Making Connections: Innovative Integration of Utilities in Panelized Housing Design

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1. Abstract

The design of prefabricated housing has occupied the attention of architects in the U.S. for decades. Prefabrication offers the promise of high construction quality, material conservation, affordability, installation in almost any site condition, and technical innovation. The general term of prefabrication covers a number of different construction techniques: manufactured housing (formerly known as "mobile homes" or "trailers"), modular, panelized, component-based, and hybrids of these different systems. The greatest impact is being made by manufactured, modular, and panelized technologies, which collectively now account for about 56 percent of all the housing constructed in the U.S. (according to *Automated Builder* magazine, which closely monitors the industry). Among these, panelized construction is the largest segment (43 percent of all prefabricated homes), the fastest growing, and the most diverse. In 2006 the estimated 3,500 panel builders in the U.S. collectively built about 1.483 million units of housing.[1]

Panelization in many ways offers the greatest design flexibility to architects and builders, and the potential for the greatest innovation. The focus of this research is the interface and integration of utilities (electrical wiring, cable, communication wiring, gas piping, and other kinds of utilities) into different types of panel systems. This integration has long been the "Achilles heel" of panelization—how to deliver the promise of swift, efficient, and innovation design and construction possible through panel systems and allow for easy integration and service of a house's myriad utilities. This research identifies and evaluates panelized systems designed to address the challenge of utility integration.

This research focuses on 15 panelized systems selected and studied to understand the "state of the art" of utility integration in panelized construction. Based on what was learned through the study of these 15 systems, "Performance Standards Criteria" are used to "grade" the systems and to understand the level of integration in the types of systems studied. These criteria are built upon the documentation used for evaluating the performance of each system in relation to how the panelized systems incorporate utilities.

Based on the state-of-the-art in panelized utility integration, the research formulates 10 "integration techniques" for utilities in panelized construction derived from the 15 systems studied. These 10 techniques are evaluated according to 14 generic Performance Standards Criteria that consider such qualities as transportation, installation, covering and finishing, skill level, tools, code compliance, and compatibility with other systems in the house. The 10 integration techniques are evaluated and "scored" as to how well they satisfy the performance criteria. Each technique's score indicates how well the technique satisfies the Performance Standards Criteria overall: the higher the score, the better integrated utilities are into the panel system.

Based on this evaluation, the research presents seven "Decisive Factors" that architects, builders, homeowners, and others considering panelized systems can use in determining how innovatively a panelized system integrates utilities.

2. Introduction

This study focuses on the integration of utilities (electrical wiring, cable, telephone wiring, gas piping, and other kinds of utility systems) into different types of panel systems. The goal of this research is to help builders and architects to understand the choices available in the U.S. market for panelized systems and how they integrate utilities to ease construction in the field.

This study examines 15 panelized systems that were selected and studied to understand the "state of the art" of utility integration in panelized construction. Based on what was learned through the study of these 15 systems, Performance Standards Criteria were developed to "grade" the 15 systems and to understand the level of integration in the types of systems studied. These criteria are built upon the documentation that was collected for evaluating the performance of each system in relation to how they incorporate utilities into panelized systems.

Based on the state-of-the-art in panelized utility integration, 10 "integration techniques" for utilities in panelized construction were derived from the 15 systems studied nation-wide. These 10 techniques are then evaluated according to 14 generic Performance Standards Criteria that consider such qualities as transportation, installation, covering and finishing, skill level, tools, code compliance, and compatibility with other systems in the house. The 10 integration techniques are then evaluated and "scored" as to how well they satisfy the performance criteria. Each technique's score indicates how well the technique satisfies the Performance Standards Criteria overall: the higher the score, the better integrated utilities are into the panel system. Based on this evaluation, the report concludes with seven "Decisive Factors" that builders, architects, homeowners, and others considering panelized systems can use in determining how well a panelized system integrates utilities. These Decisive Factors will help those in the market for panelized housing systems make the right choices based on the level of utility integration desired.

3. Types of Panels

Panelized construction covers a large variety of systems that have distinctive construction and utility integration features. Because there is no definitive classification of panel systems by the homebuilding industry, this study identifies four generic panel systems that are used to compare performance.

Generic Panel Systems

Wood panels

These panel systems are framed with wood studs and clad with oriented strand board (OSB) or plywood.

Structural Insulated Panels (SIPs)

These are systems that consist of an insulated core (typically polystyrene or urethane) that is sandwiched between two sheets of oriented strand board (OSB).

Concrete panels

Concrete panels present various techniques including an insulated core sandwiched between either finished concrete panels or welded wire mesh that is sprayed with concrete. The most popular concrete panel is the ICF (Insulated Concrete Form) where concrete blocks are sandwiched between insulating materials (polystyrene typically).

Metal panels

These systems typically consist of an insulated core (expanded polystyrene typically) bonded to a galvanized steel frame.

In studying the 15 panel manufacturers selected, it was found that there is a wide variety of "integration techniques" used to marry the utilities with the panel system. Table 1 on the next page is a summary of the manufacturers of different panel types selected for this study that use these integration techniques.

Table 1. Selected Manufacturers Studied in Different Panel Types

Generic panel system	Integration techniques	Selected manufacturers
Wood panel	Surface mounted/baseboard	Bensonwood
Wood panel	Factory-installed in panel	Alman homes, Axia Buildings
SIP	Pre-cored utility chase	IB Panels, Murus, Precision Panel
SIP	Molded in place	Thermocore
SIP	Surface mounted/baseboard	Structurewall, Insulspan
Concrete panel	Installed on-site within ICF	ECO-Block
Concrete panel	Pre-cored utility chase	LIFCON
Concrete panel	Steel mesh	Sipcrete, 3D Panel System
Concrete panel	Factory-installed in panel	Dukane Precast
Metal panel	Pre-cored utility chase	Thermasteel

4. Generic Performance Standard Criteria

Taking the 15 panel systems selected for study, and boiling down their systems into 4 types (as shown in Table 1 above) that employ the 10 different integration techniques, a set of Performance Standard Criteria is used to evaluate the performance of each of the 10 integration techniques. The Criteria, which are explained below, are based either on the physical characteristics of the integration technique, its performance characteristics, or its interface characteristics.

Criterion 1: Integration level

This criterion evaluates how the integration technique is designed to allow for partial or complete integration of utilities: wiring, cable, and piping.

Criterion 2: Utility interface appearance

This criterion evaluates how "noticeable" the utility interface is once installed and how its appearance could degrade the system in terms of aesthetics.

Criterion 3: Utility interface thermal performance

This criterion defines how the installation of the utility interface affects the quality of insulation and the thermal performance of the panelized wall system.

Criterion 4: Fabrication of the utility interface

This criterion evaluates the level of utility interface achieved in the factory versus the construction effort on-site.

Criterion 5: Handling and transportation

This criterion evaluates how much protection the utility interface needs to prevent damage during transportation.

Criterion 6: On-site procedure for installing utilities

This criterion evaluates the complexity of installing utilities on site.

Criterion 7: Provisions for field changes

This criterion evaluates the complexity of making field changes to the utility interface.

Criterion 8: Ease of covering and finishing installed utilities interface

This criterion evaluates the complexity of covering and finishing the installed utilities interface.

Criterion 9: Skill level required for utility installation

This criterion evaluates the skill level required to install the utilities on site.

Criterion 10: Tools required for utility installation

This criterion addresses the tools necessary for installing the utilities on site.

Criterion 11: Availability

This criterion defines if the product is available throughout the US, only locally, or not at all.

Criterion 12: Conformance with applicable building codes

This criterion addresses compliance with local building codes.

Criterion 13: Compatibility with other house subsystems

This criterion examines if the technology can interface with other panel systems and if it is a proprietary system.

Criterion 14: Accessing utility after construction

This criterion evaluates the complexity for accessing utility interface after construction.

Rating the Performance Criteria

Each of the 10 integration techniques is "scored" from 0 to 3 according to how well the technique meets each of the 14 performance criteria explained above. Each integration technique was assigned a color code for each score level to determine how well the technique met the criterion. The color code is based on a traffic light: green is for go (best rating, 3); yellow is for caution (reasonably good rating, 2); red is for stop (a poor rating, 1); and blank is the lowest rating (little or no compliance with the criterion, 0). Table 2 on the next page provides an explanation of what each color code means for each of the 14 different performance criteria. For example, for Criterion 1: Integration Level, the color-coded score corresponds to the integration level. The higher the integration level, the better the score (green, or 3).

Grade		0	1	2	3
Corresponding color					
Criterion 1	Integration level	No provision for integrating utilities	Provision for integrating Electric wiring	Provision for integrating Electric wiring and cable	Provision for integrating all utilities: wiring, cable and piping
Criterion 2	Appearance	Apparent – bare interface	Apparent – integrated in uncommon building equipment (wire mold)	Apparent – integrated in accepted building equipment (baseboard)	Not apparent
Criterion 3	Insulation integrity	Insulation is severely affected by the utility interface	Installation of the interface on site affects insulation integrity	Designed with minimal interference with insulation integrity	Does not affect insulation integrity
Criterion 4	Manufacturing	Utilities are entirely installed on site	Little integration at the factory	Significant level of integration at the factory	Utilities are entirely integrated at the factory
Criterion 5	Transportation	Intense care during transportation	At risk of being damaged	All provisions made to avoid damage	By design, interface can't be damaged during transportation
Criterion 6	Installation	Complex technique requiring intense labor on site	Requires on-site labor effort similar to traditional construction	Easy process to implement on site	Pre-installed utilities
Criterion 7	Field changes	Are not possible	Require intense labor and/or additional equipment	Relatively minor labor	Easy field changes with no additional construction required
Criterion 8	Covering and finishing	Not possible	Labor intensive	Relatively easy	Designed to be easily accomplished
Criterion 9	Skills	Expert	Advanced	Basic	No skills required
Criterion 10	Tools	Complex, proprietary tools required	Specific tools	Basic contractor tools	No tool necessary
Criterion 11	Availability	Not available in the US	Available locally	Mostly available in the US	Availability everywhere in the US
Criterion 12	Code compliance	Does not comply with any US building code	Complies with few local codes	Complies with most local codes	Complies with all local codes
Criterion 13	Compatibility	No compatibility with other systems	Compatible with stick built construction type	Compatible with other panelized systems	Fully compatible with any type of system
Criterion 14	Accessibility post construction	Cannot access utilities	Requires major construction work	Relatively minor labor	By design, very easy to access

Table 2. Criterion Rating

Grade		Corresponding color
0	Points	○
1	Point	●
2	Points	●
3	Points	●

Weighting Process

Before the criteria scores are applied to the integration techniques, it is necessary to establish a weighting process because some criteria have a greater affect on overall performance than others. For example: "appearance" (weight = 1) has a smaller impact on overall performance than "manufacturing" (weight = 3). This gives the criteria a better balance in helping builders, architects, and others to determine what system type might best serve their particular needs. Table 3 below shows how each criterion is weighted. Criteria with a weight of 3 address superior standards used for designing panelized systems that overcome the weaknesses of integrating utilities in traditional stick-built construction. Product availability (Criterion 11) also has a weight of 3 because of its relevance for product distribution. A weight of 1 is given to criteria that relate to standards that are commonly addressed by manufacturers, such as protecting the panels during transportation (Criterion 5) or ensuring that utility interface is not intrusive (Criterion 8). All other criteria have a weight of 2.

Scoring Process

Finally, with their weights and ratings applied, each integration technique is given a score. The higher the score, the better overall the integration technique is in achieving integration of the utilities within the panel system. Each integration technique is evaluated by applying the rating process and the weighting process. The final score is a computed value between 0 and 81.

		weight
Criterion 1	Integration level	2
Criterion 2	Appearance	1
Criterion 3	Insulation integrity	2
Criterion 4	Manufacturing	3
Criterion 5	Transportation	1
Criterion 6	Installation	2
Criterion 7	Field changes	2
Criterion 8	Covering and finishing	1
Criterion 9	Skills	2
Criterion 10	Tools	1
Criterion 11	Availability	3
Criterion 12	Code compliance	2
Criterion 13	Compatibility	2
Criterion 14	Accessibility post construc-tion	3

Table 3. Criterion Weighting

5. Evaluation and Scoring of Integration Techniques

On the following pages are found evaluations and scoring for each of the 10 integration techniques that were studied. The evaluations and scoring are based on the Generic Performance Standard Criteria that are defined above and are applied to each of the 10 integration techniques identified.

The format used in the presentation consists of a one-page summary of each integration technique, making it easier for the reader to comprehend the total impact of the performance criteria on the integration technique. The final score, computed per rating and weighting process described above, is highlighted in black at the bottom of the page.

Panel system: **Wood panel**

Integration technique: **Surface mounted/baseboard**

Reference manufacturers: Bensonwood

Criteria		Rating	Measure
Criterion 1	Integration level		A built-in wiring chase within a baseboard system allows for a continuous interface between panels. There is no provision for integrating piping, but manufacturer is testing a "corewall" system where all ducts and plumbing are pre-installed at the factory. Interface with subsystems consists of drilling through plates.
Criterion 2	Appearance		The baseboard system is apparent but not intrusive.
Criterion 3	Insulation integrity		The system does not affect the panel insulation.
Criterion	Manufacturing		The wiring interface is integrated into the wall panels at the plant. Electric conduits and junction boxes are also pre-installed.
Criterion 5	Transportation		Panel bundling is computer-assisted for shipping. Panels are wrapped with recyclable protective plastic wrapping system.
Criterion 6	Installation		Electrician runs wires and cables through pre-installed conduits and horizontally in the baseboard system. Plumbing is similar to stick-built construction. The corewall system would allow reducing plumbing time on site.
Criterion 7	Field changes		Wiring and cabling field changes are very easy to make because of the baseboard design. Plumbing is done on site.
Criterion 8	Covering and finishing		The baseboard system has a finished surface.
Criterion 9	Skills		Wiring requires basic electrician skills for pulling wires into pre-installed conduits and in the baseboard. Plumbing requires basic skills similar to stick-built construction.
Criterion 10	Tools		Basic electrician and plumber tools.
Criterion 11	Availability		Technology is available in most parts of the country.
Criterion 12	Code compliance		Complies with all local construction codes.
Criterion 13	Compatibility		A proprietary system that is not compatible for an easy integration with other panel systems.
Criterion 14	Accessibility post construction		Wiring is very easy to access after construction by removing baseboard cover. Offers utilities disentanglement capability. Plumbing is similar to stick-built construction.

SCORE: 60

Panel system: **Wood panel**

Integration technique: **Factory Installed in panel**

Reference manufacturers: Alman homes, Axia Buildings

Criteria		Rating	Measure
Criterion 1	Integration level		Panel system is pre-wired and pre-plumbed at the factory using standard stick-built techniques. Final connections are done on-site.
Criterion 2	Appearance		Utilities are totally integrated into the system.
Criterion 3	Insulation integrity		Although prefabrication allows for better insulation integrity, wiring and cable run in the insulation material.
Criterion 4	Manufacturing		Offers an integration level near 90%.
Criterion 5	Transportation		Panels that have utilities are placed vertically in truck. Panels can be wrapped.
Criterion 6	Installation		Final connections are fast and easy to make in the field.
Criterion 7	Field changes		Changes in utility installation are not labor intensive.
Criterion 8	Covering and finishing		Panel is a finished interior surface.
Criterion 9	Skills		Installation of utilities require basic skills
Criterion 10	Tools		Requires basic electrician and plumber tools.
Criterion 11	Availability		Technology is available in most parts of the country.
Criterion 12	Code compliance		Complies to all local building codes.
Criterion 13	Compatibility		This prefabricated system is not designed to be installed with other panelized construction, but it allows for connecting to stick-built construction.
Criterion 14	Accessibility post construction		Like stick-built construction, it is difficult to access and upgrade utilities after construction.

SCORE: 58

Panel system: **SIP**

Integration technique: **Pre-cored utility chase**

Reference manufacturers: IB Panels, Murus, Precision Panel

Criteria		Rating	Measure
Criterion 1	Integration level		Although IB Panel provides an optional plumbing core, most of the panel manufacturers provide a pre-cored chase for electric wiring only. Cables are pulled within a separate conduit. Manufacturers recommend not installing plumbing in exterior wall panels.
Criterion 2	Appearance		Wiring chases are not apparent.
Criterion 3	Insulation integrity		Wiring chases are molded within the insulation, which has minimal interference with the insulation integrity.
Criterion 4	Manufacturing		Only the pre-cored wiring chases are prefabricated. Wires are not installed at the factory.
Criterion 5	Transportation		Panels are trucked and covered with tarp.
Criterion 6	Installation		Wires have to be pulled through cores on site. On-site labor for cabling and plumbing is similar to stick-built construction.
Criterion 7	Field changes		Horizontal and vertical wiring chases offer flexibility for field changes.
Criterion 8	Covering and finishing		Covering and finishing over the wire chase is easily accommodated by design.
Criterion 9	Skills		Installation of utilities requires basic skills.
Criterion 10	Tools		Requires basic electrician and plumber tools.
Criterion 11	Availability		Technology is available in most part of the country.
Criterion 12	Code compliance		Complies with all local construction codes.
Criterion 13	Compatibility		Manufacturers design their product with various wiring chase diameters and cores placed at different heights in the panel, which make the products incompatible with other panel systems.
Criterion 14	Accessibility post construction		Wiring chase diameter offers very little flexibility for upgrades after construction. Piping and cabling, like stick-built construction, require intensive labor to upgrade.

SCORE: 44

Panel system: **SIP**

Integration technique: **Molded in place**

Reference manufacturers: Thermocore

Criteria		Rating	Measure
Criterion 1	Integration level		Wiring and cabling are pre-engineered and entirely installed at the factory. There is no provision for plumbing, which is installed on site using traditional methods.
Criterion 2	Appearance		Wiring and cabling interfaces are not apparent.
Criterion 3	Insulation integrity		Wiring and cabling are run within the insulation, which has minimal interference with the insulation integrity.
Criterion 4	Manufacturing		All provisions are made to optimize wiring and cabling installation at the factory.
Criterion 5	Transportation		The closed panel design avoids risks for utility damage. Panels are coated in a water-resistant wrapping during shipping.
Criterion 6	Installation		All wiring and cabling are pre-installed.
Criterion 7	Field changes		Field changes require intensive labor.
Criterion 8	Covering and finishing		Utilities are hidden within the panels.
Criterion 9	Skills		All wiring and cabling are pre-installed. No special skills required.
Criterion 10	Tools		All wiring and cabling are pre-installed. No tools required.
Criterion 11	Availability		Technology is available in most parts of the country.
Criterion 12	Code compliance		Complies with all local construction codes
Criterion 13	Compatibility		A proprietary system that is not compatible with other panelized construction.
Criterion 14	Accessibility post construction		Because wiring and cabling are embedded in the panels, technology offers very little flexibility for upgrades after construction. Piping, like stick-built construction, requires extensive labor to upgrade.

SCORE: 58

Panel system: **SIP**

Integration technique: **Surface mounted/baseboard**

Reference manufacturers: Structurewall, Insulspan

Criteria		Rating	Measure
Criterion 1	Integration level		A surface-mounted raceway is the interface for running electric wiring and cable. There is no equivalent for plumbing, which is installed using traditional methods.
Criterion 2	Appearance		Appearance of wiring molds is not usually accepted in residential buildings. Baseboard systems would be much easier.
Criterion 3	Insulation integrity		Because molding is surfaced-mounted, there is no interference with panel insulation.
Criterion 4	Manufacturing		There is no manufacturing effort for integrating the utility because raceways (the interface) are installed on site.
Criterion 5	Transportation		The interface is installed on site, so there is no risk of damage during transportation.
Criterion 6	Installation		All utilities and raceways are installed on site, which increases site labor.
Criterion 7	Field changes		N/A because interface is entirely installed on site.
Criterion 8	Covering and finishing		The interface is apparent and hinders installation of interior finishes.
Criterion 9	Skills		Requires skilled electricians for running properly wiring and cabling on site.
Criterion 10	Tools		Requires basic electrician and plumber tools.
Criterion 11	Availability		Molding and baseboards systems are available anywhere in the US.
Criterion 12	Code compliance		Interfaces are compliant with all electric codes.
Criterion 13	Compatibility		Raceways can be installed on any wall panelized systems. However, surface-mounted raceways are inferior to other panel systems that offer an integrated interface.
Criterion 14	Accessibility post construction		Very easy by design to open a raceway and upgrade wiring and cabling systems.

SCORE: 55

Panel system: **Concrete panel**

Integration technique: **Installed on-site with ICF**

Reference manufacturers: ECO-Block

Criteria		Rating	Measure
Criterion 1	Integration level		There is no provision for interfacing utilities. Runs for wiring and cable utilities are carved out in panel insulation. Piping is not intended to run in panels.
Criterion 2	Appearance		Interface is not visible once the panel is covered with gypsum board (drywall).
Criterion 3	Insulation integrity		Use of hot knife and chain saw for carving the insulation severely affects insulation integrity. There is no control over how much insulation is carved on site to run wiring.
Criterion 4	Manufacturing		Utilities are entirely installed on site.
Criterion 5	Transportation		Because utilities are installed on site, there is no risk of damage during transportation.
Criterion 6	Installation		Design implies that all utility interfaces be installed on site. Routing in panel insulation is labor intensive.
Criterion 7	Field changes		N/A. Interfaces are installed at the site.
Criterion 8	Covering and finishing		The interior face of the panel is covered with a gypsum board. Technique is easy.
Criterion 9	Skills		Requires basic electrician skills to install wiring in panel insulation.
Criterion 10	Tools		Requires tools such as a special bit for router or chainsaw guide to install electric wiring.
Criterion 11	Availability		Technology is available everywhere in the US.
Criterion 12	Code compliance		Complies with all local construction codes.
Criterion 13	Compatibility		Technique is not compatible with other panel construction outside of similar product.
Criterion 14	Accessibility post construction		Wiring and cable cannot be accessed after construction. Upgrading these utilities with wired technologies is a problem.

SCORE: 36

Panel system: **Concrete panel**

Integration technique: **Pre-cored utility chase**

Reference manufacturers: Lifcon

Criteria		Rating	Measure
Criterion 1	Integration level		Technique has provisions for the integration of electric wiring and cable that are run through hollow vertical cores. Interface to subsystem requires drilling in plank core. Plumbing is installed on interior framed walls.
Criterion 2	Appearance		Interface is not apparent.
Criterion 3	Insulation integrity		Because wiring and cable run within the concrete panel, there is no interaction with insulation.
Criterion 4	Manufacturing		The manufacturing effort consists of creating hollow cores in the panels, requiring extensive labor for installing electric wiring and cable on-site.
Criterion 5	Transportation		Because concrete is a solid material, it is very unlikely that interface would be damaged.
Criterion 6	Installation		Requires quite intensive labor to pull wiring through conduit or concrete holes. Drilling concrete panels is time consuming.
Criterion 7	Field changes		Although vertical cores are spaced at a uniform distance, field changes are difficult.
Criterion 8	Covering and finishing		Relatively easy because any mis-cut holes can be patched with drywall.
Criterion 9	Skills		Installation of utility interface requires basic to semi-skilled personnel on site.
Criterion 10	Tools		Standard electrician tools are required to install utilities.
Criterion 11	Availability		New technique that was recently introduced in the US.
Criterion 12	Code compliance		Only complies with local codes.
Criterion 13	Compatibility		The interface is generic but would not be installed with other generic panel system such as SIPs.
Criterion 14	Accessibility post construction		Very difficult to access and upgrade utilities once the gypsum board covers the panel.

SCORE: 41

Panel system: **Concrete panel**

Integration technique: **Steel mesh**

Reference manufacturers: Sipcrete, 3D Panel System

Criteria		Rating	Measure
Criterion 1	Integration level		A steel mesh and clip systems allow for securing all utilities on the panel system prior to applying sprayed concrete.
Criterion 2	Appearance		The interface is entirely covered after spraying concrete.
Criterion 3	Insulation integrity		Minimum interference with panel insulation because wiring runs within the gap formed between the polystyrene core and the welded wire fabric. However, cutting through panel insulation and drilling are necessary for accessing subsystem.
Criterion 4	Manufacturing		Manufacturer provides a steel mesh that is used on site for installing utilities.
Criterion 5	Transportation		Damaged steel mesh would compromise utilities installation. Panels are stacked vertically on sides to avoid damage.
Criterion 6	Installation		Installation of utilities is labor-intensive as it requires either fastening to wire mesh of running utilities in the gap formed between polystyrene core and the mesh.
Criterion 7	Field changes		Very easy prior to spraying concrete, but very difficult thereafter.
Criterion 8	Covering and finishing		Spraying concrete over interface is part of the panel installation process.
Criterion 9	Skills		Although designed by the manufacturer to be a "do-it-yourself" installation, implementation of technique requires personnel with minimum skills.
Criterion 10	Tools		Specific tools are required to fasten the utility interface.
Criterion 11	Availability		While SIPcrete is available in the UK only, 3D panel has a limited number of distributors in the US.
Criterion 12	Code compliance		Where available, complies with local building codes.
Criterion 13	Compatibility		Although considered generic, this technique is not likely to be installed with other generic panel systems.
Criterion 14	Accessibility post construction		Wiring and cable cannot be accessed after construction. Upgrading these utilities with wired technologies is difficult.

SCORE: 39

Panel system: **Concrete panel**

Integration technique: **Factory Installed in panel**

Reference manufacturers: Dukane Precast

Criteria		Rating	Measure
Criterion 1	Integration level		Electrical and cable conduits are placed in the walls at the factory. There is no provision for integrating plumbing, which is designated to run in interior walls.
Criterion 2	Appearance		Utilities are embedded in the panels during the precast process at the factory.
Criterion 3	Insulation integrity		There is no interference with insulation.
Criterion 4	Manufacturing		All conduits for wiring and cabling are installed at the plant, which provides a significant level of integration.
Criterion 5	Transportation		Transported in tub trailers, panels are pinned and protected at the interfaces.
Criterion 6	Installation		Electrician simply pulls wires and cable through pre-installed conduits. Plumber runs piping similarly to stick-built construction in interior walls.
Criterion 7	Field changes		Very difficult to change conduit location as concrete is poured over the interface.
Criterion 8	Covering and finishing		Covering and finishing over the wire chase is not a problem by design.
Criterion 9	Skills		On-site, requires basic electrician skills for pulling wires through conduits and traditional plumbing skills for installing piping. At the factory, requires trained and licensed technician.
Criterion 10	Tools		Basic electrician and plumbing tools.
Criterion 11	Availability		Available across the US.
Criterion 12	Code compliance		Complies with all local codes.
Criterion 13	Compatibility		This technology is proprietary for exterior walls, and other subsystems. Interfaces quite simply with interior, stick-built walls
Criterion 14	Accessibility post construction		Other than plumbing, utilities cannot be accessed after construction.

SCORE: 53

Panel system: **Steel panel**

Integration technique: **Pre-cored utility chase**

Reference manufacturers: Thermasteel

Criteria		Rating	Measure
Criterion 1	Integration level		Provides optional vertical and horizontal chases for running electric and cable wiring. There is no provision for integrating piping, which is recommended to run on interior walls.
Criterion 2	Appearance		Interface is not apparent.
Criterion 3	Insulation integrity		Wiring chases are molded within the insulation, which has minimal interference with the insulation integrity.
Criterion 4	Manufacturing		Only the pre-cored wiring chases are prefabricated.
Criterion 5	Transportation		Panels are trucked and covered with protective wrapping.
Criterion 6	Installation		Wires have to be pulled through cores on site. On-site labor for cabling and plumbing is similar to stick-built construction.
Criterion 7	Field changes		Horizontal and vertical wiring chases offer some flexibility for field changes.
Criterion 8	Covering and finishing		Covering and finishing over the wire chase is not a problem by design.
Criterion 9	Skills		Installation of utilities requires basic skills.
Criterion 10	Tools		Requires basic electrician and plumber tools.
Criterion 11	Availability		Technology is available in most parts of the country.
Criterion 12	Code compliance		Complies with all local construction codes.
Criterion 13	Compatibility		Although utility interface is generic, the width of the panel does not allow for compatibility with other generic panel systems.
Criterion 14	Accessibility post construction		Wiring chase diameter offers very little flexibility for add-ons. Piping and cabling, like stick-built construction, require extensive labor to upgrade.

SCORE: 48

6. What it All Means

Which Integration Techniques Received the Highest Scores?

The highest score is 60 out of a possible 81 points for the wood panel system with an integrated baseboard, while the lowest score was 39 out of a possible 81 for an ICF system that offers little provision for integrating utilities. The scored techniques can be broken down in three groups:

- Techniques scoring between 58 and 60 (3 out of 10) include wood panels with much of the utility integration taking place in the factory.

- Techniques scoring between 44 and 55 (4 out of 10) include panels with pre-cored utilities chases inside the panel (SIP, metal panel) or concrete panels where utilities are installed in panels in the factory.

- Techniques scoring between 36 and 41 (3 out of 10) include concrete panels that require extensive labor on site for installing utilities.

Performance Criteria: Issues to Carefully Consider

There is no technique that could fulfill, or nearly satisfy, all of the Performance Standard Criteria — in other words, there are no panel systems that perfectly integrate utilities. However, builders, architects, developers, or homeowners shopping for a panel system with a high degree of integration of utilities should consider the high points of integration within each of the 14 criteria.

Criterion 1: Integration Level

Except for ICFs, panelized systems are designed to integrate utilities. The best scores go to pre-manufactured systems that reduce installation on site, although they require significant pre-engineering. Typically, manufacturers provide means for integrating electric wiring and cable, but very few provide integration for piping. The reason for this is that piping rarely runs on exterior walls because of risks of freezing and the difficulty in repairing leaks. Nevertheless, a few manufacturers offer this option.

Criterion 2: Appearance

Only surface-mounted and baseboard systems are visible utility interfaces. While baseboard systems are non-intrusive because they look like decorative baseboards, techniques like surface-mounted molding are not typically seen in the US residential sector and might have trouble gaining market acceptance.

Criterion 3: Insulation Integrity

Because ICFs have no provision for integrating utilities, interfaces have to be carved into the insulation material on site, with no control over how much insulation is carved away. This can result in poor thermal performance, which is why this technique has the lowest score. Conversely, surface-mounted and baseboard techniques do not interfere with insulation integrity at all and have a higher score. Techniques that present wiring chases built into the insulation have a slight impact on insulation integrity, but because the panels come to the site from the factory with chases already in place, the risk of damaging the insulation on site is limited.

Criterion 4: Manufacturing

This criterion has a large spread because some manufacturers promote pre-engineered, virtually 100% utility integration at the factory, while others have no provision at all for the integration of utilities. Factory-built technologies get the highest score under this criterion, which also has the highest weighting of 3. Techniques that require minimal installation time are generally found to be more efficient.

Criterion 5: Transportation

All manufacturers accommodate panels and utility interface protection during transportation with the use of protective wrapping. When techniques do not have a factory-built interface or are made of solid material such as concrete, scores are the highest. Consequently, the weight for this criterion is minimal.

Criterion 6: Installation

This criterion has a large spread because some manufacturers promote pre-engineered, near 100% utilities integration at the factory while others have no provision for the integration of

utilities. In this case, the effort to install utilities is either similar to traditional stick-built construction or requires a specific technique that is often labor intensive, such as the steel mesh technique, which requires that all utilities be installed on site, then covered with sprayed-on concrete.

Criterion 7: Field Changes

Techniques that present a high level of integration are penalized under this criterion because of the lack of flexibility for making a change on factory-built systems. The lowest score goes to concrete panels, which have very little flexibility once the utilities are embedded in concrete.

Criterion 8: Covering and Finishing

Higher scores go to techniques with finished panels that integrate utilities. Covering over wire molding can be a problem, while finishing over concrete panels such as ICFs where utilities are carved on site is time consuming. The weight for this criterion is minimal.

Criterion 9: Skills

Higher scores go to techniques with finished panels that integrate utilities. Indeed, they require minimal efforts and basic skill levels to complete utilities installation. Steel mesh requires expertise in spraying over the utility interfaces, although installing utilities on the mesh is basic. Surface-mounted wiring techniques require non-standard installation practices.

Criterion 10: Tools

Most of the techniques that were studied require standard tools for installing utilities. Those that came prefabricated to the site do not require any tools at all. ICFs and steel mesh require however routing and other specific tools for integrating utilities.

Criterion 11: Availability

Larger manufacturers typically have access to the US market-wide while smaller manufacturers or manufacturers of new techniques offer their systems only regionally. Concrete panel with pre-cored wiring chase is a technique that comes from Europe and attempts to access the US market. This criterion has a weight of 3.

Criterion 12: Code Compliance

Scores follow the same logic as Criterion 11.

Criterion 13: Compatibility

Except for a SIP surfaced-mounted utility interface that could be installed independently from panel manufacturers, most techniques have limited compatibility with other panel systems because they are proprietary.

Criterion 14: Accessibility Post Construction

Only surface-mounted and baseboard systems provide access to wiring after construction, which is a significant advantage for future upgrades. Concrete systems have limited potential by design and because of the hardness of the material. SIPs have provisions similar to stick-built construction. Accessibility to utilities and disentanglement are important attributes, so this criterion has a weight of 3.

7. Decisive Factors in Panel Choice

The purpose of the Performance Standards Criteria is to understand the performance of widely available panelized systems and how they integrate utilities. Builders, architects, and homeowners looking for optimum panel performance in terms of integrating utilities should carefully consider the following seven factors when evaluating panel systems. These factors are based on the results of the analysis presented in this study and the criteria weighting process, and are listed in descending order of significance:

1. Panelized systems that offer factory-integrated wiring and cable utilities and a finished product have the advantage of reducing installation time and installation complexity on-site (using basic skills and standard tools) while preserving the insulation value of the wall, which results in better energy performance. Pre-engineered panel systems with good utility integration do not require field changes.

2. Panel systems that are designed to make utilities accessible after construction without damaging the panel or the covering over the utility chases offer a significant advantage for future utilities upgrades.

3. Select panel systems that are widely available in the US homebuilding market and comply with building codes.

4. Panel systems should integrate electrical wiring and preferably cable. It is not critical that the system include the integration of water piping because plumbing should not be installed in exterior walls. Pipes typically run through partition walls inside the house, and vertically through chases specified for their use.

5. Panel systems that do not embed utilities in the panel's insulation core offer the best insulation integrity and easy for utility upgrades after construction.

6. Panel systems that have no visible interface are preferable, although integration techniques using decorative building components such as baseboards are a good choice.

7. Panel manufacturers should ensure that integration systems are protected during the panel's transportation to the site.

Notes

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1. *Automated Builder Magazine* website, http://www.automatedbuilder.com/industry.htm, accessed April 12, 2008.