a significant reduction in construction site CO₂ emission.

The solution to this problem is to stay away from the conventional bearing-wall apartment design that is remodeling-incompatible, and to move toward the Rahmen structure that is not only remodeling-compatible but also uses pre-cast composite structures that can reduce the use of concrete. The Rahmen structure has not been popular at construction sites, as it costs more and is hindered by a height limitation. However, the MHS presented herein is advantageous in that it reduces the use of concrete by employing composites, and it can also maintain the same height as the conventional bearing-wall apartment. This building system provides a key to resolving current issues by minimizing construction waste and extending the service life of the building.

4. CO₂ EMISSION COMPARISON OF BEARING-WALL AND MHS APARTMENTS

Building 103 of Apartment Complex K, Yongin City, has been selected as the specimen for this study. Table 2 provides a description of the apartment. The building is 15 stories tall, and the total building area is 608.9 m² with a total gross coverage of 8,685.4 m². The base floor plan of the building is provided in Figure 1 below.

Table 2: Description of Apartment Complex K, Yongin.

Items	Description
Project name	Apartment K Construction Project, Yongin
Gross coverage	Above ground 42,177.4 m ²
	Basement 16,606.7 m ²
	Total 58,784.1 m ²
No. of stories	1 basement floor, 15 above ground floors (max. height:47m)
Structure	Reinforced concrete wall structure

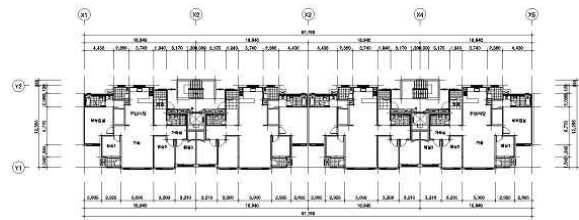


Figure 1: Base floor plan of the bearing-wall type apartment. (Bd. 103)

4.1 CO₂ Emissions of the Bearing-Wall Apartment

Figure 2 shows a plot of the aggregate CO₂ emission volume and the cumulative ratio for the 20 materials listed in Table 1. These 20 materials account for about 90% of the CO₂ emission in the bearing-wall type of apartment described in Table 2.

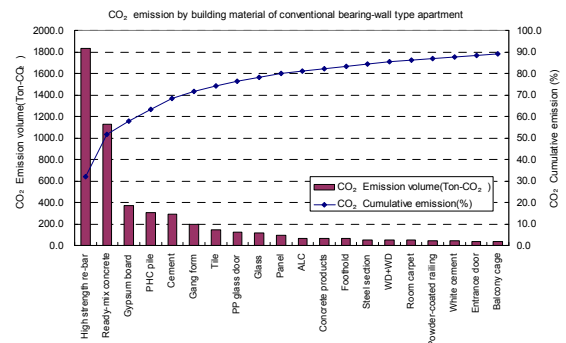


Figure 2: CO₂ emission by building material for a conventional bearing-wall type of apartment.

4.2 Principles of MHS Apartment and CO₂ Emission

The MHS composite beam allows for a smaller beam depth than a reinforced concrete beam, and it takes advantage of the combination of the steel frame and concrete. The combination properties enable a significant reduction in the amount of steel and concrete used in comparison with casing using a steel frame

only. Figure 3 shows the components of an MHS apartment developed to combine the MHS composite beam with a column of an optimum shape in order to optimize the construction cost and schedule. The column systems used in an MHS apartment include the steel column, the SRC column, and the RC column as well as the MHS column reinforced with a steel frame between PC (Pre-cast Concrete) joints. Depending on the shape of the composite beam used in combination with the column system, 27 modularized systems are available. If all the spans or partial spans of PC concrete are considered, the number of available modules increases to 54 $[(3 \times 9) \times 2]$ in total. As shown in Figure 4, the beam and column are connected in the same manner as the conventional steel frame.

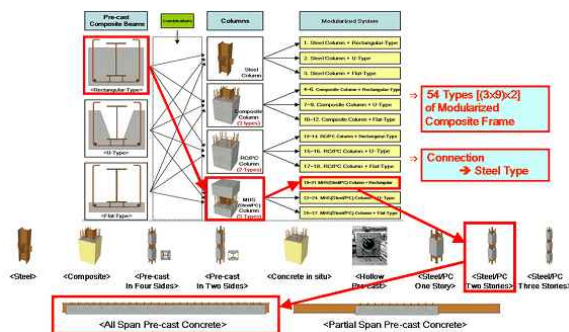


Figure 3: Module components of an MHS apartment.

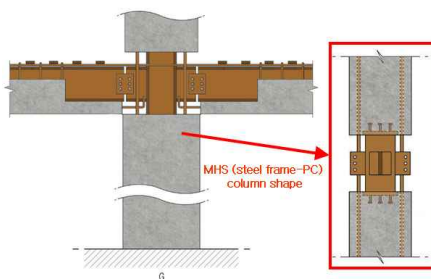


Figure 4: Beam-column connection.

Figure 5 is a base floor plan incorporating 3 composite MHS columns into a conventional bearing-wall type of apartment.

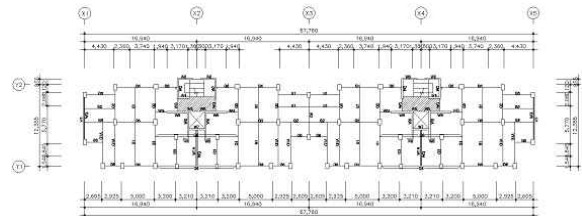


Figure 5: Base floor plan incorporating a 3 column MHS into a conventional bearing-wall type of apartment.

Figure 6 shows unit floor plans for both bearing-wall and MHS apartments. Figure 6(a) shows an individual unit of a bearing-wall type apartment. Since the bearing-wall apartment floor is partitioned by walls during the design stage, changing the floor plan or remodeling is severely constrained. In addition, excessive remodeling poses several issues relating to structural integrity. Figures 6(b)-(d) show individual units of an MHS apartment utilizing the 3 column module.

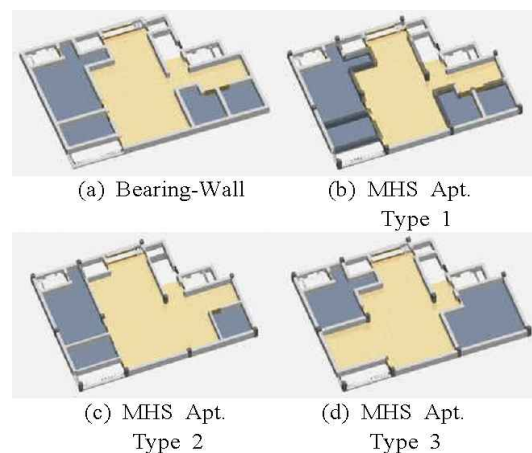


Figure 6: Unit floor plans of a bearing-wall apartment & MHS apartments.

Table 3 shows a comparison of concrete-related CO₂ emission between a bearing-wall and an MHS apartment. The CO₂ emission values in Table 1 were used for the comparison. These results show that the CO₂ emission attributable to the concrete used in the conventional bearing-wall apartment accounts for 19.6% of the total CO₂ emission from the apartment, while the CO₂ emission percentage in a 3 column MHS apartment is reduced to 12.7%.

Table 3: CO₂ emission per use of concrete & concrete product. (in reference to Bd. 103)

Item	Bearing Wall	MHS 3 Column
Total concrete use (m ³)	6,742	3,916
Total concrete product (m ³)	-	905
Gross coverage (m ²)	8,685.4	8,685.4
Concrete use per unit area (m ³ /m ²)	0.776	0.451
CO ₂ emission from concrete use (kg-CO ₂ /m ²)	130.2	75.6
Total CO ₂ emission from concrete use (kg-CO ₂)	1,130,839.1	656,616.2
Concrete product per unit area (m ³ /m ²)	-	0.104
CO ₂ emission from concrete product (kg-CO ₂ /m ²)	-	8.6
Total CO ₂ emission from concrete product (kg-CO ₂)	-	74,694.4
Total CO ₂ emission (kg-CO ₂)	1,130,839.1	731,310.7
CO ₂ emission ratio (reduction ratio)	19.6%	12.7% (6.9%)

Note: 'CO₂ emission from concrete use' was estimated based on the concrete used in a bearing-wall apartment and the total concrete amount used in each module of an MHS apartment.

Table 4 shows the CO₂ emission levels attributable to the formwork used in bearing-wall and MHS apartment construction. These values are estimated based on the CO₂ emission levels in Table 1. CO₂ emission from the formwork accounts for 3.4% of the total CO₂ emission in a bearing-wall type of apartment. The CO₂ emission percentage

from the formwork used in a 3 column MHS apartment is about 0.7%.

Table 4: CO₂ emission per formwork use. (in reference to Bd. 103)

Item	Bearing Wall	MHS 3 Column
Total formwork use (m ²)	41,834	9,213
Gross coverage (m ²)	8,685.4	8,685.4
Formwork use per unit area (m ² /m ²)	4.817	1.061
CO ₂ emission from formwork use (kg-CO ₂ /m ²)	22.2	4.9
Total CO ₂ emission (kg-CO ₂)	192,815.9	42,558.5
CO ₂ emission ratio (reduction ratio)	3.4%	0.7% (2.7%)

Note: 'CO₂ emission from formwork use' is estimated based on the formwork used in a bearing-wall apartment and the total formwork amount used in each module of an MHS apartment.

Table 5 shows the CO₂ emission attributable to the re-bar used in bearing-wall and MHS apartment construction. These values are estimated based on the CO₂ emission levels shown in Table 1. CO₂ emission from re-bar use accounts for 31.9% of the total CO₂ emission in a bearing-wall type of apartment. The CO₂ emission percentage from re-bar used in a 3 column MHS apartment is about 13.6%.

Table 5: CO₂ emission per re-bar use. (in reference to Bd. 103)

Item	Bearing Wall	MHS 3 Column
Total re-bar use (ton)	730	313
Gross coverage (m ²)	8,685.4	8,685.4
Re-bar use per unit area (ton/m ²)	0.084	0.036
CO ₂ emission from re-bar use (kg-CO ₂ /m ²)	211.2	90.4
Total CO ₂ emission (kg-CO ₂)	1,834,356.5	785,160.2
CO ₂ emission ratio (reduction ratio)	31.9%	13.6% (18.3%)

Note: 'CO₂ emission from re-bar use' is estimated based on re-bar used in a bearing-wall apartment and the total re-bar amount used in each module of an MHS apartment.

Table 6 shows the CO₂ emission from the steel frame used in MHS apartment construction. The steel frame is not used in the bearing-wall apartment. The emission

volume for the steel frame in the 3 column MHS apartment is about 284t-CO₂, a mere 4.9% of the total CO₂ emission of 5755.4t-CO₂ for a bearing-wall apartment (Table 1).

Table 6: CO₂ emission per steel frame use. (in reference to Bd. 103)

Item	Bearing Wall	MHS 3 Column
Total steel frame use (ton)	-	226.2
Gross coverage (m ²)	8,685.4	8,685.4
Steel frame use per unit area (ton/m ²)	-	0.026
CO ₂ emission from steel frame use (kg-CO ₂ /m ²)	-	32.7
Total CO ₂ emission (kg-CO ₂)	-	284,012.6
CO ₂ emission ratio (reduction ratio)	0%	4.90% (-4.9%)

Note: Since the steel frame and the re-bar are made of the same material, 'CO₂ emission from steel frame use' is proportionally estimated for each MHS module based on the amount of re-bar used in a bearing-wall apartment in Table 5.

Table 7 shows the CO₂ emission from gypsum board use in bearing-wall and MHS apartment construction. The CO₂ emission from gypsum board is estimated based on the CO₂ emission per unit gypsum board area in Table 1. While the lightweight partitioning wall gypsum board is not used in the bearing-wall apartment, the CO₂ emission from the interior wall finishing material must be accounted for. As a result, an emission of 289.5t-CO₂ is estimated from the 33.3 kg-CO₂/m² due to cement use.

Table 7: CO₂ emission per gypsum board use. (in reference to Bd. 103)

Item	Bearing Wall	MHS 3 Column
Ceiling finishing gypsum board use (m ²)	8685.4	8685.4
Lightweight partitioning wall gypsum board use (m ²)	-	3666.5
Gross coverage (m ²)	8,685.4	8,685.4
Ceiling finishing gypsum board use per unit area (m ² /m ²)	1	1
CO ₂ emissions from ceiling finishing gypsum board use (kg-CO ₂ /m ²)	43	43
Total CO ₂ emissions from ceiling finishing gypsum board use (kg-CO ₂)	373,482.2	373,482.2

Lightweight partitioning wall gypsum board use per unit area (m ² /m ²)	-	0.422
CO ₂ emissions from lightweight partitioning wall gypsum board use (kg-CO ₂ /m ²)	-	18.2
Total CO ₂ emissions from lightweight partitioning wall gypsum board use (kg-CO ₂)	-	158,074.3
Total CO ₂ emissions (kg-CO ₂)	373,482.2	531,556.5
CO ₂ emissions ratio (reduction ratio)	6.5%	9.2% (-2.7%)

Table 8 shows the combined CO₂ emission from Tables 3 through 7. The CO₂ emission for the 3 column MHS apartments is reduced to about 74.9%, significantly lower than that of the bearing-wall apartment.

Table 8: CO₂ emission comparison among the apartments. (in reference to Bd. 103)

Item	Bearing Wall	MHS 3 Column
Total CO ₂ emissions from concrete use (kg-CO ₂)	1,130,839.1 (130.2)	656,616.2 (75.6)
Total CO ₂ emissions from concrete products (kg-CO ₂)	-	74,694.4 (8.6)
Total CO ₂ emissions from formwork (kg-CO ₂)	192,815.9 (22.2)	42,558.5 (4.9)
Total CO ₂ emissions from re-bar (kg-CO ₂)	1,834,356.5 (211.2)	785,160.2 (90.4)
Total CO ₂ emissions from steel frame (kg-CO ₂)	-	284,012.6 (32.7)
Total CO ₂ emissions from gypsum board (kg-CO ₂)	373,482.2 (43.0)	531,556.5 (61.2)
Total CO ₂ emissions from cement (kg-CO ₂)	289,500.0	-
Total CO ₂ emissions from major materials (kg-CO ₂)	3,820,993.7	2,374,598.4
Total CO ₂ emissions from common materials (kg-CO ₂)	1,934,399.3	1,934,399.3
Total CO ₂ emissions (kg-CO ₂)	5,755,393.0	4,308,997.7
CO ₂ emissions ratio (reduction ratio)	100%	74.9% (25.1%)

Note: Figures in parenthesis refer to the CO₂ emission units per material. (unit=kg-CO₂/m²)

5. CONCLUSION

The aggregate CO₂ emission per unit area of a construction component and material is estimated to be 662.7 kg-CO₂/m². Reinforced concrete equipped with high-strength re-bar and ready-mix concrete account for more than 50% of the

aggregate CO₂ emission units, or 341.4 kg-CO₂/m², which is the highest among the various types of architectural work. Therefore reinforced concrete holds the key to reducing CO₂ emission in apartment construction, and it is implied that reducing the use of concrete has a direct impact on CO₂ emission.

The 3 column MHS module enables an environmental-friendly apartment that can drastically reduce the amount of concrete, as well as formwork and re-bar, used in comparison with the conventional bearing-wall type of apartment. Due to the decreased use of concrete, the MHS apartment lowers CO₂ emission by around 6.9% in comparison with the conventional bearing-wall type of apartment. Savings in formwork and re-bar reduce CO₂ emission by 2.7% and 18.3%, respectively.

During the construction phase, re-bar, ready-mix concrete, cement, gypsum board, glass, etc. have a significant impact on the CO₂ emission attributable to materials. Reinforced concrete also contributes significantly to CO₂ emission. It was also proven that a decrease in re-bar use via a drying technique in steel frame construction is highly effective in reducing CO₂ emission.

In addition, the MHS apartment offers more freedom in space partitioning, providing ease of removal, remodeling, and reconstruction. This modularity contributes more to the reduction in CO₂ emission and stands a better chance of being classified as sustainable long-lasting apartment housing.

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