NIPPON STEEL TECHNICAL REPORT No. 97 JANUARY 2008

UDC 691 . 714

Development of “Nittetsu-Super-Frame®” System and Expanding Its Market—Challenge to Enlarge the Possibility of Light-Gauge Steel-Framed Houses in the Low-Rise Building Market—

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Abstract

On Nov. 15th, 2000, light-gauge steel framed houses were legislated under a Building Standard Law in Japan as a new structural system. This system is used for light-gauge steel sections that are galvanized and a thickness of 1mm on average. The structural frame has a high potential for application to low-rise buildings. Initially, this paper introduces the history of development for steel framed houses, tackled by major steel companies in Japan on the domain of housing. Secondly, it describes the development situation of “Nittetsu-Super-Frame” as our original system that was aimed to enlarge the market and enabled construction of three stories houses having a one hour fire resistance performance, in addition to efforts for securing several types of performance, for example, sound reduction and thermal environment. In addition, advantages on global warming of “Nittetsu-Super-Frame” are also discussed.

1. Introduction

The steel frame construction method differs from the wood frame construction method in that it uses cold-formed galvanized shaped steel about 1.0 mm in thickness (**Photo 1**) in place of two-by-four wooden frame members. This method has already been put into practical use in more than ten countries, including Japan, the United States, Australia and several countries in Europe. Today, it is one of the construction methods attracting the most attention in the world.[1)]

In this paper, we shall first review the birth of the steel frame construction method and the efforts of Japan’s major steelmakers to develop this method. We shall then describe the Nittetsu Super Frame method that Nippon Steel developed for itself with the aim of pro-

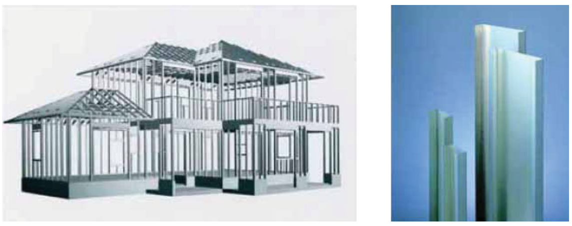

Photo 1 Light-gauge steel shapes and steel framed house

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moting application of the steel frame construction method to low-rise buildings – specifically the structure of the Nittetsu Super Frame and the company's activities to secure the performance required for dwellings, such as fire resistance, thermal insulation and sound insulation – and discuss the advantages of the Nittetsu Super Frame from the standpoint of addressing the deteriorating state of global warming.

This paper was compiled from various papers which had already been published by the Iron and Steel Institute of Japan,[1)] the Korea-China-Japan Association for Structural Steel Construction,[2)] the Architectural Institute of Japan,[3-5)] and the Japan Association for Fire Science and Engineering.[6)]

2. Birth and Characteristics of the Steel Frame Construction Method

2.1 Birth of the steel frame construction method

The first historical step toward the development of the steel frame construction method in Japan was marked in November 1994 when it was taken up as one of the themes of a meeting of the Urban Steel Society (Chairman: Masayoshi Igarashi, professor emeritus at Osaka University) sponsored by the Iron and Steel Production Division of the Basic Industries Bureau under the Ministry of International Trade and Industry. The development history of the method and enactment of related laws is shown in **Table 1**.

Of some 50,000 temporary houses constructed in the wake of the Great Hanshin Earthquake that occurred in January, 1995, imported steel-framed houses accounted for about 3,000. After the disaster, a good number of applications for official approval for construction of steel-framed houses in Japan came from abroad. Under those conditions, the Ministry of Construction announced in July of the same year its "Standards for Rating & Evaluation of Performance of Steel-Framed Houses" through the Building Center of Japan. As a result, it became possible to construct steel-framed houses in Japan with the special approval of the Minister of Construction (Article 38 of the former Building Standards Law). Then, in January 1996, Japan's six major steelmakers (Kawasaki Steel, Kobe Steel, Nippon Steel, Sumitomo Metal Industries, Nissin Steel and Nippon Kokan) set up a Steel-Framed House Committee with the Kozai Club (now the Iron and Steel Institute of Japan) as its secretariat, and launched earnest studies into the structural performance, fire resistance, durability, thermal insulation and sound insulation of steel-framed houses.

In 2000, full-scale marketing of detached houses built using the steel frame construction method of the Kozai Club (KC) type began. Application of the KC-type method expanded to studio apartments in 2001. As a result, market recognition of the method rose markedly. In November, 2001, with the Ministry of Land, Infrastructure

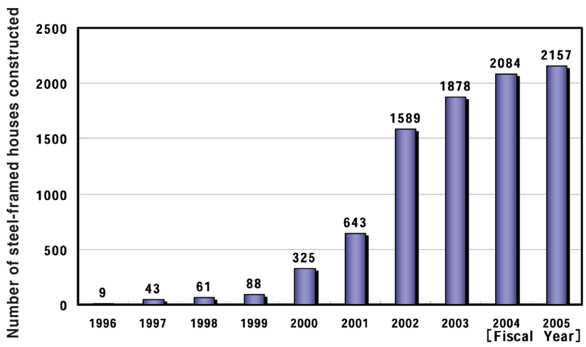


Fig. 1 Expansion in number of steel framed houses constructed in Japan

Table 1 History of development and Laws fixed for steel framed houses

1995	The Great Hanshin Earthquake Standards announced for Rating & Evaluating Steel-Framed Houses.
1996	Kozai Club (KC) establishes Steel-Framed House Committee.
1997	KC obtains approval of the Minister of Construction based on Article 38 of the former Building Standards Law.
1998	KC-type develops steel-framed houses.
1999	
2000	Enactment of Japan's Housing Quality Assurance Act Revision of The Building Standards Law [providing for detailed performance requirements] Revision of the provisions of Article 38 pertaining to KC-type steel-framed houses.
2001	Notification issued on light-gauge steel-framed houses. [Steel-framed houses officially recognized as a type of steel frame construction.]
2002	Article 1-3 of the Enforcement Regulations provides for the approval of the Minister of Construction for KC-type steel-framed houses.
2003	Revision of the Building Standards Law [24-hour ventilation] First structural rating of Nittetsu Super Frame [Design allowing for fire-resistant structures/3-storied houses]
2004	Development of market for Nittetsu Super Frame begins in earnest
2005	Second structural rating of Nittetsu Super Frame [Securing structural continuity, providing high-stiffness hardware, and improving effectiveness of spandrel and flap walls were added.]
2006	Third structural rating of Nittetsu Super Frame [Reinforcing load-bearing wall and joint hardware, clarifying design rules and establishment of more stringent design rules]
2007	Revision of the Building Standards Law [more stringent structural design, examinations and inspections] Article 1-3 of the Enforcement Regulations provides for the approval of the Minister of Construction for the Nittetsu Super Frame method

and Transport's issuance of a notification titled "Technical Standards for Ensuring the Safety of Methods of Construction of Light-Gauge Steel-Framed Structures or Structural Components," steel-framed houses were officially recognized as one type of steel frame construction under the Building Standards Law. As shown in **Fig. 1**, the number of steel-framed houses constructed in Japan has been steadily increasing. In the most recent year on record (2005), the total was 2,157 (about 20,000 units).

2.2 Characteristics of the steel frame construction method

The two-by-four wood frame construction method is a traditional method of building houses in North America. Initially, frames are made from wooden members, the cross section of which measures 2 inches × 4 inches. (These are the dimensions before lumbering. Actually, they are 38 mm × 89 mm.) Then, as shown in **Fig. 2**, a board (plywood, etc.) is nailed onto each of the frames to fabricate wall and floor panels, which are assembled into a boxlike structure. In Japan, this method is widely known as the two-by-four method.

The steel frame construction method uses galvanized shaped steel about 1 mm in thickness in place of wooden frame members. Since the shaped steel is that thin, it is possible to use drilling tapping screws, rather than nails, to joint structural members together without drilling screw holes beforehand (see **Photo 2**). In addition, the shaped steel can easily be cut using an electric rotary saw or shears. Furthermore, since the shaped steel is made from galvanized sheet, thanks to the sacrificial corrosion of the zinc plating, it is unnecessary to apply a protective coating (e.g., zinc-enriched paint) to the cut faces and joints. Thus, the light-gauge shaped steel is more like wood than steel. It may be said, therefore, that ordinary engineering firms can use the steel frame construction method in the same way as the two-by-four method.[2)]

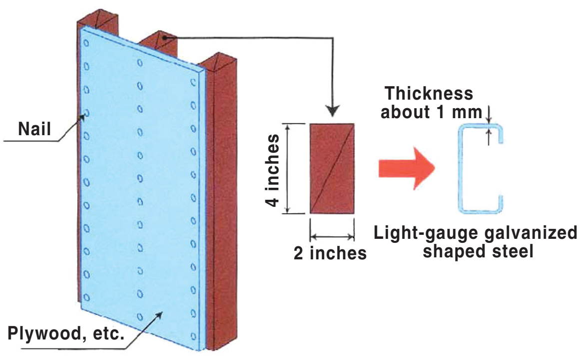


Fig. 2 2 × 4 wooden frame and light-gauge steel shapes

Photo 2 Scene of joining with drilling tapping screws

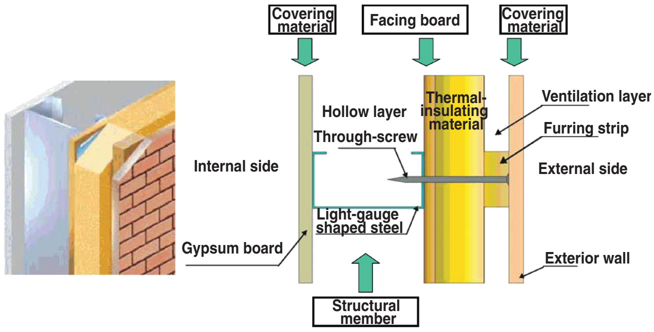


Fig. 3 Exterior wall structure of steel framed houses

The appearance of a typical exterior wall and the wall construction of a steel-framed house are shown in **Fig. 3**. On the external side of the house, a layer of thermal-insulating material and a ventilation layer are provided, which, together with light-gauge shaped steel, completely cover the entire house space, with the exterior wall as a covering material. On the internal side, gypsum board is used as the covering material. These structural members, facing board and covering materials work in combination to perform the functions required of dwelling houses, such as structural safety, fire resistance, thermal insulation and sound insulation. This is one of the salient characteristics of steel-framed houses.

3. Development and Application of KC-type Steel-framed House

Facing boards applicable to KC-type steel-framed houses are limited to wood-based ones—plywood for structures, medium-density board, or particleboard (chipboard). By using those facing boards, the approval of the Minister of Construction (Article 38 of the former Building Standards Law) for KC-type steel-framed houses was obtained in 2000 for detached houses up to three stories (including those with a shop on the first floor), row houses, two-storied semidetached houses and apartment buildings and for three-storied detached houses of mixed construction (reinforced concrete (RC) rigid-frame construction or box-frame construction for the first floor and steel frame construction for the second and third floors) (includes those having a shop on the first floor). As a result, it became possible to construct KC-type steel-framed houses by performing the simplified structural calculation process and applying for building permission as long as they fall within the scope of the above approval.

Following the 2001 Notification, the six steelmakers newly obtained the approval of the Minister of Land, Infrastructure and Transport for "KC-type steel-framed houses" based on the "Approval for omission of structural calculation documents" provided for in Item 1 of Article 1-3 of the Building Standards Law Enforcement Regulations, so that they could construct KC-type steel-framed houses simply by performing simplified structural calculations and applying for building permission as before. It should be noted, however, that the above approval was valid only for one-story houses and two-story houses with or without cricket and that three-storied houses were completely excluded from the scope of approval.

When it comes to constructing a KC-type steel-framed house, it is necessary first to join the Steel House Society and be registered as a member and then to receive technical training in design (see **Fig. 4**), work execution, etc. provided by the Society. When applying for building permission, it is necessary to obtain from the Society a certificate for the KC-type steel-framed house, a certificate of approval

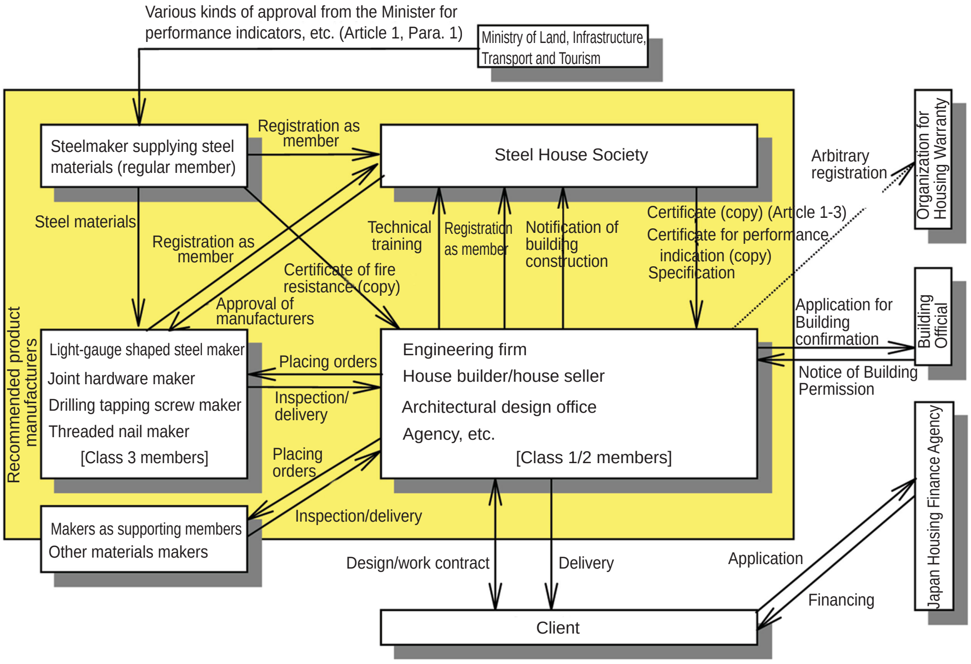


Fig. 4 Operating system for KC-type steel framed houses

for fire resistance, the design specification and the structural calculation check sheet and to prepare the necessary documents for applications. In addition, prior to construction of a steel-framed house, notification of construction work must be submitted to the Society.

4. Development of the Nittetsu Super Frame Method and Response to Mandatory Indication of House Performance

4.1 Circumstances leading to development

Table 2 shows the types of houses (three-storied or lower) in Japan and the fire resistance required of each type according to use zone, number of stories and total floor area. Assume, for example, that you are going to construct a three-storied apartment building in a fire zone. Then, regardless of the total floor area, the apartment building must be of fire-resistant construction (one-hour fire resistance). In a fire zone, even a two-storied apartment building must meet such a requirement if the total floor area is larger than 100 m^2.

On the other hand, the KC-type steel-framed house has not been approved as a fire-resistant structure, although it has obtained the competent minister's approval as a 60-minute, quasi-fire-resistant structure. When you are going to construct a three-storied apartment building of KC-type in a quasi-fire zone, it is possible as long as the total floor area is within 1,500 m^2. Even in this case, the construction work is subject to certain limitations (e.g., an evacuation route and area must be secured around the building).

In order to eliminate the existing limitations on construction sites and building scale and promote the application of light-gauge steel-framed houses in the low-rise building market, it is extremely important that Nippon Steel should develop its rational "Nittetsu Super Frame" method ("NSF" method) for "three-storied houses" and "fire-resistant construction," which the KC-type steel-framed house has not achieved, while maintaining its market competitiveness.

4.2 Development of the NSF to create "three-storied houses" and "fire-resistant structures" and activities to achieve public recognition

4.2.1 Structural performance

In the case of a three-storied house, the number of load-bearing floors is double that of a two-storied house. Therefore, it is necessary that the load-bearing walls of the first floor of a three-storied house support a load at least twice that supported by those of a two-storied house. Besides, since the light-gauge steel-framed house was clearly recognized as a steel frame construction by the 2001 Notification, it is necessary to study its seismic safety in two stages—the primary design to confirm the safety of the building in a medium-scale earthquake (seismic intensity slightly below V) which is likely to occur twice or three times during the building's service life, and the secondary design to confirm the safety of the building in a large-scale earthquake (seismic intensity exceeding VI) which may occur once during the building's service life.

In the case of steel-framed houses, including NSF ones, the facing boards of the load-bearing walls are supposed to resist the horizontal force of an earthquake. Therefore, the facing boards are required to display "high strength and high stiffness" in a medium-scale earthquake and "high energy-absorbing capacity" in a large-scale earthquake. It was found from in-plane shear tests of many load-bearing walls (**Photo 3**) that the wood-based facing boards that had been applied to KC-type steel-framed houses hardly met the above requirements.[7)]

Under that condition, Nippon Steel introduced to practical use a new ceramic-based facing board that could take the place of conventional wood-based equivalents. The salient characteristic of the newly developed facing board is that it demonstrates high strength at the deformation angle of 1/300—the principal indicator of yield strength in the primary design—and substantial energy-absorbing capacity, which is important in the secondary design. In December, 2003, the company obtained its first structural rating for a "fire-resistant struc-

Table 2 Fire-resistive performance required for buildings according to construction area and building scale

Type	Usage zone		S≦100	100＜S≦500	500＜S≦1000	1000＜S≦1500	1500＜S≦3000	3000＜S
Apartment building	Fire prevention zone	3-storied house	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure
		1 or 2-storied house	Quasi-fire-resistant structure	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure
	Quasi fire prevention zone	3-storied house	One-hour, quasi-fire-resistant structure + Evacuation Regulation	One-hour, quasi-fire-resistant structure + Evacuation Regulation	One-hour, quasi-fire-resistant structure + Evacuation Regulation	One-hour, quasi-fire-resistant structure + Evacuation Regulation	Fire-resistant structure	Fire-resistant structure
		1 or 2-storied house			Quasi-fire-resistant structure	Quasi-fire-resistant structure	Fire-resistant structure	Fire-resistant structure
	Article 22 zone	3-storied house	One-hour, quasi-fire-resistant structure + Evacuation Regulation	One-hour, quasi-fire-resistant structure + Evacuation Regulation	One-hour, quasi-fire-resistant structure + Evacuation Regulation	One-hour, quasi-fire-resistant structure + Evacuation Regulation	One-hour, quasi-fire-resistant structure + Evacuation Regulation	Fire-resistant structure
		1 or 2-storied house			Quasi-fire-resistant structure (2-storied house exceeding 300 m² in total floor area)	Quasi-fire-resistant structure	Quasi-fire-resistant structure	Fire-resistant structure
	Undesignated zone	3-storied house	One-hour, quasi-fire-resistant structure + Evacuation Regulation	One-hour, quasi-fire-resistant structure + Evacuation Regulation	One-hour, quasi-fire-resistant structure + Evacuation Regulation	One-hour, quasi-fire-resistant structure + Evacuation Regulation	One-hour, quasi-fire-resistant structure + Evacuation Regulation	Fire-resistant structure
		1 or 2-storied house			Quasi-fire-resistant structure (2-storied house exceeding 300 m² in total floor area)	Quasi-fire-resistant structure	Quasi-fire-resistant structure	Fire-resistant structure
Detached house	Fire prevention zone	3-storied house	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure
		1 or 2-storied house	Quasi-fire-resistant structure	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure	Fire-resistant structure
	Quasi fire prevention zone	3-storied house	Quasi-fire-resistant structure	Quasi-fire-resistant structure	Quasi-fire-resistant structure	Quasi-fire-resistant structure	Fire-resistant structure	Fire-resistant structure
		1 or 2-storied house			Quasi-fire-resistant structure	Quasi-fire-resistant structure	Fire-resistant structure	Fire-resistant structure
	Article 22 zone	3-storied house				Quasi-fire-resistant structure	Quasi-fire-resistant structure	Fire-resistant structure
		1 or 2-storied house				Quasi-fire-resistant structure	Quasi-fire-resistant structure	Fire-resistant structure
	Undesignated zone	3-storied house				Quasi-fire-resistant structure	Quasi-fire-resistant structure	Fire-resistant structure
		1 or 2-storied house				Quasi-fire-resistant structure	Quasi-fire-resistant structure	Fire-resistant structure

Legend:
- (light green) Scope co-developed by steelmakers
- (light blue) (quasi-fire-resistant structure and 1-hour, quasi-fire-resistant structure)
- (dark blue) Scope developed by Nippon Steel (fire-resistant structure)

Photo 3 Scene of in-plane shearing test with bearing wall

ture/three-storied house" (see Table 1).

Basically, steel-framed houses are constructed by using the platform method in which the first floor is placed on a platform, the walls of the first floor are erected on the first floor, the second floor is placed on the walls of the first floor, and so on. Therefore, the seismic force and wind pressure from the upper floor are transmitted to the walls of the lower floor via the upper floor. Generally speaking, if the through-thickness stiffness of the floor is insufficient, local deformation of the floor occurs as shown in **Fig. 5**. This local deformation promotes deformation of the entire structure as shown in **Fig. 6** (left-hand diagram).

As of the second structural rating shown in Table 1, Nippon Steel paid special attention to the above fact and pressed ahead with technological developments with the major emphasis on drastically reviewing the transmission route of seismic forces and wind pressure

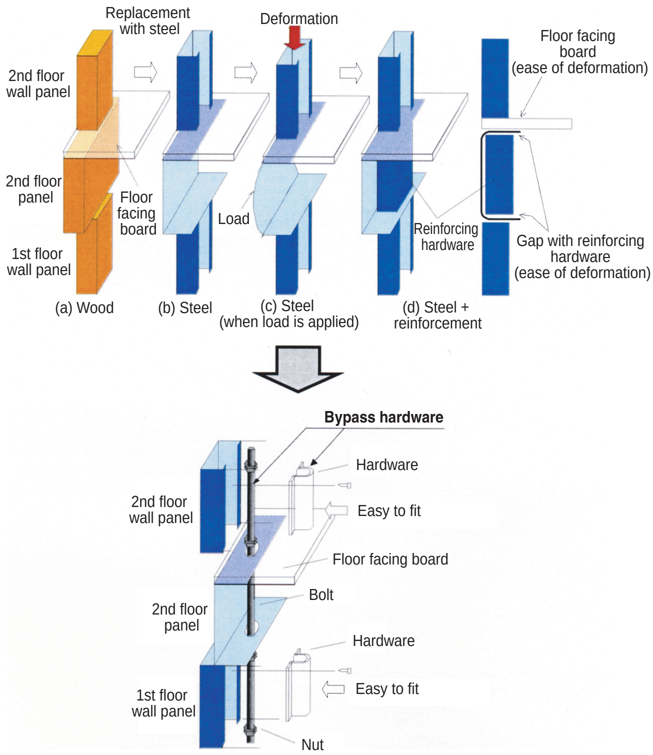


Fig. 5 Axial load transmission system to bearing walls, floor below, and foundation

from the upper-floor load-bearing walls to the upper floor to the lower-floor load-bearing walls. As a result, the company invented and put

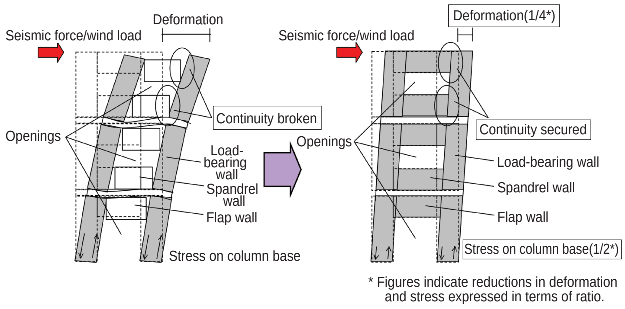


Fig. 6 Bearing improvement system by spandrel walls and flap walls

to practical use the "high-stiffness, bypass hardware" that directly connects the bearing walls of the upper and lower floors as shown in Fig. 5 (lower diagram) to allow for a load transmission process which completely prevents the transmission of overturning force to the floors—the weak points—in an earthquake or under strong wind load.

In addition, concerning the flap walls above windows and other openings and the spandrel walls under them that could not formerly be treated as load-bearing elements because the load-bearing walls are rendered discontinuous by such openings as shown in Fig. 6 (left-hand diagram), it was possible to evaluate their stiffness and yield strength as higher than before by making them continuous with the load-bearing walls at both sides (right-hand diagram in Fig. 6). That enabled application of the NSF method even to urban, three-storied apartment buildings, etc. to be constructed in confined areas for which the prescribed load-bearing walls could not formerly be secured.

In June, 2005, Nippon Steel obtained its second structural rating. Then, in 2006, the company pressed ahead with securing its third structural rating for materializing hold-down hardware, high-stiffness hardware and higher strength load-bearing walls that reflect the development advances in the market. In January, 2007, the Building Center of Japan completed its third evaluation of the NSF method. At present, with the aim of further increasing the market competitiveness of the NSF method and enhancing customer trust in our structural design, we are making preparations to secure the approval of the Minister of Land, Infrastructure and Transport for omission of the structural calculation documents for the NSF method based on Article 1-3.

4.2.2 Fire resistance

When designing a fire-resistant structure, it is important to ensure that the structure is free from damage and capable of insulating heat and flames for the prescribed time if an ordinary fire breaks out indoors or outdoors. The phrase "ordinary fire" refers to the standard heating curve specified in ISO 834. According to the curve, the atmospheric temperature reaches approximately 945℃ in 60 minutes after the fire breaks out. If the light-gauge shaped steel is exposed to such a high temperature, the steel temperature rises sharply and the steel yield strength falls sharply at the same time, causing the load bearing capacity to decline markedly.[6)]

Therefore, in the steel frame construction method, sufficient fire resistance is imparted to the facing boards as structural materials and to the interior and exterior members as covering materials so as to ensure that the structure is free from damage and capable of insulating the heat and flames for a certain time should a fire occur. Since this method secures the required fire resistance by making the facing boards and covering materials continuous, it is also called the membrane method.

The one-hour fire resistance requires that the structure be free

Photo 4 Scene of fire-resistive performance test with exterior wall

from damage and capable of insulating the heat and flames for a duration three times the heating time after the start of such heating, although this requirement does not apply to fire-preventive or quasi fire-resistant structures. In the case of a one-hour fire-resistant exterior wall, for example, it is necessary to observe the wall for three consecutive hours after it is subjected to a one-hour heating test.

Photo 4 shows a scene from a fire resistance test on an exterior wall. The ceramic-based facing board adopted as a structural facing material is nonflammable and almost free from thermal deterioration after one hour of heating. The gypsum board used as a covering material can be "stapled" to the ceramic-based facing board easily and securely. There is virtually no risk of the gypsum board slipping off even during heating.

Thanks to these efforts to improve fire resistance as mentioned above, we could develop rational one-hour fire-resistant specifications that completely clear the standards for fire resistance relating to the immunity to damage and the insulation from heat and flames, even at the end of heating and for three hours after heating. For all the main structural parts, such as the floors, boundary walls and exterior walls, Nippon Steel obtained the competent minister's approval for one-hour fire-resistance in December, 2003. As a result, it became possible to construct fire-resistant structures using the NSF method.

4.2.3 Thermal-insulating performance

Since the NSF method uses a light-gauge shaped steel having high heat conductivity for the structural frames, the "thermal insulation by lining and ventilation" method, in which those structural frames are completely covered with thermal insulation with a ventilation space provided between the thermal insulation and the exterior wall, is employed as the standard method. However, to install the exterior wall material and fix the furring strips to secure a ventilation space, use of drilling tapping screws which penetrate the thermal insulation (see Fig. 3) is unavoidable. In Hokkaido and other cold regions, there was no small concern that those screws could instigate condensation inside the wall.

If condensation occurs, it not only invites mold and house mites, but also causes the durability of the structural frames to decline sharply. Therefore, it was a serious problem that had to be solved without delay. In order to solve that problem, the internal temperature conditions, including those inside the walls, were measured and evaluated in a two-storey detached house ("Engaru specifications"; see **Photo 5**) at Engaru-cho, Monbetsu-gun, Hokkaido where the external temperature can drop to –20℃ or lower in winter.[3)]

The floor area of the above detached house of Engaru specifications is 100.2 m^2 on the first floor and 76.54 m^2 on the second floor. Taking into consideration the spacious courtyard in the living/dining/kitchen area in the center, the net total floor area becomes 202.33 m^2 (see **Fig. 7**). As thermal insulation, the roof is sprayed with polystyrene foam to a thickness of 140 mm, the foundations with the same material to a thickness of 75 mm and the walls with hard urethane to a thickness of 60 mm. For the windows, resin sashes which offer good air-tightness and thermal insulation and low-radiation double glazing (air gap: 12 mm) are used. For heating (23:00 - 07:00), a regenerative electric heater utilizing nocturnal electric power is installed. For ventilation, a central ventilation system with heat exchanger (air supply: max. 170 m^3/h, exhaust: max. 190 m^3/h, heat exchanger effectiveness: 70%) is employed.

The heat loss coefficient, Q, calculated based on the design drawings and the roof and wall specifications taking into consideration the thermal insulation, etc. was 1.32 W/m^2K (1.60 W/m^2K in the next-generation energy-saving reference area I), and the measured equivalent clearance area, C, was 0.6 cm^2/m^2.

Fig. 8 shows the thermal condition inside the walls of the living/

Photo 5 Steel framed house constructed in Engaru City, Hokkaido

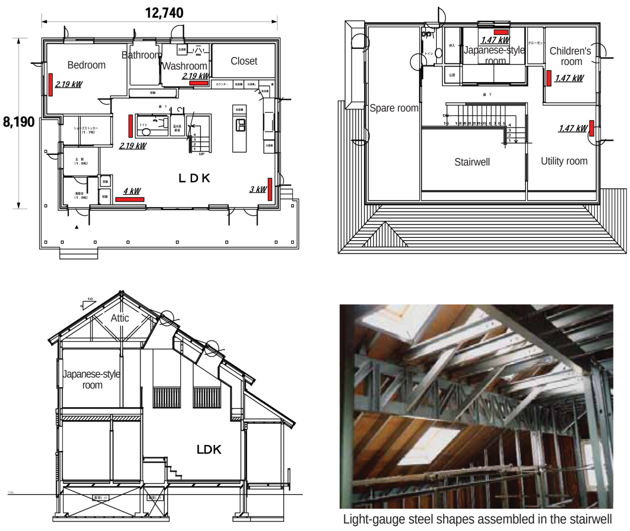


Fig. 7 Summery of Engaru-specification (1st floor plan [upper left], 2nd floor plan [upper right], section [lower left], introspective photo under construction [lower right])

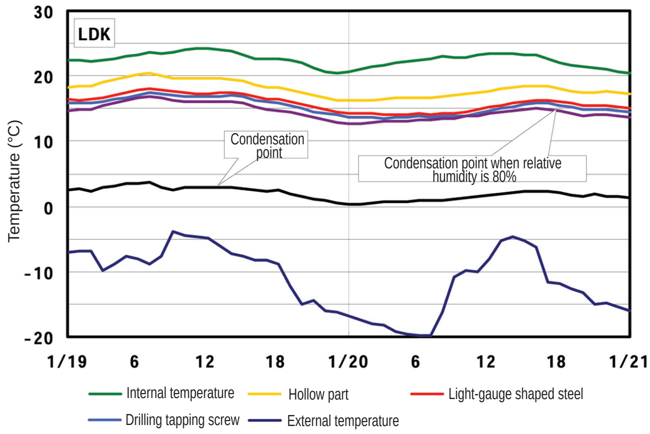


Fig. 8 Thermal environment and dew condensation decision inside wall of winter season

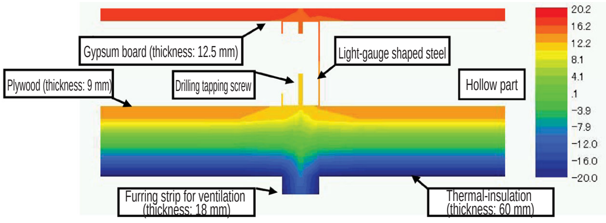
dining/kitchen area on January 20, 2002 when the external temperature dropped to –20℃. On average, the temperature of the light-gauge shaped steel is 2.2℃ lower than that of the hollow space. The temperature at the tip of the tapping screw penetrating the Thermal-insulating material is 0.6℃ lower than that of the light-gauge shaped steel in the living/dining/kitchen area. However, since the minimum temperature is 13.5℃, which is well above the condensation point of the hollow part, there is no risk of condensation. It was confirmed that condensation would not occur as long as the relative humidity of the hollow part is 80% or less.

In order to verify the above results, Nippon Steel created a three-dimensional, steady-state heat conductivity calculus of differences program which permits analyzing even walls with hollow elements. With this program, the hollow part is treated as one room by using the overall heat transmission as its heat transfer, and the hollow part temperature that makes the total sum of heat flows on the surface of the hollow part zero is obtained. To calculate the temperature of divided cross points of the solid part, the repetitive method, in which the temperatures of all points are first estimated and then they are sequentially corrected based on thermal equilibrium of the cross points, is used.

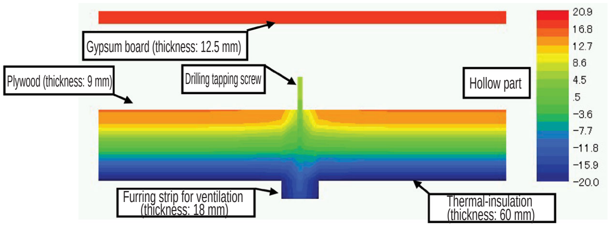
Fig. 9 shows the results of reproduction of the temperature distributions inside the walls when the external temperature was –20℃ and the internal temperature was 23℃ (see Fig. 8). The calculated temperature of the hollow part is 16.7℃ and that of the tapping screw is 13.1℃. The measured temperature is 16.7℃ for the hollow part and 13.8℃ for the tapping screw. Although there is a temperature difference of 0.7℃ for the tapping screw, considering the difference of 43℃ between the internal and external temperatures, it may be said that the analysis results reflect the actual conditions fairly well.

When a drilling tapping screw is driven into the light-gauge shaped steel (see Fig. 9(a)), the tip of the screw is heated to a temperature at which there is no risk of condensation. On the other hand, when the drilling tapping screw is not driven into the light-gauge shaped steel (see Fig. 9(b)), the possibility of condensation increases significantly. Namely, the light-gauge shaped steel itself supplies the internal heat to the drilling tapping screw that penetrates the thermal insulation, thereby restraining the creation of a cold bridge inside the wall and condensation.

Through the above analysis, we clarified the mechanism whereby the light-gauge shaped steel itself restrains the creation of a cold bridge and condensation inside the walls, and confirmed that the "ther-



(a) Case of drilling tapping screw, rammed down to light-gauge steel shapes



(b) Case of drilling tapping screw, not rammed down to light-gauge steel shapes

Fig. 9 Result of temperature distribution analysis inside wall

Table 3 Grade regarding reduction of deterioration and plated specification by "Nittetsu-Super-Frame"

	Condensation-proof type (special approval)		Rustproof type (special approval)	
	General part	Leg	General part	Leg
Class 3 (75 - 90 years)	Z27(20 μm)		Z27(20 μm)	Z45(32 μm)
Class 2 (50 - 60 years)	Z18 (12.5 μm)		Z18(12.5 μm)	Z27(20 μm)
Special remarks	The entire structure is covered and kept dry at all times. This is attainable using the "thermal insulation by lining and ventilation" method.		The foundations must not necessarily be covered or kept dry at all times. * Foundations: The structure's portion up to 1 m above ground	

mal insulation by lining and ventilation" method is effective at preventing the occurrence of a heat bridge (condensation). In addition, by taking advantage of the advantages of the NSF method, we strove to obtain a rating of condensation-proof type under "Reduced deterioration" in the house performance indication system.

In October, 2006, using a combination of the light-gauge shaped steel with a 20- μm zinc coating (Z27), which is generally used in the NSF method, and the thermal insulation lining of prescribed thickness, Nippon Steel obtained the competent minister's approval for its Class 3 condensation-proof construction (durability of 75 to 90 years)—the best rank in terms of minimized deterioration (see the hatched part in **Table 3**).

In addition, by making the most effective use of the thermal characteristics of the NSF method, the company has been striving to obtain Class 3 (compatible with the new energy-saving standards) and Class 4 (compatible with the next-generation energy-saving standards) approvals concerning the "Thermal environment" (energy saving). In June, 2007, the company obtained the above approvals for apartment buildings, etc. constructed using the NSF method. At present, the company is preparing to obtain the same approvals for detached houses, etc. built using the NSF method.

4.2.4 Sound insulation performance

From the standpoint of securing privacy and comfort, sound insulation the individual houses properly is important. The Building Standards Law of Japan provides for minimum sound insulation performances of the boundary walls between apartments of condominiums. However, the sound insulation performance of the boundary floors is left out of consideration.

On the other hand, in the financing conditions of Japan Housing Finance Agency and the housing performance indication based on the Housing Quality Assurance Act, the sound insulation performances that are required of boundary floors and boundary walls are classified as shown in **Fig. 10**. The heavy floor impact-insulating performance concerns, for example, the sound produced when a child jumps from a chair or bed onto the floor, whereas the light floor impact-insulating performance concerns, for example, the sound produced when a person walks on the floor or opens or closes doors. The penetration-loss performance of a boundary wall concerns the sound propagating from the adjoining room through the air.

The NSF method uses steel materials for the boundary floor joists and boundary wall studs. Therefore, in order to secure the required sound insulation performance, it is necessary to understand the weak points of those steel materials.

Sound propagating from its source is transformed into a vibration when it passes through a boundary floor or boundary wall. When steel is used for the floor joists and wall studs, the sound wave penetrates the floor and wall more easily than when wood is used, because the ability of steel to damp the vibration is far inferior to that of wood. Therefore, in the NSF method, separating the sound source from the sound receiving point is the basic rule. With this in mind, we have conducted technological development to secure the sound insulation performance required of the boundary floors and walls.

Fig. 11 shows an example of a boundary floor. By separating the floor joists on the sound-source side from the ceiling joists hanging from the ceiling on the sound-receiving side, the sound propagating from its source can be reduced significantly.

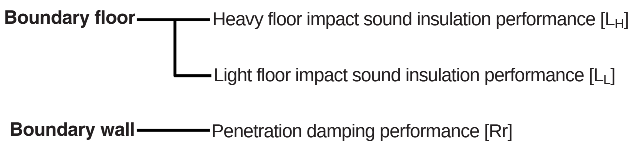


Fig. 10 Sound insulation efficiency division for boundary floors and walls

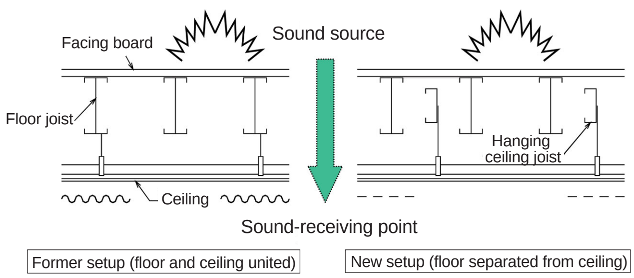


Fig. 11 Separation of sound resources and sound receiving points in boundary floor

Taking a foreign students' dormitory constructed on Kitakyushu Science and Research Park as an example, we shall describe below the sound insulation performance of the NSF method. From the standpoint of securing a high level of living comfort, sound insulation performance of Grade 2 or higher specified by the housing performance indication system was required of the boundary floors and walls of the dormitory. Measurement and evaluation of the actual sound insulation performance was entrusted to Kuroki Laboratory of the International Environmental Engineering Department of Kitakyushu Municipal University.

(1)Heavy floor impact sound-insulating performance of boundary floors

Fig. 12 shows the impact application points in Room No. 203 and the sound measurement points in Room No. 103, directly beneath Room No. 203, in the measurement of heavy floor impact sound-insulating performance of the boundary floor. The measurement results are shown in **Fig. 13**. The sound pressure level of central frequency 63 Hz is highest. The boundary floor thus demonstrates "Grade 2" sound insulation performance at L-65.

Concerning the obtaining of performance grades based on the housing performance indication system, the Building Center of Japan has just completed evaluation of the boundary floor performance as Grade 2, which corresponds to an RC floor slab thickness of 11 cm. In the future, the company intends to make further improvements to obtain Grade 3 approval, corresponding to an RC floor slab thickness of 15 cm.

(2)Light floor impact sound-insulating performance of boundary floors

Fig. 14 shows the results of measurement of light floor impact sound-insulating performance at the impact points and measuring points shown in Fig. 12. The boundary floor has Grade 2 light floor impact sound-insulating performance at L-60.

(3)Airborne Sound insulating performance of boundary walls

Fig. 15 shows the measurement points of the airborne sound insulating performance of the boundary wall, and **Fig. 16** shows the measurement results. In the low-frequency band (center frequency: 125 Hz), studs were arranged in a checkered pattern to isolate the

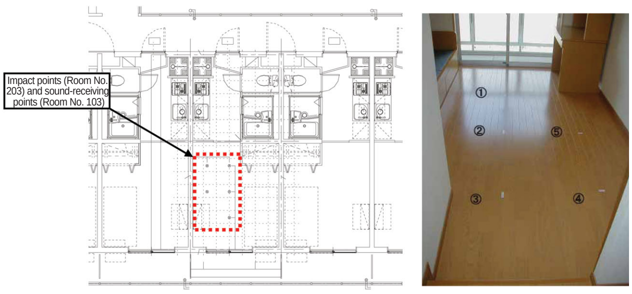


Fig. 12 Impacting points in Room No.203 and sound receiving points in Room No.103

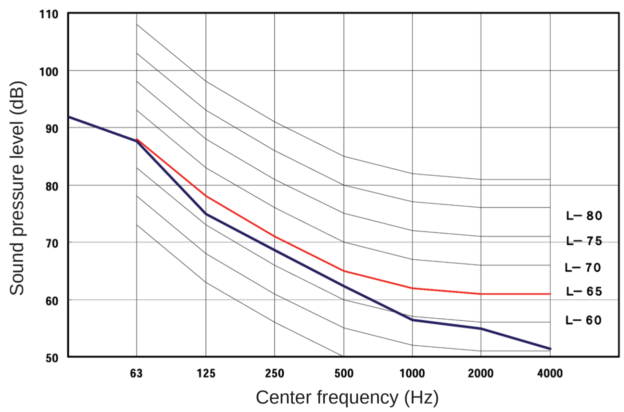


Fig. 13 Heavy impact sound insulation performance of upper floor of Room No.103

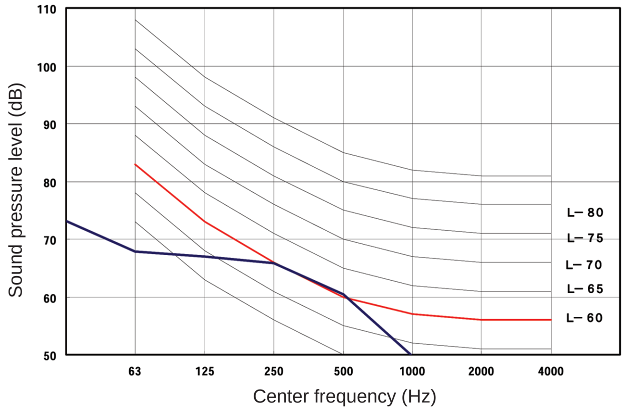


Fig. 14 Light impact sound insulation performance of upper floor of Room No.103

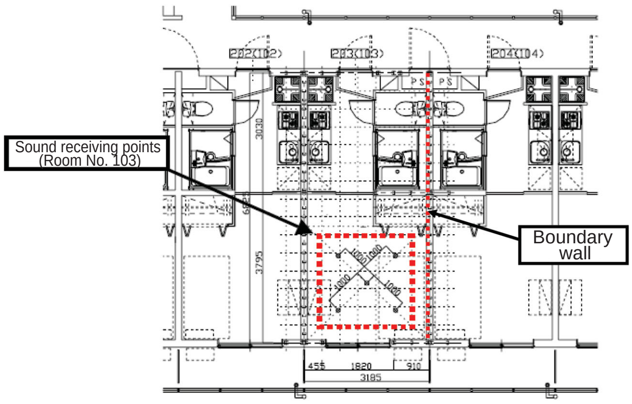


Fig. 15 Sound source points (No.102, No.104) and sound receiving points in Room No.103

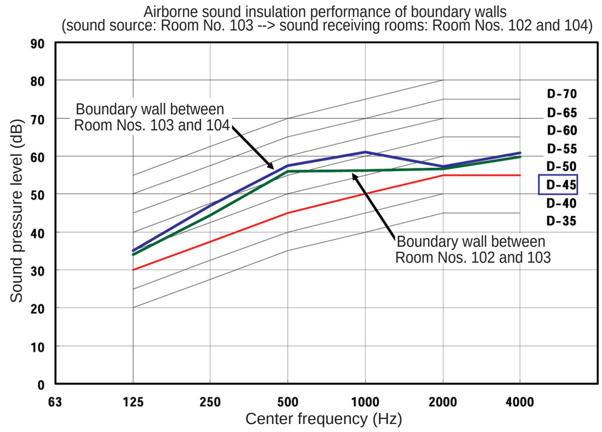


Fig. 16 Airborne sound insulation performance of boundary walls of Room No.103

power source from the power-receiving point. At the same time, in the high-frequency band (center frequency: 2,000 Hz), two gypsum boards were varied in thickness to suppress the coincidence. As a result, it was confirmed that the boundary wall had Grade 3 airborne sound insulating performance (D-45).

On the basis of the above results, the company strove to obtain the performance grade based on the housing performance indication system. As a result, approval for Grade 3 was obtained in December, 2005. Grade 3 corresponds to the performance of a concrete boundary wall having a thickness of 18 cm.

5. Advantages of the Nittetsu Super Frame (NSF) Method from the Standpoint of Countering Global Warming

In this section, we shall discuss the advantages of steel-framed houses constructed using the NSF method in terms of the reduction in environmental impact throughout their life cycle, from construction to utilization to scrapping.

5.1 Reduction of environmental impact during construction

In the case of a three-storied apartment building of reinforced concrete (RC) construction, the body weight per total floor area is about 1 ton/m^2. In striking contrast, the body weight of a three-storied apartment building constructed using the NSF method is about 100 kg/m^2, including the facing boards, one-tenth that of RC construction. Because of this, even in cases where foundation piles are required for RC construction, the NSF method seldom requires them. Thus, the NSF method helps reduce the environmental impact during construction.

Photo 6 shows a scene from the on-site installation of the structural frames, thermal insulation and furring strips for ventilation, all prefabricated into panels at the factory. All that remains to be done is to provide the exterior and interior wall linings. Thus, it may be said that the NSF method is one that permits significant shortening of the construction period and minimizing the creation of waste at the construction site because the majority of the structural members are prefabricated at the factory.

To sum up, from the standpoint of reducing the environmental impact, the advantages of the NSF method at the construction stage are "lightweight construction materials," "fabrication of main structural members at factory" and "short construction period."

5.2 Reduction of environmental impact during utilization

The NSF method achieves high levels of thermal insulation and air-tightness for a steel-framed house by completely covering the entire living space of the house. As shown in the photo at the center of **Fig. 17**, steel members with high thermal conductivity are arranged

Fig. 17 Process of high performance living space of resource productivity for space heating and cooling

inside the thermal insulation on the room side. Thanks to the steel member, the thermal energy of the heater used in cold weather spreads throughout the room interior. As is evident from the photo at the right of Fig. 17, the occurrence of temperature variance can be minimized. In districts northeast of Tokyo where the heating load is greater than the cooling load, by adjusting the thickness of thermal insulation according to external conditions and positively letting solar heat and other natural energies into the room, it is possible to create a nice and warm room environment which requires less energy for heating.

On the other hand, in districts west of Tokyo where the annual cooling load is greater than the annual heating load, even when the thermal insulation performance is raised in hot weather, the heat that has entered the room via the roof and walls and through the windows and other openings can hardly be let out of the room. In those districts, therefore, reinforcing the thermal insulation performance alone will not significantly reduce the cooling load.

In order to promote the NSF method in the warm districts west of Tokyo as well, Nippon Steel has conducted technological developments to add sun-shading technique to the "thermal insulation by exterior lining and ventilation" method. The phrase "sun-shading technique" as used here refers to technology to restrain the entry of heat (solar heat) into the room via the roof, walls and other non open parts. The basic principles of sun-shading technique are shown in **Fig. 18**.

Specifically, the above technology aims to reduce the cooling load by increasing the solar reflection rate of the surface of the exterior materials, making the entry of solar heat into the room difficult by decreasing the surface radiation rate of at least one side of the ventilation part, and enhancing the ventilation. At present, the company is conducting a verification study at building A of the conventional thermal insulation/ventilation specifications (compatible with the next-generation energy-saving standards) and building B added

Photo 6 Exterior wall panels, increasing ratio of factory production

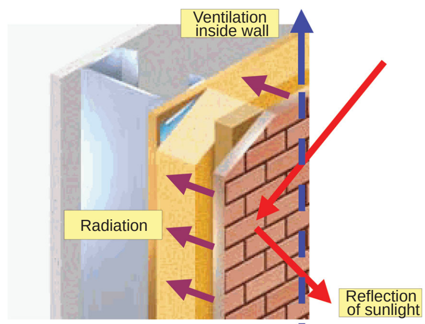


Fig. 18 Three principles of sunshading in external walls

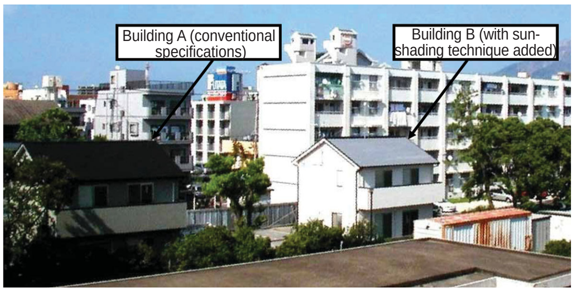


Photo 7 Two-story detached houses for on-site practical study at Kagoshima University

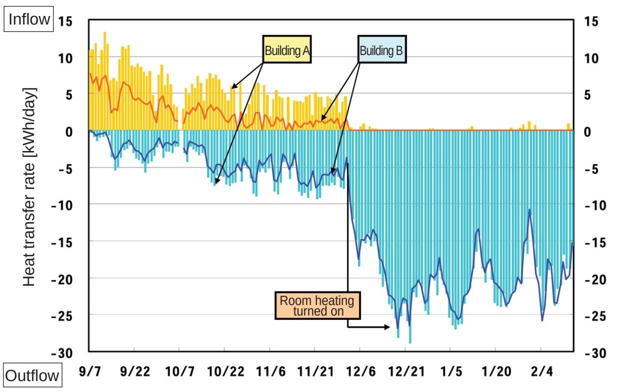


Fig. 19 Daily variation of thermal transmission quantity in whole wall and roof of two-story detached houses

with a sun-shading technique function, both constructed on the premises of Kagoshima University (see **Photo 7**).

Fig. 19 shows the daily variations in heat transfer for buildings A and B during the period from September, 2005 to February, 2006. The positive (+) side of the vertical axis represents the quantity of heat flowing into the room from the outside, and the negative (–) side represents the quantity of heat flowing out from the room to the outside. Until the room heating was turned on (December 2, 2005), building B with the sun-shading technique function added dramatically reduced the quantity of heat flowing into the room from the outside, as compared to building A. In building B, the quantity of heat flowing out of the room also decreased. It can be seen that even after the room heating was turned on, the amount of heat lost from the room to the outside fell a little.[4,5)]

To sum up, from the standpoint of reducing the environmental impact, the advantage of the NSF method in terms of utilization of the house is "high energy efficiency made possible by thermal insulation and sun-shading technique."

5.3 Reduction of environmental impact during dismantling/scrapping

As mentioned in 2.2, the NSF method does not use welding at all. It is a dry-type construction method that uses drilling tapping screws to assemble the main structural members. Therefore, steel-framed houses constructed using this method can easily be disassembled by removing those screws.

On the other hand, when it comes to demolishing an RC building constructed by the wet-type method, a large amount of energy is required to demolish the concrete. Besides, it is necessary to erect temporary walls to insulate against the resultant cacophony and sprinkle large amounts of water to prevent dispersal of particulates.

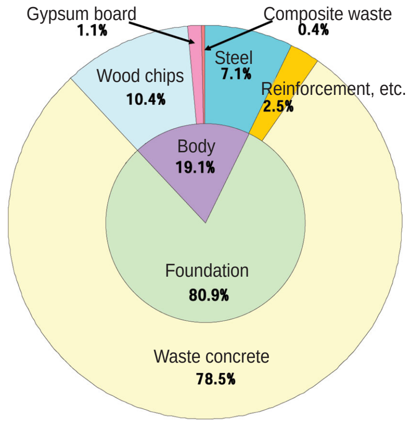


Fig. 20 Rates of recycling and reuse of resources at time of demolition of steel framed house

As already mentioned in 5.1, since a steel-framed house built using the NSF method is much lighter than an RC building, the total cost of demolition can be cut dramatically. As shown in **Fig. 20**, the waste from the average steel-framed house can be broken down into concrete used for the foundation (78.5%), wood chips and gypsum board (11.5%), steel from light-gauge shaped steel (7.1%), and reinforcement (2.5%). All the waste materials, except for composite ones, can be recycled in the form of "sub-base course materials" and "iron." Thus, the NSF method can be among the front-runners in a resource-recycling-based society.

To summarize, from the standpoint of reducing the environmental impact, the advantages of the NSF method during demolition/scrapping are "easy demolition and high rate of resource recycling."

6. Promoting Application of the NSF Method to the Low-Rise Building Market

The application of the NSF method in the field of low-rise buildings began in Hokkaido where the thermal-insulating performance of NSF steel-framed houses was very highly rated. For example, the NSF method was applied to construct group homes in Kitami City and Asahikawa City (**Photos 8 and 9**). More recently, a certain housing sales company in Sapporo City adopted urban-type, three-storied apartment buildings (fire-resistant buildings), like the one shown in **Photo 10**, as standard steel-framed houses. Since then, the number of steel-framed houses in Hokkaido has been expanding rapidly.

In the Kanto area, steel-framed houses applying the NSF method

Photo 8 Group home in Kitami City, Hokkaido

Photo 9 Group home in Asahikawa City, Hokkaido

Photo 10 Three-story apartment, city type, in Sapporo City, Hokkaido (1-hour fire-resistant building)

Photo 11 Three-story apartment, city type and narrow small area, in Minami-Ikebukuro, Tokyo (1-hour fire-resistant building)

are steadily increasing in number, especially in the field of urban-type, three-storied apartment buildings (fire-resistant buildings) built on confined grounds. For example, they can be found in Minami-Ikebukuro (2004) (see **Photo 11**), Funabashi City and Chiba City (2005), and Chofu City (2006) (see **Photo 12**).

The application of the NSF method to dormitories and company houses, too, has begun increasing steadily, such as the foreign students' dormitory in Kitakyushu City (2004) (see **Photo 13**), the Takayokosuka company house in the grounds of the Nippon Steel Nagoya Works (2006) (see **Photo 14**) and the employees' dormitory in the grounds of the Nippon Steel Kamaishi Works (2007). In the

Photo 12 Three-story apartment, city type and narrow small area, in Chofu City, Tokyo (1-hour fire-resistant building)

Photo 13 Three-story dormitory for foreign students in Kitakyushu City (60-minute quasi- fire-resistant building)

Photo 14 Three-story apartment for employees of Nagoya Works in Takayokosuka, Aichi (1-hour fire-resistant building)

Photo 15 Convenience store in Saitama City

case of the foreign students' dormitory in Kitakyushu City, in particular, it was a precondition that the land should be cleared of the building and returned to the city 20 years later. Therefore, it was very desirable that the building be such that it could be completely depreciated within 20 years. In terms of the Tax Law, the period of depreciation of a steel-framed house is 19 years since it uses thin-gauge steel sheet for its frames. The exceptionally short depreciation period, as compared with 34 years for steel-framed construction and 47 years for RC construction, was one of the major reasons why the NSF method was adopted for the foreign students' dormitory mentioned above.

The NSF method is also steadily penetrating the shop market. In many cases, shops are based on a fixed-period leasehold. In addition to the exceptionally short depreciation period mentioned above, the fact that the shop owner can start business quickly (thanks to the short construction period) and can make the most effective use of the floor space (because of the total absence of pillars or columns) is highly rated. **Photo 15** shows an example of a steel-framed convenience store.

7. Conclusion

Concerning the Nittetsu Super Frame (NSF) method, which is an improved version of the steel frame construction method co-developed by Japan's major steelmakers and which targets the low-rise building market, we have so far described the development concept and our activities to secure the required performance requirements and discussed the advantages of the NSF method from the standpoint of reducing the environmental impact. So far, our activities have been focused on "expanding the application of light-gauge steel construction materials in the low-rise building market and determining their limits."

In cooperation with METO KAKEFU (location: Kani City, Gifu Prefecture, president: Takeshi Kakefu), we have also built and accumulated CAD/CAM online production techniques to develop the potential of light-gauge steel construction materials. In this respect, the most fundamental element is "pre-notched holes" which are drilled online in the cold-forming process of light-gauge shaped steel.

By effectively utilizing the pre-notched holes, it is possible, for example, to completely eliminate the work of measuring steel materials. This can be done by providing assembly holes at both ends of the individual members according to the design information and by inserting pins into the appropriate holes for assembly. In addition, as shown in **Photo 16**, by drilling holes about 3 mm in diameter—smaller than the diameter of the drilling tapping screw—in the studs at both ends of each panes and driving screws into all such holes, it is possible to prevent some screws from being left unused and to control the work quality. Furthermore, by providing through-holes for piping in the floor joists during fabrication of light-gauge shaped steel,

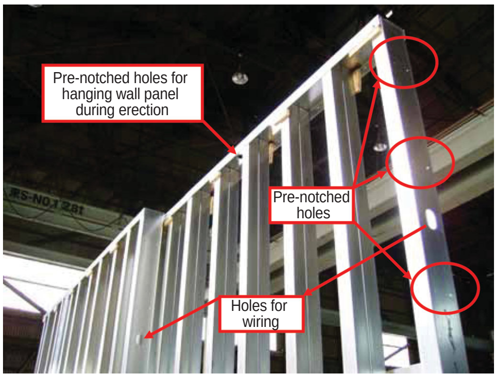


Photo 16 Pre-notched holes, raising productivity and competitiveness

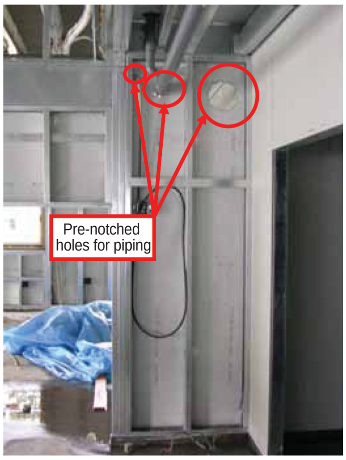


Photo 17 Pre-notched holes for piping penetration to structural face board

it is possible to render field drilling work, which can hardly be carried out efficiently, completely obsolete. This helps to improve productivity at the panel fabrication factory and at the construction site, as well as improve the construction quality.

In the future, we intend to develop higher levels of industrialized houses, for example, byincreasing the proportions of factory production of structural members, including the drilling of piping holes at the factory as shown in **Photo 17**. Since the verification study on the sun-shading technique described in 5.2 is scheduled for completion during fiscal 2007, from the standpoint of reducing the environmental impact, the NSF method can become an effective method even in countries in East Asia which are warmer than Japan. With the aim of promoting the NSF method in East Asia as a standard method of construction of houses there, we are determined to continue steadily developing the NSF method.

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