

Innovation in Residential Construction Systems in Sweden



Scott Hedges & Gregory La Vardera

www.byggghouse.com

info@byggghouse.com



Sweden stands out as the foremost innovator in homebuilding process and energy performance in Europe. 96% of Swedish Housing is built using an off-site process, and on average Swedish houses consume less than 50% of the energy of American Homes. Yet Sweden and the United States share a heritage of wood framed residential building, a result of the timber resources common to both countries. As recently as the 1970s the way houses were built in Sweden and the US was largely the same. But the global oil crisis of the late 1970s set the two countries on divergent trajectories. Sweden entered a period of rigorous innovation, improving the quality, construction efficiency, and energy performance of their houses. Their example is relevant to builders in North America because there remain many areas of commonality both in construction methods, consumer expectations, as well as the challenges presented in cold climate regions. One could consider Sweden as a “crystal ball”, showing what American House Building might look like if we had spent the past 40 years committed to improving efficiency.

Our investigation into the Swedish housing industry has occurred both in factories and construction sites in Sweden. We have documented and analyzed our observations in order to understand the Swedish common building process, and determined how key components have been altered across their industry to support these techniques. We have examined construction drawings and technical documentation from dozens of houses from multiple factories to come to an understand of key characteristics of Swedish residential building system conventions. And finally we have systematically applied these principles to wall and framing prototypes based on American building products in order to lay out a road map to implementing these techniques in the US. These are manifested in a series of prototype wall systems we generically call Nordic Layered Walls, and in a next generation development of Western Platform Framing which we have come to call Swedish Platform Framing.

We will present a photographic overview of the Swedish approach to offsite construction and discuss the defining features of both job site and factory process and practices. We will explain how these processes contribute to the superior average energy performance of Swedish houses. Last we will look in detail at the Swedish Wall itself, and our application of their concepts in Nordic Layered Walls and Swedish Platform Framing.

- How Swedish houses are built
- Industrial Production Process
- Application to US practices



This presentation will cover three areas.

- How Swedish houses are built: a brief overview of the site assembly of a typical house.
- Overview of the Industrial Production Process: innovations in off-site fabrication.
- Application to US Practices: adapting key innovations to American building.

How Swedish houses are built

Almost all Swedish homes are built with some form of off-site construction. It is a very lean process, everything arriving on site at the time it is needed, and in the quantity required, with very little waste of time, effort, or material. In contrast with American site building, which you are all familiar with.

How Swedish houses are built



We are going to watch a time lapse video of the site assembly of a Swedish house, but first I'd like to mention a few things you are going to see. The house perimeter is fully scaffolded, which means the workers can quickly and safely access the construction without ladders, and without the time needed to carry and move ladders. There are going to be four men working on this house, two on the ground staging and feeding the crane, and two on the house placing and securing the panels, plus the crane operator. In the US you may see 4 or 5 carpenters on an American home building site. They will be there for a few weeks framing a house. The Swedes will be done the same day they started, minus lunch and a few coffee breaks.



A short video will be presented here documenting a house installation. This will be followed by more images of the assembly process to highlight key points from the video.

This shows a floor panel being lifted into place. The cross furring is a typical technique used to facilitate passing wiring without boring holes through the framing. We will look at this more closely later in the presentation.



Here a floor panel being placed. I'd like to call attention to the top of the exterior wall, and note that the floor is being placed flush with the top of the wall, and not on top of the wall. We can also see the sill plate of the second floor wall which forms the "tongue" side of a tongue and groove joint that aligns the second floor wall when it is placed. Also visible is the gasket under the sill plate that will form the seal between the 1st and 2nd floor walls. So, before the wall is placed, it has already been precisely positioned, and sealed. There will be no need to carefully align the wall when it is dangling from a crane, the worst possible moment to need to be precise, nor will a worker need return to this joint with a caulk gun to seal it. When the second floor wall is placed, the joint is complete. By placing the floors inboard of the wall, they have reduced two field joints to one, and eliminated the need to finish an exterior band corresponding to the floor thickness. There are also energy performance ramifications to this configuration which we will cover later.



Another close-up of this wall panel joint.



Here we can see the racking used to transport the wall panels, and hold them in the vertical orientation. Temporary strapping is attached to the walls to protect sill and flashings from damage.



These braces which prop up the wall panels until everything is secured are also innovative. They adjust in length by twisting a grip in the mid section. This adjustability allows a single worker to quickly plumb the walls before they are secured permanently in place.

The blue plastic visible at the tops and sides of the panels is the heavy plastic vapor barrier sheet used at the interior side of all Swedish walls. We will look more closely at the composition of these walls later in the presentation.



Here we see the second floor walls in place, and the materials needed to complete the framing, gypsum wall board, and floor finishes all staged for the completion of the house. None of these materials will need to be carried in and up the stairs.



Here the roof assembly which was built on the ground the previous day has been moved into position to be lifted on to the house. You can see another roof assembly underway in the distance. These are also built of off-site fabricated elements - trusses and end wall panels.



The roof is lifted and guided into position, then secured from the inside.

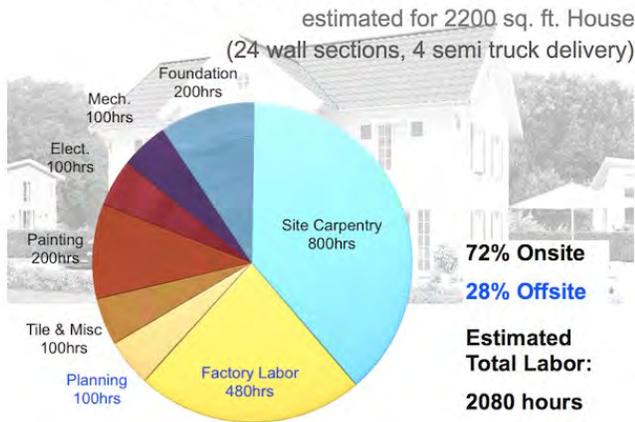


The last major operation is the staging of the roof tiles by one of the workers with the assistance of the crane. This man will do very little carrying, primarily lifting tile off the pallet to distribute them to the final location.



At the end of the day the house is "closed in", and for the most part water tight, the exterior walls were painted in the factory, all windows and doors installed and sealed, and a good deal of the wiring and plumbing is already complete. In this case an attached garage remains to be finished, as well as some interior partitions, finishes and painting. The house is roughly 75-80% complete.

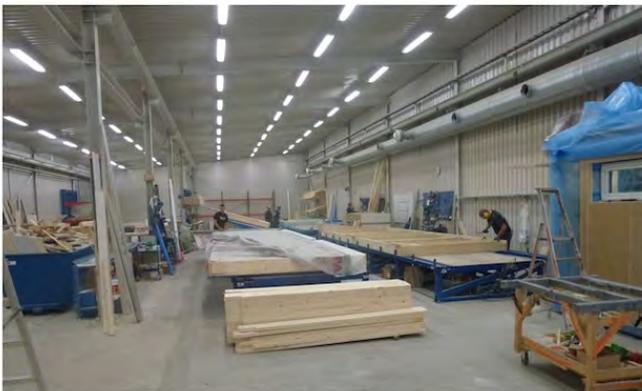
Distribution of Labor



A sample of the data from a single manufacturer indicates that the total amount of time spent on off-site construction is only about 28% of the total time it takes to build a typically sized 2000 sqft house.

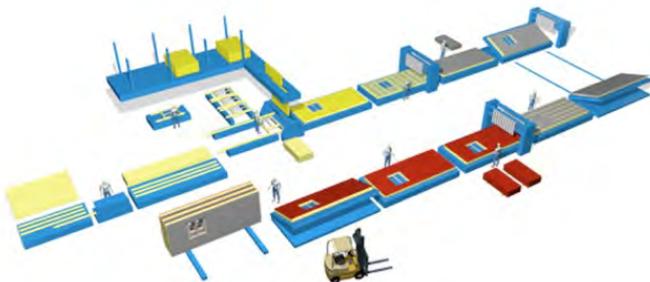
Overview of the Industrial Production Process:

Panel or Modular?



The assembly process we just watched used what we would call closed or both-sides-finished wall panels. This is the almost universal way in which walls are built in Sweden. In the US the predominant off-site method for houses is Modular. Modular also exists in Sweden, it is called Volume Element building, and it represents a smaller percentage of homes built than Panel, or Wall Element building. However modular builders in Sweden build their modules from closed finished-both-sides wall panels. And both Modular and Panel builders build walls using the same manufacturing process.

Standard Panel Process



The Standard Production Process can be highly automated, or completely manual. It can be a linear assembly line, or a static work-station model. All of these scenarios share key characteristics:

- Wall panels are fabricated on the flat.
- Panels are flipped to finish both sides.
- Completed panels are racked and transported in the vertical.
- Work goes from 2d to 3d at last possible moment.

Source: Randek, Falkenberg, Sweden

Walls - built on the flat



Working on the Flat provides numerous benefits to the building process.

- Working with gravity, not against it.
- Workers stand on the floor working waist high.
- Tools and supplies are always immediately at hand.
- No ascending/descending ladders.

This facilitates the efficient manufacture of complex high value assemblies. Swedish walls are sophisticated multi-layer assemblies that achieve high energy performance. This lends itself to interwoven trade sequences, such as carpentry-insulation-carpentry-insulation. Because there is little time or cost penalty for making walls with components in an assembly sequence that optimizes performance, they are able to invest more value into the wall assembly for less relative cost.

The mature process we see in Swedish home manufacturing is the result of a strong commitment from the entire industry. Almost all building components have been modified or adapted in some way to facilitate the manufacturing process.

Redesign of building components



In this example we look at the window installation process. On the right is a window being installed in an American modular factory. The process is essentially the same as site building, except it is taking place indoors. Once the window is in place the worker will be up the ladder we see in the background to sink fasteners into the nailing flange of the window. It will be taped to flash it to the house wrap layer. Later another worker will apply caulk or inject foam sealant.

On the left is a window workstation in a Swedish factory. The first step is for the worker to apply a butyl gasket around the perimeter. The window unit is then clamped into the jig with pre-cut lumber for jamb studs, head, and sill members which are then nailed together. The window is fastened to this subframe with adjustable fasteners that allow adjustment and squaring of the window unit.



Here we see staged window assemblies waiting to be incorporated into the wall panels as they are framed. What has just transpired? Essentially this window is installed, and sealed, and the wall has not even been framed yet. Nobody has to return to this assembly to finish it, or seal it, and if subsequent handling leads to any misalignment the unit is easily adjusted via its fasteners. This is a very lean process that has been totally reinvented for off-site fabrication.

Components - plumbing



Similar innovations have taken place with other major systems. Pex tubing for plumbing is something we are familiar with here in the US but less familiar is that this was a Swedish innovation. With PEX, the flexible plastic piping can simply be left in a small coil where it exits the panel and easily passed through a hole in adjacent work to be connected later. Because of this it is possible to plumb and ship the walls with the piping in place, and to easily connect the piping after wall panels are installed.

Electrical systems have also been adapted to off-site building in Sweden. The key issue is making connections between panels rapidly when the house is being assembled on site. American residential wiring relies on plastic shielded wire which is inexpensive, but it binds together the conductors and the protective casing. This prevents any panel to panel connection from happening without a junction box.

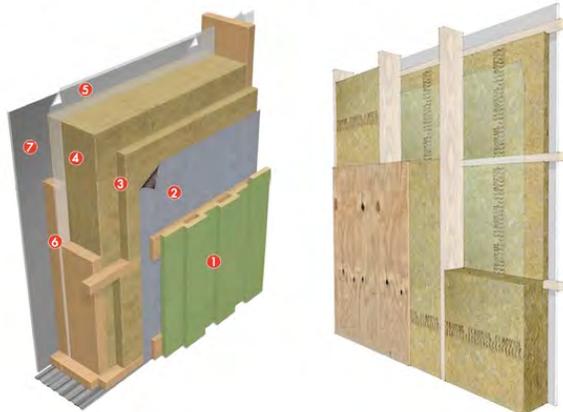
Components - electrical



The Swedes instead have a light weight plastic conduit system, that conceptually works more like our metal shielded commercial conduit systems. It simply snaps together easily in the field allowing joins to be made wherever needed. The conducting wires are simply pulled through later where conduits have crossed panels. Junction boxes have also been rethought to speed installation. Their circular openings work with a magnetically centered saw to quickly locate and cut box openings in wall board.

This kind of innovation is pervasive throughout Swedish house building and not limited to these few examples. All contribute to more efficient manufacturing process, better energy performance, and higher levels of quality.

Application to US practices

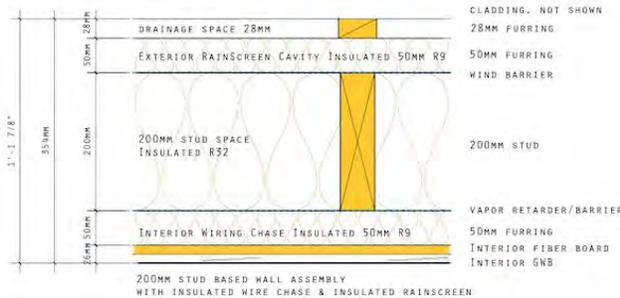


Application to US Practices

These building innovations are very transferrable to the US. Both countries use a stud framed house building model, and as such these Swedish innovations can be looked at as a natural evolution of practices here in the US. Demand for better energy performance is just emerging in the US, and market pressure for gaining efficiency through off-site construction is also growing. In that context we have studied how to apply elements of these Swedish techniques to American building practices. Today we'll look at prototypical wall assemblies, and also at a slightly larger scale whole house framing strategies.

This diagram represents a typical Swedish house wall, distilled from studying the standards of numerous Swedish factories. While there is some variation between factories this represents the major components of a typical wall. The main stud space is 200mm deep, just shy of 8". This is fully filled with stone wool insulation of approximately R32.

Typical Swedish Wall



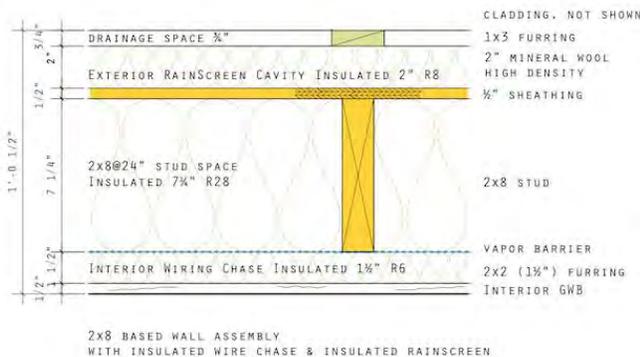
To the interior there is a heavy vapor barrier layer, which is then covered with 50mm furring to create a wiring chase. This is insulated with a 50mm batt of R9. This layer breaks the continuity of the framing to overcome thermal bridging. Over the furring is a particle board layer that adds bracing, and last Interior wall board. Note that wiring is kept completely within the Vapor Barrier layer which also serves at the primary air-tight layer for the house.

At the exterior the studs are covered with a wind-break barrier. Then with a continuous 50mm semi rigid stone wool insulation layer of R9. Over this is furring and last is heavy wood siding.

Our goal was not to recreate the Swedish Wall, but rather apply the energy efficient characteristics to a wall built with standard American materials, using the same trades and skills currently common here.

These are heating climate walls which we generically refer to as Nordic Layered Walls. There are 2x6 and 2x8 versions, both with a *Good/Better/Best* paradigm that applies these innovations in graduated steps. The purpose is to allow builders to step up performance as comfort level and market allows. We are going to look at the *Best* version of these walls.

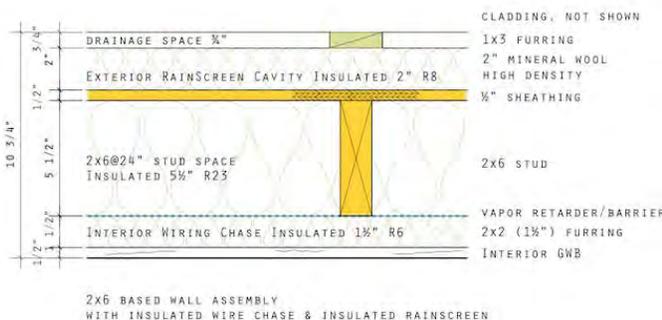
USA New Wall 2x8



At the core of the Nordic Layered Wall is a conventional stud wall with exterior sheathing. In the 2x6 version the stud space is insulated with 5.5" of stone wool of R23. In the 2x8 version the stud space has 7.25" of stone wool of R30.

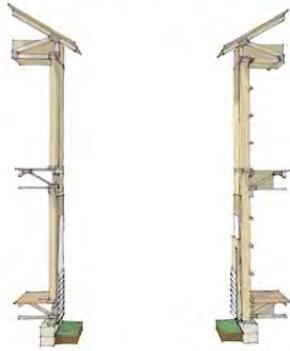
To the inside we first cover that stud wall with a vapor control membrane with variable permeability which allows the wall to respond favorably to the flip of the vapor profile in summer. This is important because air conditioning is so common in the US. This vapor control layer forms the primary air tight layer for the house. Over this is 2x2 furring for the wiring chase which is insulated with 1.5" of stone wool of R6. Interior wall board last.

USA New Wall 2x6



On the outside of the sheathing the typical american house wrap or building paper layers are installed, which are then covered with 2" of semi rigid stone wool insulation of R8 value. Over this is furring forming a drainage space, and siding panels mounted over that furring.

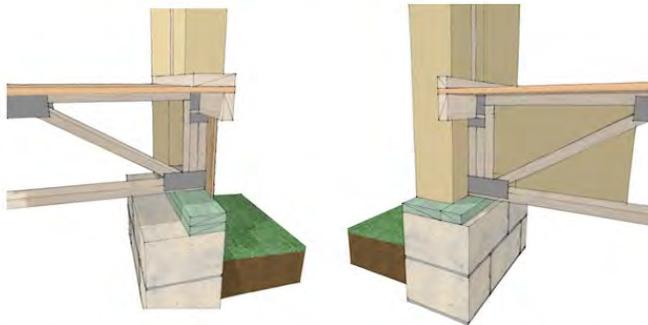
Platform Framing Innovations



Western Platform Framing

Swedish Platform Framing

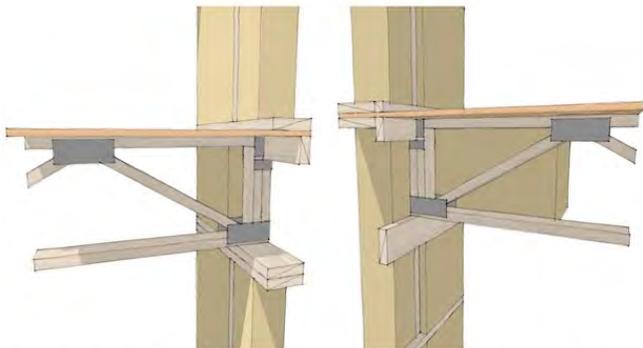
Ground Floor Condition



Western Platform Framing

Swedish Platform Framing

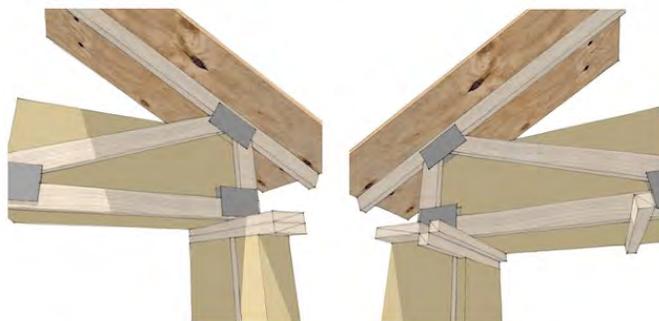
Second Floor Condition



Western Platform Framing

Swedish Platform Framing

Roof Condition



Western Platform Framing

Swedish Platform Framing

The second part is about whole house framing strategies. The predominant framing model for stud built houses in the US is Western Platform Framing. The Swedes have made several distinct changes to the Western Platform Model in order to facilitate off-site building, as well as resolve shortcomings of the energy performance and air-sealing characteristics of Western Platform Framing.

We've again translated this to American materials. It is referred to as Swedish Platform Framing.

At the ground floor of the Western Platform Frame the spaces between joists are difficult to insulate and air seal effectively, and the joist ends form a thermal bridge into the house. Sill Plates and wall sole plates form additional thermal bridges from the exterior.

The Swedish Platform Frame is configured differently. Wall studs extend all the way down to the foundation top, and floorjoists are moved inboard of the wall. The interior vapor control layer can extend all the way down to the top of the foundation wall for better air sealing. Multiple sill plates are eliminated, and thermal bridging of the assembly greatly reduced.

At the second floor the Western Platform Frame wall terminates under the floor joist with a double top plate, and resumes again above the floor with a single sole plate. Again the space between the joists is difficult to insulate and air seal.

In the Swedish Platform Frame the wall extends up to the second floor level, again allowing the wall insulation to pass outside of the floor framing. The vapor control/air tight membrane extends up to the second floor deck maintaining the integrity of the air tight envelope. This is made possible by the floor joists being supported on a ledger located within the depth of the interior wiring chase. The overall quantity of wood members forming thermal bridges is reduced, and the air tightness of the wall maintained.

At the roof the Western Platform Frame uses a double top plate to top the second floor wall. The Swedish Platform wall in 2x8 configuration will often be able to suffice with single top plate which reduces the thermal bridging. The furred wiring space continues here across the ceiling which reduces the thermal bridging from the roof trusses, as well as continues the vapor control and air tight layer across the ceiling completing the envelope.