COMPOSITE INDUSTRIALIZED ENERGY EFFICIENT CONSTRUCTION FOR HOUSING: CASE STUDIES OF RECENT DANISH AND SWEDISH HOUSING PROJECTS AND IMPLICATIONS FOR U.S. MULTI-FAMILY HOUSING

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The countries of Scandinavia have been on the leading edge of housing design including construction technology for the past 20 years. In Denmark, housing innovation such as the current "co-housing" movement, has been and continues to be a way of life. In Finland, Tapiola was the pioneering example of the planned community. Having greatly improved U. S. wood frame technology by industrialization, Sweden has produced the most advanced wood frame house in the world. Because of its setting and climate, Norway has been experimenting with Artia housing which has important international implications in housing design. Given this history of innovation it is timely that we carefully examine the technology of housing in Scandinavian countries. The research reported here is supported in part by a grant from the U.S. Department of Energy.

SWEDISH FACTORY CRAFTED HOUSING

Sweden has a long history of prefabricated wooden house construction. During the mid to late 1800's, Sweden pioneered small solid wood panel construction technology which was utilized in modernized form until after WW II. Large suburban areas surrounding Stockholm were developed using these early owner assembled solid panel construction systems. The housing of the Eskilstuna section of Stockholm is an example of this early industrialized building technology.

Overview. Sweden has developed a highly sophisticated wood frame industrialized housing production industry. The Swedish Factory Crafted (SFC) housing industry produces almost all single family housing built in Sweden today. SFC panelized systems come in two forms - small and large panel. Panel production in SFC plants produce both single family and multi family housing types, each on separate production lines. Prefabricated production includes floor panels called "cassettes", exterior wall panels, gable end panels, roof trusses and specialty items such as dormers and bay windows. Cabinetry is provided as a prefabricated package for each house. Interior walls, plumbing, wiring, roofing, interior finishes and paint are usually completed on site in conventional ways. While considered to be highly industrialized, the actual amount of " value" produced in the SFC panel factory setting is less than 50% of the total value of an SFC house. That portion of the SFC house that is produced in a factory setting is highly automated. Swedish housing companies are vertically integrated with the key to their success being management of the whole process of housing delivery from production to marketing and assembly. A single company such as Hultsfredshus produces, sells and arranges for installation of a compete house for an individual customer. Major companies have sales offices throughout Sweden. Customers work with a sales person in selecting a house and in making any changes needed to accommodate the unique needs of the purchaser. Most customers have their own sites, there are few "subdivisions" in Sweden. Houses are produced at the factory for a specific customer. Orders of customers are then produced by the plant and then sent to the construction site. Assembly on the site is usually contracted to a local specialist company that does assembly and erection of the house.

In 1983 there were about 100 housing plants in Sweden with production capability up to 44,000 housing units per year [Coming in From the Cold, Lee Schipper et al, 1985]. Production of SFC housing

varies considerably based on the nature of the housing market in Sweden and on export potential. Housing production has declined in recent years from a high in 1977 of 44,000 housing units to current production of about 15,000 units. Even at It's peak, production is only 5% of the total U.S. housing production capacity. Each factory has a set of standard models that they produce. Virtually every standard plan is modified to some extent by the customers to suit their needs. Within the Swedish house type, designs are quite varied and offer a good range of choice of plan, house form and color. Materials are much more constrained with exterior siding being predominantly board on board solid wood material with clay tile roofing. Sales offices are well stocked with brochures and sales materials for houses, appliances and furnishings and also provides complete financing packaging.

Production. SFC plants are highly automated but only operate one shift per day due to Swedish labor laws. Factories vary greatly in their degree of industrialization. Typically, panel lines begin with framing machines which assemble a floor or exterior wall panel by automatically nailing frame members. Window and wall units (produced on a sub line) are placed into walls as they are framed. Wall segments then move to the insulation station where insulating material is usually cut and placed by hand in the the frame. Moving on from the insulation station, interior sheathing is places on the frame and automatically nailed. After leaving this area, the wall is flipped over and building paper, stripping then siding (prefinished solid board on board siding) is installed. Each panel is stamped with identification numbers to insure that panels for a particular job remain together at the plant. Floor cassettes follow a similar process.

SFC technology has been applied to a very narrow and particularized part of the house - the exterior wall and floor panels. Manufacturing processes are directed toward the full automation of these building components. The most recent innovations in this technology are present in the Myresjo Hus production facility where new equipment has recently been installed that fully automates the floor and wall panel production system including a machine that places insulation in the voids between studs. With the development of this new technology, the only hand operations carried out in the wall panel line is the insertion of integrated wall and window/door elements by an operator into the panel line at the right location in a wall assembly.

Energy Efficiency. A major factor in the success of Swedish Factory Crafted Housing industry has been it extremely good energy performance. The current SFC house is the most energy efficient wood frame construction technology available in the world today. In additional to market forces that stress energy efficiency, Swedish governmental policy has encouraged innovative housing construction technology that will also be energy efficient. Traditions of high levels of energy performance have been further reinforced by the policy to decommission all nuclear power plants in Sweden by the year 2000. In order to achieve high levels of energy efficiency in single family detached houses, wall insulative values have gone from values of R-18 in 1973 to R-33 in 1984 and from R-24 to R-43 in ceilings. These code requirements have more doubled the energy conservation of such housing. Research reported by Schipper in the book titled Coming in from the Cold , demonstrates that energy conservation strategies in the ELAK SFC house could reduce energy consumption for a climate like Minneapolis by 80% or more from typical U.S. practice as of 1982. New housing energy consumption has also been reduced by 30% from pre 1941 housing. Paul Kando writing in a paper titled When the Best Costs Less, reports that an energy comparison of U. S. housing built to current (I988) standards with SFC housing also built to U.S. standards would yield energy savings of 28%, presumably just the result of higher construction quality. Building to Swedish standards would save even more. However, there are questions about the economics of energy saving technology in SFC housing.

The most important technical advance which could have significant application to the US energy efficient industrialized housing industry is the method of creating thermal breaks within building walls. Wood frame housing in the USA uses solid wood studs, plates, headers and framing members which create significant amounts of thermal tranmissency. SFC housing employs factory made wall framing members that virtually eliminates direct thermal contact between interior and exterior surfaces of the building wall. The "truss" stud is a truly significant improvement to the thermal performance of wood frame construction. Truss studs use composite materials of wood and steel. Industrially manufactured studs

employ small cut lumber members (usually 2 x 2) which are held together by thin steel truss plates. The whole assembly looks like a "ladder". The air space between truss stud cords is then filled with insulation. The thickness of the stud is a function the energy needs of the house with standard sizes being approximately 250 and 300 mm. While a variety of "hybrid" studs are in use, the truss stud will probably become the primary wall framing member in energy efficient industrialized housing plant as it is the most material efficient and can be "thickened" to accommodate increasing amounts of insulation.

Advanced energy efficient window technology is currently being used in SFC housing. The ultimate goal of this window technology is to produce window systems whose thermal performance is at about the same as SFC wall systems. Through a combination of 3 and 4 layers of glass, combined with window coatings and electrically charged gases, Swedish window technology is quite advanced and sophisticated. One of the primary goals of this research is to reduce the need for heating elements to be positioned under the window in the exterior wall of the house. This would then eliminate the need for ducting or piping to the exterior wall of the house which would save the cost of this equipment, eliminate line losses, reduce insulation compaction at the exterior wall, and improve overall heating efficiency.

Affordability. Swedish Factory Crafted houses are quite expensive, even by Swedish standards. The cost of a typical SFC house in Sweden (excluding land cost) is about $97 per sq. ft. in 1989 U. S. dollars. In order to achieve affordability, the Swedish government subsidizes financing costs in the first 5 years of a house loan by "buying down" interest charges to about half of market rate financing. Housing consumers seeking a lower cost housing alternative will probably buy a multi family housing unit. A comparison of Swedish housing costs using SFC housing with housing costs in the U.S.A. show that U. S. production built housing is about 1/2 the cost of SFC housing.

Several attempts to develop SFC plant technology have been attempted in the USA. The majority of these attempts have not been a financial success and all of the earliest attempts have failed. Factories have been tries in Minnesota and in New England. The most notable housing projects constructed in the USA using SFC construction technology is located in Laconia, New Hampshire. This is a condominium development in an area of second (vacation) homes.

DANISH HOUSING EXPERIMENTATION

Housing production in Denmark is quite different than that in Sweden. Denmark does not have the timber resources which Sweden possesses and housing has traditionally been built with concrete and masonry construction technology. Since W W II, Denmark has been a leader in the development of panelized concrete housing technology. Projects built in Gladsaxe and Albertslund areas near Copenhagen in the 1950's and 1960's were considered the most advanced housing technology of their time. Prefabricated wall and floor panels were used to create large number of housing units quickly in order to rebuilt housing stock lost during the war and to provide housing in rapidly growing suburbs around the major cities of Copenhagen, Aahus, Odense and Aalborg. Such systems were the standard in much of Europe including East block countries and the USSR between 1950 and up to the mid 1980's. Such technology is still in wide use today in many places.

While having a significant amount of single family housing, Danish innovation has been in multi-family housing design and construction. Being a small country, Denmark has had to conserve land. The goal of Danish housing has been to develop ways to create supportive environments for people living in a somewhat more dense environment than is the case in other Scandinavian countries. This challenge has been at the center of much of Danish innovative housing development.

Energy Conservation and the Development of Composite Construction Systems. The traditional concrete panel construction system is not very energy efficient. Attempts to improve the thermal performance of such systems has not been very successful. In fact a major new housing initiative is underway in Denmark and elsewhere in Europe to retro fit concrete panel building projects built in the 1950's and 60's to improve both their general physical condition and energy performance.

The realization that the traditional concrete panel method of housing construction was unable to provide the level of thermal performance needed in the future has lead to the development of a new housing technology that makes use of both concrete and wood panels, each used in a way to exploit their best potential. In addition, the desire to create housing environment that are better scaled to meet the needs of families has resulted in a decline of mid rise housing construction in favor or two and three story town and row housing construction in Denmark.

Danish housing construction systems have been developed that demonstrate considerable innovative thinking. The goal of much of contemporary housing construction technology is to remove the weight from industrialized building systems through the experimentation with light weight materials. Composite construction systems utilize precast concrete slabs (usually in a core slab form) for floors and concrete wall panels for party walls. Used in these locations, concrete can perform its role as a mass based material. Concrete inhibits sound transmission and also provides a thermal mass for passive solar gain in the interior of housing units. Exterior walls are predominantly built of factory made prefabricated wood framed open panel construction which allows high levels of insulation. Roof construction utilizes wood trusses and clay tile roofing.

The traditional exterior material in Denmark has been the brick. While some brick is utilized as an exterior material in composite construction, most recent housing utilizes thin light weight material called Concrete board, a derivative material of Cement Asbestos board but with a different "binder" than asbestos. The material can be applied directly over building paper wrapped wood frame exterior wall with screws or nails. Batts are used to cover the fastenings and can be arranged to give interest and scale to building walls. In addition, there has been some interesting experimentation with steel wall cladding systems. Other exterior components are prefabricated such as stairs, fences and porches.

Other examples of Technical Innovation in Danish Housing. Unlike the U. S. A. where housing innovation is highly market driven, Danish housing experimentation seeks to encourage the development of new ideas about housing design and construction which may have only marginal market appeal at the time of initial design and construction. Past innovative projects such as that at Galgabaaken near Albertslund and the Tingarden 1 ecological community near Koge as well as more recent "Co-housing" experiments provide ample evidence of this fact. The Byg and Bo housing exhibition just outside of Odense on the Island of Fenn has several examples of innovative materials uses over composite construction framework. In addition, both social and energy efficient design concerns are represented in the projects in the Byg and Bo site. Opened in 1988, the exhibition is yet another in a long line of experimental housing sites in Denmark where significant new ideas in housing design and construction are demonstrated. Projects represent a wide range of architectural design theory from that of materials and structural expressionism to the uses historic forms and precedents to derive architectural content. Overall, the project is not architecturally very successful because of the location of the site and the lack of overall housing plan that would significantly contribute to making a clear expression of community. While the overall planning of the project is not inspired, the opportunity to view a wide range of contemporary projects is an excellent laboratory for materials and form exploration in housing design. Innovative design and construction ideas represented in Byg and Bo exhibition include the pervasive use of composite construction systems, the use of glazed decks known as "sun spaces", innovative wall finish materials including steel panels and fiberglass roofing materials, the inclusion of glass enclosed atria and the programming of SRO housing units for teenagers, single young adults and single elderly persons.

The ideas developed in the Byg and Bo exhibition and in other innovative housing projects, make Denmark among the most advanced housing design countries in the world. Current ideas that offer opportunities for other countries including the U.S.A. include the now popular "co-housing" movement which offers significant energy efficiency opportunities in addition to the more obvious social and communal benefits. An active program to encourage alternative energy forms has lead to a high use of active solar collection systems and a national effort to make wind power a key energy source in the future. The co-housing project called "Sun, Wind and Light" has integrated social and technical concerns into one housing community that seeks to benefit from the use of a wide variety of innovative housing ideas.

Atrium Housing. Perhaps the area of Danish housing experimentation that offers the most interesting new design ideas is the development of atrium housing. Atrium housing is not reserved only to Denmark, all countries in Scandinavia have some level of atrium housing experimentation underway. The Swedish National Building Research Institute is conducting long range testing of two quite large atrium projects in the suburbs of Stockholm. Norway also has projects that is it testing. Atrium housing concepts in Denmark have been utilized in the context of more modest housing development than has been the case in Sweden. The Jystrup Sawmill Collective co-housing project utilizes a central glass enclosed "street" which links all of the individual housing units together. In Fredericia on Jutland near the bridge to the Island of Fenn, an atrium has been utilized to simply link row houses together thus creating a pleasant interior street that can be comfortably used for an additional two months of the year. Such atrium spaces also have energy efficiency implications, though of rather modest significance.

CONCLUSION

Housing innovation in Sweden and Denmark provide a laboratory for technical ideas which have potentially great benefit for housing in the U. S. A. Swedish Factory Crafted housing industry has taken the traditional technology of the U.S. timber frame house and greatly improved it by factory production. In addition, through incremental technical improvement the Swedes have created a single family detached dwelling of remarkable energy efficiency and quality which has set the world standard for wood frame housing production. The Danish housing industry, through a long commitment to innovative experimentation, has developed many important new ideas about multi-family housing that could have wide spread application in the U.S.A. The composite construction systems of concrete and wood frame will greatly improve the energy performance of traditional concrete panel housing construction. In addition such experiments as Co-housing and atrium housing offer both better energy and a more lively and rational social environment for housing. All of these experiments offer challenging new ideas which can be explored in future U. S. housing design.

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