

How Smart are Today's Smart Homes?

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Recent years have seen a dramatic increase in the number of “smart” devices available for residential buildings. Some experts expect global market growth to double to \$150 billion in sales from 2018 to 2024. [1]. But, how smart are smart homes? Modern car technology helps drivers operate their cars more efficiently and safely and catches major problems before they happen. That type of feedback is not yet available to homeowners. This column describes opportunities presented by advances in smart home technology that could impact our homes and how we interact with them.

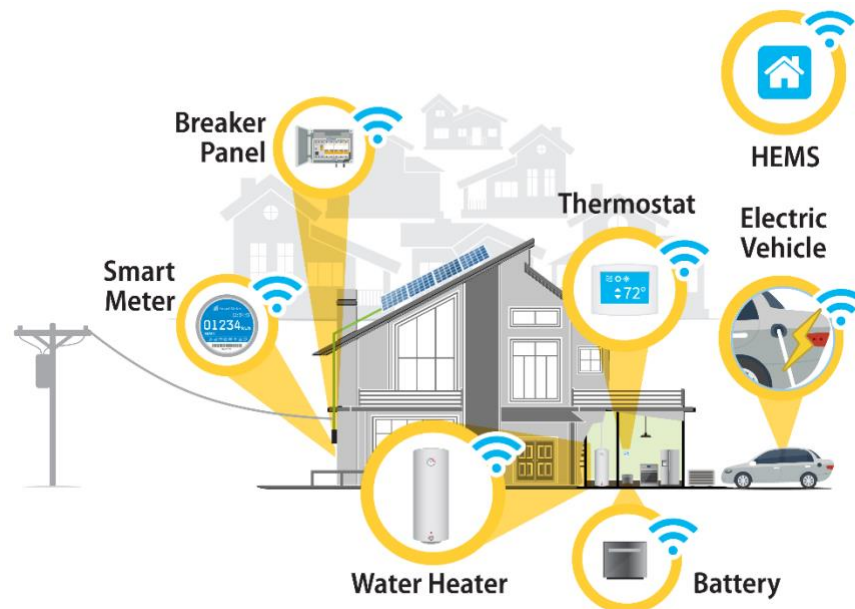







Figure 1. A smart home with communicating appliances and home energy management system (HEMS) for advanced whole-home control.

“Smart” is used in this column to describe a product that uses sensors, controls, and communication capabilities to provide consumers with information, controls, and/or recommended actions. Today’s mainstream smart home devices are mostly focused on convenience, but they have the potential to enable more benefits for residents. Smart technology will enable improved energy efficiency and increased load flexibility that are key to creating grid-interactive efficient buildings and achieving U.S. President Joe Biden’s goal of a zero-emission electric grid by 2035. [2, 3].

While efficiency and flexibility could lead to cost savings for consumers, other smart home technology benefits are driving their adoption. Table 1 summarizes these benefits. Icons in the discussion below about the state of the art and in Table 1 identify potential benefits of addressing existing technology gaps.

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Table 1. Smart home benefits. The icons shown column identify the potential benefits of addressing existing technology gaps.

	<p>Comfort, Convenience and Security Connected smart home products give consumers different ways of controlling appliances in their homes and provide the ability to add schedules for safety and comfort. Some products are focused on security, with cameras and door sensors able to provide alerts to consumers when they are away from home.</p>
	<p>Health and Indoor Air Quality (IAQ) Air quality sensors can provide better insight into the health of our homes, including how the IAQ has changed over time. These benefits are relevant today, but the health monitoring benefits of smart home technology were drivers for elderly and disabled populations before the COVID-19 pandemic.</p>
	<p>Energy Efficiency Equipment efficiency is mostly driven by the equipment and not by external controls, but there are opportunities to control equipment in ways that save energy. Most of the benefit of smart home technology for energy efficiency lies in the ability to turn off equipment that is not needed, which can be done more easily with better external controls and better sensors to detect occupancy and indoor comfort.</p>
	<p>Load Flexibility More renewable energy is being added to the electric grid and utilities are already faced with a strained grid during periods of peak use. As a result, utilities are asking residential customers to provide support for the grid by responding to demand response signals or following a time-of-use schedule in which the price of electricity changes during the day. Many smart home products today allow people to use schedules, like a setpoint schedule for a thermostat or water heater. Adding the ability to autonomously respond to utility pricing or demand signals will help consumers lower their energy bills and help utilities add more renewable energy to the grid.</p>
	<p>Resiliency Some areas of the country experience regular power outages, often driven by extreme weather events such as hurricanes and blizzards. Generators have traditionally been the main source of back-up power, but more recently solar panels and batteries are being adopted for resiliency. While backup power systems are not always cost effective, the peace of mind in having power in an emergency is a powerful motivator. Smart home technology can give people more control over their home during an outage and can make it easier to use solar energy and batteries to support critical loads during times when the grid is unavailable.</p>

1. Smart HVAC:

HVAC is the largest load in most residential buildings, and smart thermostats are a popular smart home product. They make it easy to set up schedules or change setpoints remotely for improved comfort and energy savings. They often integrate extra sensors to monitor temperature and humidity for the whole house. Some can learn schedules and use weather forecasts to automatically optimize thermostat setpoints. They can follow time-of-use prices with a setpoint schedule or participate in utility demand

response programs. However, areas still exist in which smart home technology could do more for HVAC equipment.

Thermostat Compatibility: 🏠 🌿 ⚡

Currently, smart thermostats are designed to work with central air conditioners, central air-source heat pumps and forced air furnaces. However, the most common smart thermostats do not work with some HVAC technologies, such as window air conditioners, minisplit heat pumps and some types of electric heating systems [4]. Also, many are not compatible with the newest, variable speed heat pumps and air conditioners, which may require advanced thermostats made by the same company as the HVAC system and may have very limited external controls. Some new products bring communication and control capability to smaller HVAC equipment (window air conditioners and mini-split heat pumps), but app functionality is less sophisticated since they have not had as much development time as leading smart thermostat apps.



Figure 2. Smart thermostat.

Interoperability between HVAC systems: 🏠 🌿

Combining controls for different equipment, such as ceiling fans and a smart thermostat, could ensure optimal operation of these complementary systems for improved comfort and reduced energy consumption [4, 5]. Some signs exist that the industry is moving in this direction, but the controls available are simple and usually require the user to define them. The process of optimizing operation of different HVAC equipment is complicated, and preset modes would help ensure maximum benefit without asking consumers to figure out a complex control strategy on their own. Some examples of equipment that could be integrated for improved performance include mini-split heat pumps, ceiling fans, central HVAC systems, motorized window shades and dedicated ventilation equipment like energy recovery ventilators.

Better Occupancy Sensors: 🏠 🌿

More accurate occupancy sensors and better coverage within a home would enable better control [4]. Current methods for detecting occupancy—motion sensing at the thermostat or with remote sensors, or geofencing using phone location—have significant limitations, so controls must be conservative to avoid making the home uncomfortable if people are home when the sensors did not detect occupancy. More accurate occupancy sensors could achieve more energy savings and improve comfort. For example, improved occupant-based control of room-level HVAC systems, like mini-split heat pumps or zoned central systems, would provide the ability to condition only rooms where people are.

Quality Installation and Automated Fault Detection and Diagnostics (AFDD): 🏠 🌿

HVAC installation faults are common and can lead to higher energy use and inadequate heating and cooling [6, 7, 4]. Better sensors and real-time feedback to the installer can ensure issues are identified immediately. A few products are available that verify quality installation. If they were used for all HVAC installations, the comfort improvements and energy savings would be significant.

A similar process can also be used for quality installation and automated fault detection and diagnostics, which monitor key aspects of the HVAC system during normal operation to identify problems as soon as they occur and before they lead to system failure [8, 6, 4]. Catching changes in performance before the equipment fails makes it possible to fix the problem quickly—or to allow more time to identify an efficient replacement option.

Indoor Air Quality (IAQ):

Smart technology can improve indoor air quality (IAQ) in numerous ways. Sensors can measure a wide range of pollutants, such as formaldehyde, volatile organic compounds, particulate matter, CO₂ or CO. And, it could be used to turn on a ventilation system or to run an air handler to make use of the air filter [4]. In older homes without a dedicated whole-house ventilation system, sensors could automatically turn on spot ventilation equipment, such as a bathroom fan or a range hood, when an increase in pollutants is detected [9]. Newer, tighter homes usually have dedicated ventilation systems, but the ventilation fan is usually on all the time or operates on a schedule. Using IAQ sensors to trigger the use of the ventilation fan can reduce energy consumption while still providing enough fresh air [9, 10]. Outdoor air sensors and occupancy detection should also be included in smart ventilation controls for energy and IAQ benefits [10, 11]. Outdoor air quality (OAQ) sensors can inform ventilation controls, shifting ventilation hours to avoid short duration OAQ events (such as afternoon ozone spikes) or recirculating whole-house filtration during long duration OAQ events (like wildfire smoke). To improve efficiency, occupancy detection could be used to reduce ventilation energy when the home is unoccupied.

2. Smart appliances

As smart home technology gains popularity, manufacturers have started to build communication and control into everything. Some appliances could see more significant gains in efficiency or demand response capabilities with integrated communication and controls. Highest priority smart appliances are listed below, with existing gaps.

Improved Control for Water Heaters:





Figure 3. Heat Pump Water Heater with external communication module.

Tank-style water heaters have inherent thermal storage that can be used to provide flexibility. Energy Star and the U.S. Department of Energy have finalized new specifications for connected water heaters, which communicate using open standards and respond to remote control signals [12]. Manufacturers are adding new sensors and controls to water heaters focused on demand response functionality, but the same set of sensors and controls could be used to improve efficiency, comfort and enable more complex controls [13, 14]. For example, user-facing controls could give occupants more insight into how their water heater operates and how to make changes to suit their needs.

Electric Vehicles (EVs) and EV Charging:

Electric vehicles (EV) are gaining popularity rapidly and will have profound impacts on the electric grid. Currently, most EVs charge when people come home, typically coinciding with afternoon/evening peak, further straining the grid. Therefore, the ability for homeowners or utilities to manage charging for the growing number of EVs will be critical for grid stability. Increased EV adoption could benefit the grid, as they represent a new source of electric utility revenue. Flexibility around charging could be used for grid support [15]. However, a lack of communication between car and home currently exists [16]. The car monitors the state of charge of the battery, calls for charging and can regulate the charging power. But in most cases, the car's battery management system does not talk to the electric vehicle supply equipment (EVSE). Some EVs have mobile apps that provide feedback on the battery's state and can be used to set up a charging schedule, but they usually do not allow integration with a home energy management system. Multiple communication protocols exist for vehicle/grid integration, but car manufacturers, EVSE manufacturers and utilities have not settled on a common protocol for managed charging [17].

Batteries:  

Lithium-ion batteries are generally limited to providing backup power, but when paired with on-site solar, batteries could help homeowners use more local generation by storing the energy until it is needed after the sun goes down. That strategy only makes financial sense if the home is on a time-of-use utility rate or does not get paid by the utility for PV generation that is put back on the grid [18, 19]. Batteries can power a home during grid outages but only if they are installed with a grid-forming inverter, critical loads panel and transfer switch to keep the home isolated from the grid during the outage. Those additional components make battery costs even higher. Batteries and other energy storage systems will be critical to achieve a clean energy grid by 2035, but more work is needed to encourage adoption. As long as residential utility rate structures remain flat, batteries will likely remain a niche backup power option. With dynamic or time-varying utility rates, batteries can play a key role in reducing costs for homeowners and helping utilities shift load to times with available renewable energy [19].



Figure 4. Residential battery and inverter.

3. Power Measurement & Management

Even as more equipment in homes becomes smart, we will not truly have smart homes unless there is a way to measure and coordinate the control of the various smart appliances. This area of smart home technology development is the furthest from becoming mainstream, but companies and research organizations are working to bring whole-home monitoring and control to maturity. **Whole Home**

Power Metering:    

Monthly utility bills are the only feedback most people receive about their energy use. More frequent feedback is needed to improve home energy management. Smart meters can provide more frequent use data, but even that is generally not granular enough for consumers to use. Some new products can measure whole-house power consumption at high frequencies and can use that data to identify power consumption of specific appliances [20]. These systems can provide feedback to help homeowners take action to reduce energy use based on their usage patterns.

Smart Utility Panels:

Emerging new smart utility panel technologies and other advanced power management devices can provide more control, as well as circuit-level monitoring [21]. These will enable more integration of advanced systems like batteries and on-site solar panels. Some advanced smart utility panels make it easier to use batteries for backup power by including an integrated transfer switch and giving users the ability to select their critical loads during an outage, rather than having a separate critical load panel that cannot be easily changed. Circuit-level monitoring and circuit-level control, combined with more flexible off-grid use of a battery, make smart breaker panels an exciting new technology for smart homes.

Home Energy Management Systems:

Home energy management systems (HEMS) provide coordinated whole-home control, analogous to building automation systems common in large commercial buildings. HEMS can be implemented using a stand-alone device in the home or could live in the cloud and control Wi-Fi-connected devices using application programming interfaces (APIs). HEMS could control all major systems, automatically taking into account the many different control objectives a house may experience including comfort, efficiency, grid service requests and prioritizing the use of renewable energy [22]. Homeowners should dictate how their house is controlled, but they should not be expected to manually manage all their loads individually. Especially as grid service requests become more common, it will be important to have a central controller to ensure that control of individual appliances does not adversely impact comfort or safety [23].

Conclusion

Smart home technology has the potential to make homes more comfortable and efficient, use more clean energy and be more resilient. Despite the progress across many aspects of smart home technology, there are still technical gaps to tackle before a more complete, more useful smart home is possible. Major appliances built with more sensors and better controls will enable more advanced control, better identification of faults and the ability to respond to demand response requests. New technology like EVs and batteries give homeowners more control over when they draw power from the grid, but also will increase the total electric load in homes. Ultimately, the ability to measure where electricity is being used in homes and optimize control at the whole-home level will be needed to ensure smart home technology improves costs, comfort and load flexibility and does not create more work.

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