



(Nordic Industrial Fund project 02077)

Wood components in steel and concrete buildings – In-fill exterior wall panels

Study compiled for the Nordic Timber Council, December 2003

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Executive summary and recommendations

Summary

This project is a pre-study performed by Nordic Timber Council and co-financed with the Norwegian Institute of Wood Technology, the Swedish Forest Industries Federation, Wood Focus Finland and the Nordic Industrial Fund (project 02077). The **objectives** were to:

1. Describe current use and potential for in-fill exterior timber frame walls (see illustration).
2. Describe currently dominating construction for larger (4-10 storeys) structures.
3. Analyse the possibility for a harmonised European (and Asian) system approach.



The geographical markets included in the pre-study were UK, the Netherlands, France, Germany, Poland, China and the Nordic countries (Sweden, Norway and Finland).

The study has revealed that the technique dominates the market for housing not only in the Nordic countries but also in the Netherlands. Numerous building examples have also been found in Germany, Austria and France as well as one project in UK and one in China. Furthermore, a growing interest in using the technique for non-residential buildings such as offices, schools etc and a potential use in renovation and improvement of housing and other buildings has been found. Examples from all these sectors are shown in the report. The report also summarises the most important technical aspects and solutions that have been pointed out by the current users interviewed in the study.

The primary **benefits** that can be exploited for promotion of the technique are:

- Excellent thermal insulation properties are easily achievable.
- The usable building area is significantly increased as compared to a similarly insulated building with masonry walls because of lesser wall thickness.
- Savings in on-site labour and construction time through a systematic off-site manufacturing process.
- From an environmental (LCA) perspective, timber frame structures virtually always out-perform the competing techniques.
- The in-fill timber frame wall panel technique facilitates a high degree of architectural freedom of building shape and cladding materials.

The main **weaknesses** that need to be dealt with through further development work are (apart from the lack of widespread knowledge commented above):

- A certain sensitivity to moisture exposure during the construction phase.
- A lack of handbooks or other guidance material and market support from the panel suppliers.

On the whole, there appears to be a huge **development potential** for timber frame in-fill walls in numerous markets and market segments at this point in time. In the countries where the technique has been used continuously for a longer period of time, the in-fill wall panels are the strongly dominating technique and the technique is common knowledge in the building sector in these countries. The study shows that if this pattern could be spread to the rest of

Europe (and to other parts of the world) there is a considerable potential for increased use of timber in the construction sector, both in the in-fill panels themselves and in spin-off developments for other wood based building components. Examples of such components are partitions, cladding and joinery. There is also a potential for an increased use of load-bearing timber frame and other wood based building systems through the increased and better spread knowledge of the benefits and potentials of wood based construction products and components.

Recommendations

The recommendations from this pre-study are therefore to (sorted chronologically):

Perform a proper market analysis.

- Detailed estimates of the market potential.
- Potential economic benefits for the building and the wood components industry.
- Estimate the value of panel elements at different prefabrication and delivery/installation package levels.
- More closely examine the potential in the renovation market.

Facilitate an exchange of knowledge between current users – Create user forum.

- High-level seminars and workshops for current and prospective users among architects, engineers, builders and timber frame panel manufacturers.
- To avoid many of the early mistakes and expensive prototype building examples.
- Complemented with articles in wide-spread construction sector journals.

Assemble the current best practice as example solutions.

- Collected through the user forum.
- Disseminate openly and without charge via Internet.
- Easily updated throughout the development work suggested below.
- Inspirational as well as handbook type of material.

Coordinate a common technical development programme.

- More competitive solutions for the jointing and sealing of the elements to the structure.
- Develop the moisture resistance of the panel elements and their components.
- Further improve overall competitiveness of the technique through a systematic cross-examination of different existing solutions, components and materials.
- Incorporate more high-tech components for e.g. energy efficiency
- Create a framework for quality assurance for fabrication, handling and installation of the in-fill panels and finish work on the building site.
- Potential harmonisation and European approvals (EOTA) of such solutions and components.
- Demonstration projects.

Organise systematic promotion and training programme.

- Disseminate the results and material created, through journal articles, seminars and training courses, visits to architectural and engineering practices as well as builders and fabricators, distribution of printed material and advertising.

All of the above recommended actions could probably be incorporated into a European Collective Research Project.

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1. Background and research methodology

The combination of timber construction and mineral material or metal construction is nothing new. Timber floor structures in stone buildings have been used since we started building houses. Half-timbered structures were frequent for hundreds of years in Central and Northern Europe with walls filled in with brick or clay. In modern days, however, timber has primarily been used for smaller buildings such as single family houses and concrete has replaced many of the earlier uses of timber. In the Scandinavian countries a new method of mixed construction with non load-bearing exterior timber frame panel walls was developed in the 1950's to increase the usable building space (decreased wall thickness despite higher thermal insulation standards) and the site productivity in concrete and masonry buildings (see figure 1). This technique has spread primarily to the Netherlands, France and recently also to Austria, Switzerland, Germany and UK. The possibility of increasing the use of wood based components in the building industry through measures stimulating this development is the starting-point for this study.



Figure 1. A recent example in UK of in-fill timber frame wall panels in the exterior walls of a housing development. The Nightingale Estate in Hackney. Source: Southern Housing group.

The European building sectors is experiencing a rapidly increasing shortage of skilled on-site workforce. A possibility is then to significantly increase the degree of prefabrication of building parts. Wood based, prefabricated construction parts are an important part of the solution. A major obstacle to an increased use of such parts and components is a lack of knowledge and often a perceived lack of competitiveness of wood based construction systems. A major explanation to this is the lack of harmonisation across Europe of wood based building systems or prefabricated building parts. This pre-study has thus aimed to investigate the potential for a development towards such harmonised systems for, primarily, exterior in-fill wall panel elements in larger scale steel and concrete based structures. The initiative to the study was taken by the Nordic Industrial Fund's "Ad Hoc group Wood". The project has been carried out by the Nordic Timber Council with financial support from Wood Focus Finland, Swedish Wood Association/Forest Industries Federation, Norwegian Institute of Wood Technology and the Nordic Industrial Fund (project 02077). The main consultant to Nordic Timber Council for this project and the author of this report has been Per-Erik Eriksson, Regilverket 2-tum-4.

The objectives of the current pre-study were:

4. To describe the current use and the potential for in-fill exterior timber frame walls in the most important European (including Eastern Europe) and Asian markets.
5. To describe the currently dominating construction systems for concrete and steel frame larger (4-10 storeys) housing structures.
6. To analyse the possibility for a harmonised European (and Asian) system approach (cross-country standardised components/connections)

It should be noted that the pre-study was thus limited in scope primarily to in-fill exterior wall panels and primarily to housing. To some extent, however, other types of buildings such as offices, hotels, schools and other institutional buildings have been included as well, as has some other applications of wood based components than exterior walls.

The geographical markets included in the pre-study were:

- UK
- The Netherlands
- France
- Germany
- China

Also, a limited assessment of the current status has been undertaken for:

- Poland

In addition, the current practice in the Nordic countries (Sweden, Norway and Finland) has been analysed and, furthermore, information on ongoing development in Austria is included as well.

The project has been carried out in co-operation with wood (and construction) industry research and promotion organisations in the selected countries. The method to meet the first two objectives above has been through a series of interviews with key players in the respective markets. This study is also part of the ongoing Nordic Timber Council project “Building Europe”. The project report of the first phase of this project (Ref. [1]) gives background information on the different construction markets and from that phase also key contacts for interviews were identified. Furthermore the NTC project “New Markets” has provided information on China. In addition to the field interviews, background research has been carried out by Mr. Anne Terpstra, Ingenieursbureau Boorsma, for The Netherlands, Mr. Yves Rodarie, consultant to FIBC, for France, Mrs. Elina Huovinen-Schüdde, Nordic Timber Council, for Germany, Mr. Wojtek Nitka, Centrum Budownictwa Szkieletowego, for Poland and Mr. Hans Dutina, Nordic Timber Council, for China. I would like to express my sincere thanks to all of them and all others that have contributed to the study.

2. Dominating construction techniques by segments and markets

In order to analyse the potential for an increased use of wood based components in construction, an attempt has been made to summarise the currently dominating building techniques in residential and non-residential construction (offices, hotels, schools and other institutional buildings whereas industrial and retail buildings are excluded). It should be emphasised that the ambition has been to give a fair but rough picture and not a detailed analysis. The background to the conclusions below is presented in the country research reports in chapter 6.

Residential construction – low rise (<3 storeys)

In all analysed countries except the Nordic countries and to some extent the Netherlands, masonry construction totally dominates this segment for load-bearing walls (normally all exterior walls plus some interior). The masonry blocks are either concrete, aerated (light-weight) concrete or limestone blocks. In most countries the energy use regulations have been increased over the last years such that exterior masonry walls require extra insulation, normally applied outside the masonry structure. The floor structure used in this type of buildings is either concrete or timber joist floors. Timber joist floor structures dominate in the UK for intermediate floors (ground floor is normally a concrete slab) whereas in Germany, France and the Netherlands, the floor is normally of concrete. The roof structure is predominantly of timber with trussed rafters dominating in UK and timber frame panels in the other countries.

In the Netherlands, for larger scale developments of e.g. row-houses, concrete structures are used to a large extent. Normally these are cast in situ using tunnelforms to form the separating walls and the floor at one time, whereas the exterior walls are non load-bearing in-fill panels, predominantly of timber frame construction, see chapter 3.

In the Nordic countries, timber frame construction (load-bearing) dominates this segment with markets shares of some 90 %. Apart from the Nordic countries, UK and Germany have the highest timber frame construction shares: around 15 %.

Residential construction – medium rise (3-10 storeys)

The normal construction technique for this segment is either masonry or, for higher buildings, reinforced concrete (cast in-situ or prefabricated elements). The transition from masonry to concrete structures occurs at various building heights. In the UK, masonry is considered competitive only up to around 4 storeys, whereas in the Netherlands, limestone masonry structures are used up to some 8-10 storeys. In Poland, masonry also dominates up to and sometimes above 10 storeys. In China, a very large number of flats are built currently in urban areas, normally with 6 storeys (maximum without lifts), using in-situ cast concrete structures for columns, slabs and roof.

Exterior non-load-bearing walls are in the Netherlands normally pre-fabricated timber frame in-fill panels (alternatives are masonry or concrete element sandwich panels) whereas in UK, they are either masonry walls, light-gage steel stud walls or concrete element panels (normally not sandwich panels). In all other countries in the study, masonry is still the normal technique also for non load-bearing exterior walls and interior partitions (fig. 2). The masonry walls are today normally insulated on the outside with a rigid insulation. In Germany, the

normal wall thickness is thus approx 200 mm masonry blocks plus 150 mm insulation plus (thin render) cladding.



Figure 2. A typical 4 storey multi-family masonry building under construction in Darmstadt, Germany.

In the Nordic countries, concrete construction dominates this segment (see figure 3). Normally with a larger proportion of prefabricated concrete elements than in the rest of the analysed countries. There is also an increasing use of steel in combination with concrete element floors. For both these construction methods, the exterior walls are predominantly timber frame in-fill panels.



Figure 3. Multi-family housing structure of concrete and steel waiting for the in-fill timber frame exterior wall panels. Linköping, Sweden.

The European “market leader” for medium rise timber frame (load-bearing) structures is probably UK. With a market share similar to that in low rise construction, timber frame has become an alternative that is normally considered up to 7-8 storeys. The technique is also becoming relatively common in the Nordic countries and Austria and Switzerland. The

market share in these countries are however probably below 10 % and the technique is normally used up to 4-5 storeys.

In the major parts of Europe, medium rise and higher buildings have a relatively small market share of the residential construction (new-build) market. Multi-family housing was found to be less than a third of the market in all countries analysed in the “Building Europe” study (ref. 1) except Sweden, Finland, Austria and Poland where the market share was 50 % or more.

Residential construction – high rise (>10 storeys)

High rise residential construction is quite unusual in Europe today, except in some rather exclusive locations in densely populated cities. Typically these have concrete structures with a shift to steel for taller buildings (normally more than 20 storeys). The exterior walls are normally built in the same way as for medium rise buildings, except that for more exclusive projects, curtain wall systems with a large share of glass cladding are more frequent.

Non-residential construction (offices, hotels, schools and other institutional buildings)

As a general rule, the non-residential construction sector (particularly offices) uses steel to a considerably larger extent than the residential sector. The main reason for this is that these buildings generally have more open floor plans or need a larger flexibility in floor plan over time than the residential buildings, i.e. they need the larger spans that are more easily provided using a steel post and beam structure. However, concrete structures are also very frequent, especially for medium rise projects. Compared with the residential sector, the degree of prefabrication is generally larger.

Partitions are generally light-gage steel frame drywalls and exterior walls are normally either composed of an interior such drywall and an exterior cladding of brick or prefabricated concrete elements or curtain wall systems with a large proportion of glazing. In the Nordic countries, prefabricated concrete sandwich (insulated) panels are frequently used (or curtain walls), but also timber frame panel walls. The latter is also used to an increasing extent in the Netherlands for low and medium rise office buildings.

Some use of timber frame structure also exists in the non-residential sector. Particularly for schools and hotels and particularly in UK and the Nordic countries as well as in Austria and Switzerland.

3. Current use of timber frame in-fill panels for exterior walls

For background to the information in this chapter, see also the country research reports in chapter 6.

Dictionary

The following names are used for the technique in the various countries covered by this study. It should be noted no well established name of the technique in English has been found due to a limited use in the UK.

Sweden: "Utfackningsväggar"

Norway: "Utfyllende bindingsverk" or "Påhengselementer"

Netherlands: "Gevelsluitende elementen" or "Gevelvullende elementen"

Germany: "Holztafel mischbauweise"

France: "Facades légères" ("Facades rideaux", "Facades semi-rideaux" or "Facades panneaux")

Nordic countries (Sweden, Norway and Finland)

The technique of combining a load-bearing wall concrete structure with a light-weight insulated timber frame ("non-structural") exterior wall and a cladding of brick, render or sheathing was developed in Sweden in the 1950's. The main purposes were to:

- increase the usable building space and at the same time increase the thermal insulation of the exterior walls. The timber frame in-fill walls were only about half as thick as the masonry walls commonly used. The relative increase in usable space was about 3 % for a normal multi-family building.
- increase productivity in the construction of multi-family housing.

In those days and to some extent even today, the concrete structure was cast in-situ using form tables or tunnelforms to form a structure of open boxes, into which the exterior wall panels were fitted, see fig. 4. Today, the structure is more often composed of prefabricated concrete wall elements or steel columns and prefabricated pre-tensioned hollow-core concrete floor elements or half prefabricated concrete slabs ("Filigran"), but the same type of in-fill wall panels are used for insulating the exterior wall and carrying the cladding. The technique is normally the most competitive in the Nordic countries for blocks of flats with 4-5 storeys or more. The current market share in Swedish multi-family construction is believed to be at least 90 percent.

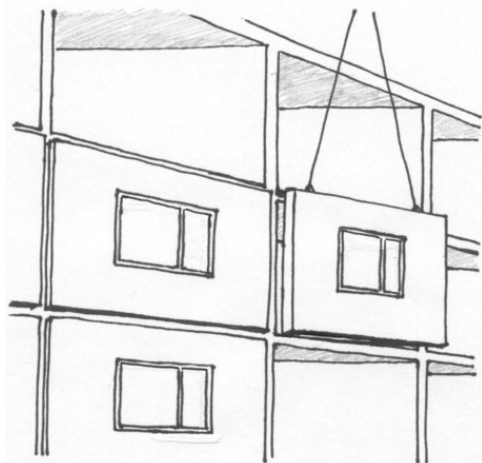


Figure 4. Installation of in-fill wall panels into a concrete structure.

The in-fill wall panels are typically factory prefabricated with a minimum of the timber frame and an outer exterior quality gypsum board wind breaking layer. The windows and balcony doors are also fitted into the element during fabrication. Often, the pre-fabricated elements are also equipped with insulation and the inside vapour barrier and sometimes also with the interior lining boards. The timber frame in-fill wall elements are either manufactured in a factory and transported to the building site or manufactured in a “site factory”. Today factory prefabrication dominates.

There is relatively little handbook or guidance material on the technique. In Norway there is a technical guidance brochure specifically for this technique (ref. [2]). Some guidance for Sweden is provided in reference [3]. Furthermore, design guidance is provided by gypsum board and insulation manufacturers.

Netherlands

In housing construction in general the in-fill timber frame wall panel technique is dominating the market, currently amounting to an estimated 50 percent of all housing construction. The in-fill exterior walls are primarily used in combination with masonry load-bearing as well as reinforced concrete (tunnelform) structures (see fig. 5) and sometimes also in steel structures. It is estimated that the sawnwood use in in-fill walls far exceeds that in timber frame construction (currently a market share of about 6%).



Figure 5. In-fill timber frame wall panels in a) limestone masonry housing structure and b) concrete tunnelform row-house structure. Source: Ref [4].

The market share in commercial and other construction is increasing. A strong driver for this increase has been a bigger interest in the exterior impression/architecture of low to medium rise commercial buildings that previously were often monotonous box-shaped metal framed and clad or pre-cast concrete buildings. The use of timber frame in-fill wall panels for the building envelope has allowed a higher degree of architectural freedom without sacrifices in cost. Two examples are shown in figure 6. The technique has also successfully been used for renovating larger scale concrete office buildings (replacing the exterior walls).



Figure 6. A hotel in Almere and a Movie Palace, both in The Netherlands. Source: Ref. [4]

The technique has been used in its present form since the 1980's, introduced partly through a promotion activity by the Nordic Timber Council (then the Swedish-Finnish Timber Council). In the 60's and early 70's, however, there was also a quite extensive use of simpler, poorly insulated wood in-fill walls (called "Norwegian facades") in larger scale housing developments, see also the section on France below. Just as in France, this technique disappeared with the large scale concrete housing developments.

There is some technical guidance material available in the Netherlands through SBR (ref. [5]) and also through the wood industry organisation for quality certification, SKH (Stichting Keuringbureau Hout).

Germany

It has been estimated that some 100 projects using this technique have been built in Germany over the last 10 years. The timber frame in-fill wall panels have been used in masonry as well as concrete structures. A 1995 research report (reference [6]) pioneered the technique in the German market, with a thorough analysis of potential regulation barriers, technical aspects, potential market acceptance and competitiveness.

The dominant part of the built projects is in residential construction (see examples in figure 7) but there is also a considerable number of examples in offices and administrative buildings. A large proportion of the projects have been projects with "low-energy" profile such as many "passive house" projects.

A very interesting, large and very high profile commercial project is currently under construction using the in-fill wall panel technique. It is the new administration building for the German Ministry of the Environment (Umweltsbundesamt) in Dessau. It will be a 4-storey office building with a total of 40000 sqm floor area. It is currently under construction (see figure 8) and will be finished in 2004.

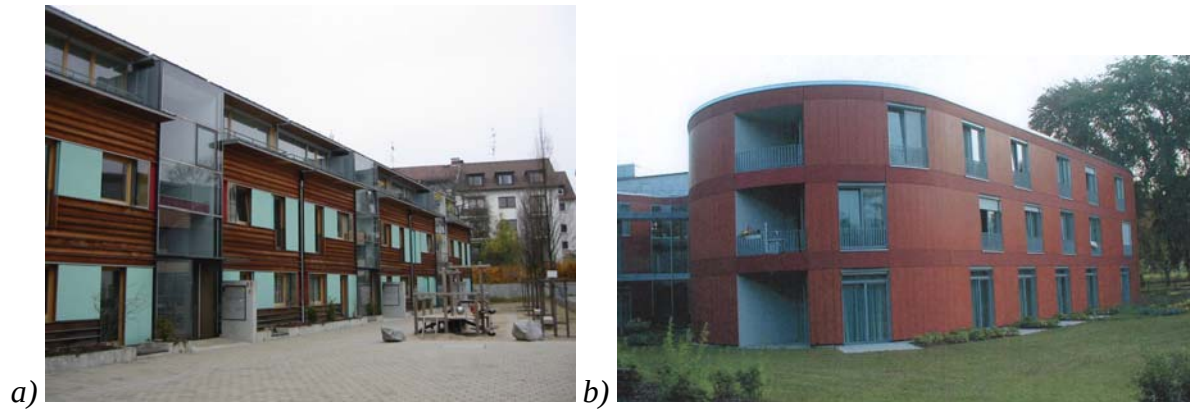


Figure 7. a) A residential building in Darmstadt, Germany and b) a retirement home in Köthen (source: Sieveke Zimmerei GmbH).



Figure 8. The construction site for the new German Ministry of Construction in Dessau. For a construction detail see also figure 11b. Source: www.umweltsbundesamt.de.

France

They are quite a lot of examples of in-fill timber frame walls over time in France, the most prosperous period being between 1960 and 1975. An early version of in-fill walls (“panneaux de façade”) was developed in conjunction with the development of industrialised concrete construction for larger scale housing projects and was frequently used in this housing production era, see fig. 9. The use of the in-fill panels terminated with the end of this large scale housing production in the mid 70’s.

The technique had another climax in the late 80’s with the Disneyland production near Paris, reintroduced from North America. The later resulted into a new set of norms for this type of exterior walls. Recent examples are also available as new building, for instance in Evreux (27 dwellings), in Reims (office building), hotels in many places in France etc. Also noticeable is that many prefabricated concrete wall panels built in the 1970’s are being replaced by timber framed in-fill wall elements (e.g. offices in Clermont-Ferrand).

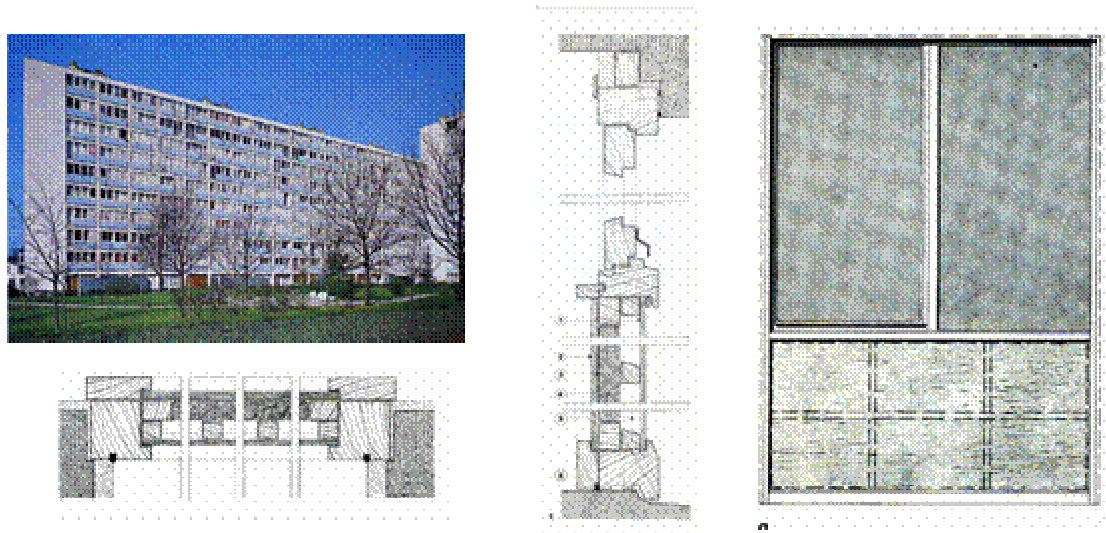


Figure 9. “Panneaux de façade” – a wood based in-fill wall panel system used in the large scale housing developments in France (and Netherlands) in the 1960’s and early 70’s.
Source: Ref. [7]

UK

Only one example of in-fill timber frame panels of recent dates has been found in this study (fig. 1). The project is a major housing project in Hackney, London (the Nightingale Estate), which will consist of 600 homes, 200 of which have been built to date. The project is built by the housing association Southern Housing Group. The technique used is adapted from the Netherlands through a technology exchange initiative between Southern Housing Group and a Dutch housing association. The main focus was on using the tunnelform technique for in-situ cast concrete for the building structure.

In-fill walls with steel studs, built on site, are frequent for larger multi-family projects as well as for commercial construction in combination with concrete and steel structures (also for internal walls and partitions). Normally used in combination with brick or concrete element cladding. The steel frame in-fill walls are normally built and insulated in place. No statistics on the use have been found, however.

Austria

In Austria there is currently a programme of research and development projects focusing on the mix of wood based structural or non-structural components and mineral based structures (Ref. [8]). A book has been published during 2003 (reference [9]) that gives a historical background to mixed construction, analyses the strengths of using wood based components mixed with other structural materials and lists 55 recent projects where mixed construction has been used recently. 32 of these projects are multi-family and 6 are single-family residential buildings, 9 are day-care centres for children and schools and 8 are offices and other institutional buildings. The majority of these projects have used a combination of a load-bearing concrete structure and non load-bearing timber frame in-fill panels for the exterior walls.

A following, on-going development projects emphasize finding better solutions to the connection of the timber frame elements with the structure. Another project is assessing the possibility of including “intelligent” products for heating, cooling and ventilation, such as heat collectors, photovoltaic elements etcetera in the design of the wood based elements.

Poland

Only a few projects built by Swedish contractors are believed to have used this technique in Poland. Normally, the technique is not known.

China

One full-scale show case building, demonstrating the timber frame in-fill wall systems was built during 2003 in China, initiated by the current Nordic Timber Council “China project”. The building is a new hotel and scientific centre in Chengdu (central China) with a concrete structure. This was carried out together with the Chinese Timber Structure Committee and a national fire testing laboratory, carrying out fire testing of relevant wall designs. This lobbying has resulted in a Chinese government assigned standardisation committee that will develop a national standard for timber frame non-load-bearing walls (exterior as well as separating walls and partitions) during 2004.

4. Technical solutions

There are two principally different ways of fitting timber frame elements into the (steel, concrete or masonry) structure; Either the panels can be fitted into or partly into the structure (figure 10) or outside the structure (figure 11). The two variations are for most aspects very similar and will both be called in-fill wall panels in this report, but they have different pros and cons regarding certain building physics and production/construction aspects. These differences are commented below in the different sections.



Figure 10. Sketch and schematic detail at floor level of timber frame elements mounted partly into a concrete structure. Source: Ref. [3].

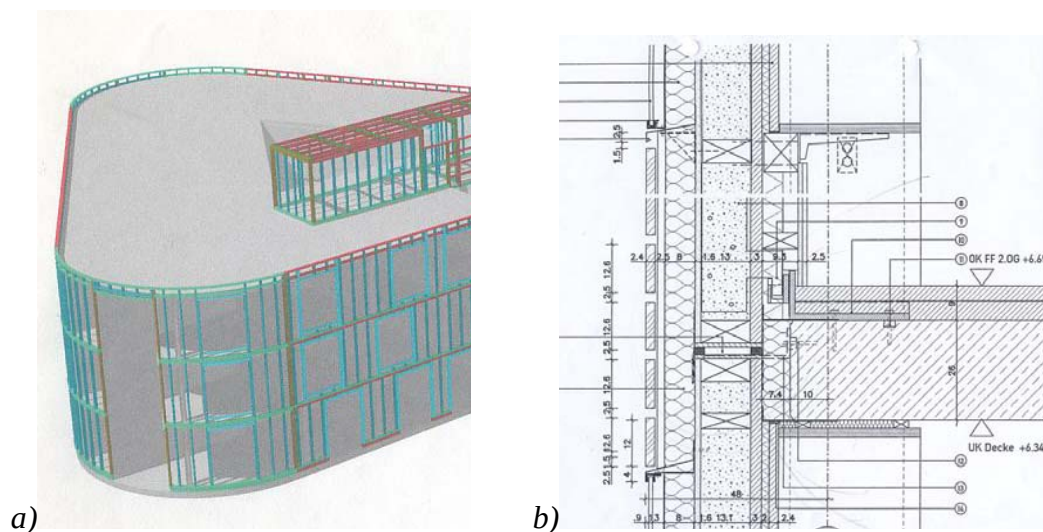


Figure 11. 3D-CAD overview and detail at floor level of timber frame elements mounted outside a concrete structure with a site-built inner wall layer. The wall panels are self supported from the ground slab in a) and hanging from the floor in b). Sources: Sieveke Zimmerei GmbH (a) and Deutsche Umweltsbundesamt (b).

Building physics aspects

Energy conservation

One of the primary advantages of using a timber frame “shell” around a mineral or steel based structure is of course the potentially superior heat insulation properties of timber frame panels with a very limited wall thickness compared to alternatives (especially externally insulated

masonry walls). Whereas other construction techniques in principle can achieve the same energy efficiency, it always tends to be easier and more competitive to raise the insulation standards of the timber frame panel. This is not least illustrated by the fact that in the parts of Europe with most severe climate, the Nordic countries, this is the predominant technique and by the fact that a large proportion of the “passive houses” in Germany and Austria has also used this technique. There are primarily three aspects of energy conservation aspects that are relevant to timber frame in-fill walls, namely:

- Heat insulation
- Air leakage
- Cold bridges

The required heat insulation properties of the wall will simply determine the required thickness of the normally used mineral wool insulation. The (moderate) timber stud cold bridges will naturally have to be taken into consideration unless these are broken through the use of I-shaped studs or crossing layers of studs or by an externally applied insulation layer. In most cases, however, ordinary timber studs are used and the dimension of the studs are normally determined by the required insulation thickness since the wall panels are not load-bearing. Typically 45x195 (or 170) mm studs are used in the Nordic countries with 195 (or 170) mm insulation plus an additional external layer of insulation. In the Netherlands, the stud sizes are typically 38 or 45x145 or 38 or 45x170 mm. In the latter case, normally without additional insulation. In UK, the stud depth would normally be 120 mm. However, all national building regulation nowadays acknowledge the fact that the whole house energy performance is the important measure and not the envelope U values and thus insulation thicknesses are not necessarily comparable.

Air leakage and cold bridges are very important aspect for the energy performance of the building and also for the perception of a good indoor climate. It is not easier to reduce air leakage by using timber frame in-fill panels than other techniques. The reason for this is that the connection of the panel to the structure is rather complicated, not least since construction tolerances for the structures are quite often rather poor. Considerable care therefore has to be taken to seal around the edges of the in-fill panels, particularly for the variant installed into the structure. Different solutions have been tried in the different countries using mineral wool insulation, expanding foam sealing tapes and polyurethane expanding foams, see further below under “Connection into structure”. The sealing against air leakage to and from the outside is considerably easier to solve using panels installed outside the structure.

Also regarding potential cold bridges from floors and load-bearing walls, the variant with elements fitted outside the structure is somewhat advantageous. However, this is normally efficiently solved also for the variant with panels fitted partly into the structure, simply by filling the void between the elements with insulation after the panels are installed, simultaneously with installing the cladding from the outside.

Fire resistance

The fire resistance aspects shall not be significantly dealt with here. The reason is that the construction regulations in most European countries are performance based nowadays and not prescriptive and timber frame wall components have proven sufficiently efficient in providing fire resistance. This applies in particular to the insulation (E) and integrity (I) parts of the performance requirements that are in effect the only requirements on these non-load-bearing walls. The normal requirement for medium rise buildings is that there should be a fire protection equivalent to EI60 for fire spread between dwellings or other different fire

compartments. For the exterior wall, this can be seen as the sum of the fire resistance from the inside of the wall of the fire compartment where the fire started plus that from the outside of the other fire compartment's wall. This is easily fulfilled for most insulated timber frame wall.

A particular problem for this technique is again the intersections with the structure. Here, normally the panels fitted into the structure provide an easier way of avoiding fire spread through the joints than those fitted outside the structure. In the latter case a site-built inner layer will possibly have to be installed in order avoid fire spread but even more to avoid noise transmission and air leakage between dwellings (if the floor or load-bearing wall is a dwelling separating structure).

Moisture resistance

The exposure of the timber frame panels to moisture can occur:

- During transportation and building site storage and handling (easily avoided with proper protection and handling).
- Due to the initially high moisture content of a concrete structure.
- Directly after installation of the panels, before the breather membrane (or similar) entirely covers the envelope.
- Due to leakage through the roof before it is completely water-tight.
- At balconies and recessed (roof) terraces before the cladding has been completed and metal flashings are installed.

After the construction phase, the wall panels should not normally be exposed to any moisture, provided that a proper vapour barrier (plastic film or watertight boards) have been installed on the inside and that the cladding and cladding details such as flashings are properly designed and installed.

Again, the wall panel edges and connections to the structure are most important. A rapid closing of the element joints and exterior coverage of the wall is highly beneficial. A polyurethane insulation foam can solve parts of this but the use of such foams are avoided in some countries (e.g. Sweden) for two primary reasons; The first is a labour health and safety concern since the foams emit isocyanates during installation and the second reason is that the rigid foams cannot take up differential movements between the panels and structure which may result in cracks and poor thermal insulation.

The most sensitive part of the wall panels is the top plate. This should be protected during the installation and remaining construction phase using the outside breather membrane pulled over the top of the panel, a temporary plastic cover or similar. Also the bottom of the panel constitutes a certain risk if (rain) water is allowed to remain on the floor structure. This risk can be entirely eliminated if the elements are not insulated before installation. However, this means a lesser benefit of the prefabricated construction method and should not be necessary if detailing and handling of the elements on the building site is carried out carefully, the built-in timber moisture content is sufficiently low and the installed walls are protected from excessive water and moisture exposure. It may also be feasible to develop short-term systems for timber protection to further decrease this risk and to ascertain builders of the low risks. The protection could be harmless impregnation methods with a durability of only a few months or even paint or wax. In the Netherlands, the bottom timber plate in the elements and sometimes the top plate and edge studs as well, are often painted in the factory and sometimes even pressure treated.

After all wall panels have been installed on one side of the building, the space between the panels outside the structure (floor or wall) is insulated and the breather membrane from the panel above (or to one side) is pulled over the panel and fastened, thereby providing a (relatively) rain-proof building envelope (see e.g. figures 10 and 14). This is normally done from scaffolding from which the cladding can then be installed.

The excess water in the concrete (or masonry) structure does not normally cause any problem for the elements if the bottom plate is protected by a gap or a damp proof layer. However, it is important that there is some kind of vapour barrier (plastic foil or interior sheathing with sealed joints) in the wall panel in order to avoid condensation internally in the panel from this moisture exposure as well as the continuous exposure during the usage phase.

Noise insulation

There are two aspects to noise insulation that are important for the use of timber frame in-fill wall panels, namely noise transmission from the outside of the building and flanking transmission from the adjoining dwellings or other premises.

Noise from the outside is relatively easily tackled with standard timber frame exterior wall panels. A standard build-up of the wall panel with an interior sheathing of gypsum board or similar, 145 mm mineral wool insulation (and studs), an exterior sheathing board and a timber (weatherboard) cladding would have a reduction value R_w for airborne sound transmission of around 40-45dB (consideration of windows not included). With a brick or render cladding this value would be some 10 dB higher.

The flanking transmission through the exterior wall to premises below or above or sideways, as illustrated in figure 12, is generally a bigger problem if the floor or wall separates different dwellings. This fact applies to virtually all construction technique alternatives. As shown in the figure, this is more difficult to solve if the wall panels are mounted outside the structure. This variant of the technique will probably require an interior, site built and well noise insulated, extra wall layer. For panels installed into (or partly into) the structure, it will normally be sufficient with the sealing measures required for air tightness and fire spread.

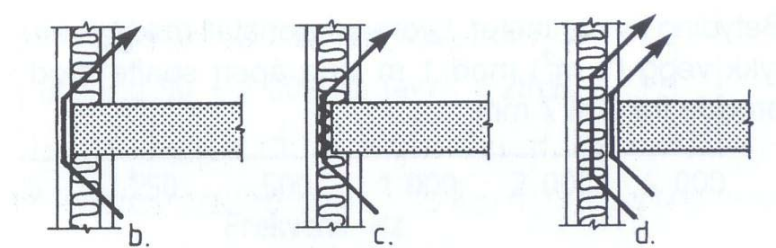


Figure 12. Flanking sound transmission paths through the exterior walls for different ways of installing the in-fill wall panels, where b) is the best and d) the worst case. However, only cases c) and d) are normally acceptable from a thermal insulation point of view. Source: Ref. [10]

Build-up of timber frame panels

Several versions of how the wall panels are built up exist. Mostly they are “national” differences reflecting the relative strengths in the respective markets of different material and component suppliers.

Stud sizing

The stud sizing is generally determined by the required insulation thickness, since in most cases the wall is built up by one stud layer (see section on Energy conservation above). The only essential load on the wall studs is wind load, which unless it is a high building or one with very large window openings, will generally not lead to required stud depths larger than some 95 mm. Indeed, some panel producers in the Netherlands use 95 mm studs and add an additional insulation layer on the outside without studs in order to minimize the cold bridges. Additionally the self-weight of the cladding should be considered. In some cases when the panels are installed outside the structure, the whole envelope has been a self-supporting structure. Either directly from the ground floor slab (e.g. the example in fig. 11) or from a ground floor wall panel hung from the first floor. The panels can of course also in this case be hung from each floor level.

Standard stud widths (thickness) vary relatively strongly from the American standard of 38 mm which is used relatively frequently in UK, Belgium, Netherlands and Poland, via the Northern European standards of 45-47 mm (also frequently used in UK and Netherlands) to the German standard of 60 mm. In case of 38 mm studs, these are normally doubled at sheathing board joints.

Interior lining and vapour barrier

The most usual interior lining materials are gypsum boards or gypsum fibre boards. The gypsum boards are beneficial for the interior finish works, whereas the gypsum fibre boards are preferred for their higher resistance to damage during transportation and installation. Behind the lining, there is normally a plastic vapour barrier. In Germany, the panels normally have an OSB (tongue and groove) sheathing on the inside with taped joints and no vapour barrier. For interior finish, this normally requires adding a lining board or other finish on site, sometimes on an extra wall layer for electricity installation etcetera.

Exterior panel sheathing and breather membrane

In the Nordic countries, exterior quality gypsum boards dominate as exterior sheathing of the panels (cladding is applied outside this). These are used without any additional breather membrane and provide stability to the panels during transport and installation, even when “open” panels are used, i.e. without interior sheathing. Under normal conditions these gypsum boards withstand at least 3 months weather exposure before the cladding is installed.

In the Netherlands, only an exterior breather membrane is increasingly used. Previously it was normally supported by an OSB sheathing board but with the use of a thicker and tougher breather membrane this can be avoided without an increased risk of damage during the construction phase. A perforated plastic foil is sometimes used as an alternative (with board backing) but this can create condensation problems.

In Germany, the common practice nowadays seems to be an MDF (tongue and groove) board as panel sheathing and breather membrane. In some cases, higher requirements on fire safety (for limited distance between building) has led to the use of cement bonded chipboards instead.

Cladding

Virtually all types of cladding materials and systems have been used in combination with timber frame in-fill panels. The most usual are render, brick or timber (weatherboards). There

are also numerous examples (particularly in the Netherlands) of the use of various cladding board products such as fibre cement boards, ceramic tiles and also wood cladding boards (three-layer boards, particularly in Germany and Austria, and plywood). The use of timber cladding is very limited in Sweden and Finland for medium rise buildings due to fire safety regulations, whereas the regulations for exterior cladding are more liberal in e.g. Norway, Germany and the Netherlands.

Timber and brick (and board) cladding is normally installed outside a ventilated air space, whereas render is normally applied on an additional layer of mineral wool or EPS (extruded polystyrene insulation), installed directly on the outside of the wall panel, see figure 13.

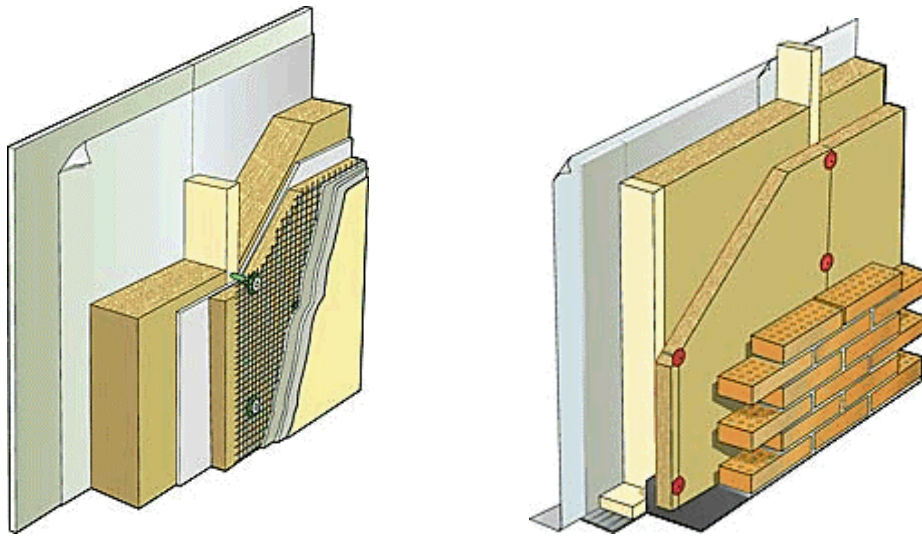


Figure 13. Cladding of render and brickwork respectively on timber frame in-fill panel walls. Source: Paroc AB.

Panel production and installation aspects

The factory production of the in-fill wall panels is not a highly technically advanced process. Normally the production process is considerably less automated than the production of panels for prefabricated timber frame houses. The reason is that the panel elements are much less standardised than those normally used by the timber frame housing industry. A strict quality control process is however equally essential in both cases, especially for the production of “closed panels” (with insulation and sheathing/lining on both sides).

The machinery normally used for the production of wall panels is production tables together with a traverse crane or a tilting production jig to be able to turn the panel elements around and move them to a transporting device of some sort. Pneumatic tools are normally used for nailing. If all studs and other timber components and sheathing boards are delivered pre-cut, this is virtually all that is needed. The same type of “factory” can therefore also relatively easily be set up at the building site. However, this is normally considered to be a competitive method only for larger scale developments.

The most frequent prefabrication level of the elements is “closed” panels, at least including the external sheathing (and/or breather membrane) or internal lining (and/or vapour barrier) and the insulation. Normally, windows are also installed in the factory. In the Netherlands, where the internal lining is normally factory installed, the electrical wiring conduits are also pre-installed. The windows are also normally installed but not the window panes. In

Germany, some of the projects also had pre-installed cladding. This requires very tight tolerances if the wall panels are fitted into the structure, whereas it is considerably easier with the wall panels outside the structure. Provided that the tolerance problems can be solved this could mean that scaffolding will not be needed at the building site at any time. Problems have, however, been reported regarding the handling of such finished elements on site at a relatively early construction stage (dirt, damages etc).

An important issue with this technique, as with all prefabrication techniques are the tolerances. In this case it is the exactness of a site-built structure that the wall panels shall fit into that is the main issue. Normally the panels are designed with a gap of 15-20 mm to the structure, which is not always sufficient for the panels to fit in. And the opposite; If the gap becomes too large (more than say 50 mm) it will be difficult to achieve a high quality sealing around the edges. As discussed above, the tolerance problem is smaller when installing the wall panels outside the structure.

Connection into structure

The wall panels are connected to the structure using steel angles or similar. The metal connectors are installed on the floor structure below and above the element or on the elements before the installation of the panels. In Sweden, the steel angles are mounted such that they are fastened to the inside of the wall panel (figure 14), whereas in the Netherlands, the connectors are fastened to the floor or wall edge (the outside of the structure) as in figure 15. It can also be noted that in the Netherlands, the elements are normally also fastened along their vertical edges (into the concrete walls) whereas this is not normally done in Sweden.

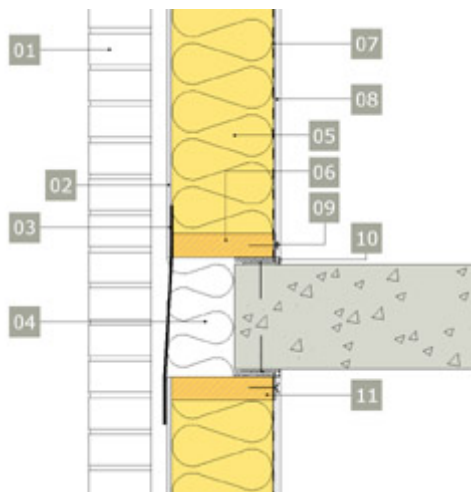


Figure 14. Typical Swedish wall panel installation detail. 1 = Brick cladding or other cladding, 2 = External sheathing (normally outdoor quality gypsum boards), 3 = Breather membrane, 4 = Floor edge insulation (and fire stop), 5 = Mineral wool insulation, 6 = Bottom plate, 7 = Vapour barrier, 8 = Interior lining (normally gypsum boards), 9 = Steel angle connector, 10 = Insulation, 11 = Top plate. Source: Ref. [3].

The main load on the connections is naturally wind loads and to a lesser extent self-weight from the panels and the cladding (unless for self-supporting brick cladding). Normally the wall panels are not used for stabilising the structure.

As has been discussed above, a main issue and potentially weakest point of this technique is how to provide sufficient sealing around the edges of the wall panels. The sealing is needed for:

- Air-tightness for heat insulation purposes
- Air-tightness to avoid smells spreading from one premise to another
- Fire stopping
- Noise insulation
- Moisture and rainwater protection (from the outside)
- Vapour stopping (from the inside)

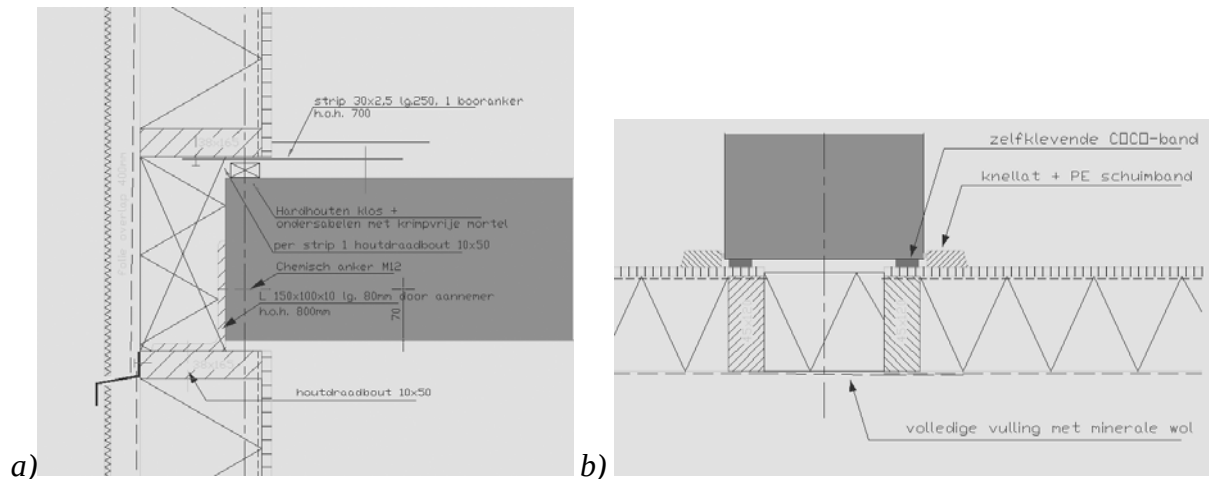


Figure 15. Typical Dutch wall panel installation details for a masonry or concrete structure. A) Vertical section. B) Horizontal section. Source: Ref [4]

The gap filling and sealing thus has to possess a range of properties and is therefore normally built up by a number of different materials. In Sweden, the normal method is to first fit mineral wool insulation from the outside into the gap between the panel and the structure, then to fill the space between the elements outside the structure with mineral wool and after that fitting the breather membrane (and sometimes also the exterior gypsum board) from the panel above down over the panel top (and the same procedure for vertical joints), see figure 14. From the inside, again mineral wool is fitted into the gap as well as an acrylic sealant to secure the edges of the vapour barrier plastic foil. In the Netherlands, either an expanding foam sealant tape or a polyurethane foam is used instead of the mineral wool in the gap between the panel and the structure. It should be noted that these products, as well as the mineral wool should be fire rated.

In the Netherlands a special floor and wall edge is normally shaped in the concrete when using tunnelforms for the concrete structure, see figure 16. This facilitates the sealing process, since the indented shape allows for somewhat larger tolerances whilst the panels can still be sealed against the vertical surface of the indent rather than the horizontal floor and ceiling surface. In fact this method provides some of the benefits of having the wall panel elements mounted outside the structure with the benefits of mounting the panels into the structure.

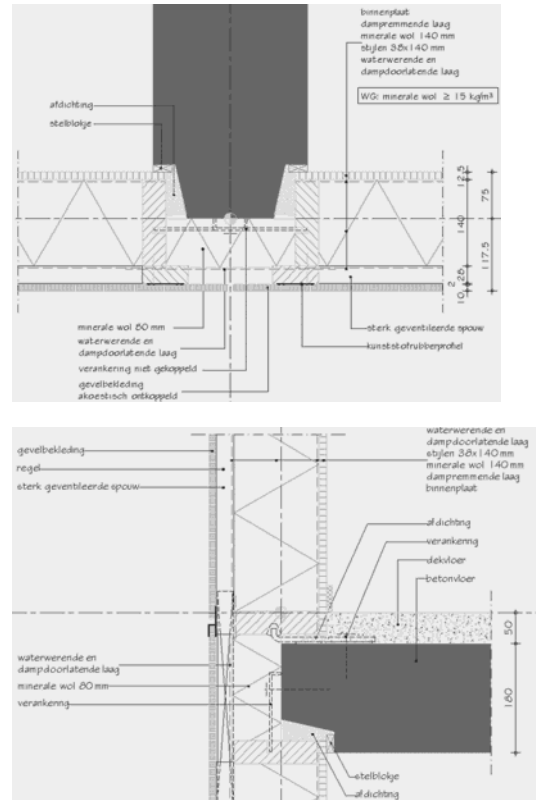


Figure 16. Concrete floor and wall edges shaped when casting with tunnelform to facilitate the sealing around the wall panels. Horizontal section in top detail and vertical section in bottom detail. Source: Ref [4] (photo) and ref [5] (details).

5. Arguments for in-fill timber frame exterior walls

The main arguments for the timber frame in-fill wall panel technique can be summarised as:

- Excellent thermal insulation properties are easily achievable.
- The usable building area is significantly increased as compared to a similarly insulated building with masonry walls because of lesser wall thickness.
- Savings in on-site labour and construction time through a systematic off-site manufacturing process.
- From an environmental (LCA) perspective, timber frame structures virtually always out-perform the competing techniques.
- The in-fill timber frame wall panel technique facilitates a high degree of architectural freedom of building shape and cladding materials.

The main weaknesses are:

- A certain sensitivity to moisture exposure during the construction phase.
- A lack of handbooks or other guidance material and market support from the panel suppliers.

Energy savings benefits and increased usable area

In virtually all countries that have been studied there has recently been a tightening of regulations with respect to energy usage in buildings and, in most countries, further development in this direction is anticipated. In the Netherlands where the technique was already well represented, the increased demands on energy efficiency has led to a market domination of the in-fill panels. There are of course alternative construction methods that can achieve the same levels of thermal insulation as a timber frame wall but in general the learning curve for builders is steeper for these new technologies than it is for only adjusting the timber frame wall and insulation thickness.

Another highly beneficial factor is that the timber frame wall can generally achieve a certain level of thermal insulation in a thinner wall than competing techniques, especially masonry walls, which means more rentable or sellable area per total building area. The standard externally insulated masonry wall in Germany today is about 350 mm thick (excluding cladding) whereas a timber frame in-fill wall could achieve the same insulation standard with a thickness of roughly 200-250 mm. This means an increased usable floor area of up to 3 % for a 10 meters deep building.

Off-site construction benefits

A strong selling point for the technique is the considerable potential for savings in on-site labour. In all (western) European markets this is important and likely to become even more important in the short to medium term future. The speed of erection compared to masonry walls as well as in-situ cast concrete is also an advantage, whereas the competing techniques with sandwich concrete panels and light-gage steel in-fill walls are comparable in terms of speed of erection.

Light-gage steel in-fill walls are comparable in most aspects. Provided that the steel studs are properly perforated and that the metal is very thin, their cold-bridging effects is nearly identical to that of timber studs. However, for factory prefabrication purposes, these steel studs are normally too slender to ensure sufficient element stability during transportation and building site handling, unless the panel elements have sheathing material on both sides.

Environmental benefits

In the best of worlds this should clearly be the number one selling point for all timber construction. However, the superior performance of timber frame construction compared to other structural alternatives (see e.g. reference [10]) does not yet result in any larger commercial competitive edge. The reason is the construction sector's heavy focus on cost and the fact that there are still virtually no economic incentives in any country to stimulate the decreased global warming potential and energy use facilitated by timber construction. Therefore, in the foreseeable future, this is not likely to become a strong driver for this extremely cost and efficiency driven construction segment. For other potential external wall systems with visible wood, e.g. curtain wall systems, the environmental benefits may well be more "sellable".

Architectural benefits

This has in particular been pointed out and used in the Netherlands where it has been one of the primary factors for an increased use of the technique for commercial construction. In fact it has also been the major reason for the total domination in housing in the Nordic countries over the last years, since the technique can be combined with virtually any cladding material without loss of competitiveness and visible wall element joints can thus be avoided.

Weaknesses

The technique's main weakness is a certain sensitivity to exposure to moisture. In the finished building this is no problem provided that the cladding and other moisture protection measures are correctly installed. If the panel elements are correctly protected during transportation and while they remain exposed in the building, the risk is also small. However, it should be possible to further develop the jointing techniques between structure and panels to completely avoid this risk and at the same time make the installation and jointing more efficient. It may also be feasible to develop efficient and harmless timber protection systems with a limited durability, i.e. for a short exposure time after panel element installation.

The second main weakness is the eternally weak support to architects and builders from the industry that supplies wood based construction products. For the in-fill wall panel technique this support is even weaker than for e.g. timber frame structures. Virtually no handbook material has been found in this study even though the technique has been used extensively in the Nordic countries and the Netherlands for many years and to a considerable extent also in other countries. The explanation in this case is that this technique was from the start primarily developed by the builders and the architects with very little contribution from the suppliers.

6. Development potential in different markets and segments

Development potential – Housing

Housing is the primary sector where an increased use of timber frame in-fill walls seems most feasible. This is in general the sector where the use of timber in construction has remained strongest or has best regained market shares. In markets such as Germany and UK where timber frame housing has a reasonable market share and a large proportion of architects have worked with timber projects, it seems likely that they could be persuaded to try the in-fill walls, especially since the structure would be the traditional or a slightly modified traditional. That could also be somewhat easier for the consumer (house or flat buyer) to accept than a load-bearing timber frame structure.

In the UK, load-bearing timber frame structures already have a strong market position also for the medium rise segment and is virtually always considered as an alternative technique. The risk of actually strengthening the masonry alternative through the introduction of more efficient techniques for exterior walls should therefore be considered. On the other hand, the in-fill panels could well be a very suitable product for a gradual build-up of production capacity in the timber frame industry. It is also likely that when offering both technical possibilities it would be easier to expand the total market. If the energy part of the building regulations that is due for revision again in 2005 will raise the requirements as significantly as projected, there may also be a possibility to take some market share from steel stud in-fill walls in the higher end of medium rise and for high rise projects (similar market as commercial sector). If, furthermore, the current drive towards more off-site production will have effect, it is also likely to lead to more factory prefabricated light-weight wall components, which, as mentioned above is an advantage for timber over light-gage steel.

In Germany it should be quite possible to gain significant market shares in both single-family and multi-family housing. Multi-family timber frame construction is very scarce but the emerging use of timber frame in-fill panels in “energy conscious” and “high environmental profile” projects could give the technique a considerable good-will. This apparently applies to a large extent also to Austria (see refs. [8] and [9]). In single-family housing there is of course, just as in UK, a certain risk of conflicting interest with the timber frame housing production.

In France, there is also a strong market development potential for timber frame in-fill walls currently even though the timber frame technique in general is not as strongly established there as in UK and Germany. The technique has been used rather extensively in the past and together with the current government aim to decrease the energy use and to increase the use of timber for environmental reasons (global warming), a well organised promotion activity with developed technical solutions and “packaged offers” from the industry should yield good results. This naturally applies to UK and Germany as well.

The Chinese market for housing is huge and there is currently a very strong government requirement for better thermal insulation and environmentally more viable solutions than the dominating clay bricks. This is also manifested through the fact that the Ministry of Construction has commissioned a standard for timber frame walls (exterior as well as interior) that will be produced during 2004.

In the Netherlands and in the Nordic countries, the in-fill panels are already the dominating technique and thus the primary focus should be to remain the market leader by developing even more competitive solutions and systems. In both markets, there is also a considerable potential for an increased use of load-bearing timber frame in multi-family construction, in the Netherlands also in single family housing.

Development potential – Commercial construction

In the commercial sector (offices, hotels, schools and other institutional buildings) there is a significant potential for the technique to grow, not least shown by recent development in the Netherlands and Germany.

The growth in this sector is a little bit more limited in terms of market share. A large part of office construction has curtain walls with a large proportion of glazing. For this market, curtain wall solutions with timber would have to be developed. This should however also be considered since there is a considerable demand currently for aesthetically high profile and (visibly) environmentally correct solutions in Europe, into which timber curtain wall systems would fit extremely well.

For the more ordinary office construction as well as hotels, hospitals, schools etcetera the technique is readily applicable in all frequently used structural systems. In this field the competition from the light-gage steel industry is very strong however, since steel drywall technique has been used for partitions as well as for exterior walls for a long time. Particularly in UK, this is believed to be a very difficult competition. A benefit for timber is again the better possibility for factory prefabrication of wall panel elements than for light-gage steel.

Development potential – Renovation and improvement

For replacement of exterior wall panel in large scale buildings constructed primarily in the 60's and 70's, the light-weight timber frame in-fill panels are an interesting option. In virtually all European countries, there is a huge stock of housing in large scale developments from this era. During this era, the structures were predominantly constructed from prefabricated concrete wall and floor elements and the exterior walls were non load-bearing concrete elements or light-weight panel elements, i.e. exactly the type of building that best fits the in-fill panels. These buildings are all poorly thermally insulated and increasing focus is being spent on the possibility of raising their energy efficiency. In many cases, it has also been found that the exterior walls are in a bad shape, whereas the structure is normally sound.

Furthermore, there is an interest in most countries to make these large-scale housing developments (housing estates) more physically attractive. However, “face-lifts” and higher energy efficiency can be achieved also by externally applying additional insulation and new cladding. At the moment, in most European countries there is relatively little activity in this field because of lack of funding. Therefore it is very difficult to estimate how attractive the possibility for replacement timber frame in-fill walls is and thus how large the market potential is.

Quantified market potentials – an initial attempt

It has not been within the objectives of this study to estimate the market potential for the technique in detail. However, some rough estimates can be made fairly easily for the European countries in the study (China is not included in the reasoning below).

A normal flat in a multi-family building built today in Europe is about 100 m² (ref. [1]). In the smaller scale buildings built today this means somewhere between roughly 20 and 30 length metres or 50-80 m² wall area of (potentially) non load-bearing exterior wall. The sawnwood use in infill panels with 170 mm deep studs (in one layer or divided in crossing layers) would normally be roughly 0,02 m³ per m² wall area, i.e. a total of 1-1.5 m³ per flat.

The current production (2001) of housing units in multi-family housing in the countries in the study are given in the table below. The total number of flats (units, new-build) in multi-family buildings with timber frame in-fill exterior walls is there estimated to some 45 000 units per year of a total of roughly 300 000 units per year in all studied countries or an overall market share of 15 %. The current use of the technique thus consumes some 45-70 000 m³ sawnwood per year plus additional use in single-family housing and commercial construction. With the same market share in all countries as in the Nordic countries and the Netherlands, i.e. some 70-80%, the sawnwood consumption in flats would be an additional 180-300 000 m³ sawnwood per year. In addition, there could be a similar magnitude of use in single-family housing. This is of course an extremely optimistic scenario and the reader is encouraged to make his/her own estimates.

Country	Housing units/year (total) (Ref. [1])	Housing units/year in flats (Ref. [1])	Estimated timber in-fill panels market share in flats (%)	Estimated flats (units) with timber in-fill panels per year
Sweden	16000	11000	90	10000
Norway	24000	9000	75	7000
Finland	32000	20000	80	16000
UK	162000	35000	<1	100
Netherlands	75000	18000	80	14000
Germany	285000	100000	<1	100
France	303000	58000	<1	100
Poland	104000	62000	0	0
Sum	1001000	313000		47300

In addition to the potential in new-build housing, there is clearly a large potential in commercial construction and renovation and improvements. These potentials are, however, not possible to quantify at this stage.

It should also be emphasised that there may be considerable side effects and synergies for the wood industry in such a development. Provided that competitive systems for partitions are developed and introduced in parallel to this, it is quite likely that the in-fill panels can provide the positive “pull” needed for a successful such re-introduction. There is also a possibility of an increased use of timber cladding and joinery in combination with the in-fill panels. Finally there is the inevitable spin-off in terms of a more widespread knowledge of the benefits and possibilities of timber in construction which can potentially lead to an increased use of timber frame (load-bearing) structures and other wood based building systems and the combination possibility to build up production capacity for timber frame through an increasing market for in-fill panels.

7. Conclusions and recommendations

On the whole, there appears to be a huge development potential for timber frame in-fill walls in numerous markets and market segments. In the four countries in Europe where the technique has been used continuously for a longer period of time (Sweden, Norway, Finland and the Netherlands), the in-fill wall panels are the strongly dominating technique and the technique is common knowledge in the building sector in these countries. The study shows that if this pattern could be spread to the rest of Europe (and to other parts of the world) there is a considerable potential for increased use of timber in the construction sector, both in the in-fill panels themselves and in spin-off developments for other wood based building components. Examples of such components are partitions, cladding and joinery. There is also a potential for an increased use of load-bearing timber frame and other wood based building systems through the increased and better spread knowledge of the benefits and potentials of wood based construction products and components.

The primary **benefits** that can be exploited for promotion of the technique are:

- Excellent thermal insulation properties are easily achievable.
- The usable building area is significantly increased as compared to a similarly insulated building with masonry walls because of lesser wall thickness.
- Savings in on-site labour and construction time through a systematic off-site manufacturing process.
- From an environmental (LCA) perspective, timber frame structures virtually always out-perform the competing techniques.
- The in-fill timber frame wall panel technique facilitates a high degree of architectural freedom of building shape and cladding materials.

The main **weaknesses** that need to be dealt with through further development work are (apart from the lack of widespread knowledge commented above):

- A certain sensitivity to moisture exposure during the construction phase.
- A lack of handbooks or other guidance material and market support from the panel suppliers.

The **recommendations** from this pre-study are therefore to:

- Perform a proper market analysis.
In order to get more detailed estimates of the market potential and assessments of the potential economic benefits of the technique for the building industry as well as the wood components industry, a regular market analysis should be performed. This should include estimates of the value of panel elements at different prefabrication and delivery/installation package levels. It should also more closely examine the potential in the renovation market.
- Facilitate an exchange of knowledge between current users – Create user forum.
This could have the form of organised high-level seminars and workshops where current state of the art in the different countries is presented in-depth and discussed. Through the creation of such user groups with architects, engineers, builders and timber frame panel manufacturers, many of the early mistakes and expensive prototype building examples could be avoided in countries starting to use the technique. Naturally, this should be complemented with articles in wide-spread construction sector and architectural journals.

- Assemble the current best practice as example solutions.
One of the results of the user forum should be an assembly of current best practice recommendations and solutions for various applications and on different structural systems. This information should be disseminated openly and without charge via Internet (and possibly in print as well) through a multi-lingual dedicated service as well as through the web services of the national promotion organisations around Europe. The structure should be such that the information can be easily updated continuously throughout the development work suggested below. The material should include inspirational and handbook type of materials for all actors in the process as well as model solutions as CAD drawings.
- Coordinate a common technical development programme.
As listed in this report, there are a number of issues that need further technical development. These are e.g. more competitive and safer solutions for the jointing of the elements to the structure and the sealing of the joints. Also, the moisture resistance of the panel elements and their components could be further developed. The overall competitiveness of the technique (and the components) could probably also be improved, e.g. through a systematic cross-examination of different existing solutions, components and material. Furthermore, the potential for incorporating more high-tech components for e.g. energy efficiency should be further exploited (c.f. the current Austrian development programme). The development programme should also include a framework for quality assurance for fabrication as well as handling and installation of the in-fill panels and finish work on the building site. The outcome of this development programme could be a harmonisation of solutions and components and possibly European approvals (EOTA) of such solutions and components. Demonstration projects should also be an integral part.
- Organise systematic promotion and training programme.
The dissemination of the results and material created through the actions suggested above can be made in a variety of ways, including journal articles, seminars and training courses, visits to architectural and engineering practices as well as builders and fabricators, distribution of printed material as well as advertising.

All of the above recommended actions could probably be incorporated into a European Collective Research Project in e.g. the European Commissions Framework Programme 6 scheme “Horizontal Research Activities involving SMEs”. There is currently a call in this scheme with closing date 6 April 2004, that is almost ideal for a collective application along the recommendations outlined above.

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Appendix: Interview summaries for each country

This chapter contains a compilation of the interview answers from each country to the main research questions in this project. The findings have also in all essential parts been included in the chapters above.

Research questions, UK

Interviews with:

- Dr. Vahik Enjily, Mr. Rob Grantham, Mr. Tim Reynolds, and Dr. Tim Yates, BRE
- Mrs. Jill Beaver, Southern Housing Group (Housing Association)
- Mr. Luciano Vitiello, Watkins Gray International (project architect for the Nightingale Estate)
- Mr. Steven Costello and Mr. Doug Harker, Broadway Malyan (Architects)
- Mr. Bob Gordon, MACE (Construction Managers)
- Mr. John Fletcher, Wood for good Ltd

Statistics (if available)

- The use of timber frame in-fill walls presently (volumes and market share):
 - Multi-family
Very little, see below. In-fill walls with steel studs, built on site, are relatively frequent for larger multi-family projects as well as for commercial construction, see further under “Standard construction practices...”. No statistics on the use have been found, however. Timber frame construction (load-bearing timber frame) is growing in terms of market share and has now a significant market share for residential construction up to seven storeys, see further under “Standard construction practices...”.
 - Offices, schools, hotels etc
No known examples.
- The use of timber (trussed rafters or other systems) for roof construction in these types of buildings:
Trussed rafters are the normal technique for single family housing.
- The current statistics for multi-family and commercial/institutional building construction (production volume, number of storeys, construction technique etc):
See ref. [1].

Previous experience of timber frame in-fill walls or wood curtain wall systems

- How many examples (roughly) are there of the combination of steel/concrete/brick structures and timber frame in-fill wall elements or wood curtain wall systems?
Only one example of recent dates has been found in this study. The project is a major housing project in Hackney, London (the Nightingale Estate), which will consist of 600 homes, 200 of which have been built to date. The project is built by the housing association Southern Housing Group. The technique used is adapted from the Netherlands through a technology exchange initiative between Southern Housing Group and a Dutch housing association. The main focus was on using the tunnelform technique for in-situ cast concrete for the building structure.
- In which market segments has the technique primarily been used (housing 1-3 storeys, housing 4-10 storeys, other.....)?

The project studied is a combination of blocks of apartments four to seven storeys high and 2-3 storey single family row-houses.

- What are the experiences in terms of:
 - Competitiveness compared to alternative building techniques?
The competitiveness of the in-fill walls has not been measured or estimated in this project. The tunnelform concrete structure has caused considerable difficulty for the builder in terms of a steep “learning curve”. The overall quality standards for the project were also raised above the normal. Indications are that the technique is some 0-10 % more expensive than masonry or timber frame, depending on the scale of project and the repetition of units and elements. However, for the timber frame in-fill wall panels, the experiences are positive.
 - Practical experiences from erection (e.g. structural tolerances/fit of elements, difficulties in providing air tightness, protection against water during construction)?
Some problems with tolerances have been experienced but on the whole the concrete structure was within tolerances.
 - Interest from architects/builders/contractors?
The project architect has been very strongly engaged in the adaption of the “new” building technique and is on the whole very positive. The tunnelform requires a larger amount of repetition in the projects and is thus a limitation. The building contractor has been reported to be sceptical to the tunnelforms but positive to the in-fill panels.
 - Legal limitations (standards and codes) to the use of the technique?
None
- Is prefabrication done on site or in factory?
The panels were factory prefabricated.
- Degree of prefabrication (frame + outside sheathing + insulation + inside vapour barrier and sheathing + windows/doors)?
The first phase of the project was built with “open” wall panels, i.e. only the exterior sheathing and breather membrane installed on the studs in the factory. In the later phase, “closed” panels” with insulation, vapour barrier and interior sheathing, were used. In both cases, the windows were installed after the fitting of the elements into the structure. Fitting the windows in the factory is being considered for future phases.
- How are elements typically built up (outside sheathing, insulation (and frame) thickness, inside vapour barrier and sheathing)?
The outside sheathing was a cement bonded chipboard with a breather membrane outside. The insulation in the closed panels was “EPS type” closed cell plastic insulation while in the open panels, mineral wool was used. The inside sheathing was gypsum board. No vapour barrier was used in the closed panel elements.
- Which firms supply factory built wall components?
Two different “timber frame” factories delivered the panels. The open panels were delivered by Llewellyn and the closed panels by Space4.
- Is there any documentation (handbooks, standards etc) available on the technique?
None on this specific technique.
- Is there a market for renovating larger scale concrete structures (primarily with concrete elements in the exterior walls) and has this technique been used in any such projects? (Typically large housing projects from the 60’s and 70’s).

There may well be but so far few renovations have included replacing the exterior walls.

Standard construction practice(s) for multi-family housing

- Brick and block type construction:
 - The dominating technique for single-family housing and multi-family up to 3-4 storeys is masonry load-bearing walls (either traditional concrete blocks or aerated concrete). In single-family housing, normally the ground floor is a concrete slab but the intermediate floors are timber joist floors.
 - o Concrete floors (prefabricated elements or cast in-situ)?
Normally used between apartments in masonry structures.
 - o Load-bearing exterior walls?
Normally in case of masonry structures
 - o Additional insulation needed for current energy standards?
Yes, normally applied on the outside of the masonry structure.
- Concrete construction in situ:
 - Over 3-4 storeys, the dominating technique.
- Prefabricated concrete elements:
 - Less frequent than in-situ
- Steel structures and steel/concrete structures:
 - Only used for high-rise buildings for housing.
- Timber frame:
 - Has become the normal alternative to masonry construction and concrete structures up to approximately 7 storeys. The overall market share in UK housing is believed to be around 15 % and rising and most architects and developers are now reasonably aware of the technique and its potential.
- What ranges in terms of number of storeys normally applies to the competitiveness of the various techniques?
 - Masonry is competitive up to 3-4 storeys, timber frame up to 7 storeys, concrete structures up towards 20 storeys.
- Any use of light-weight (metal or timber) non-structural elements (partition walls, exterior walls)?
 - Substantial use of light-gage steel stud in-fill in exterior walls in combination with concrete and steel structures (also for internal walls and partitions). Normally used in combination with brick or concrete element cladding. The steel frame in-fill walls are normally built and insulated in place. There is even a technique and range of machinery to manufacture the studs on site from sheet metal.
- The use of curtain walls and the most frequent type?
 - For high-rise and exclusive projects.
- Is there any trend currently towards higher degree of prefabrication which may affect the interest for in-fill wall systems?
 - Strong interest currently, which is likely to affect the normal construction techniques. Also strong driver towards increased use of timber frame.
- Is there any trend/legislation currently towards higher energy efficiency which may affect the interest for in-fill wall systems?
 - Yes, the legislation will take a further substantial step towards more energy efficient buildings in 2005. Issues such as air tightness are now being discussed

to a higher extent and are likely to be raised further in the next energy conservation standards (Building Regulations part L).

Standard construction practice(s) for offices, schools etc (for detailed questions, see housing above)

- Brick and block type construction
- Concrete construction in situ
Standard construction practice for low to medium rise construction.
- Prefabricated concrete elements
- Steel structures
More often than in housing. Normally with a composite steel-concrete floor.
- Timber frame:
Timber frame structures have a relatively strong position in market segments such as hotels, schools and also to some extent for low and medium rise offices. Market share unknown.

- What ranges in terms of number of storeys normally applies to the competitiveness of the various techniques?
No information.
- Any use of light-weight non-structural elements (partition walls, exterior walls)
Light-gage steel stud walls (“steel drywalls”) are the standard practice for internal partitions and for exterior wall in-fill (see housing).
- The use of curtain walls and the most frequent type
A large proportion of the market for medium to high-rise commercial construction (especially for high profile projects). These walls are normally supplied and installed by specialised sub-contractors. Wood curtain walls have been considered in some “environmentally high profile” office projects but normally fail due to the fact that there are no readily available systems.
- Is there any trend currently towards higher degree of prefabrication which may affect the interest for in-fill wall systems?
No information.
- Is there any trend/legislation currently towards higher energy efficiency which may affect the interest for in-fill wall systems?
Currently a strong awareness due to the fact that a more frequent use of air-conditioning is anticipated in UK office buildings.

Research questions, Netherlands

Interviews with:

- Mr. Anne Terpstra, Ingenieursbureau Boorsma b.v.
- Mr. Arie Mooiman, Centrum Hout
- Mr. A. Oosterveld, Timmerfabriek Houkesloot
- Mr. D. Wijnia, Friso b.v.

Statistics (if available)

- The use of timber frame in-fill walls presently (volumes and market share):
 - Multi-family
In housing construction in general the in-fill timber frame wall panel technique is dominating the market, currently amounting to some 50% of all housing (80 % of multi-family housing) construction, whereas timber frame construction (timber structure) is still at some 6 % market share. Estimated that the sawnwood use in in-fill walls far exceeds that in timber frame construction.
 - Offices, schools, hotels etc
The market share in commercial and other construction is increasing. No statistics available.
- The use of timber (trussed rafters or other systems) for roof construction in these types of buildings
Dominating technique in Holland is timber frame panel roofs, partly the hinged roof products.
- The current statistics for multi-family and commercial/institutional building construction (production volume, number of storeys, construction technique etc).
See ref. [1].

Previous experience of timber frame in-fill walls or wood curtain wall systems

- How many examples (roughly) are there of the combination of steel/concrete/brick structures and timber frame in-fill wall elements or wood curtain wall systems?
This is currently the dominating technique for housing construction (see above). Used both in combination with concrete and limestone masonry structures. Sometimes also in steel/concrete structures. The technique has been used since the 1980's, introduced through a promotion activity by the Nordic Timber Council (then the Swedish-Finnish Timber Council). There was also an earlier extensive use of timber based exterior wall panels during the period 1960-75 in the large scale housing developments of that era with prefabricated concrete structures. These were called "Norwegian facades".
- In which market segments has the technique primarily been used (housing 1-3 storeys, housing 4-10 storeys, other.....)?
Primary use has been in low to medium-rise housing (1-10 storeys). Recently, the use in commercial and institutional construction has increased. There is also a housing project of around 20 storeys high under development in den Haag that will use this technique.
- What are the experiences in terms of:
 - Competitiveness compared to alternative building techniques?
No specific (official) studies of the competitiveness have been found. However, the practical use indicates that the technique is currently the most competitive. The main competition is prefabricated concrete sandwich panels.

- Practical experiences from erection (e.g. structural tolerances/fit of elements, difficulties in providing air tightness, protection against water during construction)?
The connection of the panel elements to the structure is clearly the detail that needs most attention in the design stage. For the separation of apartments, it is considered important that the panels are installed standing on the floor, i.e. partly fitted into the structure. The reason for this is that noise insulation and air tightness is easier to solve in that manner. For single family housing and commercial buildings (2-3 storeys), the elements may sometimes be mounted on the outside of the structures, in which case the upper panels are supported by the bottom panel. In (tunnelform) concrete structures, a special shape at the concrete edge is generally created in order to facilitate the fitting and tightening of the elements. Air tightness is generally provided by flexible foam sealing bands (e.g. Illbruck “Cocoband”) around the edges that fill the gap to the element and additional sealing is generally provided by insulation foam and/or mineral wool. Water damages of elements during construction has not been experienced as a major problem, provided that the builder handles the panel elements correctly.
- Interest from architects/builders/contractors?
Generally, there is a reasonable understanding of the technique among architects since it is fairly widely spread. However, with the increasing use, there is also an increasing need for further information and knowledge, not least regarding the technical aspects of window placement on the panel elements and cladding systems. High interest from architects currently for commercial buildings, since the technique allows for a greater freedom in building form and expression.
- Legal limitations (standards and codes) to the use of the technique?
None
- Is prefabrication done on site or in factory?
The panel elements are always factory manufactured.
- Degree of prefabrication (frame + outside sheathing + insulation + inside vapour barrier and sheathing + windows/doors)?
The wall panels are virtually always closed panels, i.e. with exterior as well as interior sheathing, insulation and electrical conduits installed. Windows and doors are also installed in the factory but not the window panes (glass).
- How are elements typically built up (outside sheathing, insulation (and frame) thickness, inside vapour barrier and sheathing)?
The standard build-up today is a strong textile breather membrane (e.g. Polytex 3 by Meuwissen Isolatiefolie) on the outside and a plastic vapour barrier and gypsum boards or gypsum fibre (Fermacell by Xella or Rigidur by BPB) on the inside. The gypsum fibre board is more robust for handling in transportation and at site but more difficult for interior finish. The insulation is either glass fibre or rock wool, today typically with a thickness of 170 mm. The timber studs are most often 38 mm wide (2 side by side at panel joints), sometimes 45 mm. Cladding is not normally fitted on the panel elements. Cladding materials are brick, timber, render or various sheath materials.
- Which firms supply factory built wall components?
The panels are delivered either by the prefab timber frame housing companies as an additional product to their normal production or by specialised panel manufacturers. The design and manufacture of elements is normally conducted

under a quality control program called “KOMO Attest”. These programs are applied to all types of building components. For timber frame construction, the certificates (and handbook on approved solutions) are handled by an organisation called SKH (Stichting Keuringsbureau Hout). The manufacturers are also sometimes responsible for installing the pre-fabricated panels in the structure on site (5-10% of the market).

- Is there any documentation (handbooks, standards etc) available on the technique?
There are no specialised documents on the use of in-fill wall panels. However, there is the documentation from SKH on approved technical solutions and there are also recommended standard details available from SBR (Stichting Bouwresearch), see ref. [5].
- Is there a market for renovating larger scale concrete structures (primarily with concrete elements in the exterior walls) and has this technique been used in any such projects? (Typically large housing projects from the 60's and 70's)
Yes, the technique has been used successfully for the renovation of e.g. larger scale office buildings.

Standard construction practice(s) for multi-family housing

- Brick and block type construction:
The dominating technique for housing in the Netherlands is masonry with limestone blocks.
 - o Prefabricated floor elements with/without in-situ concrete on top?
Separating floors are most often massive concrete floors, normally a half prefabricated slab (Filigran) with in-situ concrete topping. Non-separating floors are usually hollow core prefabricated concrete elements.
 - o In situ cast floor slabs?
Not in combination with masonry structures.
 - o Load-bearing exterior walls?
One of the alternatives to in-fill panels. Less competitive today because need for additional insulation (sometimes in combination with additional timber frame structure to carry timber or sheath cladding).
 - o Additional insulation needed for current energy standards?
Yes, since the limestone blocks have little insulation. A minimal insulation corresponding to about 145 mm mineral wool is usually needed. The requirement is however on the building performance as a whole (including heating system etc) and not specifically on wall components.
- Concrete construction in situ
In-situ cast concrete using tunnelforms is increasing again after a slump in market share, since the housing production is now re-directed again towards more of series production in larger projects, less single project production. Here load-bearing walls and floors are all cast in-situ, with installations cast into the concrete. This is the traditional open cell construction, very well suited for in-fill panels.
- Prefabricated concrete elements
Less frequent in housing production, except for exterior wall elements.
- Steel structures and steel/concrete structures
Only for high-rise housing.
- What ranges in terms of number of storeys normally applies to the competitiveness of the various techniques?

- Masonry and tunnel form are typically competitive up to around 10 storeys
- Any use of light-weight (metal or timber) non-structural elements (partition walls, exterior walls)?

Yes, partitions will normally be timber frame as well as separating walls in the attics when using tunnelform construction for lower storeys.
- The use of curtain walls and the most frequent type?

Relatively seldom in housing projects.
- Is there any trend currently towards higher degree of prefabrication which may affect the interest for in-fill wall systems?

No information
- Is there any trend/legislation currently towards higher energy efficiency which may affect the interest for in-fill wall systems?

This has clearly been beneficial for the timber frame in-fill panels.

Standard construction practice(s) for offices, schools etc (for detailed questions, see housing above)

- Brick and block type construction

No
- Concrete construction in situ

No
- Prefabricated concrete elements

Yes, the most frequent. Either in combination with steel vertical structure or concrete.
- Steel structures

See above.
- What ranges in terms of number of storeys normally applies to the competitiveness of the various techniques?

No information
- Any use of light-weight non-structural elements (partition walls, exterior walls)

Most often light-gauge steel drywalls in commercial buildings.
- The use of curtain walls and the most frequent type

Frequently used. No specific information.
- Is there any trend currently towards higher degree of prefabrication which may affect the interest for in-fill wall systems?

No information
- Is there any trend/legislation currently towards higher energy efficiency which may affect the interest for in-fill wall systems?

No information

Research questions, Germany

Research by Elina Huovinen-Schüdde, Nordic Timber Council

Interviews with:

- Prof. Heinz Hullmann, Hullmann, Willkomm & Partner
- Mr. Buhr and Mr. Logemann, Zimmerei Sieveke GmbH

Statistics (if available)

- The use of timber frame in-fill walls presently (volumes and market share):
 - o Multi-family
No statistics available, see below.
 - o Offices, schools, hotels etc
No statistics available, see below.
- The use of timber (trussed rafters or other systems) for roof construction in these types of buildings
The use of wooden roof construction (pitched roof constructions) is very common in Germany in all kind of buildings. Roof trusses are used less, since the total volume is normally used for living area. Roof construction is traditionally a typical carpentry work in Germany.
- The current statistics for multi-family and commercial/institutional building construction (production volume, number of storeys, construction technique etc).
The latest available statistics from Statistisches Bundesamt are from 2001. Residential construction amounted to a total of 256000 units, of which 83000 units are in buildings with 3 or more units. The average number of units per multi-family building is 7.5. The market share of pre-fabricated construction was 13 % for single-family housing and 3 % for multi-family. The vast majority of this is timber frame construction. The statistics for “dominating building material” shows a market share for wood of 13 % in single-family and 2 % in multi-family. Masonry has 81 % and 88 % respectively and the remaining market shares are concrete buildings.
In non-residential construction, the statistics show a total construction of 35000 buildings, 3000 of which were offices or administrative buildings and 19000 industrial or (retail) trade buildings. The 3000 office and administrative buildings had a total floor area of 5.2 million m². The share of pre-fabricated construction is higher than in the residential sector with 26 % of the office/admin buildings, but the share of wood as dominating building material is lower at 6 %. Masonry has 48 %, concrete 35 % and steel 9 %.

Previous experience of timber frame in-fill walls or wood curtain wall systems

- How many examples (roughly) are there of the combination of steel/concrete/brick structures and timber frame in-fill wall elements or wood curtain wall systems?
It has been estimated that some 100 projects using this technique have been built in Germany over the last 10 years. The timber frame in-fill wall panels have been used in masonry as well as concrete structures. A 1995 research report “Holztafelbauweise im mehrgeschossigen Wohnungsbau” by Hullmann & Bredenbals (ref. [6]), pioneered the technique in the German market, with a thorough analysis of potential regulation barriers, technical aspects, potential market acceptance and competitiveness.

- In which market segments has the technique primarily been used (housing 1-3 storeys, housing 4-10 storeys, other.....)?
The dominant part is in residential construction but there is also a considerable number of examples in office/admin buildings. A large proportion of the projects have been projects with “low-energy” profile (see further under “Standard construction housing” below).
- What are the experiences in terms of:
 - Competitiveness compared to alternative building techniques?
Because of the special/experimentary character of the projects using non-bearing walls there is often no real cost benefit for the technique yet. In Prof. Hullmann’s analysis, the conclusion is that the technique should have the potential to become highly competitive. However, there are strong initial obstacles such as the difference in structure of a normal construction project organisation and that of a prefabricated single family housing project. The standard construction process is divided into 10-15 different contracts, carried out by separate craftsmen/companies organised directly by the project management (=architect as “Bauleiter”), whereas the prefab housing industry is organised for projects of “turn-key” type and not used to sub-contracts within a larger project organisation. The timber builder Sieveke also pointed out that the wall manufacturer normally gets involved in the project far too late; In tendering after the design has been completed by the architect. Therefore modifications of the details are often necessary. This unnecessary double work for details could be avoided if the construction company participated already in the design phase, especially in this early development stage for the technique when architects are not sufficiently used to it.
 - Practical experiences from erection (e.g. structural tolerances/fit of elements, difficulties in providing air tightness, protection against water during construction)?
Technically the interface between the wall panel elements and the floors and walls of the structure causes most problems in practice. Also, the difference between traditional methods (concrete and masonry) and modern pre-fabrication causes practical difficulties on building site, e.g. if completely finished walls are delivered and erected in a relatively early phase there is a high risk for damage. The timber builder also mentioned the coordination between professions and different companies on the building site as a problem.
 - Interest from architects/builders/contractors?
Currently there seems to be an increasing interest from architects in applying the technique, particularly in more “energy and environment conscious” developments. However, there is no guidance available for the detailing, which causes many of the problems mentioned above.
 - Legal limitations (standards and codes) to the use of the technique?
In general, there are no limitations in the building regulations of the different German states (Bundesländer). However, there are still some states that will not allow combustible material even in a non load-bearing wall for medium and high-rise building. The report by Prof. Hullmann describes the regulation status of 1995 and concludes that, in general, timber frame in-fill wall panels with a 30 minute fire rating (EI30) would be permissible up to approx. 8 storeys (22 meters from ground to top storey floor).
- Is prefabrication done on site or in factory?

Most of the examples have used factory prefabricated wall panels. However, there are also examples of “site factory” prefabrication as well as of in-fill walls built in place.

- Degree of prefabrication (frame + outside sheathing + insulation + inside vapour barrier and sheathing + windows/doors)?
Varying degree, c.f. above. Today it seems most common with a relatively high degree of prefabrication, even including the exterior cladding in some cases.
- How are elements typically built up (outside sheathing, insulation (and frame) thickness, inside vapour barrier and sheathing)?
According to Sieveke, the normal wall panel (for this technique as well as for timber frame structures) in Germany today has an inside OSB sheathing with taped joints (plus an inside gypsum board installed after wall panel installation), no vapour barrier, mineral wool insulation and an exterior MDF board sheathing as breather membrane (taped joints) or cement bonded chipboard for higher fire safety requirements.
- Which firms supply factory built wall components?
Sieveke estimated that there are about 20-30 manufacturers in Germany able to manufacture and take responsibility for the installation of the elements. They are either prefab house manufacturers (Fertighaus) or carpentry industries (Zimmerei).
- Is there any documentation (handbooks, standards etc) available on the technique?
None. A strong need for handbook type documentation for architects was pointed out by Sieveke; “The technique is a very good building method with great potential. Everything is possible - which is also the biggest problem, since every project is still a prototype.”
- Is there a market for renovating larger scale concrete structures (primarily with concrete elements in the exterior walls) and has this technique been used in any such projects? (Typically large housing projects from the 60’s and 70’s).
Prefabricated concrete block of flats, mostly in the Eastern Germany area, could be a potential market for this kind of technique. However, in the renovating of such buildings an alternative is that the existing concrete facades get a new insulation and surface instead of replacing them with new outer wall panels. However, there are some projects where the concrete elements have been replaced with timber frame panels, often with a special ecological background (energy savings, solar technology etc)

Standard construction practice(s) for multi-family housing

- Brick and block type construction:
Masonry construction dominates the residential sector strongly. Today light-weight (aerated) concrete blocks or limestone blocks are standard practice. The floors are either cast in situ or partly prefabricated with an additional in-situ topping.
 - Load-bearing exterior walls?
Always for low-rise masonry housing and usually also for medium rise.
 - Additional insulation needed for current energy standards?
Yes, the typical wall would be a 200 mm (aerated) concrete or limestone block with 150 mm rigid insulation bonded to the outside.
- Concrete construction in situ
- Prefabricated concrete elements

Concrete construction systems are unusual in residential buildings. In wall structures, brick and block methods are dominating, though normally in combination with concrete slabs.

- Steel structures and steel/concrete structures
Steel as structural system is very unusual in housing.
- What ranges in terms of number of storeys normally applies to the competitiveness of the various techniques?
This is somewhat difficult to tell at the moment since the vast majority of residential projects are low and medium rise buildings, where the “traditional” masonry construction is used. There are very few projects with more than 6 storeys.
- Any use of light-weight (metal or timber) non-structural elements (partition walls, exterior walls)?
Virtually no use of metal studs in exterior walls. Some use for partitions but quite unusual even there in the residential sector.
- The use of curtain walls and the most frequent type?
Little use in the residential sector. Load-bearing exterior walls dominate.
- Is there any trend currently towards higher degree of prefabrication which may affect the interest for in-fill wall systems?
Prefabrication is often mentioned as a future building method. The share of prefabrication has raised from 7,2% (1991) to 12,5% (2001) in ten years. BDF (the Prefabricated Housing Industry Association?) reports a share of 13,5 for 2002, of which 80% are prefabricated wood houses of domestic production and 20% import and other construction systems. However, the change towards more prefabrication is not seen by all players as a major trend. Some factors that have hindered a strong development towards industrialised building methods:
 - Local business - small companies
 - Strongly divided contracting systems - little cooperation between professions
 - Design and project practices based on traditional methods
 - Attitudes
- Is there any trend/legislation currently towards higher energy efficiency which may affect the interest for in-fill wall systems?
Energy standards for building were reformed in 2001 (valid since February 1st 2002). The previous low-energy standard is now the usual building regulation. Appr. 25-30% improvement/energy savings compared to previous regulations. No U-values prescribed for the construction, i.e. there is a possibility to compensate lower thermal performance of the construction through e.g. equipment. In-fill timber frame wall systems are used relatively often in “passive house”-projects – houses with very low energy consumption. Most passive houses however are 1- and 2-family.

Standard construction practice(s) for offices, schools etc (for detailed questions, see housing above)

- Brick and block type construction
The share of masonry construction is about half of that in the residential construction sector. However, masonry is still the biggest technique (41 %) also in non-residential buildings.

- Concrete construction (in situ or prefabricated concrete elements)
Unlike in housing construction, concrete systems are frequently used in non-residential building. Also the share of prefabrication is notably higher in non-residential than in residential construction. For example, in office and administrative buildings where masonry and concrete are dominating, the share of pre-fabrication is 26%.
- Steel structures
Primarily used in industrial and retail buildings. 9 % market share in office and administrative buildings.
- What ranges in terms of number of storeys normally applies to the competitiveness of the various techniques?
No information
- Any use of light-weight non-structural elements (partition walls, exterior walls)
Relatively common in the non-residential construction sector.
- The use of curtain walls and the most frequent type
No information
- Is there any trend currently towards higher degree of prefabrication which may affect the interest for in-fill wall systems?
See housing above
- Is there any trend/legislation currently towards higher energy efficiency which may affect the interest for in-fill wall systems?
See housing above

Research questions, France

Research by Mr. Yves Rodarie, Consultant to FIBC, Paris, see ref. [7], and Mr. Michel Daleau, Nordic Timber Council (translation and extract from ref. [7])

Interviews with:

Mr. Aimé Rochet, Consultant Timber in Building, Bletterans

Mr. Dominique Millereux, FIBC & SNCCBLC, Paris

Statistics (if available)

- The use of wood frame in-fill walls presently (volumes and market share):
 - o Multi family
No statistics exist.
 - o Offices, schools, hotels, etc
No statistics exist.
- The use of timber (trussed rafters or other systems) for roof construction in these types of buildings
The use of wooden roof construction (typically roof trusses) is the most common in France. According to Sycode who studied this market for the year 2000, wooden roof are used in 98% of the detached one family houses, in 59% of multi family building and in 14% of the non-dwelling buildings. This study does not give any share of trussed rafters against traditional carpentry.
- The current statistics for multi-family and commercial/institutional building construction (production volume, number of storey, construction technique etc).
The full year statistic available now is for the year 2001. These statistics are issued by the DAEI/CASP.
Single-family housing represents 25 760 000 m² or 191 800 dwellings. Multi-family represents 8 395 000 m² living area or 111 000 dwellings. Most of the multi-family buildings are 3-storey (lifts are mandatory for 4 and more).
The other usage sectors are; Offices 4 538 000 m²; Industry 14 167 000 m²; Trade 4 720 000 m²; Cultural 1 973 000 m²; Health & Retirement 1 567 000 m²; Schools 2 127 000 m²; Others 15 199 000 m².
The share of wood construction in the different sectors are approximately 35% in agricultural buildings, 25% in sport halls, 5% in commercial or industrial building and 4% for single family housing. Only a few multi-family building uses this techniques, they are estimated at less than 1% of the market.

Previous experience of wood frame in-fill walls or wood curtain wall systems

- How many examples (roughly) are there of the combination of steel/concrete/brick structures and wood frame in-fill wall elements or wood curtain wall systems?
They are quite a lot of examples, the most prosperous period being between 1960 and 1975. An early version of in-fill walls ("panneaux de façade") was developed in conjunction with the development of industrialised concrete construction for larger scale housing projects and was frequently used in this housing production era. The use of the in-fill panels terminated with the end of this large scale housing production in the mid 70's. The technique had another climax in the late 80's with the Disneyland production near Paris, reintroduced from North America. The later resulted into a new set of norms for this type of exterior walls. Recent examples are also available as new building, for instance in Evreux with 27 dwellings, in Reims with offices building, hotels almost everywhere in France, dwellings in Burgundy etc. Also noticeable is the

refurbishing of many prefabricated concrete wall panels built in the 1970 being replaced by timber framed in-fill wall elements, i. e. offices in Clermont-Ferrand.

- In which market segments has the technique primarily been used (housing 1-3 storeys, housing 4-10 stories, other.....)?

The technique has been used in all kind of building, housing up to 8 storeys high, housing 3 and 4 storeys, hotels, offices,
- What are the experiences in terms of:
 - Competitiveness compared to alternative building techniques?

No explicit competitiveness studies of these walls in the past or presently have been found in this study. Today, the new insulation requirement brings a new interest to the timber in-fill walls. Material costs are still higher in France when one compares timber walls with timber cladding with concrete walls, but the speed and cost of erection balances and offsets more and more this difference.
 - Practical experiences from erection (e.g. structural tolerances/fit of elements, difficulties in providing air tightness, protection against water during construction)?

There is no standard solution to this issue but it seems under control. The typical version of the technique in France today is to fit the in-fill panels outside the structure (see Ch. 4 of the report) and then to site-build an additional interior wall layer (called “murs semi-rideaux”. The structural tolerance are then relatively easily controlled using elastomer foams and bands or mineral wool and less frequently expanding polyurethane foams. The protection against water was not mentioned as being a specific problem.
 - Interest from architects/builders/contractors?

The architects rely upon the builders who in most cases have there own engineering specialists able to give a practical recommendation to the architects and designers.
 - Legal limitations (standards and codes) to the use of the technique?

They are no legal limitations to this technique. Some 12 different norms and/or standards refers to it.
- Is prefabrication done on site or in factory?

Prefabrication is almost always done in factory. However, there are also examples of wall panels being built in place (e.g. the Evreux project mentioned above)
- Degree of prefabrication (frame + outside sheathing + insulation + inside vapour barrier and sheathing + windows/doors)?

There is no industrial offer with a catalogue of components while for concrete and steel frame components, the standardisation is much more effective. The prefabrication varies a lot with the various builders. In general the outer cladding, the breather membrane and the insulation are part of the prefabrication package. It can also includes the window frames or even the complete windows.
- How are elements typically built up (outside sheathing, insulation (and frame) thickness, inside vapour barrier and sheathing)?

The typical assembly in France includes the outside cladding (a great variation exists but timber cladding is relatively frequent), the breather membrane, possibly an OSB sheathing, the frame and mineral wool insulation and a vapour barrier. There is often an additional interior wall layer (often with steel stud framing) to which the interior gypsum board lining is attached.

- Which firms supply factory built wall components?
This is supplied mostly by glulam manufacturers, roof trusses manufacturers and more seldom by timber frame houses manufacturers.
- Is there any documentation (handbooks, standards etc) available on the technique?
There are none devoted exclusively on this technique but there is some guidance for technical solutions in a publication from CSTB from 2002 (mainly on additional insulation systems for existing walls, however).
- Is there a market for renovating larger scale concrete structures (primarily with concrete elements in the exterior walls) and has this technique been used in any such projects? (Typically large housing projects from the 60's and 70's).
The replacement or the covering of exterior walls is definitely a growing market. It has been estimated to amount to approximately 800 000 m² wall surface per year.

Standard construction practice(s) for multi-family housing

- Brick and block type construction:
The dominating technique for all types of housing constructions
 - Additional insulation needed for current energy standards?
Yes
- Concrete construction in-situ
Used very seldom.
- Prefabricated concrete elements
Used very seldom since the termination of the large scale housing projects in the mid 70's. You find them mostly in flooring components and in opening lintels (headers).
- Steel structures and steel/concrete structures
Same thing as for prefabricated concrete elements
- What ranges in terms of number of stories normally applies to the competitiveness of the various techniques?
Concrete masonry construction techniques are competitive up to 4 storeys high, prefabricated structures are competitive above 4 storeys (few housing projects are currently built higher than 3 storeys).
- Any use of light-weight (metal or wood) non-structural elements (partition walls, exterior walls)?
Internal walls and partitions mostly use light-gage steel studs, distributed by the plaster board producers and are even used in timber frame houses.
- The use of curtain walls and the most frequent type?
Seldom in residential buildings.
- Is there any trend currently towards higher degree of prefabrication which may affect the interest for in-fill wall systems?
The lack of qualified working force in the field of construction will certainly have a positive effect on a higher degree of prefabrication in France.
- Is there any trend/legislation currently towards higher energy efficiency which may affect the interest for in-fill wall systems?
The new thermal insulation rules are affecting this market and in-fill wall systems are providing a sensible answer. A new law, not yet in force, will also encourage builders to use more wood in these systems.

Research questions, Poland

Research by Wojciech Nitka, Centrum Budownictwa Szkieletowego

Statistics (if available)

- The use of wood frame in-fill walls presently (volumes and market share):
 - o Multi-family
Virtually no use.
 - o Offices, schools, hotels etc
A couple of projects built by the Swedish contractor Skanska.
- The use of wood (trussed rafters or other systems) for roof construction in these types of buildings
Timber roof structures are standard praxis, at least in single family housing.
- The current statistics for multi-family and commercial/institutional building construction (production volume, number of stories, construction technique etc).
See reference 1.

Previous experience of wood frame in-fill walls or wood curtain wall systems

- How many examples (roughly) are there of the combination of steel/concrete/brick structures and wood frame in-fill wall elements or wood curtain wall systems?
There are virtually no examples in Poland of this technique except a couple of projects built by the Swedish contractor Skanska.

Standard construction practice(s) for multi-family housing

- Brick and block type construction:
The standard construction method is masonry using hollow concrete or aerated concrete blocks. The floor structures are usually in-situ cast concrete or prefabricated concrete elements with additional concrete cast in-situ. Non-loadbearing walls are typically masonry as well (cavity/cellular brick).
 - o Additional insulation needed for current energy standards?
Yes. Normally polystyrene insulation with thin plaster cladding.
- Concrete construction (in situ or prefabricated)
Less frequent than masonry structures but used to some extent. In-situ concrete is used more often than prefabricated elements.
- Steel structures and steel/concrete structures
Very seldom in housing construction.
- What ranges in terms of number of stories normally applies to the competitiveness of the various techniques?
The typical multi-family building built today in Poland is either 5 storeys or 11 storeys or more. 5 storeys is the limit without lifts. Masonry construction is used even for 11 storey buildings.
- Any use of light-weight (metal or wood) non-structural elements (partition walls, exterior walls)?
Light-gage steel is used to some extent or partitions but very rarely for exterior walls.
- Is there any trend currently towards higher degree of prefabrication which may affect the interest for in-fill wall systems?
No

- Is there any trend/legislation currently towards higher energy efficiency which may affect the interest for in-fill wall systems?
No

Standard construction practice(s) for offices, schools etc (for detailed questions, see housing above)

- Brick and block type construction
Most popular for e.g. schools, up to 4 storeys
- Concrete construction in situ or prefabricated
Used frequently for office building of virtually all heights.
- Steel structures
Used for taller office buildings.
- Any use of light-weight non-structural elements (partition walls, exterior walls)
Light-gage steel stud are typically used for partition walls. Exterior walls are typically brick masonry or curtain walls.
- The use of curtain walls and the most frequent type
Relatively frequent use of steel/glass curtain walls in office buildings.

Research questions, Nordic countries (Norway, Sweden, Finland)

Interviews with:

- Mr. Johstein Byhre Baardsen, Norwegian Institute of Wood Technology
- Mr. Mikko Viljakainen, Wood Focus Finland
- Mr. Hans-Eric Johansson, HE Bostadsutveckling
- Mr. Thomas Stohm, Skanska, Sweden
- Mr. Johnny Kellner, JM, Sweden
- Mr. Tommy Jörntell, Skanska Teknik, Sweden

Statistics (if available)

- The use of timber frame in-fill walls presently (volumes and market share):
 - o Multi-family
This technique dominates multi-family construction in all three countries. In Finland there are statistics showing that timber frame exterior walls are used in 78 % of potential cases (including commercial construction) and 37 % of all exterior wall area was timber frame in new-build (2002). In Sweden, the estimated market share in multi-family construction is around 90 % (as a share of projects rather than wall area, i.e. rather comparable to the first Finnish figure).
 - o Offices, schools, etc
No separate statistics exist for this sector.
- The current statistics for multi-family and commercial/institutional building construction (production volume, number of stories, construction technique etc).
See ref. [1].

Previous experience of timber frame in-fill walls or wood curtain wall systems

- How many examples (roughly) are there of the combination of steel/concrete/brick structures and timber frame in-fill wall elements or wood curtain wall systems?
Numerous. The technique of combining a load-bearing wall concrete structure with a light-weight insulated timber frame (“non-structural”) exterior wall and a cladding of brick, render or sheathing was developed in Sweden in the 1950’s to increase the productivity in the construction of multi-family housing and to gain usable floor space compared to the thicker masonry walls. In those days and to some extent even today, the concrete structure was cast in-situ using form tables or tunnelforms to form a structure of open boxes, into which the exterior wall panels were fitted. Today, the structure is more often composed of prefabricated concrete wall elements or steel columns and prefabricated pre-tensioned hollow-core concrete floor elements, but the same type of in-fill wall panels are used for insulating the exterior wall and carrying the cladding. The technique is normally the most competitive in the Nordic countries for blocks of flats with 4-5 storeys or more. Another example of the technique that is frequently used in Finland is in two storey single-family row houses (semi-detached houses). In those houses the walls between the units and the floors are made of concrete. The walls are prefabricated concrete element or in-situ cast concrete and the floors are prefabricated (hollow core) floor elements with in-situ concrete on top. The timber frame walls are built as a coat for the building. The timber frame exterior walls are also the load bearing structure for the roof structures (trusses in most cases).

- In which market segments has the technique primarily been used (housing 1-3 storeys, housing 4-10 storeys, other...)
 - For housing, see above. The technique has also been used frequently for offices, schools, hotels and other institutional buildings as well.
- What are the experiences in terms of:
 - Competitiveness compared to alternative building techniques?

The only alternative technique that is normally considered for multi-family housing construction is prefabricated concrete sandwich elements (two layers of concrete and a sandwiched layer of insulation). In the current market situation and for the current scale of projects (no really big developments built by one developer/contractor) the competitiveness is fairly even or slightly in favour of the timber frame in-fill panel. What also weighs in favour of the in-fill panels is a general desire to avoid the visible division of the external walls into element-sized rectangles.
 - Practical experiences from erection?

Some problems have been experienced with moisture penetrating insulated elements (“closed panels”) in Sweden which has led a number of contractors to switch back in degree of prefabrication to “open panels”. The main reason for the problems however seems to have been a poor timber material selection in combination with poor handling of the panels before and after installation on the building site and in combination with extraordinarily heavy precipitation during the autumn 2000. Some issues concerning moisture content of the timber when built in, behaviour of gypsum boards when exposed to excessive moisture etcetera still remain partly unresolved, however. Another major issue are different tolerances of the concrete and timber frames. The sealing around the elements is sometimes the weak point of this technique, especially due to poor structural tolerances. This is particularly so since the polyurethane (rigid) foams were more or less abolished in the 90’s for worker health and safety reasons. In Finland, therefore in many cases frames are built on site.
 - Interest from builders/contractors.?

The technique is common knowledge.
 - Legal limitation (standards and codes) to the use of the technique?

None that are different from all other wall types and materials.
- Is prefabrication done on site or in factory?
 - In Sweden, the wall panel elements are virtually always factory prefabricated.
 - In Finland, both methods are used. Also site factory is developed to combine the good experiences from both.
- Degree of prefabrication (frame + outside sheathing + insulation + inside vapour barrier and sheathing + windows/doors)?
 - Previously, all the mentioned components except sometimes the plastic vapour barrier and the internal lining were included in the prefabricated elements. In Sweden, since the moisture problems in year 2000, the degree of prefabrication has decreased. The outside sheathing in the Nordic countries is typically an exterior quality 9 mm gypsum board (e.g. BPB Gyproc U) and the internal lining is standard gypsum boards.
- Which firms supply factory built wall components?
 - Numerous firms. Most often these are small assembly workshops that specialise in timber frame wall panels. The prefabricated timber frame housing industry will also deliver this type of panels if there is available capacity in their factories. From Finland it was reported that during the spring and summer

period the house manufacturers can have capacity problems to supply wall elements. Therefore production on site is also competitive.

- Is there any documentation (handbooks, standards etc) available on the technique?
There is relatively little handbook or guidance material on the technique. In Norway there is a technical guidance brochure specifically for this technique (ref. [2]). Some guidance for Sweden is provided in reference [3]. Furthermore, design guidance is provided by gypsum board and insulation manufacturers.
- Is there a market for renovating larger scale concrete structures (primarily with concrete elements in the exterior walls) and has this technique been used in any such projects? (Typically large housing projects from the 60's and 70's)
This type of buildings represent a big share of the building stock especially in Finland and Sweden and to a somewhat lesser extent in Norway. Some examples of replacing the exterior walls exist but in most cases the concrete element wall panels are structurally sound and therefore normally maintained. In Finland, there is a growing interest for adding insulation and a timber cladding to the outside of the walls but so far timber cladding is not allowed for buildings with more than two storeys, except in sprinkled buildings.

Standard construction practice(s) for multi-family housing

- Brick and block type construction:
The market share is very low in all Nordic countries (in multi-family housing in Finland, it is only 1 %) for structures.
- Concrete construction in situ
The market share of this technique in Finnish construction (includes all) is 10 %. In housing most common use of the in situ construction is in basements and in load bearing walls. Possibly the use is somewhat more frequent in Sweden and Norway but the use is steadily decreasing in all Nordic countries.
- Prefabricated concrete elements
This is the most common technique in multi-storey houses. In Finland, there is also a frequent use in row house frames together with in-fill exterior walls as explained above. The floor elements are normally 1200 mm wide prefabricated hollow core floor elements with in-situ concrete or a raised installation floor on top. Alternatively, the floors are half prefabricated elements (50 mm thick Filigran type elements) with in-situ concrete.
- Steel structures and steel/concrete structures
In Sweden, there has been an increasing use of steel column and beam structures in combination with precast concrete floor elements in the last years. Otherwise this technique is primarily used in office construction. Light-gage steel frame technique is very rarely used for structural applications.
- Timber frame:
Timber frame totally dominates the building segment less than three storeys. In those houses the market share of timber frame is around 90 % in all three countries.
- What ranges in terms of number of stories normally applies to the competitiveness of the various techniques?
For houses more than two storeys, the market share of concrete and steel is very high. In Finland it is reported to be 98 % (timber 2 %) and it is likely that the situation is approximately the same in Sweden and Norway. Timber frame construction is competitive up to around 4-5 storeys according to a range of

studies but is still rarely used, mainly because of a lack of experience in the construction companies.

- Any use of light-weight (metal or timber) non-structural elements (partition walls, exterior walls)?
Very popular techniques. Timber, see above. Light-gage steel framing is the most common for non load-bearing interior walls and is also being introduced in exterior walls (perforated studs to avoid some of the cold bridging).
- The use of curtain walls and the most frequent type?
Very limited in housing.
- Is there any trend currently towards higher degree of prefabrication which may affect the interest for in-fill wall systems?
Very much contractor oriented question since it is partly depending on the labour market. At the moment, however, there is a rather strong trend and belief that prefabrication is likely to increase.
- Is there any trend/legislation currently towards higher energy efficiency which may affect the interest for in-fill wall systems?
In Finland, building codes were changed in October 2003 for higher energy efficiency requirements. In Sweden no recent changes have been made and none are anticipated.

Standard construction practice(s) for offices, schools etc (for detailed questions, see housing above)

- Brick and block type construction
- Concrete construction in situ
- Prefabricated concrete elements
- Steel structures
For schools and hotels, virtually the same applies that has been said about housing. For offices the dominating technique is a column and beam structure that can be made of steel or concrete. Steel frame buildings have in most cases prefabricated concrete floors (hollow core).
- What ranges in terms of number of stories normally applies to the competitiveness of the various techniques?
No information
- Any use of light-weight non-structural elements (partition walls, exterior walls)
Normally light-gage steel. Sometimes timber frame for exterior walls but virtually no use for partitions. Very popular with post and beam structure. Also sandwich concrete elements are used for exterior walls.
- The use of curtain walls and the most frequent type
Very frequent in office buildings
- Is there any trend currently towards higher degree of prefabrication which may affect the interest for in-fill wall systems?
No information
- Is there any trend/legislation currently towards higher energy efficiency which may affect the interest for in-fill wall systems?
No information

Country summary, China

Research by Mr. Hans Dutina, Nordic Timber Council

Interviews with:

Mr. Zhang Shaoming, Consultant to NTC, Beijing

Mr. Yang Xue Bing, China Southwest Architectural Design and Research Institute, Chengdu

Mrs. Qiu Fei Fang, Tianjin Fire Research, Tianjin

Brief overview of Chinese residential construction and standard construction practice

Since China started its open policy reforms some 20 years ago, huge changes have taken place in the country's economy. The cities in the many provinces have developed in a steady economical rate of 5-10 % per year.

The construction volume per year of residential housing in urban areas is ~8 million apartments per year in ~700 cities, steady rate more than a decade. Another ~10 million dwellings are built in poor rural/farming areas. This in total is representing ~1.5 billion square meter per year. The vast majority of the urban residential buildings are typically 6 storey dwellings. Price per square meter dwelling in Beijing is Euro 400-800 excluding all interior decoration and installations. Price index for some major cities: Beijing 210, Shanghai 150, Tianjing 100. Since 1999 a new reform was launched allowing private ownership of dwellings as well as buying and selling for market price.

The building system in urban areas is very much influenced by the cooperation with Soviet Union and based on reinforced concrete as structure material for slabs, columns and horizontal roofs. Bricks and mortar are used for making interior partitions and exterior walls. Clay bricks have totally dominated the wall construction but are since year 2000 not allowed in urban areas due to environmental reasons. A national Wall Reform Program is looking for new solutions and materials for mass fabrication of walls. Roofs are traditionally flat/horizontal but a clear trend to make sloping roofs in concrete or steel exists. Requirements for thermal insulation in exterior walls and roofs in the geographical heating zone were introduced two years ago. An energy tariff reform will be introduced in 2005 shifting the payment of energy for heating of residential buildings from the government (social right policy) to the individual apartment owner (energy monitoring systems will be mandatory in new construction in many cities).

Important official government policies in residential building and construction are:

- Energy saving in residential housing – heating/cooling costs
- Substitute for clay bricks in walls – promoting more sustainable solutions
- Material saving in building and construction - promote lightweight systems
- Shifting the industry from on-site construction to pre-fabrication concepts

Previous experience of timber frame in-fill walls or wood curtain wall systems

Nordic Timber Council is executing a promotion project in the Chinese market since 2001 (from 2004 jointly with CEI-Bois) The project is prioritising wall and roof systems in concrete and steel structure buildings. One full-scale show case building, demonstrating the timber frame in-fill wall systems was built during 2003 in China, initiated by the current Nordic Timber Council "China project". The building is a new hotel and scientific centre in Chengdu (central China, 6 million inhabitants) with a concrete structure. The in-fill exterior timber frame walls (also timber frame partitions and separating walls in the building) were

constructed in place in this project, using timber studs imported from Europe. The project has also organised fire testing of different designs of walls (gypsum board, mineral wool, timber frame) were conducted in a Chinese laboratory. Six national type approvals (certificates) of fire resistance have been issued for various wall designs.

As the building system promoted in China is based on well insulated timber frame construction using wood from sustainable forests, it very well fulfils the Chinese government policies specified above. Influential government officials within Ministry of Construction (MOC) also confirm the “European technology” as solutions following these policies. They also declare active support from the government in form of new standards supporting the wall system.

Thus this project has resulted in a new national standardization committee for non-load-bearing lightweight wall systems (interior and exterior wall applications) based on timber frame design has been established. The committee work started in September 2003 and deliver a new national standard to the Ministry of Construction in September 2004.