PATH
concept home

Concept Home Principles -

Integrated Functions

Research Summary

July 2005

Acknowledgements

Preparation of this report was coordinated by Dr. Carlos Martín of the U.S. Department of Housing and Urban Development's Office of Policy Development and Research. The text was developed by Christine Barbour, Tate Era, and James Lyons, P.E., of Newport Partners, LLC.

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Background

The array of mechanical systems in housing has grown tremendously in recent decades and continues to expand as houses become more and more sophisticated. Consider common building systems such as electrical power, communications, security, lighting, heating and cooling, ventilation, central vacuums, hot and cold water supply, water treatment, wastewater and venting, fire suppression, and even photovoltaics (PV) and back-up power systems. Each of these systems provides some particular function to the home, and in most cases is designed and installed to operate independently. Many of these systems, however, share common operating characteristics, such as heat generation, as either the goal of the system or a by-product. Integrated Functions explores opportunities to take advantage of these common operating characteristics to create multi-functional systems that operate with greater efficiency, require less equipment, and result in simplified installation.

The concept of combining systems in this manner challenges traditional manufacturing and installation approaches for residential systems. Manufacturers are accustomed to separate product lines and often benefit from a non-integrated approach that requires more equipment instead of less. Builder and contractor resistance to integration is rooted in the traditional labor structure of the industry. Specialized contractors, familiar only with their particular trade but not qualified to work with other equipment, install each system in a home. This creates general coordination problems and acts as an impediment to integrated systems, which require expertise in several trades. Regulatory and contractor licensing requirements also maintain these labor divisions. However, the evolution of technologies that overlap traditional labor boundaries, such as integrated PV roof tiles and solar thermal systems, have already started to challenge this structure. In fact, attempts to integrate solar thermal collection technologies into the building envelope represent some of the earliest efforts at integration, dating back to the 1940s (Archibald, 1999).

Looking forward, a greater degree of logical integration holds benefits throughout the industry. Manufacturers that innovate stand to gain market share through the creation of new products and new markets. Builders who recognize the value of cross-trained crews will realize general production efficiencies and be in a better position to adopt integrated technologies. And, since integrated functions generally result in reduced equipment needs with better overall efficiency, consumers are likely to save on the purchase and operation of systems, while gaining useable floor space.

Performance Objectives

Integrated functions promotes increased production efficiency and building performance by combining the functions of multiple systems into combined or hybrid systems. Such combinations use the specific features of one building system and capitalize upon them to contribute to the function and performance of another building component.

Based on this objective, a potential conflict could exist between integrated functions and organized/accessible systems, since the former principle combines functions to improve efficiencies, while the latter works to separate functions for the same reason. The paper on organized and accessible systems refers to reducing and controlling the physical interdependencies of major building layers such as the structure, interior partitions, and mechanical systems. By developing rational interactions among these major elements, a home is easier to repair, service, and renovate. An example is Bensonwood Homes Open-Built® system (www.bensonwood.com), where the timber frame provides structure, interior partitions are non-load-bearing, and mechanical systems are easily accessible for repairs and upgrades.

Integrated functions combines building system functions in a rational manner that simplifies the separation of systems and enhances overall performance. While most of this report focuses on combinations of *mechanical* systems (e.g., combining hot water heating with space heating), integration also may combine the function of a structural or finish system with a mechanical system (e.g., photovoltaic shingles). For instance, Bensonwood Homes uses a prefabricated wiring chase in its foam core wall panels to facilitate electrical distribution in exterior walls. The chases also are made accessible through the use of a removable base molding system. This design speeds on-site electrical installation and provides excellent long-term access to the electric system for upgrades and repairs. In this case, the rational integration of mechanical systems with the building envelope actually *reduced* entanglement – the goal of organized/accessible systems – while also enhancing system organization and long-term performance.

Supporting Technologies

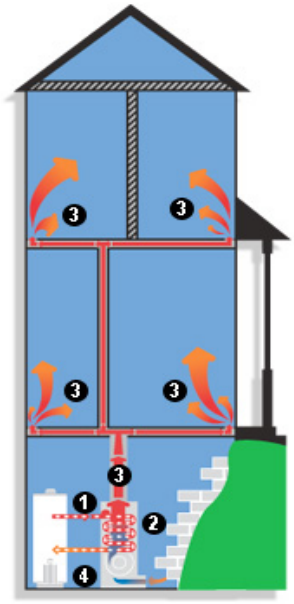
A cross-section of integrated technologies is discussed below. While several of the examples address the potential integration of HVAC and plumbing services, additional integration involving systems such as energy generation and lighting also may be possible as residential technologies continue to evolve. Along with this evolution, integrations of more than two functions may develop, creating systems that could incorporate several different capabilities. Also included below are examples of integrated technologies that could supplement or even replace other components in a building, such as elements of the building shell.

Integrated Hot Water and Heating Systems

Most residential hot water tanks serve a single purpose – to heat and store domestic hot water. However, integrated hot water and heating systems combine a high output water heater and a space heating system together to provide both the potable hot water and the space heating for a home.

In the case of forced-air heating systems used with an integrated hot water heater, hot water is delivered to the air handler by a high output domestic water heater via plumbing lines. These lines deliver hot water into a heat exchanger, which then heats the airflow passing through the air handler unit. This heated airflow is delivered to the house through a traditional duct network. In this way, hot water from the water heater replaces the need for a separate space heating source such as natural gas combustion. Systems of this type also can incorporate a separate cooling coil to provide air conditioning.

One example of an integrated hot water and forced-air heating system is the HydroHeat, manufactured by Apollo HydroHeat & Cooling (www.mindreactor.com/apollo/). The HydroHeat system delivers hot water from a high-efficiency gas water heater to the central air handling unit (Step 1 in the figure below). The water is circulated through a water-to-air heat exchanger (Step 2), which heats the system airflow and provides warmed air to heat the house (Step 3). The hot water exiting the heat exchanger is then returned to the water heater, where it is available for domestic potable hot water needs (Step 4).



Steps in the HydroHeat process
Image Source: www.mindreactor.com/apollo/

For hydronic heating systems used with an integrated water heater, the system operates in a similar fashion to traditional water-based heating systems, except for the hot water source. In an integrated system, hot water is provided by a high output water heater. The hot water is pumped through radiant heat piping under the floor or in pipes along the baseboards to heat living spaces. Water is then recirculated back to the water heater to be reheated. In most integrated hot water and heating systems, the potable water is on a separate loop from the radiant heating water circulated through the flooring or baseboards. The water heater portion of this system can be fired by gas, oil, propane, or electric power.

Potential benefits of integrated hot water and heating systems include:

- Energy savings
- Space savings (if the hot water and heating equipment is combined into a single unit)

The costs for integrated hot water and heating systems vary widely and depend on the size of the intended system. One integrated unit made by Lennox, the CompleteHeat™, is no longer in

production[1]. For smaller residential heating loads of two tons or less, the cost of an integrated system can be less than the sum of a hot water heater and a separate heating unit. However, in houses with heating loads greater than two tons, the economics and system performance levels tend to favor separate systems.

In addition to systems that rely upon a high output water heater, another variation of combined hot water and heating systems involves the use of tankless hot water heaters for both space heating and hot water[2]. With this approach, the tankless water heater is located near the fixture locations. Hot water lines from the tankless heater also are routed to a radiant floor heating system or baseboard heaters. This approach is more applicable to small living space areas rather than an entire house. It also may offer a viable approach to providing heating and water supply to a future living area such as an unfinished room above a garage. To provide for the initial rough-in, a single cold water supply line and a fuel or electric line for the future tankless water heater would be all that would be required for this type of system.

In terms of code issues, the International Residential Code (IRC) requires that when water heaters are also used for space heating, piping and other components connected to the water heater for space heating applications also must be suitable for use with potable water (in the case of systems where heating and potable water mixes). The IRC also requires the use of a mixing valve to temper domestic hot water if the system temperatures for space heating exceed 140˚F.

What About Appliances?

While this research is primarily focused upon the integration of mechanical system functions, what about the long list of household appliances that heat and cool? These separate units may individually heat a confined space (oven), clothes (dryer), or even a room (fireplace) - at the same time that the house is heated by a furnace and hot water is heated for the washing machine. It's not hard to envision scenarios when multiple heating or cooling operations are underway, resulting in several pieces of equipment that provide similar processes for different applications. Harnessing these operations to promote efficiencies and save equipment is no small task. It would require addressing different operating characteristics, different duty cycles, separate physical locations, and many other issues. But given the growing number of appliances and their sophistication, it's worth thinking about.

The Gas Technology Institute (GTI) has sponsored the development of *Guidelines for Sizing and Installing Combo Systems in the Southeastern United States and Southern California*. The guidelines for integrated hot water/forced-air heating systems ("combo" systems) are applicable for the entire range of climatic conditions where combo systems are commonly used. The report includes a collection of laboratory and field application data, and five integrated system sizing charts covering the five basic heating zones in the U.S. Use of the integrated system sizing guidelines can help HVAC designers avoid oversized systems, which can significantly increase first costs. The Guidelines are available from GTI (www.gastechnology.org).

[1] Telephone Communication with Lennox Technical Assistance, April 2005.
[2] See ToolBase Web site (www.toolbase.org) under Water Heaters with Space Heating Capability.

Central Fan-Integrated Mechanical Ventilation Systems

Central fan-integrated mechanical ventilation systems are an approach to mechanical ventilation in homes that combines the functions of heating, cooling, *and* ventilation into the central forced-air system. By using the central forced-air blower and duct network for mechanical ventilation, these systems offer cost savings compared to mechanical ventilation systems that require independent duct systems and fans. More information on this technology is included in the Organized and Accessible Utilities report.

Heat Pump Water Heaters

Heat pump water heaters are combined water heating and space conditioning systems that act similar to a residential A/C system. A heat pump unit extracts heat from the area in which the unit is installed through a refrigerant compression system, much like a typical A/C system. Heat pump water heaters then transfer this heat to water, creating hot water, instead of rejecting the heat to the outdoors as occurs with an A/C system. In this way, heat pump water heaters cool and dehumidify an indoor environment *and* make use of the extracted heat by transferring it to hot water, which then is used for domestic supply or some other hot water application.

In commercial applications, heat pump water heaters are targeted for buildings with high hot water requirements, such as restaurants and laundry facilities in hotels and health care facilities. For residential applications, these systems are best suited for households with high hot water needs and high utility costs for heating water. For example, the E-Tech R-106 from AERS produces 200-300 gallons of hot water per day, which is significantly more than the average daily residential demand (www.aeretech.com/heatpump.html#residential). The E-Tech R-106 unit mounts on top of the water heater itself and is integrated into the hot water tank.

E-Tech R-106 mounted on a storage tank
Image Source: www.aeretech.com

Air that is cooled and dehumidified by these units is viewed as a secondary output, and can be used as auxiliary cooling for a living space or as a means to dehumidify an area like a basement. Heat pump water heaters operate most efficiently in an area with good air circulation and moderate temperatures (35-100°F), making areas such as basements suitable locations.

According to the U.S. Department of Energy (DOE), heat pump water heaters are typically 33-50 percent more efficient at heating water than most electrical resistance water heaters. DOE states that because heat pump water heaters tend to be more expensive to buy and maintain than ordinary electric water heaters, their use is usually economical only in situations where:

- Water use is high
- Natural gas is unavailable

- Electricity rates are significantly high
- Relatively constant warm air temperatures exist where the unit is to be installed
- Where the extra space cooling and dehumidification is needed

Given the volatility in retail prices for natural gas and electricity, however, the competitiveness of these systems with natural gas-based water heaters may shift.

Wall Hung Gas Boilers

Wall hung gas boilers are fully self-contained, on-demand natural gas or propane boilers that provide residential heating and/or domestic hot water supply from one high-efficiency appliance. These boilers are compact and space-efficient, allowing them to be installed in different areas within a house. No mechanical room is necessary and the units are relatively simple to hang and vent.

The BlueRidge Company (www.blueridgecompany.com) manufactures the Baxi Luna line of wall hung boilers designed for use with in-floor heat, radiator heat, or forced-air systems. The boilers measure 30”x18”x14” and can modulate between 35,000-106,000 BTUs of energy output. The Luna 310Fi model can replace both a furnace and a domestic hot water heater, and offers the longer life expectancy of a boiler system (~40 years). BlueRidge claims that through the prioritized and isolated domestic water system provided by the Baxi Luna boilers, continuous and unlimited hot water is achievable for showers and taps at all times. The 310Fi model delivers around four gallons of hot water per minute, but an indirect holding tank with a 25-80 gallon capacity also can be added to the system if needed. The potable hot water piping is in a closed loop, separate from the radiant heating loop. However, separate domestic hot water heaters or separate holding tanks are still typically used in homes with wall hung gas boilers due to temperature increases and design installation issues associated with the combination boilers.

Some factors to weigh when considering the use of these systems include:

- Initial costs
- Price of natural gas or propane
- Approaches to air conditioning (if a radiant heating system is used)
- Complex control systems
- Need to temper domestic hot water

Baxi Luna 310Fi
Image Source: www.blueridgecompany.com

Integrated Boiler Heating and Hot Water Systems

Integrated boiler heating and hot water systems perform the same basic functions as the wall hung boilers described above, except they are the same size as traditional boilers. These larger floor-mounted boilers provide the home with potable hot water, as well as the hot water that is used for the radiant floor heat.

Two approaches can be used to provide potable hot water to the home. In the first approach, which may be considered "tankless," no hot water tank is used in the system. Instead, a heat exchanger within the boiler provides domestic hot water on demand. While this approach avoids the initial cost and space requirements of a separate hot water tank, the operational efficiency is not ideal. Whenever domestic hot water is demanded, even in mild summer months when the boiler is not operating, the boiler needs to cycle up and heat water to meet the demand.

A second approach involves the use of an indirect water heater. Within this separate tank, a heat exchanger delivers hot boiler water, which is used to heat water in the storage tank. The flow of boiler water to this heat exchanger is governed by a thermostat, valves, and a circulation pump. Under this approach, the boiler operates periodically to heat water within the storage tank, but is not subject to firing every time there is hot water demand in the house.

Multi-Function Mechanical System Alternatives

Mechanical systems in homes provide functions such as heating, lighting, and electrical power. Within the scope of integrated subsystems, most of the discussion has focused on ways to combine mechanical systems to realize cost savings, efficiency improvements, or some other benefit. However, non-mechanical alternatives exist that can provide some of these same functions. For example, passive solar design in homes makes use of sunlight to provide both heating and lighting in a home, and also can be used to reduce cooling demand.

A few key features of passive solar design include:

- Orienting the house with the long axis running east-west
- Designing a floorplan to optimize natural lighting ("daylighting") in heavily used living areas (e.g., kitchens)
- Selecting and orienting glazing to enhance winter heat gain and minimize summer heat gain
- Selecting building materials that provide thermal mass to store thermal energy from sunlight
- Designing overhangs to provide shading during the summer while still allowing direct sunlight during the winter

Integrated boiler heating and hot water systems can be fired by oil, gas, liquefied petroleum (LP), or electric. Floor-mounted boilers may require more room for installation compared to wall hung units, and are typically located in a mechanical room or basement space.

As an example, New Yorker® (www.newyorkerboiler.com) manufactures cast iron and steel boilers that can be integrated for heating and hot water purposes. The boilers are fired using either natural gas, LP, or oil and have varying capacities to suit most residential and small commercial loads (50-230 kBTU/hour). New Yorker® is one of many boiler manufacturers whose products have the ability to integrate the hot water and radiant heating processes to reduce the amount of equipment and installation time required. When considering the use of these systems, the same issues apply as for the wall hung boilers discussed above.

Photovoltaic (PV) Roof Shingles

PV roof shingles are elements with integrated solar cells on standard roof shingles to provide for an energy-generating roof system. The PV shingles can replace the need for bulkier PV modules typically mounted on rooftop racks. PVresources (www.pvresources.com) states that PV roof shingles typically are produced with crystalline or thin-film solar cells laminated on glass or metal substrates or crystalline solar cells on a metal background.

PV Roof Shingle Installation
Image Source: www.toolbase.org

PV Roof Tiles

PV roof tiles are another variation in which PV tiles can take the place of roof shingles, instead of being laminated on top of them. PV roof tiles, such as PV Solar Tiles produced by PV Solar Energy (www.members.optusnet.com.au/pvsoleng/ms/homepage.html), can be used as a roofing or wall cladding material. The manufacturer states that using PV roof tiles eliminates the need for conventional roofing in the area of the tiles. Instead, the PV roof tiles and its framing support system seal the roof against the elements while also providing for electrical power generation. PV Solar Tiles also are claimed to endure foot traffic and have undergone Australian test standards for wind uplift and exposure to extreme temperatures.

PV systems can be used in conjunction with utility-supplied power. Any excess power produced can be routed back to the utility grid; electricity can be drawn into the home when demand is greater than what the PV roofing can supply. According to ToolBase (www.toolbase.org), small residential PV systems commonly have a peak power production of about 500 watts, while whole-house PV systems can produce between 2,000 and 4,000 watts.

Some issues to assess when considering the use of PV roofing include:

- High initial cost
- Require unobstructed exposure to sunlight for maximum efficiency
- Long-term durability and maintenance requirements remain unknown

SmartWrap™ Building Membrane

SmartWrap™ building membrane is a micro-thin composite that offers the potential to replace traditional wall components and other building systems with a multi-functional membrane. This composite product integrates printed-on or adhered technologies to provide thermal insulation, power generation, and protection from wind, rain, and lighting. More information on SmartWrap™ is contained in the Alternative Basic Materials report.

Conclusion

This report highlights technology possibilities that combine distinct building components into more integrated systems. These integrated technologies offer potential benefits in terms of enhanced performance and production efficiencies. As plans and specifications are developed for the PATH Concept Home, not only will these possibilities be considered for inclusion, but also further opportunities will be sought for effective integration that also supports functionality and serviceability.

Looking ahead into the future of integration in this manner invites the question of what is ultimately possible. What functions are embedded in our homes, and what possible integrations of these functions might be feasible? Table 1 on the following page suggests potential integration of sample building functions that the leaders of the next generation of manufacturers and product innovators will seize. Opportunities such as these will provide further functional integration in the American home.

Table 1: Matrix of Potential Functional Integrations

Matrix of Potential Functional Integrations	Attenuate noise	Collect rainwater	Collect solar thermal	Control internal moisture	Cool & Heat spaces	Distribute communications	Distribute data	Distribute domestic water	Distribute electrical supply	Distribute security signals	Drain water	Filter/circulate air	Generate on-site power	Heat water	Humidify spaces	Provide fresh air	Provide internal lighting	Provide daylight	Reduce air infiltration	Reduce heat conductance	Separate spaces	Shield building from elements	Suppress fires	Vent combustion systems	Vent plumbing systems
Attenuate noise	X		X	X	X	X	X		X	X			X	X	X				X		X	X	X		
Collect rainwater		X	X	X	X			X			X			X	X			X	X				X		
Collect solar thermal	X	X	X		X			X					X	X	X			X				X			
Control internal moisture	X	X		X	X			X				X				X			X		X	X		X	
Cool & heat spaces	X	X	X	X	X			X			X	X	X	X	X	X		X	X			X		X	
Distribute communications	X					X	X		X	X			X				X		X		X				
Distribute data	X					X	X		X	X			X				X		X		X				
Distribute domestic water		X	X	X	X			X						X	X								X		
Distribute electrical supply	X					X	X		X	X			X				X		X		X				
Distribute security signals	X					X	X		X	X			X				X		X		X				
Drain water		X			X						X			X									X		X
Filter/circulate air				X	X							X													
Generate on-site power	X		X		X	X	X		X	X			X	X		X		X	X			X			
Heat water	X	X	X		X			X			X		X	X	X			X			X	X	X	X	
Humidify spaces	X	X	X		X			X						X	X	X		X							X
Provide fresh air				X	X								X		X	X		X							
Provide internal lighting						X	X		X	X							X	X			X	X			
Provide daylight		X	X		X								X	X	X	X	X	X				X			
Reduce air infiltration	X	X		X	X	X	X		X	X			X						X			X		X	X
Reduce heat conductance	X			X	X	X	X		X	X			X						X	X					
Separate spaces	X			X		X	X		X	X				X			X				X				
Shield building from elements	X		X	X	X								X	X			X	X	X			X		X	X
Suppress fires	X	X						X			X			X									X		
Vent combustion systems				X	X									X					X			X		X	
Vent plumbing systems											X				X				X			X			X

A cursory assessment of this matrix indicates that integrations are more likely among systems with like-functions, such as systems that heat and cool. However, potential integrations are not limited to these relationships, as evidenced by possibilities such as “light panels” using solid-state lighting, which could provide light and serve as a wall or ceiling panel. And beyond this basic two-dimensional matrix of building functions, further possibilities for integration will exist in the future. Technologies that integrate three or more functions, such as SmartWrap, go beyond two-system combinations. And, as completely new building functions such as building systems that monitor occupant health become possible, so will new integrations.

Bibliography

Archibald, John. “Building Integrated Solar Thermal Roofing Systems: History, Current Status, and Future Promise”. American Solar Roofing Company. 1999.

Cooper, Gail. “Air-Conditioning America”. Baltimore, MD: Johns Hopkins University Press, 1998.

Ogle, Maureen. “All the Modern Conveniences”. Baltimore, MD: Johns Hopkins University Press, 1996.

Talbert, Sherwood G.; Osborne, Rodney L.; Solan, John P.; Jakob, Frank E. “Guidelines for Sizing and Installing Combo Systems in the Southeastern United States and Southern California.” GRI, December 2000.

Tobey, Ronald C. “Technology as Freedom: The New Deal and the Electrical Modernization of the American Home”. Berkeley, CA: University of California Press, 1996.

U.S. Department of Housing and Urban Development, Office of Policy Development and Research. “Organizing Residential Utilities: A New Approach to Housing Quality”. 2004.

U.S. Department of Energy: www.eere.energy.gov/consumerinfo/factsheets/ad6.html