CASE STUDY NO. 3

Oak Haven Modular House
Another generic type of residential construction is factory-built housing. What distinguishes this category of housing is that most of the components of the house are assembled in a factory rather than on the parcel of land where it will reside. There are some important distinctions in relation to building codes, energy standards, permits and regulations, which are discussed below, but there are also low-energy design strategies and opportunities that differ from conventional methods of housing construction.

This case study is intended to illustrate these differences while at the same time showing the special capabilities of this type of product for ZNE performance compared with standard site-built housing.

General Background: Factory-Built Housing

The ZNE Potential of Factory-Built Housing

It seems logical that houses, at least from the foundation upward, should benefit from being built in the controlled environments of factories just like cars, airplanes and furniture. To a large extent, this has been true in industrialized parts of the world since the early 20th century: Sweden, Germany and other northern European countries have developed a strong industry of factory-built houses that parallels their automobile industries in relative product quality and design.

In Sweden, for example, 85% of the housing is factory-built, which has been the same consistently high share of the market for decades. One of the reasons for this high percentage is the climate, where rapid construction time is valuable and favors the remarkably quick erection time of factory-built components. The result of this cold climate has also been the development of highly energy-efficient houses as a standard. Thirty years ago, Swedish factory-built houses were approaching current Passive House standards—super-insulation, airtight construction and even heat recovery ventilators (HRVs) to maintain indoor air quality in these high-precision products.

There has always been the potential—realized in these other countries—for producing all these energy-efficient characteristics at lower cost, less intensive labor methods and much less on-site construction time by utilizing a factory-built approach. Adding solar PV systems to such houses is another potential path to the development and growth of one type of robust ZNE housing sector—one that is affordable and of consistent high quality construction.

Factory-Built Housing in the United States—A Historical Anomaly

By contrast with the Swedish factory-built housing industry, accounting for 85% of all new housing construction there, United States factory-built housing is only 2%-3% of all new housing built in this country in recent years. This small share has also remained consistent throughout the last few decades. Given the great potential across all categories (consistent product quality, cost, time), including ZNE performance, what has historically held back the widespread adoption of factory-built housing in the United States and what are the prospects for change?

The history of factory-built housing in the United States in the first half of the 20th century matched that of the rest of the industrialized world and has been well documented\(^2\). At mid-century and partly as the result of World War II, the need for housing spiked everywhere and the interest in factory-produced housing grew in the industrialized countries. While Sweden developed its

\(^1\) https://www.census.gov/construction/chars/pdf/conmethod.pdf


\(^3\) http://www.searsarchives.com/homes/
Oak Haven: General Vicinity Plan
factory-built housing industry as the result of the central government’s ambitious Million Homes Programme, private ventures were undertaken in the United States in a more limited way.

The home-building industry in this country has always been greatly decentralized, characterized primarily by small independent developers and contractors, strong labor unions in the various building trades and large numbers of independent local government agencies with jurisdiction over construction. Combined with temperate climates and a relatively long building season, strong reasons to turn to factory-built housing were not apparent. Contributing to these negative factors was the early experience of post-war factory-built homes as primarily trailers and mobile homes, which created a negative impression about design and general construction quality. This poor-quality stigma still persists in this country, especially in the market of mass-produced houses in the suburban setting.

The result since the mid-20th century has been resistance to the use of factory-built housing in the place of the overwhelmingly-favored site-built (“stick-built”) approach.

Recently, however, there has been resurgent interest in the advantages offered by factory-built housing, driven primarily by cost escalation and disappearing affordability of housing (especially in California) and the interest in low-energy (and ZNE) performance. This case study is a description of one such approach that produced a housing product that succeeded in delivering both affordability and ZNE performance.

General Background: Definitions

Before describing this project, however, it is important to address nomenclature that evolved in this post-war period and which affects both the perception of factory-built housing and the regulation process that has such an important effect on it.

Site-Built Housing

Also referred to as “stick-built”, this is the standard method of construction in the United States, used in almost all housing. Each house is assembled on-site, piece-by-piece, using multiple trade sub-contractors. The local city or county government agency issues a building permit based on a unique set of construction documents and sends building inspectors to the site on a periodic basis for review and sign-off.

“ Manufactured Home”

Until 1976, this type of housing was known as a Mobile Home. The mobile home was built on a non-removable steel frame, known as a chassis, which was used for transporting the home and was an integral part of the structure. These types of manufactured homes were typically limited in width to the size of a traffic lane since they were transported via highway. They were often placed on foundations and formed the structures seen in a typical trailer park. Historically, they came to represent the public perception of factory-built housing: generally inferior design quality, impermanent and culturally labeled.

In 1976, the federal government adopted regulations of these manufactured homes due to concerns about safety, which became embodied in a building code under the U. S. Department of Housing and Urban Development—usually called “the HUD Code”. The manufactured home is not subject to local building codes, but only to the national HUD Code. A structural foundation is now required by the HUD code (thus the home is no longer called “mobile”).
“Modular Home”

A modular home is the general name for a factory-built house, which can be pre-assembled at a factory either as a panelized system (walls, floor panels, roof panels, trusses, etc.) or as whole modules. Both types of modular home systems can be transported by truck to the site where a foundation has been prepared and then joined together to create the whole house. (Swedish factories produce panelized houses based on a customer-selected design from a catalogue.) The modular home is the type of factory-built housing that has such great potential for ZNE performance.

The modular home is typically of much higher quality than a manufactured home and, because the factory-built components are assembled on site, there is no size limitation. In fact, it is usually the case that the appearance of a modular home is indistinguishable from that of a “stick-built” home when finished.

Modular homes are different than site-built homes, however, in terms of the approach to regulation. Because the components are built into the panels or modules in the factory, the usual procedure of having the local building department carry out plan review and approval, as well as inspection of the in-process assembly, cannot be carried out. Therefore, the California Department of Housing and Community Development (HCD) assumes responsibility for the approval process at the state level. The local agencies are still responsible for planning/zoning review and the foundation construction.

HCD reviews the design and construction of the specific modular home design at the factory for state building code compliance and, in particular, California Title-24 energy standards. When completed, an HCD-approved label for that model of modular home can be attached to every identical house that is shipped from the factory. There is an advantage with the state agency having jurisdiction since the design and construction of a modular home then is uniform throughout the state and not subject to the possible variable requirements of local building departments.

Specific Background: The Case Study of a Factory-Built Housing Project

There is currently housing construction activity in this sector of the housing production industry in California, namely modular housing, primarily by developers who partner with modular housing factories. A subset of these developers has been specializing in very-low-energy and ZNE-Ready houses. This case study is a description of one of these housing developments and of a representative house within this development, with a performance analysis of this individual structure.

A New Idea—The Zero-Net-Energy Factory-Built House

The idea of using the model of the energy-efficient Scandinavian factory-built house and adapting the techniques to the United States modular housing industry has been tried intermittently over the past several decades. With the advent of the zero-energy house and the marketing

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4 Prefabricated house, or “Prefab Home”, is often used interchangeably with modular home or to refer to only panelized modular homes, but to avoid confusion we will use only the term, “modular home” to signify this type of factory-built housing.
5 https://www.energy.gov/eere/buildings/zero-energy-ready-home. For certified energy compliance software (EnergyPro) that allows demonstration that a residential building meets the ZNE definition that the California Energy Commission describes in the CF1R document, see http://www.energysoft.com/zne-ready/.
The cachet associated with that term, more developers have brought such projects to market working with the available U.S. production framework of modular house factories.

The approach is to apply the proven ZNE design and engineering strategies for residential structures to the factory-built houses and to take advantage of the factory environment to provide quality control, tight tolerances, testing and inspection and consistency of production, thus assuring the ultimate ZNE performance.

**Project Process**

The developer for this case study project contracted with a factory located in Phoenix, Arizona, to produce modular house designs to the developer’s ZNE-features specification and a construction company in California to build the foundation, assemble the house components on site and connect the utilities. In this case, the modular houses were assembled from whole modules rather than flat panels.

The 22-lot housing development in Ojai known as Oak Haven offered “Modular Net Zero Green Homes” to potential buyers in 2009. Each house was customized with additional features, such as a deck or porch, as well as a particular “style” as defined by exterior finish, decorative elements and roof shape. A potential buyer ordered the preferred design using images provided by the developer or based on the model home initially constructed on the larger site. In this approach, the project was not unlike a conventional single-family housing development in its final appearance, but the intrinsic differences were that this project used factory-built modules of high construction quality and it incorporated advanced design techniques that could provide a ZNE performance.

The representative house in Oak Haven is the house on Lot 18, 1885 Maricopa Highway, which was purchased by a retiree attracted by the development’s green house construction with ZNE performance capability. After the buyer selected the preferred floor plan and a “Santa Fe” style, the developer ordered the house from the Arizona factory, specifying the ZNE features (described below). The foundations were built on Lot 18 and the two house modules were delivered to the site in a matter of weeks, where they were lifted into place by a crane and tied together in the same day. Finish features and the solar PV system were then added to complete the construction of the house.
Oak Haven Modular House - Lot 18: Floor Plan and Assembly Diagrams
ISOMETRIC OF THE TWO HALVES

ROOF PLAN
**Building Program**

The plan selected by the buyer contained a master bedroom suite with a master bathroom, a second bedroom, a separate bathroom, laundry room, an exterior porch and living spaces consisting of kitchen, dining and social areas, for a total of 1,152 sq. ft. This program fit neatly into two modules that were 11’-8” X 46’-0” each, easily transported by two trucks.

**Site Constraints**

The lots and streets of the Oak Haven neighborhood of green homes are not configured to favor a southern orientation for the rooftop PV panels, nor as a result are the houses themselves because of the small lot size. But since the roofs have a shallow slope, the reduction in energy production of the PV systems located on the west-facing roofs, which includes the house on Lot 18, is only roughly 10%-15% compared to the optimal orientation of the panels.

**Low Energy Design Strategies**

**General Design Considerations**

The developer, Modular Lifestyles, worked with the factory to develop a series of options to present to the buyers, typical of modular house design. For the houses at Oak Haven, the company also specified construction that would exceed California Title-24 requirements by approximately 20% and have a number of additional low-energy features common to ZNE-performing houses.

**Building Envelope – Insulation and Windows**

The factory was given direction to construct the walls of the modules thicker than the standard and filled with insulation, achieving R-28. The roof space between the shallow trusses was filled with 12” of blown cellulose insulation to create a high R-42 value. The plywood roof sheathing is a radiant barrier, with low-emissivity foil facing the interstitial space and suppressing heat gain in that small volume.

Windows are double-glazed, as required by Title-24, but they have the additional feature of argon gas within the glass unit, lowering the U-value of the window by an additional 33%. There also a low-e coating on the glazing, which reduces the thermal transmission via radiation, further improving performance.

**Building Envelope – Air Tightness**

The factory was also directed to seal the envelope at the window joints and penetrations, which was straightforward to execute at the factory. The developer took the additional step of testing the completed module for air tightness after it left the factory and before it was delivered to the site.
Daylighting and Electric Lighting

General lighting throughout is provided by 10"-diameter solar tubes\(^7\). Daylight admittance, which can produce bright lighting on sunny days, is controlled at the ceiling to create an unusually well-illuminated, glare-free interior in addition to reducing energy use. Where appropriate, electric light fixtures are used. These employ LED or CFL lamps for energy efficiency.

Heating, Ventilating and Cooling Systems

Heating and cooling is provided using an Energy Star air source heat pump with a SEER\(^8\) rating of 13. This is more energy efficient than a combination of a gas heater and traditional air conditioner—it is also carbon-free. Energy Star now requires a minimum SEER rating of 14.5, but at the time of construction of the house of Lot 18, 13-SEER was the minimum to qualify for Energy Star.

Conditioned air is delivered to the various rooms via air ducts in the shallow attic space. In addition, a 90-cfm whole house fan can be utilized to pre-cool the house at night when the temperatures are low enough to be effective. This reduces the cooling load during the following day.

Domestic Hot Water

To keep cost as low as possible, the domestic hot water is supplied via a gas-fired water heater rather than a more expensive add-on feature to the heat pump system. However, the houses were pre-plumbed to add a solar-thermal water heater at a later date.

Plug Load and Equipment

All electric appliances meet the Energy Star standard, providing energy-efficiency guarantees for internal equipment loads. A gas stove is utilized for cooking.

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\(^6\) See the discussion in Case Study No. 1, p. 12 of this Volume 3.

\(^7\) Solar tube is the generic name for a tubular skylights, which basically consist of a clear acrylic dome at the roof, roof flashing, flexible or rigid tubing with a highly reflective interior surface, and a diffusing lens at the ceiling. They are compact and effective daylighting devices for interior spaces during the day; they are usually equipped internally with high-efficiency electric lamps to provide light when daylight is unavailable.

\(^8\) The SEER rating of any cooling device is the cooling output during a typical cooling season divided by the total electric energy input during the same period. The higher the unit’s SEER rating, the more energy efficient it is. 13-SEER is roughly equivalent to a COP (Coefficient of Performance) of 3.2.
CASE STUDY NO. 3
OAK HAVEN MODULAR HOUSE

Zero Net Energy Residential Case Study Buildings: Volume 1

PHOTO: LAWRENCE ANDERSON

PHOTO: LAWRENCE ANDERSON
Renewable On-Site Energy Supply

The on-site solar PV system consists of eight 250-watt LG Solar panels for a total power rating of 2.0 kW (DC).

The house of Lot 18 is one of eight houses whose lot configuration requires the low-slope gable roofs to face east and west. As noted above, the slope is shallow enough so that the effect on production efficiency of the PV arrays is only slightly reduced from optimal.

For price competitiveness in the particular market for these types of houses, the installed size of the solar PV system was set at 2 kW. Though advertised as Modular Net Zero Homes, these houses were not likely to produce a ZNE performance for an average owner. The idea was to provide roof space and connections for future additional PV panels once the energy use characteristics of the occupants could be evaluated and the required number of additional panels for actual ZNE performance thereby determined.

The houses were therefore initially more than ZNE-Ready and would actually achieve full ZNE if desired by the owners by adding the appropriate number of PV panels after a period of time.
Energy Performance  
Post-Occupancy Measurement

Energy Use—Monitoring and Measurement

California Solar Electric Systems Inc. in Ojai was hired to install and monitor the solar PV system performance for all the houses at Oak Haven using the Enphase Enlighten monitoring system. The PV system energy production for the house on Lot 18 was recorded for a full year beginning in October 2016. Electric energy use of that house was not separately monitored, but Southern California Edison provided net meter data for that period so the monthly and annual energy use totals could be calculated using the Enlighten data with the net meter data. Natural gas use for that period was taken from the owner’s gas bill. (The energy use of the house on Lot 18 is charted on the opposite page for the monthly and annual totals.)

The total annual energy use for that house for the period 10/2016 through 9/2017 was 6,285 kWh, or 21,450 kBtu. For the 1,152 sq. ft. house, this gives an EUI of 18.6 (kBtu/sq. ft.), an exceptional performance number.

Energy Production versus Energy Use: Zero Net Energy Performance

The solar energy production data of the PV system installed on the house on Lot 18 was recorded for that same period and totaled 2,940 kWh, just less than half of the annual energy use from all sources and about ¾ of the annual electric energy consumption.

As expected, the initial installation of the solar PV system was not large enough to produce ZNE performance. But this data permits a calculation based on actual energy use patterns, which indicates that an addition of 2.5 kW capacity would theoretically produce about 6,600 kWh annually and result in a Net Positive performance. This translates to ten solar panels of the same performance rating as the original system, placed on the roof in the space planned for them. (These ten panels are shown dashed in the Roof Plan on p. 51) Energy production efficiency of solar panels has improved in the interim, so that only six or seven panels of the currently available models would deliver the same amount of power.

The chart on the next page (top) show the energy use of the house on Lot 18 over the course of the year (10/2016-9/2017) and the corresponding energy production of the initially installed solar PV system (2.0 kW). The dashed curve represents the energy production of a full-size PV system (4.5 kW) that would result in ZNE performance.

The second chart on the next page (bottom) shows the cumulative net energy production for the house with this measured energy use over this same period and the energy production of the full-size PV system. (Again, this chart shows the progression of the energy performance toward ZNE by adding each month’s net energy performance to the previous month’s total. If, at the end of the year, the curve remains on the positive side of the zero axis, then the house is indeed performing at ZNE.) The chart confirms that the full-size system of 4.5 kW would result in the house performing slightly better the Net Zero.
Measured Energy Use
House at Lot 18
(2016 - 2017)

6,285 kWh/year
Measured EUI = 18.6

Energy Use (Gas) 36%
Energy Use (Electricity) 64%

Measured Monthly Energy Use
House at Lot 18 (2016 - 2017)

kBtu/sq.ft.

Energy Use (Electricity)
Energy Use (Gas)
Solar Photovoltaic System Performance
House on Lot 18 (2016 - 2017)

Cumulative Net Energy Performance
House on Lot 18 (2016 - 2017)
Post Occupancy: Observations and Conclusions

The primary observation is that the Oak Haven project demonstrates that modular housing can be built for ZNE performance at market prices.

One can apply ZNE design strategies in the same way as in “stick-built” houses—insulation, high-efficiency heating and cooling systems, Energy Star equipment, solar PV systems—and the Oak Haven houses show that this is possible within the normal profitability goals of a developer. This may be due in part to the appeal of a project like Oak Haven to a sector of the market that values this kind of quality construction while at the same time the modular product reduces cost due to the type and speed of construction.

Post Occupancy: Building Envelope

Of particular interest is how ZNE modular house construction fits within the general discussion of the technical advantages of factory-built housing and the consistent quality of the product that is possible. The principal aspect where this seems to occur is with the building envelope, particularly its thermal integrity (continuous, tight-fitting insulation) and the air-tightness components. Given the importance of these features for low energy use, the high degree of good quality control possible in a factory setting undoubtedly results in a consistently superior energy performance compared to the range of quality with “stick-built” structures.

In particular, air-tightness seems to be well-suited to factory construction and testing. The controlled environment of the factory plus the routine methods of quality assurance in the factory setting would seem to make air-tightness a noteworthy advantage of the factory-built house. Again, the potential consistency of this feature in the product provides the advantage of the modular house over the “stick-built” house.

The developer of the Oak Haven project carried out the air-tightness testing separately from the factory, thus not taking advantage of the complete set of possible quality control procedures. Ideally, as ZNE techniques and features are adopted in the factory environment, it would be routine for construction methods of air-tightness to be employed and tested to ensure consistently good results.