ANNEX 5-A

BEST PRACTICE FOR STEEL CONSTRUCTION IN HOUSING AND RESIDENTIAL BUILDINGS IN EUROPE

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BEST PRACTICE FOR STEEL CONSTRUCTION IN HOUSING AND RESIDENTIAL BUILDINGS IN EUROPE

1. INTRODUCTION

Developments in the innovative use of steel in the residential sector have increased rapidly in the last years thanks to much effort made in the last 20 years. Research and promotion on the use of steel in housing has never stop but quite large efforts have been made from the 90's in the frame of the ECSC and now RFCS research programme frame.

A wide range of steel products and systems are now available, from the single construction elements up to complex module systems including all the necessary equipments for a fast track and efficient building construction. Some of these elements are now based on various degrees of prefabrication in factories. This allows high quality and high productivity standards. The steel sector "supply chain" has also reached a capacity where it is able to meet demand promptly and cost-effectively.

This document will address 3 generic forms of construction:

- Light steel framing for single insulated housing or medium-rise buildings,
- Primary steel framed buildings with steel infill walls for medium to high-rise buildings,
- Modular construction, including modular works "wall, slabs, roofs, panels, etc" or modular standard living cells with all the equipments already fitted leaving the factory site.

Note that standardised has not the meaning of uniform or single form elements but the meaning that they shall fit together without any connection problems.

The market for steel framing is increasing in the residential building sector, which mirrors its success in other sectors. Steel components take many forms, from hot rolled steel in primary frame to light steel framing in low-rise buildings and secondary members.

Steel possesses important value benefits in terms of speed of construction, quality, flexibility of space utilisation, and architectural opportunities, which are emphasised in these case studies.

The benefits of steel can be regarded in terms of:

- Speed of construction,
- Freedom for internal planning,
- Lightweight,
- Reduce impact on the locality during construction,

- Improved performances characteristics,
- Highly valuable and recyclable material,

Steel can also take part as composite elements in Steel/Concrete works as composite slabs and beams, or composite columns. The needs to reach better structural performances has made material to joint their performances optimising their characteristics "i.e. Steel for traction members, concrete for compression strained elements", so that the global performance is quite more than the simple addition of the performance of each material by itself.

The opportunities for steel can be regarded as:

- From regulation requirement + energy saving concerns,
- Market opportunities,
- Sustainability issues,
- Social demand,
- Economical assessment,
- Industrial capability.

Research has been made to:

- Develop opportunities for light steel construction in low rise buildings,
- Develop opportunities for "mixed" primary steel frames and light steel construction.

Architectural concerns

Construction process, using of steel-intensive components and/or sub-assemblies can also appeal **aesthetic contents** to be used in urban habitats. Steel components constitute an innovative set, extremely flexible in its uses and possessing the necessary technical requirements suitable for their maximum serviceability and interchangeability in the construction.

Objectives are set in terms of main basic requirements as:

- Maximise use of specified available space and propose good comfort,
- Minimise cost of construction,
- Minimise running cost and social bill,
- Minimise the use of primary energy,
- Obtain architectural quality.

Secondary advantages, which are deemed to become more and more important for any type of building, are:

- Modularity of space occupancy in the life time of the building,
- Rapid change and adaptability to future demands from customers,
- Good response to environmental issues.

1.1 OPPORTUNITIES FOR STEEL IN THE HOUSING SECTOR

Regulation opportunities

New codes are regarded as an opportunity for steel:

- "Eurocodes", structure and loading: At the present time great changes are in way with the structural design. Eurocode 3 «Design for Steel Buildings» will shortly replace national structural code for steel construction. This is a good opportunity to use the Eurocode to promote steel in building construction.
- "New thermal regulations": It includes new European Approach in legislative issues including latest consequences of the Kyoto agreement. The project should be able to minimise thermal losses of the building construction system. From the KYOTO agreement and the concerns of green house situation, a new European approach has been developed on the thermal performance of building "Energy performant Buildings". This is transferred at national level by drafting new thermal codes. In France the RT2000 new thermal performance code is applicable from June 2001 and has already been redrafted for increased performances in 2005. It will be applicable in June 2006 and the result should be an increase of 5% on the global energy consumption performance. This new standard for thermal behaviour including thermal conforms, summer and winter behaviour, energy consumption and green house performances.

These codes include both residential and individual sector. This is already in application. Sustainability and Energy consumption are key points and can also be analysed from answers at the WP1 results. One of the main goals of the analysis is to show that steel based construction can achieve good performances especially in the cost/comfort ratio. The evaluation points out regarding expected high level of energy consumption efficiency in way to reduce energy use of fossil fuels in operation.

Structural code with the implementation of Eurocode will also induce changes in the design of structural frames. This is of prime interest as the plastic design will be promoted and create more opportunities to take count of all aspect of the design. As a reminder live load in European countries for housing and some other buildings are summarized in the following table.

The following table gives requirements and safety factors for variable loads in buildings.

Table 1 Live loads in buildings

Load (daN/m²)	Residential	Office	Theatre	Safety factor	Code
Belgium	CR = 200	CR = 300	CR = 300	1,5	NBN B03-10-

					1986
France	CR = 150	CR = 250 to 400	CR = 400 to 500	1,5	NF – P – 06 - 001
UK	CR = 150	CR = 350 to 750 5 categories	CR = 500	1,6	Building Regulations – BS 6399 Part 1
Germany	CR = 150 CC = 200	CR = 200	CR = 500	1,7	DIN 1055
Italy	CR = 200 - CC = 400	CR = 200 to 500	CR = 500	1,5	C 24.5.82 N22631
Switzerland	CR = 200	CR = 300	CR = 400 to 500	1,5	SIA 160
Spain	CR = 200	CR = 200 to 400	CR = 300 to 500	1,5	
Netherlands				1,7	
Sweden	CR = 50 + 150	CR = 100 + 150	CR = 100 + 150	1,3	
Finland	CR = 150	CR = 200 and 250	CR =250 to 400	1,6	Rak Mk B1

NB: The values indicated above are a synthesis of the normative elements relating to the loads. Details of the requirements are actually more significant than what is indicated. The reading of the standard remains necessary. In Switzerland, the cantons have their own requirements. CR = distributed loads, DC = concentrated loadings when that is considered. In general, when heavy equipment are not present, the current experience indicate that the floors can be calculated with a load uniformly distributed indicated in the table + an additional self weight load to take count of partitions walls (100 daN/m² as example for the residential buildings).

2. UNITED KINGDOM

The use of light steel framing as a method of house construction has increased significantly throughout Europe in recent years. Apartments and larger residential buildings generally use primary steel frames with secondary light steel infill walls. The steel industry has supported an intensive technical development, and housing systems are now available from several European companies. In the UK, the market share for steel has reached approximately 9% of current house and apartment building and this share has doubled since 2002. In the USA and Australia, the market share for steel has reached over 15%, mainly in regions associated with hurricanes and insect infestation. Some success is being experienced in other European countries, notably France, Netherlands, Sweden and Finland. The market expansion is underpinned by intensive research and development at a European level, especially in the areas of structural design, acoustic insulation, thermal performance and modular construction.

2.1 LIGHT STEEL FRAMING

Light steel framed housing comprises walls and floors fabricated from galvanised C, Sigma or similar cold formed sections of 1.2 to 3.2 mm thickness. The most common form of light steel construction involves prefabricated wall panels and floors in which the joists are installed as individual elements. This is known as 'platform' construction shown in Figure 2.1. Construction of the second floor begins using the first floor as a working platform. The framework of a typical house is shown in Figure 2.2. The roof space can be occupied and internal walls are re-locatable to increase flexibility in use of the space internally.

Figure 2.1 *Installation of light steel frame in housing*

Figure 2.2 *Typical house framing with habitable roof space*

Advantages of light steel construction in comparison to more traditional construction systems are:

- Rapid construction times
- Ability to easily achieve good thermal efficiency (important in northern European climate)
- High levels of dimensional accuracy and long term dimensional stability
- Good strength to weight ratio
- Robust and ductile in the event of accidental damage
- Structural sections are easily recycled
- Freedom from insert attack and rot
- Resistance to hurricanes and seismic events

This technology has expanded partly as a result of important demonstration projects, which include the Oxford Brookes student residence constructed within European MegaProject 5, and the Murray Grove apartment building in London, which is notable for its use of light steel construction in modular form. The results of building physics tests for the Oxford Brookes building are summarised, and the paper concludes by introducing concepts of hybrid (combined panellised and volumetric construction) currently being explored.

2.2 PANELISED HOUSING SYSTEMS

The Oxford Brookes Demonstration building was intensively monitored between 1997 and 2000. The building formed part of European MegaProject 5. It was designed using the Corus ‘Surebuild’ system of light steel framing, to emphasise the best features of light steel framing, and to be representative of developer-led housing in the UK (see Figure 2.3).

Figure 2.3 *Oxford Brookes demonstration building*

The demonstration building includes habitable open roof spaces, has a high level of thermal insulation, relocatable internal walls, light versatile foundations, and is designed for rapid erection. The building has approximately 275m^2 of usable floor area and consists of a two-storey house attached to a three-storey studio apartment building. The three-storey portion of the building includes three studio bedrooms and shared kitchen, plus a self-contained two person flat in the open roof space. The semi-detached house is self-contained and is typical of the good quality modern house construction in the UK. It has three bedrooms plus a habitable roof space that may be used as an office, playroom or fourth bedroom.

The framework comprises prefabricated storey-high wall panels constructed using 75mm deep steel studs, and floors constructed using 150mm deep joists. The platform construction uses the walls and floors to form a stable box. The roof members comprise 'C' shaped sections in an attic truss configuration on the two-story side of the building and purlins spanning between flank walls on the three-storey side of the building.

Before construction, the structural performance of the light steel framing was verified by an extensive series of full-scale tests under vertical and horizontal loads carried out by Corus in South Wales. The light steel framework was tested under horizontal load firstly without, and then with its brickwork cladding. A horizontal load test on the light steel framework is illustrated in Figure 2.4.

The load tests were carried out under a horizontal wind pressure of 0.85 kN/m^2 and a floor imposed load of 1.5 kN/m^2. A load factor of 2.2 was applied under horizontal load, and no failure occurred. These tests demonstrated the structural resistance and stiffness of light steel framing, and show how this form on construction may be used to resist seismic events and hurricanes.

Figure 2.4 *Testing of light steel frame under horizontal loads*

In terms of energy efficiency, the measured U-value of the wall was 0.216 W/m^{2}K, which compares well with the theoretically calculated value of 0.2 W/m^{2}K. The small difference between the two figures is expected because of the effect of thermal bridging and also because of the effect of air movement within the thickness of wall. The U-value achieved in this wall construction compares very favourably with current Building Regulations requirements, and current recommended best practice in the UK.

The air change rate at 50 Pascals was measured as 7.7 ach^{-1}, which equates to a background infiltration rate of approximately 0.38 ach^{-1}. This is better than the UK average air-tightness for all dwellings of about 13 ach^{-1} at 50 Pa. It is approximately equal to the average air-tightness achieved in new houses in the UK, although considerably more than the 2 to 3 ach^{-1} and below that are achieved in some low energy homes, and which is standard practice in Sweden, for example.

Table 2.1 *Summary of the acoustic performance of the Oxford Brookes University demonstration building*

Oxford Brookes University demonstration building (dB)	D_{nTw}	C_{tr}	$D_{nTw} + C_{tr}$
Airborne sound insulation of wall (D_{nTw})	65	-9	56
Airborne sound insulation of floor (D_{nTw})	57	-8	49
	L_{nTw}	$D_{nTw} + C_i$	
Impact sound transmission of floor (L_{nTw})	54	54	

The acoustic performance of the building is summarised in Table 2.1. The acoustic insulation of the walls considerably exceeds the requirements of the current UK Building Regulations by at least 5 dB. The C_{tr} value represents a correction factor for low frequency sound which is required by the 2003 Regulations. The tests demonstrate that light steel framing may be used in multi-occupancy dwellings.

2.3 MODULAR HOUSING SYSTEMS

The Murray Grove housing project in Hackney, London was designed by architects Cartwright Pickard for the Peabody Trust, a major housing association in the UK. The client wished to procure a building that was architecturally interesting, of a high and reliable quality, and which could be constructed quickly. A modular approach was therefore adopted and the design was developed together with manufacturers, Yorkon.

The building is 5 stories high and is located on a tight corner site as shown in Figure 2.5 and Figure 2.6. The majority of the accommodation was constructed using 3.2m wide modules. Two modules were used for one-bedroom flats and three modules for two bedroom flats. Other building elements including the cylindrical stair tower, external access balconies and monopitch roof, were all prefabricated. Stability to the access ways was provided by external bracing. The external façade to the street consists of terracotta tiles, whilst the façade to the courtyard behind the building incorporates steel balconies to all of the apartments.

The 80 modules were installed in only 3 weeks and the whole construction process from foundation level took 3 months, approximately half that of more conventional on-site construction.

Figure 2.5 *Murray Grove module installation*

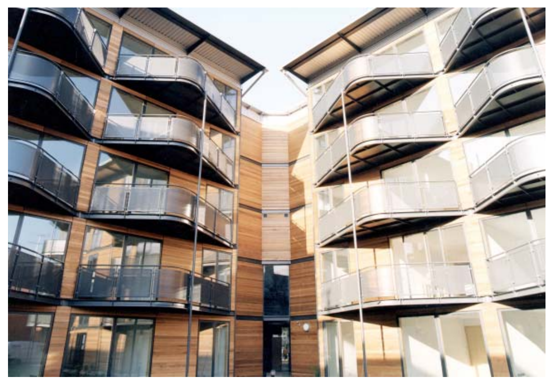


Figure 2.6 *Murray Grove courtyard elevation*

Modular construction has also been used for refurbishment projects. A recent project for student accommodation in Plymouth carried out by a specialist key worker accommodation provider 'Unite', and has involved placing 28 modular bedrooms on the roof of a 4 storey former office building. The modules were fully fitted out and were fully serviced before delivery to site. They include en-suite bathrooms, power and data cabling and security systems. The roof-top extension was clad using a proprietary curtain walling system.

The modules comprised 75mm deep $\times$ 1.6 mm wall studs and 225mm deep lattice joists (see Figure 2.7). Square hollow sections were introduced as corner posts on the front façade so that windows could extend over the module width. The modules were constructed with an open side to that adjacent modules could be placed together to minimise the internal wall thickness and meet tight internal planning requirements. Installation of the modules took only 3 days.

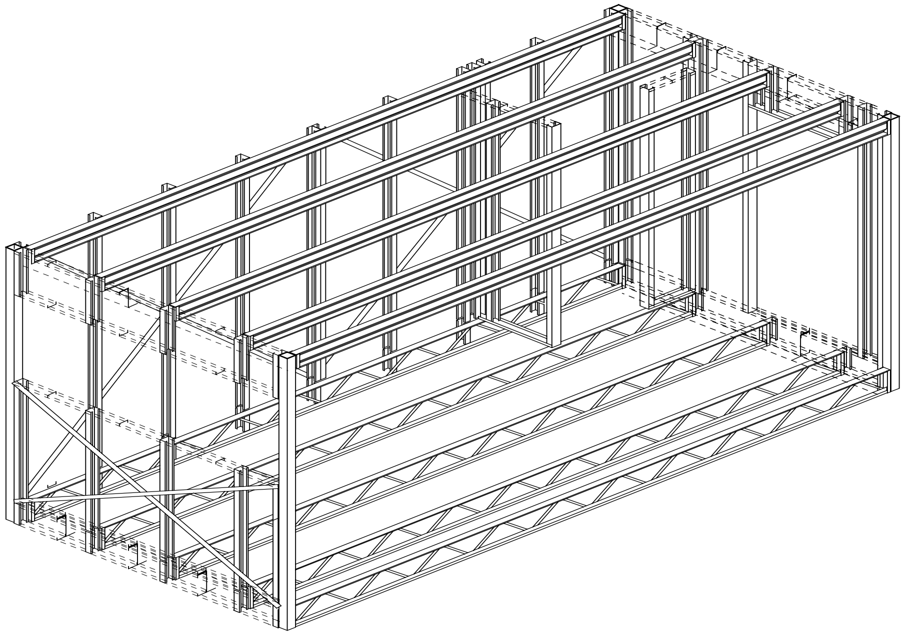


Figure 2.7 *Open-sided module used in the roof-top extension*

2.4 INFILL WALLS AND PARTITIONS

The recent introduction of small-scale roll-forming machines has dramatically changed the economics and availability of light steel framing. These roll-formers can produce C sections of 65 to 150 mm depth in steel thicknesses of 0.9 to 1.6 m. Wall panels can be designed by lap-top computer, and are manufactured and assembled accurately using pre-punches holes for screw connections. This type of production has been mainly used for non-load bearing infill walls, but can also be used for single storey housing.

The use of light steel framing is generally combined with plasterboard for acoustic insulation and fire resistance. Boards are fixed in place using self drilling, self tapping screws, as shown in Figure 2.8.

Figure 2.8 *Screw fixing of plasterboard to light steel infill walls*

The use of light steel infill walling is a steel framed building (using *Slimdek*). This is illustrated in Figure 2.9. Excellent acoustic insulation can be achieved in double layer separating walls

Figure 2.9 *Infill walling used to support cladding in a steel framed building in Slimdek*

2.5 FLOORING SYSTEMS

Light steel floor joists are usually in C or Sigma-shape and are 150 to 200 mm deep depending on their span. They are designed to relatively strict deflection limits in order to reduce vibration sensitivity. For lightweight floors, it is recommended to design for a total deflection under imposed load and self-weight of less than span/350 and not exceeding 15 mm. This limit ensures that the natural frequency of the floor does not fall below 8 Hz, which means that resonant effects due to rapid walking do not occur, and vibrations are minimised.

Lattice joists have been developed for longer span applications (4.5 to 6 m). Figure 2.10 shows a load test on a 225 mm deep lattice joist floor using 65 mm × 1.2 mm C sections, produced by a small-scale roll-former. The test demonstrates that an imposed load of at least 2.5 kN/m^2 can be supported.

Figure 2.10 *Load test on 4.5 m span lattice floor (each steel coil weighs 350 kg)*

2.6 ADAPTABLE AND SUSTAINABLE CONSTRUCTION

A recent European demonstration project has resulted in 5 housing and residential buildings that are designed for rapid construction and excellent performance characteristics. A 'hybrid' panel and modular building was constructed in which the toilet-bedrooms, kitchens and stairs were all constructed as modules. The load bearing walls and floors were constructed as 2D-elements. The completed prototype building is illustrated in Figure 2.11, and the construction sequence is illustrated in Figure 2.12.

Figure 2.11 *'Hybrid' modular and panel building constructed in an ECSC demonstration project*

The floor system consists of a plyweb beam that comprises C section flanges and two plywood webs. These 320 mm deep beams span 5.25 m between load-bearing walls and internal walls could be positioned to suit user's requirements. They also possess excellent acoustic and thermal insulation properties, as established from on-site tests.

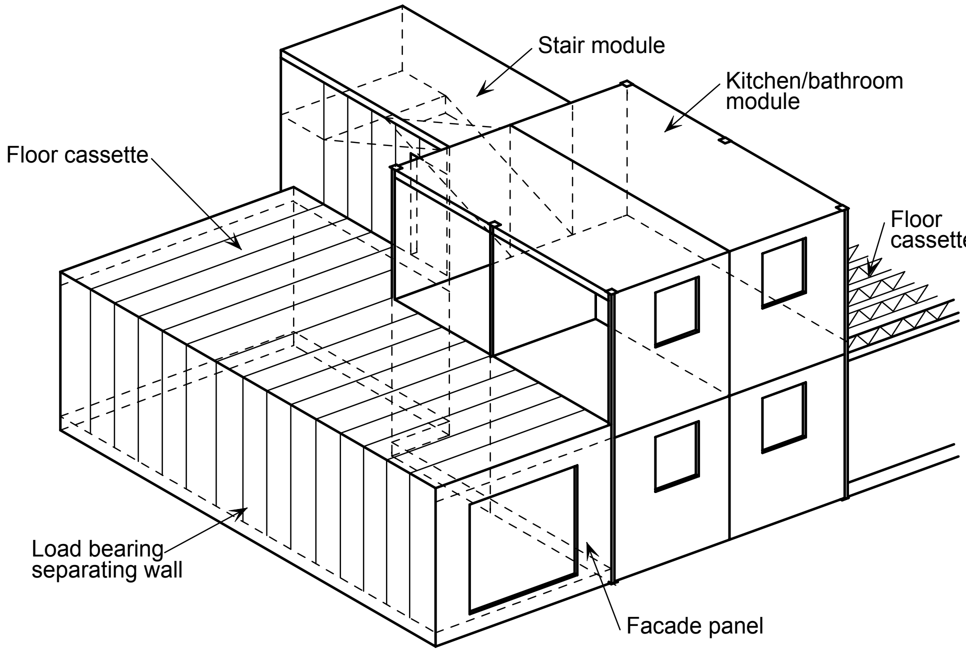


Figure 2.12 *Mixed use of modular and panel construction*

Similar demonstration projects have been completed in Finland, Sweden, Germany, France and Italy. In principle, this 'hybrid' technology could be used to create a new way of building for urban locations, as illustrated in Figure 2.13.

Figure 2.13 *Urban street-scape created by mixed use of panels and modules* (courtesy HTA Architects, London)

2.7 MEDIUM-RISE BUILDINGS IN STEEL

In the UK, the market for steel in 4-8 storey residential buildings is also growing and has reached 20% of the apartment sector, which is itself close to 40% of current house building. The following images in Figures 2.14 and 2.15 show recent examples of steel in composite construction and in *Slimdek*, a system developed by Corus.

Figure 2.14 *16 storey apartment building using composite construction in Manchester*

Slimdek achieves the advantage of a floor of minimum depth without downstand beams, which means that walls can be positioned without concern for beam positions. Often square hollow section (SHS) columns of less than 200 mm are used, in order to fit within separating walls. Light steel infill walls and separating walls are used in all forms of construction, as they are lightweight and can be installed rapidly (see Figure 2.9).

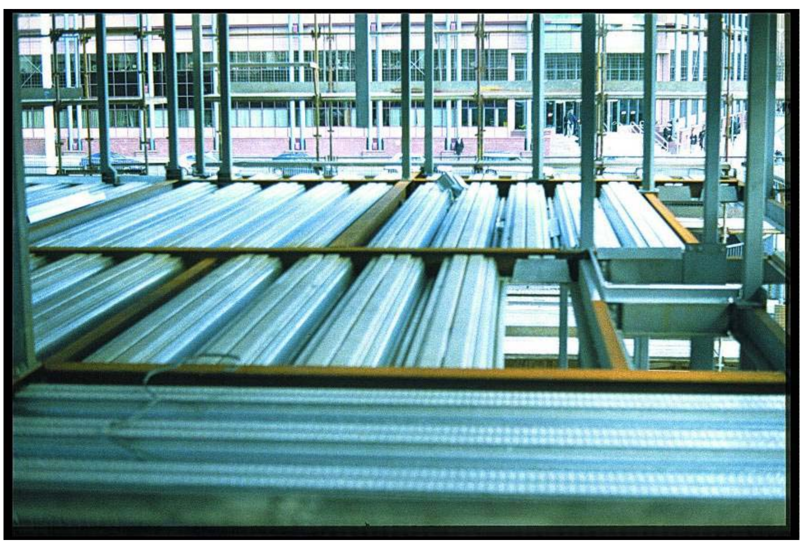


Figure 2.15 *Slimdek construction in an apartment building in Glasgow*

The world's largest modular building was constructed in Manchester in 2002 and consists of over 900 modules, as shown in Figure 2.16. Modules are completely finished before delivery to site. Stability is provided by braced steel cores located at the corner of the building. It was constructed in 6 months to meet the start of the academic year.

Figure 2.16 *Modular building in Manchester consisting of over 900 modules*

Installation of a typical light steel module is shown in Figure 2.17. In this design, the modules are continuously supported around their perimeter. Alternatively, modules can be supported at their corners in which case they can be designed with open sides. A corner-supported module is illustrated in Figure 2.18.

Figure 2.17 *Installation of finished module showing safety cage*

Figure 2.18 *Corner-supported module in light steel framing*

Modular construction is currently limited to 6 – 8 storey buildings, and future developments will concentrate on the mixed use of primary steel frames and modules. In this case, slim floor beams may be used to support the modules, which are manufactured with recessed corners and sides in order to minimise the wall and floor depth. The primary structure is braced, and may be designed up to 20 storeys, depending primarily on fire resistance and stability requirements.

2.8 LIGHT STEEL FACADES

Light steel cladding may be used in residential buildings and are supported by light steel infill walls. The types of light steel facades that may be used are:

- Composite panels (sandwich panels) for roofs
- Large cassette panels
- Profiled sheeting (particularly for roofs)
- Brick-tiled systems with steel backing sheets
- Vitreous enamel bonded sheets

An example of the use of large steel cassette panels with a metallic finish in Corus Celestia range as used in the Ashorne Hill Management School, illustrated in Figure 2.19. These panels were attached directly to the supporting modules. Brick-slip and clay tiled systems have been used on some housing projects to improve the speed of installation. Insulated render cladding is increasingly used in apartment buildings.

Figure 2.19 *Large cassette panel used in modular construction*

2.9 FUTURE DEVELOPMENTS

Future developments of steel is housing in residential buildings will include:

- Mixed use of light steel, hot rolled steel and modules in open building systems.
- Development of light steel composite construction, involving steel and timber, or steel and gypsum screed.
- Energy efficient solutions for cladding using steel.
- Effective integration of services.
- Off-site manufacturing techniques to increase speed of installation and to improve productivity and reduce waste.
- Roof-top extension to buildings inn renovation projects.
- Development of steel technologies for high-rise residential buildings.

2.10 REFERENCES

[1] Steel Construction in Housing – Brochure of four demonstration buildings for the UK, France, Germany and Finland

[2] Lawson R. M., Grubb P.J., Prewer J and Trebilcock P. J., *Modular construction using light steel framing: An Architect's Guide*, The Steel Construction Institute Publication 272, 1999

[3] Lawson R. M., Ogden R. G. and Hicks S. J., *Steel in multi-storey residential buildings*, The Steel Construction Institute Publication, 2004

[4] Steel in Residential Buildings for Sustainable and Adaptable Construction. Final Report of ECSC Project 7215/PP/058 (published in September 2004)

3. FRANCE

3.1 STEEL FRAMED AND STEEL ENVELOPE BUILDING

3.1.1 THE PRISM CONCEPT

All the systems with good thermal and acoustic performances that allow a rapid, simple and safe construction have a considerable potential. In that way, industrial products, ready to fix, provide good opportunities to achieve gains in term of market parts. The PRISM system of building concept (PRISM = Produits Industriels et Structures Manufacturées) is a relevant answer to provide the building market with steel solutions.

The goal is to evolve in the development of steel based elements including other material producers and to develop new economic and productive concepts for building. This concept is developed by the synergy with any kind of material being complementary of steel, to optimise the combination of steel with the other materials and develop new industrial proposals. This is made in co-operation between all actors of the building act including industrial producers, small size contractors, and technical centres.

The PRISM Concept started first with columns - beams frame system called 3PM concept "Poteaux, Poutres et Produits Manufacturés ". In this concept, columns were composite hollow sections (RHS or CHS) filled with concrete and the beams were unsymmetrical I sections embedded in the floor system. The 3PM concept was an attempt to replace the structural concrete sections with composite ones, columns and beams.

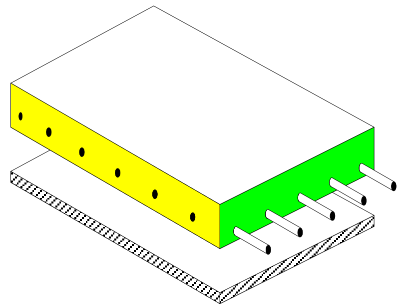
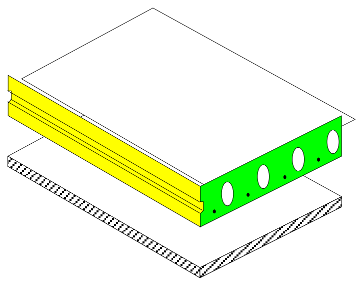
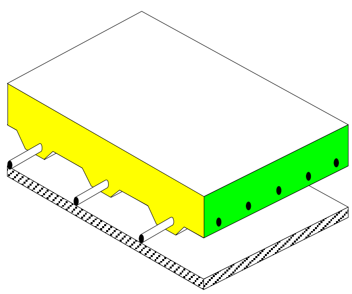
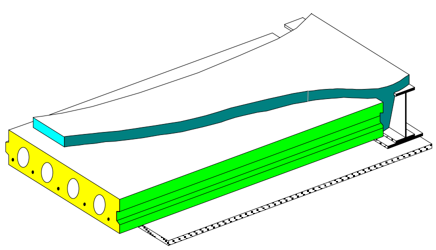
Slabs

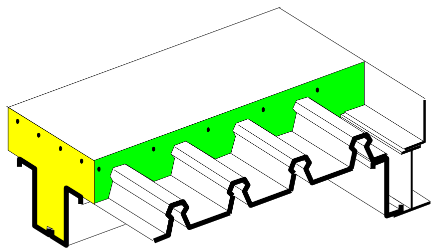
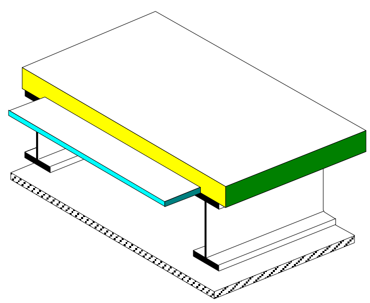
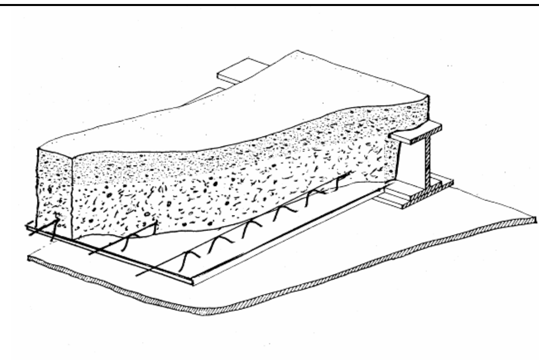
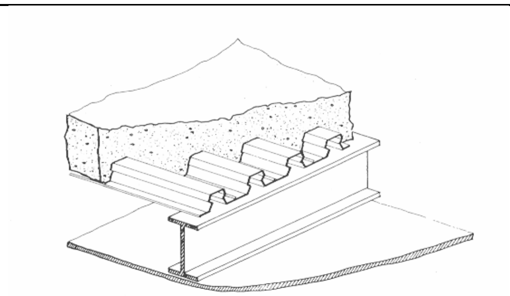
The slab can be of several types including:

- Concrete planks (pre slab and poured concrete),
- Hollow core concrete slab,
- Composite slab (steel sheeting and poured concrete),
- Long span slab composed of steel shuttering (cold formed section and steel sheeting) with poured concrete,
- Classical dry systems (light steel slabs, wooden slabs,...).

Table 1 shows different slabs systems of floors in residential buildings with information on required thickness.

Table 1 Different slabs systems for residential buildings

	Type	description	Total thickness
1		Plain reinforced concrete slab130 mm thick + plaster board ceiling Limited span	230 mm + Beam depth
2		Prefabricated reinforced hollow core concrete slab 160 mm thick + plasterboard ceiling Need a T shape section for support Limited span	260 mm + beam depth
3		Prefabricated ribbed concrete slab 250 mm + Plasterboard ceiling Limited span	350 mm + Beam depth
4		Hollow core concrete slab, prestress and prefabricated. Need a T section for support	250 mm

	Type	description	Thickness
5		Composite slabs 150mm + Z Shape support. Support beam is imbedded with concrete	450 mm
6		Plain reinforced concrete on concrete planks, 150 mm thick. Supports on joists. Slab's span up to 4 m	380 mm
7		Plain concrete on reinforced concrete planks. Need to use props during erection	200 mm
8		Composite slabs. Need to use props during erection.	430 mm

Note: Systems 4, 5 and 7 need un-symmetrical support beams (Lower flange is wider than upper one) to allow support on the lower flange. Fabricated industrial beams are used.

The structural concrete allows also for acoustic performances between apartments. One consider usually that a concrete thickness of 22 cm will allows enough acoustic resistance to comply with the requirement. Other acoustic resistance system can be used in combination with these proposals.

Note: Solution 8 is not convenient when acoustic resistance shall be required for housing. Partition wall are not efficient with this system.

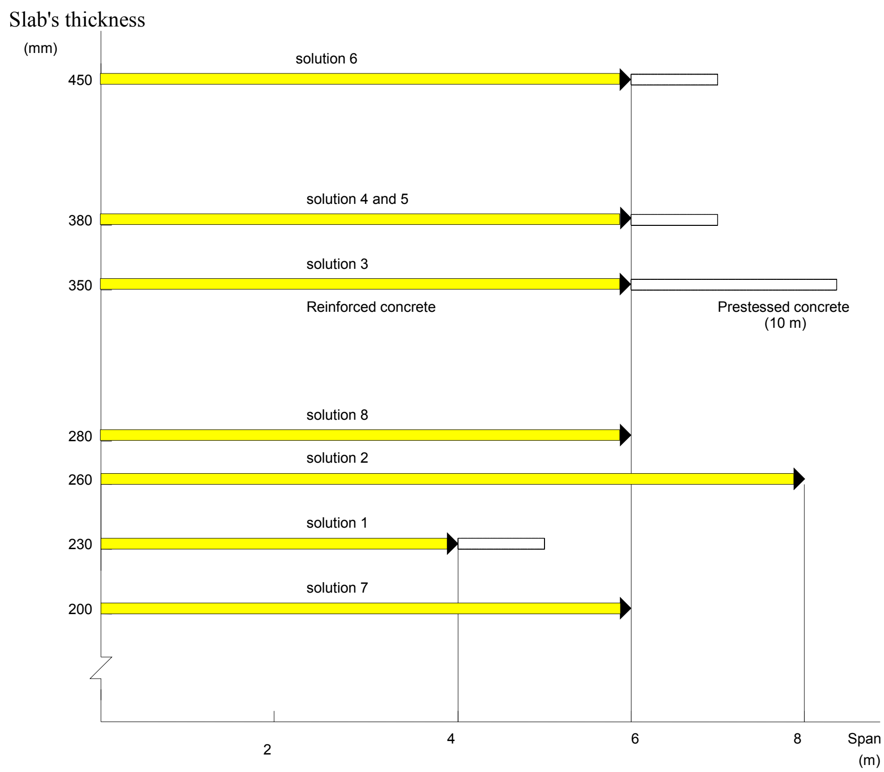


Figure 3.1 Practical slab's spans for systems

Envelope

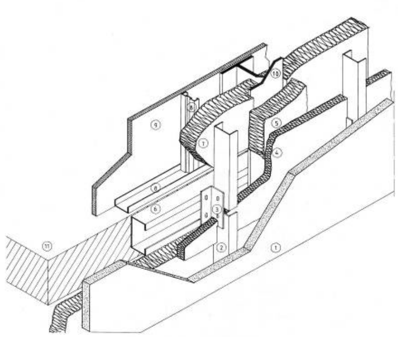
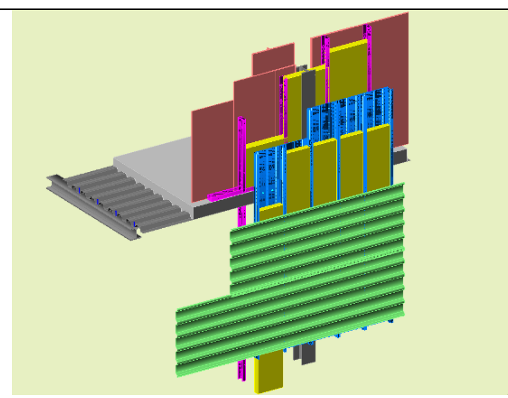
External walls are semi-curtain walls. The supports of the external wall are not the columns but the slabs. In this system, the building is erected beginning with the frame and the slabs from bottom to top, the roof system is built and the external walls are built from top to bottom. Thermal insulation is fixed on the wall and as a whole, the frame is considered as thermally isolated. Inner parts of the external wall are built from slabs to slabs on sub-structural frames (cold formed sections) and are fitted with plaster boards.

All the components of the system are common and well distributed on the market. They are heavily prepared in workshops and the site work can be deeply reduced. This system uses intensively cold formed sections for all the wall substructures (external and internal). This system is mainly devoted to building in the field of the collective habitat but most of the proposed solutions extend up to the field of tertiary sector.

Figure 3.2 The PRISM system during erection: Steel frame, roof and external façade sub-frame ready to receive external thermal skin.

PRISM proposes two systems for the facades. One with terra cotta element fixed on a steel sub-frame, and one with stucco fixed on steel sheeting.

External part of the facade

Terra cotta proposal	**Stucco proposal**
	
The external skin made of terra-cotta elements: Weight: 32 DaN/m², Thickness: 36 mm including lattice sections, Lattice C section 22 x 36 x 22 x 15/10, and Maximum lattice frame interdistance: 305 mm or less. The lattices are fixed on the vertical	A galvanised steel sheeting HACIERBA 1.400.90 SR (75/100) set vertically. This sheet is 93 mm thick, a 20 mm thick air circulation integrated into the next HACIERBA steel sheet, The waterproof polypropylene film,

studs. A waterproof polypropylene film is fixed on the studs. This external skin is for architectural aspect and is not integrated into the thermal design of the envelope. It also protects the envelope from rains. In this system, terra-cotta elements can be removed for replacement or for maintenance. The total thickness of the external elements is 180 mm.	The external skin made from a stucco skin pasted on the steel sheeting using a fabric mesh to fix the stucco on the steel sheet, The internal volume of the steel sheeting is filled with thermal resistant glasswool material, 75 mm thick. The total thickness of the external elements is 160 mm.

Figure 3.3 External part of the wall – two proposals

Internal part of the facade

The internal part of the wall is composed from outside to inside:

- A void of 48 mm permitting the inclusion of thermal protection of the slab's edges and the structural columns,
- A 85 mm thick glasswool thermal resistant material,
- The steel sub-structure for plasterboard wall. This is composed of horizontal rails and vertical studs,
- Two fire resistant (1 hour) plasterboards 13 mm thick each.

The total thickness of the internal elements is 154 mm.

The slabs edge and columns are thermally protected from outside by a 30 mm thick thermal resistant glasswool material avoiding for thermal bridge. The total thickness of the wall can vary between 290 and 320 mm.

Plaster boards fixed on steel sub-frame, are used for internal face of the façade. Extra thermal insulation can be fixed to reach the level of thermal insulation required for the façade.

All the frame of the building is protected from the outside leading to optimised thermal performances. Need for thermal insulation in positioned in the external volumes and in internal volumes if extra needed.

Figure 3.4 The PRISM system: Example of external skin envelop – Terra-cotta proposal

Partitioning

Internal partitioning is made of plasterboards fixed on an internal steel sub-frame. This technique as for example Pregymetal from the Lafarge Company is well known and largely used for building construction. It permits to reconfigure the slabs layout after several years of use (reconfigurable building).

3.1.2 SPECIFIC KEY ADVENTAGES OF STEEL FRAME

- A steel frame has the advantage of generating important volumes thus allowing a great modularity in the organisation of spaces.

- For the construction of slabs, concrete is flowed on concrete pre-slabs put on the lower flanges of the steel beams, imbedding the steel beams into concrete. This fulfils fire resistance requirements and eliminates the problem of corrosion. Generally, a thickness of 20 cm is sufficient for acoustics requirements.

- The external facade of the building realises the complete closure and envelops the building, thermally isolating the frame from the outside conditions. The internal part is composed by a complement of thermal insulation, one steel sub-frame and plasterboards.

- Partition walls are plasterboards panels screwed on a galvanised steel sub-frame fixed between the floors. They are not supporting elements and can be replaced allowing the resetting of spaces according to needs.

This concept based on the rational use of steel, gives great flexibility and adaptability in regards to technical and economical requirements. It offers solutions integrating the need for durability, consumption of energy and recycling of material. This form of construction is most economic for apartment buildings of one or more storey height.

General key advantages are:

- Rapid construction using steel framing,

- Mixed steel and concrete for long spans,

- Large storey floors available for storage of the material during construction, important because of lack of site area,

- Non bearing wall allowing wide internal open space,

- Adaptable internal space,

- Good acoustic insulation using light partition walls,

- Frame incorporated in the building skin, reduced heat looses, good thermal performances,

- Reducing running costs,

- Lightweight facade,

- Use mostly recyclable materials.

Figure 3.5 Example of building made with the PRISM system

3.2 SLABS SYSTEMS

3.2.1 PCIS

The PCIS is a dry system for slabs to be used in residential collective buildings. Beams are integrated into the slab's thickness.

Supporting beams are non symmetrical structural steel sections, the lower flange is wider the the upper one. The sections can be fabricated or by another way, a complementary plate is welded under the lower flange of a symmetrical section. The beams are simply pinned on the supports. Slab's depth is 32 cm. The steel beam are spanning from 3 up to 6 meters.

The composition of the slabs is as follow, from bottom to top:

- Transversal support "structural slab" is made from galvanized profiled steel sheeting's HACIERCO, 1,5 mm thick, fy=320 N/mm² minimum, from the Haironville company. The steel sheeting is screwed "self tapering screws" to the supporting beam.

- A mineral wool, 3 mm thick, 230 g/m², Vélimat, is bedded to realize a regular support for a triplex wooden panel, 12 mm thick. Theses panels are screwed on the steel sheetings,

- A PREGIPLAC, 13 mm thick plaster panel with hard finishing's for circulation support,

- Ground circulation and finishings, hard or soft.

The slab is completed with a ceiling material:

- Thermal and acoustic insulation, mineral wool TELSTAR, 45 mm thick for fire resistance 30 minutes or rock wool ALPHALENE, 70 mm thick for 60 minutes fire resistance,

- Two plaster boards BA 13 PREGYPLAC (fire resistance 30 minutes) or PREGYFLAM (60 minutes fire resistance).

The PCIS is a dry system, no needs of concrete. All materials are easy to fit and can be operated by a small team of workers.

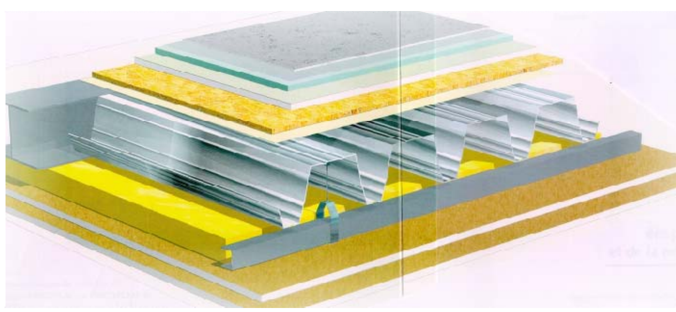


Figure 3.6 3D cut of the PCIS slab – From commercial document

Performances:

- The slab is designed for a live load of 150 daN/m² (housing) and spans up to 6 m. The total load to be supported is 250 daN/m². The slabs system acts also as bracing if a parametrical connection is realized. This is the case in the actual realization by screwing the steel sheetings on the parametrical beams. Nevertheless a classical cross bar bracing is still used.

- Vibration requirements are met at a 3Hz level.

- Fire resistance is minimum 30 minutes depending of the choice of plaster boards.

- Acoustic performances are Dn aT > 66 db (A), Ln aT > 54 dB (A) for impacts, ΔL = 13 dB (A).

As the slab is not designed for service integration, all services shall be distributed in partition walls with vertical raisers columns.

Modularity of the system id high and reconfiguration are alternative opportunities.

Ground slabs are nevertheless designed as composite steel/concrete slabs. PCIS is used only for upper levels. All materials are easily available on the market.

As the part of concrete for slabs in the total weight of a building is usually quite important, the use of the PCIS system will deeply reduce the total weight of the building by a large part and thus reduce foundation works.

3.2.2 COFRADAL 200

3.3 LIGHT STEEL FRAMING

In the housing construction sector in France, the cultural way of thinking about building processes are still "traditional way of doing", based on mortar assembled mineral elements. If other countries have historically developed industrial construction systems using manufactured elements, the single-family dwelling remains in mind of the French people a "stone or bricks made for life" construction.

Nevertheless since about fifty years and taking count of technical progress with materials, several innovative systems have made some attempts to enter the market of single dwelling housing, but most of them failed in their trial. Indeed, during the last decade, the single-family dwelling market of new construction represents approximately 150 000 units every year in France. Less than 10 000 of these are constructed with steel frames.

3.3.1 THE STYLTECH SYSTEM

The Styltech system was promoted from 1995 following an initiative from Usinor (now part of Arcelor Group) associated with large industrial partners. The system is based on the use of cold formed steel sections for the frame available for and up to 3 level buildings.

Facades and roofs can be made as well from traditional material as from steel products.

Styltech is voluntary professional sector oriented and is promoted through a network of 45 medium size company implanted in 31 departments all over France. These companies possess the basic professional skill as such as carpenters, secondary works, masonry or plaster works.

They are all approved by Styltech and are acting as "general work" contractor.

The various technical supports from Styltech are professional documents for contract drafters or contractors. Technical support can be asked from Styltech for architects, engineers, properties developers as well as first estimation of the economical approach.

Figure 3.9 Some aspect of the Styltech system

3.3.2 MPC: MAISON CONCEPT PREGYMETAL

The present system is a development proposed by LAFARGE Plasters Company, from an earlier development called MEPAC.

The frame is made of galvanized steel profiles sections. Steel thickness is less than in 1.5 mm. Limitations are set for some applications. The frame is completed with small wooden truss frame for the roof. This is a dry system of construction. Vertical faces are composed of LAFARGE plaster products and mineral wool.

MCP is not at the front edge for marketing action and has a modest number of realizations. Nevertheless, the constructions of simple forms show an aspect close to the traditional way which facilitates their integration in the country.

The last Technical appreciation "Avis Technique" set up that the system performs relatively well with Thermal behaviour. Site experience returns and the opinion of the specialized technical groups; suggest that building shall be made by general contractors or groups of contractors in a way that each work should be performed by well skilled workers.

Figure 3.10 MPC house during erection and after completion

3.3.3 MAISON PHENIX

Leader on the French market with 6000 houses delivered in 2002, with 50 years of experience, Maison Phénix is one of the most efficiently house building system distributed product. The steel frame is made from IPN / E or angle sections. The adaptability and the customization of products conduct to a wide range of housing forms. Facades can be as varied as any other products and fit well in the neighbourhood of brick and block of traditional housing.

Established with 90 agencies distributed on the whole metropolitan France, the House Phenix network is rather homogeneous, with the exception of regions Auvergne and Rhone-Alps.

For the final customer, the group MI SA "Phenix" always appears as a contractor and takes care of the relation with the partner companies.

The technical documents are customer oriented, setting in front the claim the high quality of industrial products elements and components. The offer comes along with various services as the choice of the ground, the finances program, … of the project. It can be a global offer.

Figure 3.11 Maison Phenix during erection

3.3.4 SBS: STEEL BUILDING SYSTEM

Incorporated in group KNAUF Company from twenty years, the Richter System company set up on the French market to propose a steel framed system of constructions that has been developed recently in Germany.

The whole frame is made from cold formed galvanised steel C sections (thickness 2.0 mm). To date, the system has not been checked regarding the French requirement standards but it answers the DIN requirements.

At the beginning of its development on the French market, there is still no partners' network for the system at the present time.

Technical supports are German brochures that are well detailed. This system can be use for multiple building applications. Only a few refers to single-family dwelling in Germany.

Figure 3.12 The SBS Sytem, building during erection

3.3.5 COMPARISONS AND CONCLUSIONS ON LIGHT STEEL FRAMING

Three of these steel framed systems are using cold formed sections for the main structure. Only the Phenix system uses rolled section. The structural frame are linear elements "columns and beams", with bracing elements, except Styltech who consists of stressed skin concept. For all, connections are made with bolds "rolled sections" or self tapering screws "CFS".

The dry construction is recommended for intermediate floors; Styltech and Phenix also propose concrete solution poured on site.

Excepting SBS from Germany, all systems have been checked for stability following French code. Earthquake design should be investigated if needed. For fire safety, requirements for individual housing are simple and all systems comply with using plaster board panels as fire protection. A panel of mineral wool insulation separates the internal facing from the outside facade. Sometimes associated with other thermal insulating material, this mineral wool complies with the thermal requirement.

The products proposal for the external skin (facades) is wide and can be adjusted to needs of the client. The flexibility in the composition and the choice of materials is one of the key points of these systems.

The site construction is made by a general contractor or by a partnership working in general as grouped contractors. They use the system network of contractors internal or external to the groups. In a general way, site operation shall be made by well skilled, system teached and accredited workers.

Just like the process SBS of Richter, other emergent systems were also detected in a preliminary phase of this study and seem to follow this general evolution. For other market segments that the individual housing, the proposal of these systems seems to be competitive with modular construction.

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4. SWEDEN

4.1 SYSTEMS FOR HOUSING ON THE MARKET

Swedish market surveys including data from 1988-2003 indicates market shares for different structural systems on the market. The table 4.1 shows an estimation of structural system in percentage of the residential units built during this period.

Table 4.1 Structural systems estimated market share for new residential multi-storey buildings in Sweden (Widman 2004)

Structural system	Percentage of market
In-situ concrete (incl precast floor formwork)	66
Steel frame with prefabricated concrete	15
Prefabricated concrete	13
Steel frame with light steel system (incl exterior walls)	6
Wooden structure	<2*
Other	<2*

* Here set to zero

4.2 SYSTEMS FOR STEEL IN HOUSING

The three most common systems for multi-floor buildings are:

Steel stanchions are often rolled H-profiles or squared or round tubes. Ordinary space between stanchions is 2.4-4 m.

Beams often have a wide bottom flange. Thus the bottom flange supports the floor. The floor can be:

- Prefabricated concrete floor elements, e.g. hollow core floor elements
- Partly in-situ concrete floor e.g. and composite floors
- Light gauge steel floors, e.g. floors using light gauge steel beams, mineral wool and gypsum boards.

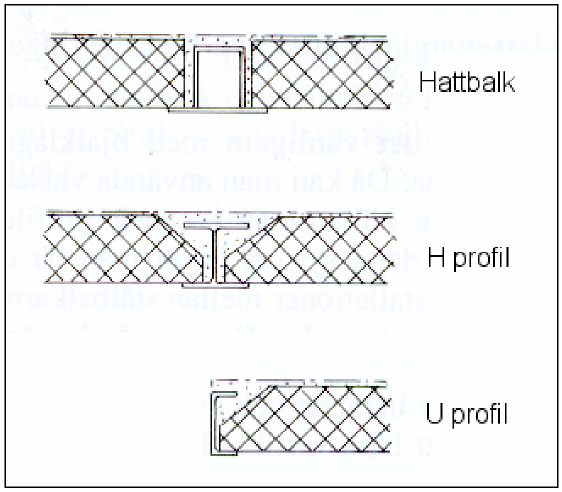


Figure 4.1 Some ordinary beams in Swedish multi-family housing. The U-profile is common along facades.

4.2.1 SYSTEMS WITH HOLLOW CORE ELEMENTS

Pre-stressed hollow core element is the most common prefabricated concrete element used in buildings in Sweden. It can be used for long spans: 9-12 m is possible with elements of 200 respectively 265 mm. The floor elements are supported by the bottom flange of steel beams of the same height as the floor element. Thus the steel beam is built in to the floor reducing the construction height and the need of extra fire protection to the steel. Concrete is used to fill in between elements etc. On top of the elements the differences in level are reduced either by a concrete or an installation floor.

Figure 4.2 Hollow core slabs and steel frames.

4.2.2 PARTLY PREFABRICATED FLOORS

Prefabricated concrete elements of 40 or 70 mm thickness with bare reinforcement on the upper side are also used. The reinforcement increases stiffness during casting and creates a composite action with the in-situ concrete. The elements are complemented with upper edge reinforcement and 140-250 mm concrete at site. The elements are supported by the bottom flanges of the beams and act as a mould for the in-situ concrete. Services can be placed on top of the prefabricated elements to be hidden in the in-situ concrete.

Spans of 8-10 m can be achieved with this technique dependant on thickness and if they are pre-stressed.

Figure 4.3 Partly prefabricated floors

4.2.3 COMPOSITE SLABS

A steel sheet with a special corrugation is welded to, or supported by, beams. On top of the steel sheet 140-250 mm concrete is casted. The steel and the concrete have composite action and use the steel sheet as reinforcement. Common height of the steel sheet is 45-120 mm with a thickness of 0.7-1.2 mm. Often a ceiling is built of aesthetic reasons.

Common spans are 6-8 m.

Figure 4.4 Composite slabs

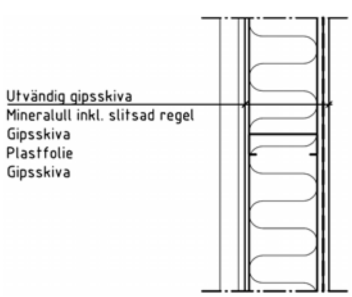
4.2.4 LIGHT GAUGE STEEL FRAMING

Light gauge steel framing is primarily used in low-rise buildings of 1-3 storeys. Slotted light gauge steel studs of the exterior walls are load bearing. Load-bearing walls with slotted light gauge steel studs can be combined with light gauge steel floors. However, presently in Sweden, light gauge steel floors are seldom used in multi-family housing. An exception is the use of light gauge steel in modular buildings, see example in Figure 4.5. Spans of up to 4 m are cost-effective.

Figure 4.5 Apartments using the OpenHouse system.

Exterior walls with slotted light gauge steel studs are built with steel studs with a space of 450 mm or 600 mm, insulated by mineral wool and with gypsum boards on both sides, see Figure 4.6. Any façade material can be chosen to complement the wall. A typical wall with 170 mm or 200 mm insulation gives a U-value for the wall of approximately 0,27 respectively 0,24 W/m²/K.

Floors with light gauge steel are constructed with load-bearing framework of cold-formed steel profiles (C- or Z-profiles) and board material, see Figure 4.6. Profiled steel sheets are screwed on top of the profiles and covered with e.g. gypsum boards. The floor is insulated in between the load-bearing profiles. A suspended ceiling is mounted flexibly to the structural C-profile. Typical height of C-profiles is 200 mm. A typical total height of floor is approximately 350 mm. In modular buildings intermediate floors are usually thicker, e.g. the floors in Figure 4.5 are building 450 mm.



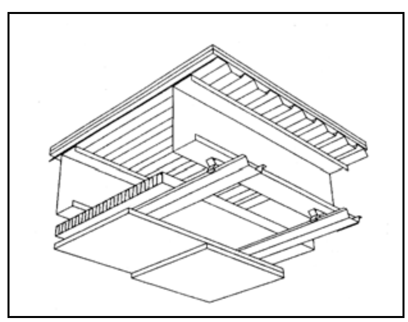


Figure 4.6 To the left: A wall with slotted light gauge steel studs. To the right: Construction principle for floors.

4.3 TYPICAL PERFORMANCE OF SWEDISH DWELLING

Indicator	
Construction time per unit	10-45 weeks
Cost of construction	
Multi family houses	€ 1,900/m²
Single family houses	€ 2,500/m²
Size of dwelling	
Multi family houses	63,1 m²
Single family houses	122,3 m²
Thermal insulation	To minimum building requirements (typical external walls with 170 mm or 145+45 mm insulation)
Acoustic performance	To minimum building requirements
Fire performance	To minimum building requirements

Figure 4.7 Light gauge steel housing at the Mälmo housing fair

4.4 A NEW EFFICIANT ON THERMAL LIGHT GAUGE STEEL PROFILES TECHNICAL APPRAISAL

Light gauge steel profiles with slotted web for exterior walls were developed in Canada during the 1960s and were introduced on the Swedish market in the 1980s. Today there are several Swedish suppliers of slotted light gauge steel profiles. The production technique and design differ slightly between suppliers but they are equivalent as to performance. This technique is common throughout the Nordic countries and an estimated market share for external walls in Sweden today is 5-10% and increasing.

The most common way to use the steel studs and rail in exterior walls is in combination with mineral wool, gypsum boards and plastic foil, **Figure 4.**. The different layers in the wall have different functions, meeting different operational requirements, e.g. shelter from rain and wind, air tightness, structural capacity, heat insulation, fire protection and acoustic insulation.

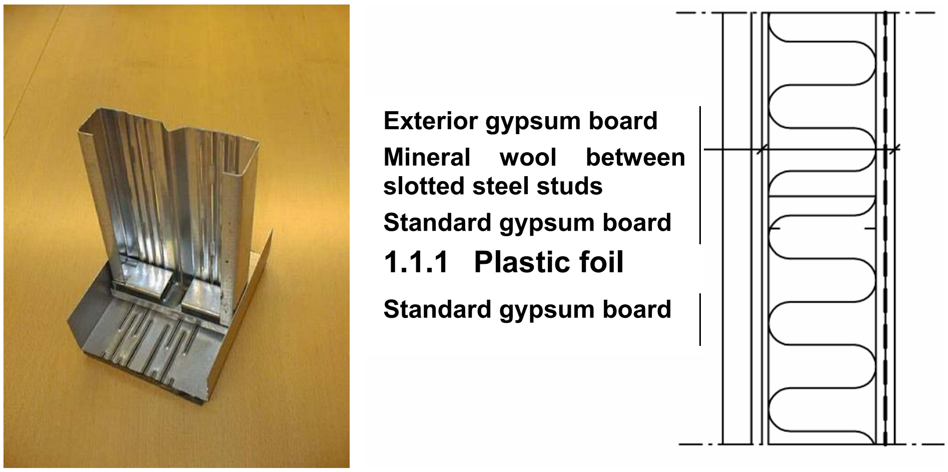


Figure 4.8 Slotted steel profiles: stud and rail, left. The steel stud in the picture has a slotted web and a centre crease in the web acting as a web stiffener. Some producers have profiles with the same function without the centre crease. An exterior wall with slotted light gauge steel profiles, right. The wall has gypsum board on both sides of the profiles. The wall is insulated with mineral wool and a plastic foil is applied in between two interior gypsum boards.

The suppliers of the steel profiles have different web depths ranging from 100 mm to 220 mm. The most common steel profiles are in the range of 150 mm to 200 mm. The thickness of the steel is from 0,7 to 1,5 mm. The profiles are made from strips of hot dip galvanized cold-rolled light gauge steel. The steel has a yield stress of $f_{yk} \geq 350$ MPa. The zinc weight is 275 g/m².

Rails and studs are delivered from the manufacturer in custom-made lengths with tolerances less than 5 mm. The depths of the profiles refer to the outer depth for studs but the inner depth for rails, as they have to fit into each other. The studs are asymmetric where one flange is approximately 5 mm longer than the other. This reduces the volume of the studs during transport.

Fastening of studs and rails are mainly bolted joints with self-drilling screws, 4.8x16 mm with only 1-mm head (in order not to damage inner layer of gypsum board). The screws can be cartridge screws. Gypsum boards are fastened with gypsum screws. Non-slotted Z- or C-profiles can be used as horizontal studs in combination with interior insulation. Other components in the exterior wall are end stiffeners, joist hangers, steel sheet or fibre boards for strengthening for fitments and different products for mounting windows, doors, radiators, façade materials etc. Wall units are fastened to the floor e.g. with expansion bolts, cartridge fire pins or angles.

Slotted light gauge steel profiles are used on-site production, but even more common in prefabricated elements. There are also producers of modules on the Swedish market.

Figure 4.9 An opened exterior wall with slotted light gauge steel profiles. In the picture the exterior gypsum board, the slotted steel profile, mineral wool, plastic foil as well as the interior gypsum board are displayed.

4.4.1 BUILDING TECHNIQUE

Structural design

The technique is mainly used for infill walls, but can also be used for load-bearing walls, especially in smaller buildings (up to two storeys). The load bearing resistance of the walls is depending on the bracing of the gypsum boards on one or two sides of the walls. The gypsum boards can also be used for stabilising the entire building, up to four storeys. Testing by the manufacturers has proved the load-bearing resistance of the steel studs. Therefore slight differences in resistance can be found.

Examples of characteristic values of load-bearing resistance are shown in Figure 4.10, 4.11 and 4.12 respectively. Figure 4.10 represents an infill wall. The transversal load, e.g. wind force, is assumed to be uniformly distributed. Figure 4.11 represents a load-bearing wall, affected by both a transversal load, e.g. wind force, and compression. The figures are based on values from the Swedish suppliers.

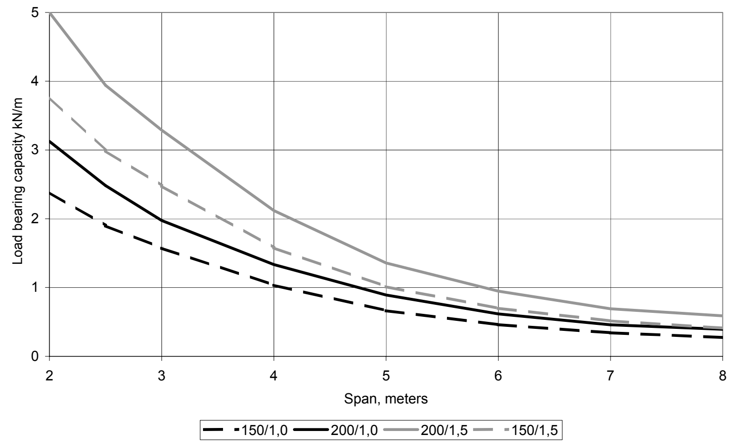


Figure 4.10 Characteristic values for load-bearing resistance for slotted steel studs in infill walls. A uniformly distributed transversal load is assumed. The values are common values for design. This value should not differ significantly from the true value. (Tengberg, 2004)

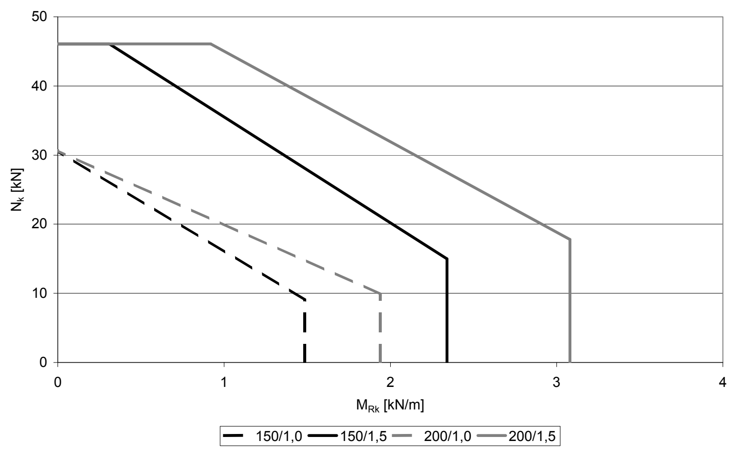


Figure 4.11 Characteristic values for load-bearing resistance for load-bearing walls with normal force combined with a static moment from a uniformly distributed horizontal load (i.e. from wind). The graph is valid for a span of 2.5 m. The values are common values for design. This value should not differ significantly from the true value. (Tengberg, 2004)

Energy performance

Energy savings is an increasingly important environmental issue. In order to create a good heat insulation function, a wall with good protection against wind and good air proofing is required in addition to the obvious requirements with respect to heat insulation. It is very important that all cavities in the wall are completely filled with insulation, particularly around the steel profiles. Mineral wool is often used. To ensure good performance the mineral wool should be of excess length and width, usually 5 mm in order to fill cavities. The Swedish suppliers of mineral wool have products with adapted measures for walls with steel profiles.

To reduce thermal bridging the steel profiles are designed with a slotted web. This provides a longer distance for the heat flow through the construction, see figure 4.12. The slots are typically in eight rows, with an displacement in between. The slots can be made with punching or slitting techniques and are usually about 8 cm long with a width of a few millimetres.

The slotted web gives a reduction of the U-value of more than 50% compared with solid steel profiles. Nevertheless it is important to use as few studs in the wall as possible and to carefully consider when designing connections to avoid thermal bridging.

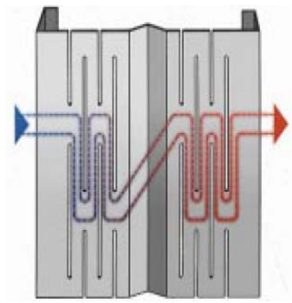
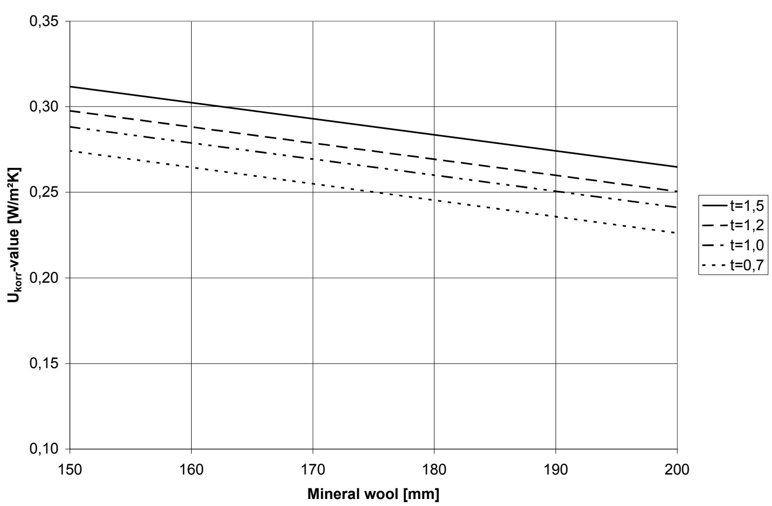


Figure 4.12 The slots provide significantly lower heat flow through the profile as the flow path is prolonged.

Examples of U-values for exterior walls with different thickness of steel profiles and insulation are shown in figure 4.13 and Figure 4.14 (Tengberg 2004). The U-values are calculated according to Swedish regulations, with consideration to correction terms due to thermal imperfections such as fasteners, narrow openings and gaps in the insulation (Isolerguiden, Swedisol 2004). Characteristic U-values for the same walls should be in the range of 0,02 to 0,03 W/m²K lower dependant on different correction terms for the design.



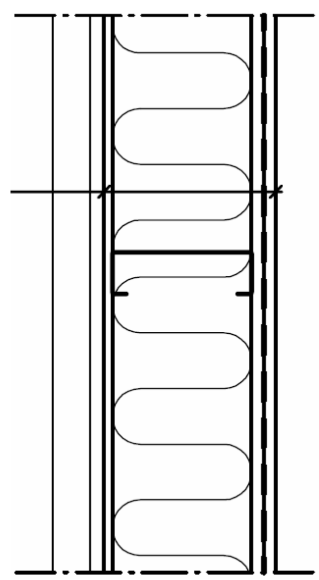


Figure 4.13 U_{korr}-value for a wall with 150 mm to 200 mm slotted light gauge steel profiles. The thickness of the material varies from 0,7 to 1,5 mm. The design of the wall is show to the right complemented with a vertical boarding. The studs are placed with s600 mm.

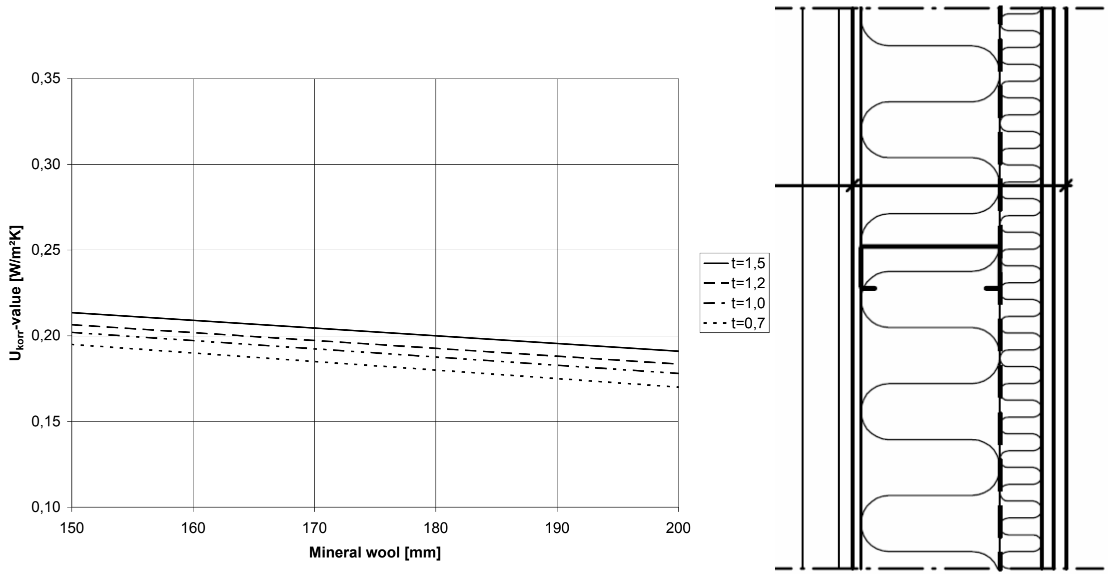


Figure 4.14 U_{korr}-value for a wall with slotted light gauge steel profiles with an internal horizontal frame of 75 mm non-slotted Z-profiles. The thickness of the material varies from 0,7 to 1,5 mm. The design of the wall is show to the right complemented with a vertical boarding. The studs are placed with s600 mm.

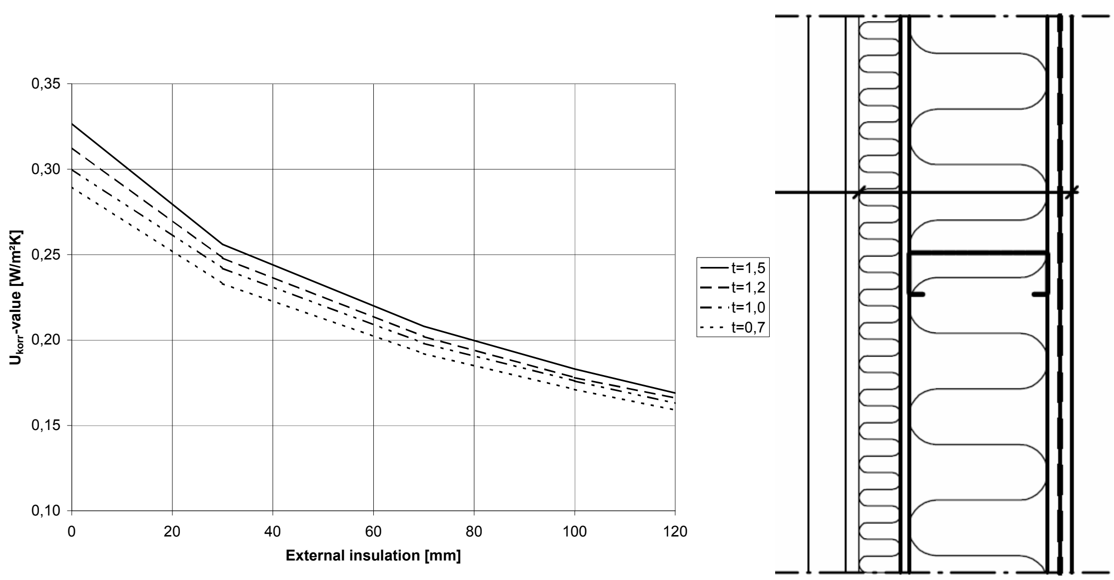


Figure 4.15 U_{korr}-value for a wall with slotted light gauge steel profiles with an external insulation of 0 mm to 120 mm. The thickness of the material varies from 0,7 to 1,5 mm. The design of the wall is show to the right complemented with a vertical boarding. The studs are placed with s600 mm.

Besides the slots in the steel profiles, in order to ensure a good thermal performance of the exterior wall, it is important to:

- Use as thin steel material as possible
- Use minimum s600 mm for the steel studs
- Use insulation material between adjacent steel profiles
- Minimise number of steel studs in e.g. corners

- Fill all cavities with insulation
- Insulate any steel framing externally
- Ensure a good workmanship
- Ensure good air tightness

Fire resistance

Fire resistance of a wall is of course of importance. Walls with slotted light gauge steel profiles can be designed to fulfil all relevant fire requirements. If the wall has fire requirements, the fire class is determined by a combination of gypsum boards, fasteners and insulation. Added layers of gypsum boards and denser fastening provide a better fire resistance. The suppliers of slotted steel profiles provide approved solutions.

Acoustic performance

The acoustic performance of the exterior wall is determined by the multi-layer construction. The number of layers of gypsum boards and the thickness of the wall give the sound insulation. Further the thickness of the steel affects the sound insulation. Thinner material gives better sound insulation, table 4.2 The sound insulation of the wall is also dependant on the façade material. For a rendered façade or a brick façade the sound insulation is mainly dependant on the façade. For light façades, e.g. vertical boarding, the design of the steel stud wall is of greater importance. Exterior walls with slotted light gauge steel profiles can fulfil the requirements on acoustic performance.

Table 4.2 An example of air borne sound insulation for three different exterior walls without façade material. The walls have 9 mm exterior gypsum board, and 2 layers of 13 mm interior gypsum boards. The depth of the profiles is 145 mm with s450 mm. The wall is insulated with 2 times 70 mm mineral wool. The values are measured in a laboratory (measurement by Lindab).

Type of wall	Steel studs	Steel studs	Wooden studs
	0,7/145 mm	1.0/145 mm	45*145 mm
R_w	54	51	45
$R_w + C_{50\text{-}3150}$	47	49	43
C_{tr}	-8	-8	-7

Production and industrial aspect

The producers estimate market shares for light gauge steel framing. In these estimations the market shares for exterior walls and interior walls are often set to 5-10% and 80-90% respectively. Within the Eurobuild project a market survey of light gauge steel in exterior and interior walls was made. Approximately 0,5-0,7 * 10^6 m slotted profiles are used for exterior walls and 20-25 * 10^6 m profiles for interior walls. As one supplier did not want to contribute to the survey with exact figures there is an uncertainty in the figures. These numbers would represent 10%

market share for exterior walls. The total weight of the material (interior and exterior walls) should be in the range of 15-20 kilo tonnes.

As for intermediate floors in buildings the market share is quite low, <5%, where the lion part is residential modules and one-family houses.

4.5 CASE EXAMPLE BUILDING: THE OPEN HOUSE SYSTEM IN THE PROJECT RIDSKOLAN, HELSINGBORG

Figure 4.16 The Open House system was used in the project Ridskolan, Helsingborg

Fully equipped modules in light gauge steel have been used and complemented at site with roofs and facades. Initially the prefabrication rate was 40% but this will be increase by integrating the facades in the modules and make separate roof modules.

The module uses slotted steel studs in the exterior walls, complemented with mineral wool and exterior and interior gypsum boards. The roof and floor of the module use light gauge steel beams, mineral wool, gypsum board and trapezoidal steel sheets. The module carries its own weight. The weight of overlying modules is taken in a separate load-bearing system of VKR columns with space 3900 mm. Each module rests on six columns. The buildings are stabilised with e.g. concrete staircases.

The exterior walls consist of (from inside and out):

- 15 mm gypsum board
- plastic foil
- 195 slotted light gauge steel studs with 195 mm mineral wool
- 10 mm weather tight board
- air gap
- façade cladding

The bottom floor consists of (from top and down):

- Parquet flooring
- Gypsum board
- Underfloor heating

- Gypsum board
- Trapezoidal steet
- 200 mm C-profiles with 200 mm mineral wool
- Steel strips supporting the insulation
- Air space
- Light aggregate clay

The roof of the modules consists of (from inside and out):

- 15 mm gypsum board
- light gauge steel profiles
- 100 mm light gauge steel beams with 100 mm mineral wool

A ventilated external roof of the building compliments the roof of the modules.

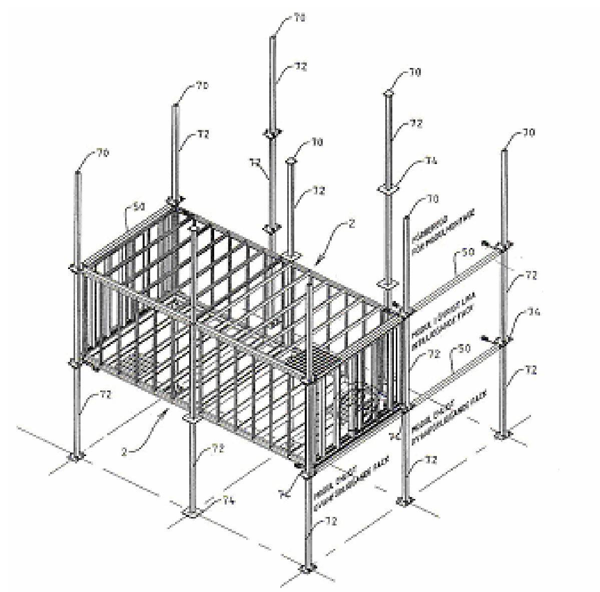


Figure 4.17 Lay out of modules and vertical framing

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5. FINLAND

5.1 LOW ENERGY HOUSING FOR COLD CLIMATE

In Sweden and Finland developments are made in way to reduce the energy consumption of the house in cold climate. A new concept with steel construction is developed and demonstrated. The aim for the demonstration project is to show that steel buildings are suitable for use in a cold climate of Finland and furthermore that it is possible to build steel buildings having a low heating energy demand. The environmental impact of using steel as load-bearing material in walls and roof trusses has been analysed and the results can be compared with the corresponding wooden and brick houses.

The demonstration building uses light steel frame, load bearing and stiffening wall panel using "thermal steel profile", dry intermediate floor, pre-fabricated bathroom modules, and a new "Snap-On" roofing panel.

Figure 5.1 Low energy house for cold climate

Two houses have been build for the Ylöjärvi exhibition fair of the habitat, one row house and one apartment building, based on the new concept. They are designed and planned with exactly the same room areas and lay-out in order to make comparison possible.

These buildings also use modular construction. They use entirely pre-fabricated room-sized modules witch are lifted into place, to form the complete building. The internal structure is usually of light steel framing which is sufficiently robust to resist transportation and lifting forces. The facades may be attached or moved or relocated as the demand in the building use changes.

Low energy houses were constructed at site using pre-cut profiles. In order to obtain better energy efficiency, enhanced thermal insulation in floor, walls and roof, special windows and special floor heating system and heat recovery system in ventilation were applied. The extra cost for these special arrangements were estimated in advance to be economical in comparison with the advantages reached by the savings in the heating energy costs.

Normal house, which was used as reference, was constructed according to the Finnish building code for thermal insulation with normal insulation in building envelop, normal windows and normal radiator heating and ventilation systems. The house frame was also designed according to Finnish construction code.

Results of the comparison show that the experimental building performs well with the chosen solution in respect of heating energy consumption. The usage of heating energy of the low energy-house is at the level of the objective – about 50% of the consumption of the building according to the Finnish building standards.

Results show, that the light-gauge steel-framed concept allows for construction of energy efficient buildings and that the environmental profile of the steel house is very profitable for the use of steel in housing for cold climate.

6. GERMANY

6.1 USE OF SMALL ROLLED SECTION - GERMANY

The use of small rolled section is very convenient for housing primary structures. During the mega 5 project 3L-PLAN developed a special connection system to be used for modular building system. This system is composed of two plates of flat steel attached to the beam web made of small rolled section. The supported beam is then hooked into the opening in the column. Figure 5.1 shows the way to assemble the two elements. The system was designed for realisation of single dwellings and semi-detached houses.

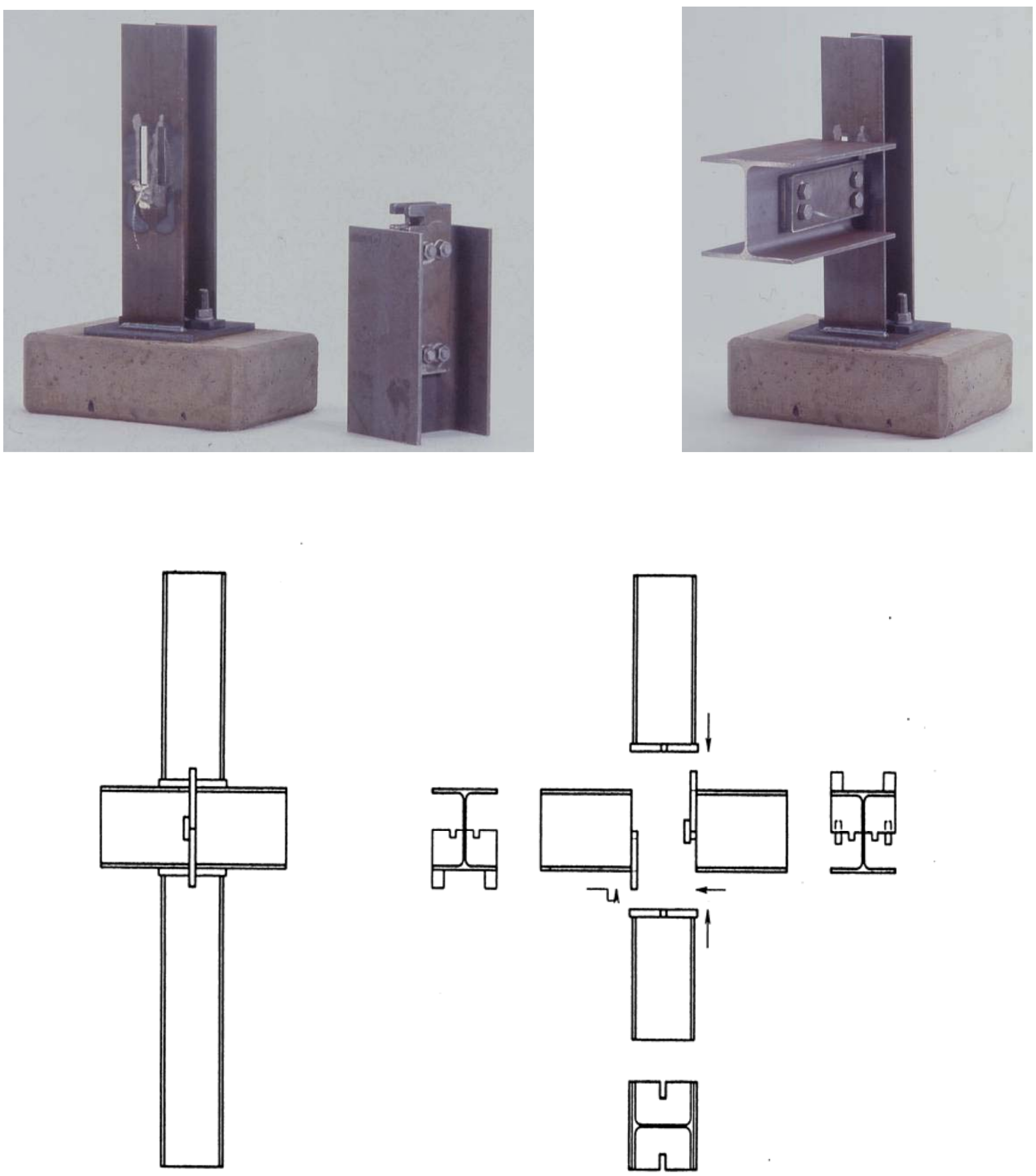

Figure 6.1 Assembly system developed by 3L-PLAN

The house construction used this simple method of connection. Small hot rolled steel beams and columns are bolted together to create the framework of the building.

The developed easy-to-fix connection, with optimised joint technique reduces the mounting time of the bearing construction and offers building clients the opportunity to take a bigger do-it-yourself part at the starting phase of the erection.

The house was constructed using hot-rolled steel sections with blockwork infill for external walls. Except for the basement they are non-bearing walls thus allowing large openings if needed. The concrete floors were poured on a pre-fabricated metal formwork of metal sheets that remain in the building after completion of the slab which is a cheap and practical solution for detached houses. Internal partition walls are non-bearing allowing great flexibility in the configuration of internal space.

The house building physics fits all the construction laws in Germany. The steel is completely situated at the interior side of a 12 cm thin brick wall. The thermal insulation material is situated on the outside part of the wall and clad the whole construction. The thickness of this insulation is selectable from regular standard – German heat protection law of 1995 – to low energy house standard that is sponsored by German taxation law.

The key advantages are:

- Steel structural frame allowing long spans without bearing,
- Grid with a maximum span of 5 meters,
- Fast construction of the building frame,
- Relocatable internal walls, reconfigurable internal space and internal adaptability,
- No load bearing walls,
- Wide internal space,
- The building can be extended horizontally or vertically in the future,
- Architectural versatility using largely available construction materials.

Depending on material used for walls,

- Low energy standard,
- High level of sound insulation.

3L-Plan developed this house for a customer who had interest in steel framing because of the benefits of long spans and internal adaptability. Additional habitable area is created within the basement flat.

 

Figure 6.2 Example of a house using the connection system developed by 3L-PLAN

6.2 FAÇADE SYSTEM RP ISO-HERMETIC– GLAZING CURTAIN WALL

The RP façade-system is a glazing curtain walls which combines the advantages of the steel with the rational assembly system. It provides facades with maximum transparency and architectural quality.

The system is not welded, but is delivered pre-fabricated and already surface coated onto the site, ready to assemble with plug and screw connections.

The façade system RP-ISO-hermetic 45 features a profile face width of only 45mm and thus offers many architectural possibilities. Due to its excellent static performance, it provides minimum workshop treatment as well as simple assembly as a plug-in system. It is also extremely economical.

Large surface glass panes with weights can be used without additional measures and when the prescribed vertical glass depth off 200mm is kept. The high watertightness is secured by the back seal, covering the profile and being guided securely in grooves. It acts as a second water-guiding level. The assembly of the glazing beads is done with self-drilling screws, guided by clamp separator bushes, with a defined clamping pressure. The system was tested for driving rain up to 1100 Pa.

A double sided pre-galvanisation process secures high anti-corrosion protection. After workshop assembly and before installation the system is either powder or wet coated. Additionally, the system provides thermal insulation values of U ≥ 1.4 W/(m²K) and fire protection of R30.

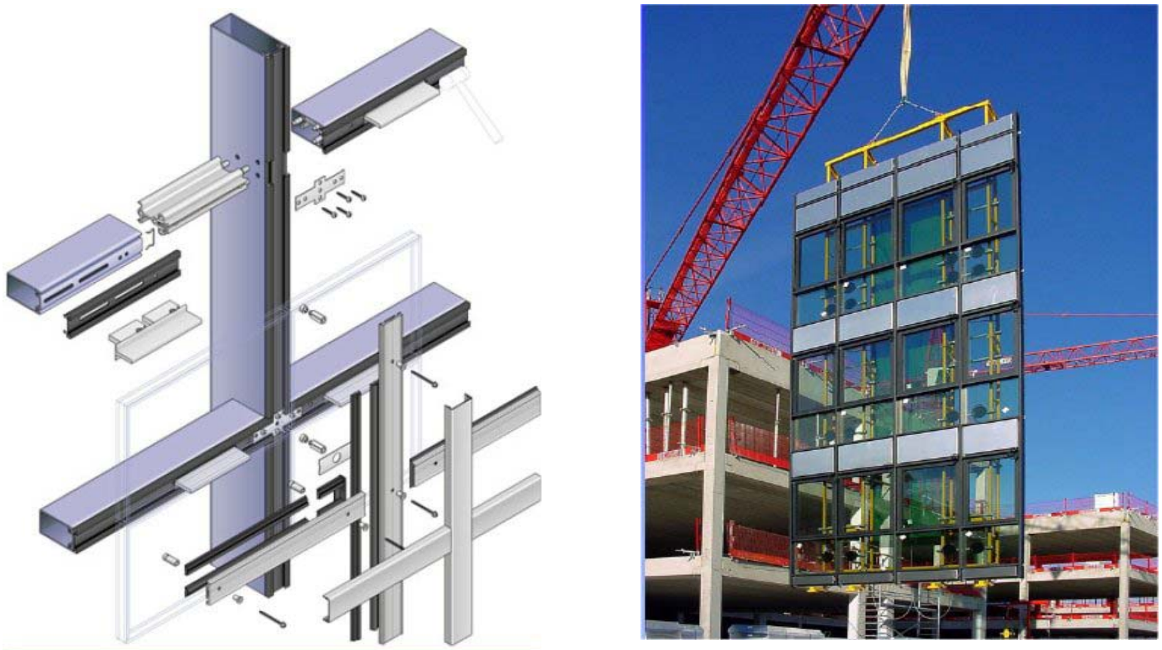

Figure 6.3 The RP façade system – Glazing Curtain Wall