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Current Functionality and Recommendations for Hanok to Achieve Carbon Neutrality: Focusing on Greenhouse Gas Emission Reduction and Absorption Strategies

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Achieving carbon neutrality requires policies that simultaneously reduce greenhouse gas emissions and expand carbon sinks, and Hanok (traditional Korean houses) are no exception.
Historically, Hanok have been viewed as buildings with low airtightness, leading to high heating costs and significant greenhouse gas emissions. However, advancements in R&D for Hanok have enabled these traditional structures to achieve higher airtightness levels, reducing emissions such that they are below the levels of standard buildings.
Furthermore, Hanoks excel in carbon storage, acting as effective carbon sinks. Research based on the Hanok classroom at Seoul Jeongsu Elementary School revealed that approximately 92 tons of carbon are stored in this structure, equivalent to the carbon absorption capacity of a forest spanning 59 soccer fields.

Climate change and global warming are causing various global issues, such as natural disasters and infectious disease outbreaks. In South Korea, the Framework Act on Low Carbon, Green Growth was enacted in 2010 to help achieve greenhouse gas reduction targets through systems such as emissions trading. Following the 2015 Paris Agreement, the Korean government announced its goal to achieve carbon neutrality by 2050. To align with this commitment, the existing Act was repealed in 2021 and replaced with the Framework Act on Carbon Neutrality and Green Growth for Coping with the Climate Crisis (hereafter referred to as the Carbon Neutrality Act).

After 2010, a national policy to promote Hanok construction was also launched, aiming to enhance the competitiveness of Hanok structures in the construction market through “R&D for New Hanok Technologies.” This initiative focused on improving the environmental performance of Hanoks, especially their airtightness and insulation, to reduce greenhouse gas emissions, and to improve living environments. Public Hanoks have been constructed to demonstrate these new technologies developed through R&D.

As Hanok primarily utilize wooden materials structures, they can reduce the reliance on steel and cement—materials commonly used in reinforced-concrete buildings and known for high carbon emissions during their manufacturing stages. Moreover, as the wood industry is optimized for consumption and supply, Hanok construction can contribute across various sectors of carbon neutrality policies. However, there is a lack of foundational data on emission reductions and carbon storage specific to Hanok, leading to a shortage of relevant policies and project proposals. In response, AURI’s National Hanok Center has been exploring ways for Hanok to contribute to carbon neutrality policies since 2022. Collaborating with specialized agencies, the Center has investigated greenhouse gas emission reduction and carbon storage capacities in relation to Hanok as promulgated through R&D demonstration projects.

This report aims to outline the concepts of “greenhouse gas emission reduction” and “greenhouse gas absorption” as defined in the Carbon Neutrality Act, to review the current functions and achievements of Hanok in these areas, and to suggest directions for future policy improvements.

● Current Systems and Policies for Achieving Carbon Neutrality

- Framework Legislation and Greenhouse Gas Reduction Policies for Achieving Carbon Neutrality

The highest level of legislation related to achieving carbon neutrality is the Carbon Neutrality Act. In this Act, carbon neutrality is defined as a state in which the net emissions of greenhouse gases (GHG) are zero, achieved by offsetting emissions with equivalent GHG absorption.[1] In other words, achieving carbon neutrality requires, first, reducing GHG emissions and, second, expanding GHG absorption and storage. Together, these two actions are collectively referred to as "GHG reduction".[2]

The associated policies are called "GHG Reduction Policies" and are outlined in Articles 23 to 36 of the Act. Of these, policies relevant to reducing GHG emissions from Hanok and other buildings are found in Article 31 (Expansion of Green Buildings), while policies related to expanding carbon sinks are detailed in Article 33 (Expansion of Carbon Sinks).

- Systems and Policies Related to Greenhouse Gas Emission Reduction

The Carbon Neutrality Act includes sector-specific policies and related subordinate regulations to reduce GHG emissions, including the Green Buildings Construction Support Act (hereafter referred to as the Green Building Act), related to Article 31 (Expansion of Green Buildings) of the Act. Based on Article 6 (Formulation of Master Plans for Green Buildings) of the Green Building Act, the "Second Master Plan for Green Buildings (2020-2024)" was formulated. The primary focus of this plan is the "Mandatory Implementation of Zero Energy Buildings in the Public Sector," set as its first priority. As part of the strategy to promote and spread zero-energy buildings, public buildings with a total floor area of 1,000 ㎡ or more were mandated to meet zero-energy standards starting in 2020, with the goal of extending this requirement to all buildings over 500 ㎡ by 2030. In line with the task to strengthen energy performance standards for small residential buildings, there is an increasing need to enhance the energy efficiency of Hanoks, which would require updates to systems such as the "Hanok Standards" to incorporate zero-energy building technologies, including renewable energy as well as passive and active energy systems.

- **Systems and Policies Related to Expanding Greenhouse Gas Sinks**

The Carbon Neutrality Act defines “GHG absorption” in Article 2 (Definitions) as the process by which greenhouse gases are removed from the atmosphere through activities related to land use, land use changes, and forestry. In addition, based on Article 8, the government is required to set medium- and long-term targets for GHG reduction, with GHG absorption as the first key target. Policies related to the expansion of carbon sinks are detailed in Article 33 (Expansion of Carbon Sinks) of the Act.

One of the key subordinate regulations covering this area is the Act on the Management and Improvement of Carbon Sinks, which focuses on domestic policies primarily targeting forestry. Although these policies include promoting the use of wood products in construction, they remain focused primarily on the forestry sector, leading to limited policy applications directly associated with construction.

> **Act on the Management and Improvement of Carbon Sinks**
>
> Article 1 (Purpose) The purpose of this Act is to respond to climate change by managing and improving the role of forests as carbon sinks pursuant to Article 33 of the Framework Act on Carbon Neutrality and Green Growth for Coping with Climate Crisis and to contribute to the realization of a low-carbon society.
>
> Article 2 (Definitions) The terms used in this Act are defined as follows: Provided, that definitions specified by the United Nations to respond to climate change shall apply, if no specific citation is made.
>
> 10. The term "carbon sink" means standing trees, bamboo, dead organic matter, soil, harvested wood products, or forest biomass energy in which carbon is absorbed and stored.

● Status of Efforts to Enhance Airtightness in Hanok to Reduce Greenhouse Gas Emissions

- **Need for Performance Improvements for Hanok**

A study conducted in 2010 by the Ministry of Land, Infrastructure, and Transport and the Korea Institute of Civil Engineering and Building Technology, titled "Environmental Assessment of Hanok," revealed that greenhouse gas (GHG) emissions throughout the lifecycle of traditional Hanok (4.2 tCO_2e/m^2) amount to nearly twice the emissions of typical reinforced-concrete housing (2.6 tCO_2e/m^2) per unit area. This study showed that 89.54% of the GHG emissions during the Hanok lifecycle come from the usage and maintenance phases of the building (Korea Institute of Civil Engineering and Building Technology, 2010, p. 341). However, total GHG emissions during the material production and construction stages were lower for Hanok compared to the control group.

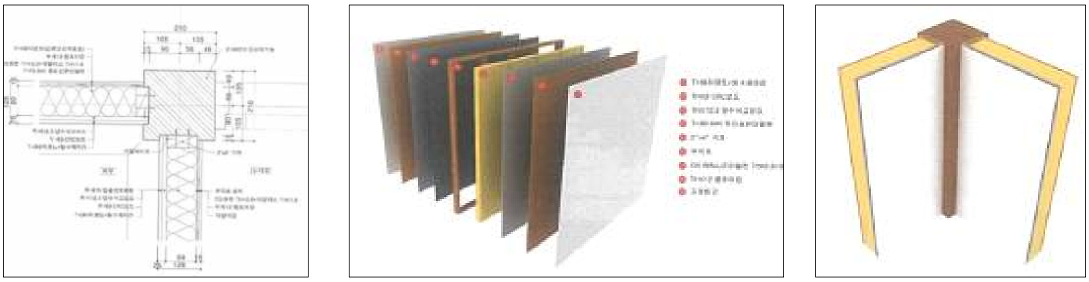
Therefore, to align Hanok with carbon neutrality policies and green building initiatives, it became essential to improve the performance capabilities of these buildings in terms of energy usage and GHG emissions reductions during their operational and maintenance phases.

- Development of Technologies to Improve Airtightness in Hanok

To reduce energy usage and GHG emissions during the operational and maintenance phases, improving airtightness and insulation is crucial. Traditional Hanok structures are particularly vulnerable in terms of airtightness due to their unique construction style. They use a post-and-beam wooden frame system where over time, the wood dries and shrinks, creating gaps between the structural members that compromise airtightness. This lack of airtightness is why winter drafts are often felt indoors in traditional Hanok.

Following the findings from the 2010 environmental assessment, the Hanok New Technology Development R&D project was launched to develop construction technologies that enhance airtightness. The key construction techniques developed include improvements in wall and roof connections to reduce air leaks.

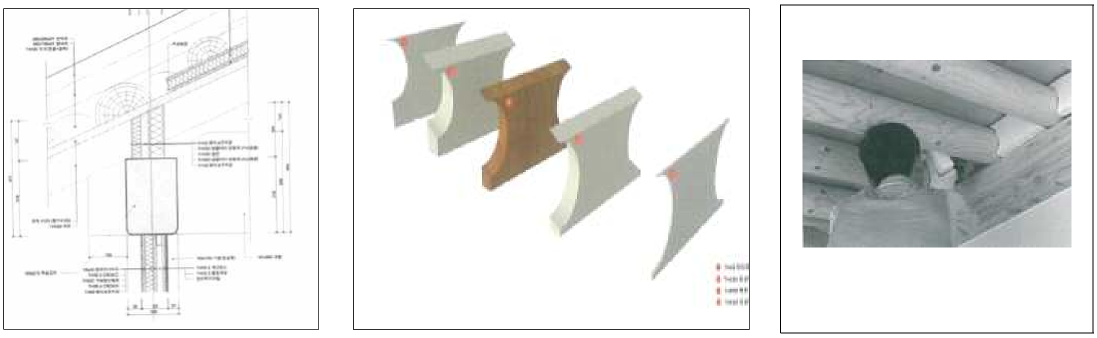
The Hanok Technology Development Research Group summarized these improvements as follows. For walls, grooves are cut into the columns where they connect to the walls to secure them firmly, with airtight tape added as a type of reinforcement. Afterward, silicone is applied between the wall and column as a final step to enhance airtightness (Hanok Technology Development Research Group, 2022, p. 163).



New Hanok Construction Technology – Wall Connections

Source: Hanok Technology Development Research Group (2022, p. 165)

For the roof, researchers have focused on the Dangol membrane, a term referring to the structural members between rafters in a Hanok. Traditional Hanoks typically use circular rafters with earth or lime plaster finishes, which are prone to defects. The team proposed a dry construction method using expanded polystyrene (EPS) to improve airtightness between rafters (Hanok Technology Development Research Group, 2022, p. 184).



New Hanok Construction Technology – Dangol Membrane

Source: Hanok Technology Development Research Group (2022, p. 165)

- Airtightness Testing of Hanok

In 2022, the National Hanok Center conducted an airtightness comparison experiment between traditional Hanok and new Hanok types equipped with technologies developed via Hanok New Technology Development R&D. The testing site selected was the Cheoinseong Education Center, the latest of ten demonstration Hanok structures constructed using R&D technologies. SOUL TECTURE, a specialized agency, measured the airtightness of a multi-purpose room on the second floor of the Cheoinseong Education Center. Data from traditional Hanok structures were referenced from existing studies for comparison.

Overview of the Airtightness Measurement Site

<table>
<tr><td rowspan="3">
View of the experimental site</td><td rowspan="3">
Interior of the Multipurpose Room on the second floor of the experimental space</td><td>Building name</td><td>Cheoinseong Education Center</td></tr>
<tr><td>Location</td><td>673, Cheoinseong-ro, Namsa-eup, Cheoin-gu, Yongin-si, Gyeonggi-do</td></tr>
<tr><td>Usage</td><td>Educational research Facility</td></tr>
<tr><td rowspan="3">
First floor</td><td rowspan="3">
Second floor, Multipurpose Room Location</td><td>Size</td><td>One basement floor, two above-ground floors</td></tr>
<tr><td>Total floor area</td><td>999.64 km^2</td></tr>
<tr><td>Structure</td><td>First floor: Wooden structure, reinforced-concrete structure
Second floor: Wooden structure</td></tr>
</table>

The airtightness test followed the ISO 9972:2015 standard, utilizing the blower door test method, which measures the air changes per hour at a 50 Pa pressure difference (ACH50). The Korean Institute of Architectural Sustainable Environment and Building Systems recommends ACH50 values of 5.0 or lower for general buildings, 3.0 or lower for energy-saving buildings, and 1.5 or lower for zero-energy buildings.[3)]

A case study of traditional Hanok airtightness measurements can be found in research by the Chonnam National University R&BD Foundation (2017, p. 133). Among 14 traditional Hanoks, the best ACH50 value was 25, while the worst was 217.

Measured Airtightness of Traditional Hanok

Classification	ACH50	Classification	ACH50
Hanok-1	86	Hanok-8	67
Hanok-2	72	Hanok-9	177
Hanok-3	60	Hanok-10	199
Hanok-4	106	Hanok-11	217
Hanok-5	91	Hanok-12	30
Hanok-6	98	Hanok-13	37
Hanok-7	73	Hanok-14	25

For comparison with traditional Hanok, a field test was conducted in October of 2022 in the multipurpose room of the Cheoinseong Education Center. The airtightness test showed an ACH50 (air changes per hour at a 50 Pa pressure difference) value of 4.09. Although this falls short of the standard for energy-saving buildings, it is below the general building threshold of 5.0, demonstrating compliance and showing significantly improved airtightness compared to traditional Hanok.

Comparison of Airtightness Measurement Results (2022) and Standards for General and Energy-Saving Buildings

Classification	ACH50	Classification	ACH50	Classification	ACH50
Cheoinseong Education Center Measurement Result	4.09	General Building Airtightness Performance Standard	5.0 or less	Energy-saving Building Airtightness Performance Standard	3.0 or less

Through the comparison of airtightness measurements between new Hanok and traditional Hanok structures, it was confirmed that the new technologies developed by the Hanok New Technology Development R&D project effectively enhance the environmental performance of the latter. This improvement suggests a substantial reduction in greenhouse gas emissions.

● Carbon Storage Capacity of Hanok as a Greenhouse Gas Sink

- Carbon Storage Function of Hanok

Hanoks, as wooden structures, function as a carbon sink due to the carbon-storage capacity of the timber used during their construction. Wood absorbs carbon dioxide (CO_2), releases oxygen (O_2), and stores the remaining carbon (C), thereby acting as a carbon sink (Kim, 2021). In practical terms, harvested wood products retain stored carbon during their usage period, delaying its release back into the atmosphere.

The Intergovernmental Panel on Climate Change (IPCC) recognizes that sawn timber stores carbon for 35 years, plywood and boards for 25 years, and paper products for two years. Given that wooden structures generally use large quantities of sawn timber, which has a longer service life than other products, they offer extended carbon storage benefits.

In addition, wooden structures can be divided into those created by light timber and heavy timber construction methods. Hanok, a heavy timber structure, generates relatively less wood waste during the processing stage for standardized lumber. Due to the substantial volume of the wood used, Hanok offers excellent carbon storage. Its prefabricated structure also allows for the partial reuse of timber components during maintenance or disposal, further extending the carbon storage period compared to typical wooden buildings.

For example, a building that uses approximately 36 ㎥ of timber stores a total of nine tons of carbon, equivalent to the amount of carbon dioxide absorbed by a 400 ㎡ pine forest over 1.5 years (Kim, 2021).

- Method for Calculating Carbon Storage in Hanok[4)]

Given Hanok's role as a carbon reservoir, in 2022 the National Hanok Center partnered with the Korea Forestry Promotion Institute to calculate Hanok's carbon storage as part of the carbon neutrality initiatives. The calculation method for carbon storage in wooden buildings adheres to international standards, with formulas developed by the National Institute of Forest Science.

Currently, international standards classify carbon storage calculations into Tier 1, Tier 2, and Tier 3, with higher tiers providing more detailed specifications for factors such as the wood density and carbon content by tree species. However, Korea's current carbon storage calculation for sawn timber is at the Tier 1 level, applying a single standard for wood density and carbon content across all tree species.

Thus, the carbon storage calculation for Hanok conducted in 2022 used the Tier 1 methodology. This approach involves multiplying the quantity of timber used in Hanok construction by the wood density, carbon content, and a CO_2 conversion factor and then subtracting any GHG emissions generated during the transportation of the materials to arrive at the final carbon storage amount. However, considering that the carbon storage project is still in its initial stages, the calculation currently includes only the carbon stored in the structural components, excluding emissions from transportation.

Method for Calculating Carbon Storage in Wooden Buildings, kgCO2eq

= {Wood usage (m^3) × Basic density of wood × Carbon content × CO2 conversion factor}[5)]

Source: National Institute of Forest Science, Korea Forestry Promotion Institute

- **Calculation and Comparison of Carbon Storage in Hanok**

The selected pilot site for calculating carbon storage in Hanoks was the Jeongsu Elementary School Hanok Classroom in Seoul, a public Hanok developed through the Hanok New Technology Development R&D project. This location was chosen for its educational potential regarding carbon storage. The building consists of a main hall, a sarangchae (guest house), and a corridor. Only the second floor of the main hall, constructed of wood, was included in the calculation, as the first floor is reinforced concrete. The sarangchae and the corridor, which are single-story wood structures, were included in their entirety.

When calculating the carbon storage of the Jeongsu Elementary School Hanok Classroom, a quantity survey owned by the Hanok Technology Development Research Group was utilized. Wood volumes were categorized as either design-based quantities or sawmill-based quantities, with variations arising from the on-site shaping of the wood. To account for losses[6] during the shaping process, the calculation relied on the actual wood volume employed during the Hanok construction process, and advice was sought from the National Institute of Forest Science.

Overview of the Carbon Storage Calculation Sites

<table>
<tr><td rowspan="3"></td><td rowspan="3"></td><td>Building name</td><td>Jeongsu Elementary School Hanok Classroom</td></tr>
<tr><td>Location</td><td>58, Jeongneung-ro 24-gil, Seongbuk-gu, Seoul</td></tr>
<tr><td>Usage</td><td>Educational research facility</td></tr>
<tr><td rowspan="3"></td><td rowspan="3"></td><td>Size</td><td>Two above-ground floors</td></tr>
<tr><td>Total floor area</td><td>316.99 m^2</td></tr>
<tr><td>Structure</td><td>〈Main Hall〉 First floor: Reinforced-concrete structure
Second floor: Wooden structure
〈Sarangchae (guest house)〉
First floor: Wooden structure</td></tr>
</table>

The main hall and corridor were classified as Zone 1, with the sarangchae considered as Zone 2 for calculating carbon storage values. The results showed that the Jeongsu Elementary School Hanok Classroom stores approximately 92 tons of carbon.

Carbon Storage Calculation for the Jeongsu Elementary School Hanok Classroom

Zone 1 (Main Hall and corridor)		Zone 2 (Sarangchae)	
Wood usage (m^3)	Carbon storage (kg/CO_2)	Wood usage (m^3)	Carbon storage (kg/CO_2)
109.2353	90,127	3.3242	2,742
Total carbon storage: 92,870kg/CO_2			

The 92 tons of stored carbon is equivalent to the annual carbon absorption of 16,794 50-year-old pine trees or the annual greenhouse gas emissions from 39 cars.[7] This also corresponds to the carbon absorbed annually by a 0.4 km² forest (roughly 59 soccer fields).[8] Constructing seven public Hanoks similar to the Jeongsu Elementary School Hanok Classroom would store an amount of carbon comparable to that by a 2.9 km² forest (Yeouido Island).

● Potential Contribution of Hanok to Carbon Neutrality Policies and Recommendations

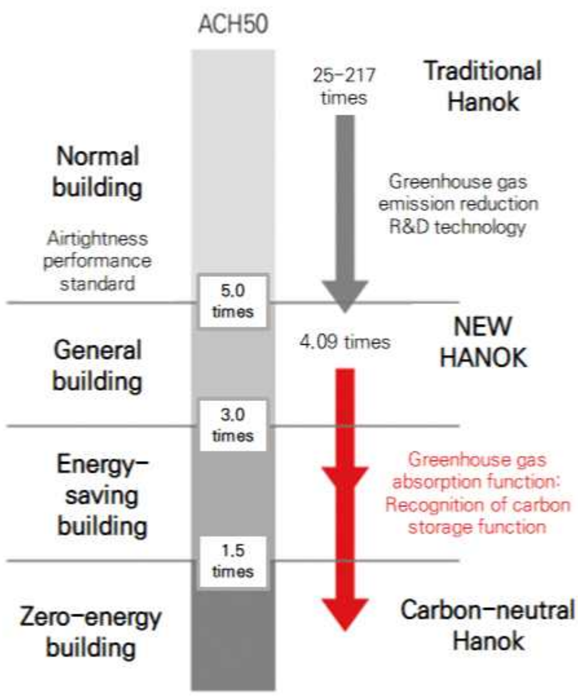
The Carbon Neutrality Act stipulates the need for policies that both reduce greenhouse gas emissions and expand greenhouse gas sinks. In 2018, the construction sector accounted for 16% of South Korea's total greenhouse gas emissions,[9] making it, alongside transportation, a primary target in carbon neutrality strategies, which are regulated by the Green Building Act. However, Hanoks are exempt from submitting energy-saving plans under this act due to their unique architectural characteristics, as stipulated by Article 26 of the Act on the Value Enhancement of Hanok and Other Architectural Assets. Early studies of traditional Hanok, which became the basis for Hanok policies starting in 2010, showed very low environmental performance in terms of energy efficiency.

Since then, the Hanok New Technology Development R&D Project has developed various technologies to improve the environmental performance of Hanok. For example, an airtightness test conducted by the National Hanok Center on public Hanoks developed through this R&D project in 2022 recorded an ACH50 of 4.09, which, while compliant, still falls short of the levels required for energy-saving buildings (3.0) and zero-energy buildings (1.5). This is largely due to the multi-component structures and exposed ceilings typical of the timber frame of Hanok structures, in contrast with the monolithic exterior shells of other buildings.

One way to address Hanok's limitations in reducing greenhouse gas emissions is to recognize the "carbon storage function" of these structures as a greenhouse gas sink, as defined in the Carbon Neutrality Act. The Jeongsu Elementary School Hanok Classroom stores 92 tons of carbon, equivalent to the annual absorption capacity of a forest covering 59 soccer fields.

However, the current focus of carbon neutrality policies and green building regulations (e.g., the Green Building Act) remains largely on reducing energy use in buildings (Ministry of Land, Infrastructure, and Transport, 2020, p. 18). Although Hanoks now achieve reduced greenhouse gas emissions and act as a carbon sink, existing green building standards—such as the Energy-Saving Design Standards for Buildings and the Zero Energy Building Certification System—primarily emphasize energy efficiency and renewable energy use, overlooking Hanok's carbon storage capacity. For Hanok to be acknowledged as energy-saving or zero-energy buildings, it will be necessary to develop supplementary technologies and revise certification criteria to evaluate and credit their carbon storage capacity.

Method for Recognizing Carbon-neutral Hanok



Promoting the construction of mid- to heavy-timber structures such as Hanok with high carbon storage capacity levels could be an effective strategy for expanding greenhouse gas sinks in keeping with carbon neutrality efforts. Amending future green building standards to recognize Hanok's carbon storage function would not only contribute to national carbon neutrality policies but would also encourage the revitalization of Hanok construction.

1) Article 2, subparagraph 3 of the Carbon Neutrality Act [Effective Jan. 1, 2024].
2) Article 2, subparagraph 7 of the Carbon Neutrality Act [Effective Jan. 1, 2024].
3) Korean Institute of Architectural Sustainable Environment and Building Systems, Standards for Building Airtightness (KIAEBS C-1:2013).
4) Prepared with reference to internal data from the Korea Forestry Promotion Institute.
5) Wood Usage: Amount of wood used in the target building; basic density of wood: wood density as per IPCC 2013 by item (uniformly applied at 450 kg/m³); carbon content: applied uniformly at 0.5 for the carbon content rate of air-dried wood, CO2 conversion factor: factor for converting carbon to CO_2 (applied as 44/12).
6) Wood loss refers to the rate of loss that occurs during wood processing to make wood usable.
7) According to data from the Korea Forestry Promotion Institute and the National Institute of Forest Science, the annual CO_2 absorption of a 50-year-old pine tree is 5.53 kg CO_2, while the average annual greenhouse gas emissions for one passenger car is 2.4 tons of CO_2.
8) One soccer field measures 7,140㎡, and spacing pine trees at 5m x 5m results in a forest area of 419,850㎡, equivalent to approximately 59 soccer fields, occupied by 16,794 pine trees.
9) The Second Master Plan for Green Buildings (2018) indicates domestic energy consumption by sector as follows: Industry (61.7%), Transport (17%), Building Sector: Residential & Commercial (16%), and Public (3%).

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