Photo 1: Equinox House kitchen features custom, eco-modern Italian cabinetry with large counter depth refrigerator, double oven, electric cooktop, microwave oven and dishwasher. Baking a turkey at Thanksgiving is sufficient to keep Equinox House comfortable for a day with freezing temperatures outside.

Low-Energy Appliances

By **Ty Newell,** Member ASHRAE; and **Ben Newell,** Associate Member ASHRAE

In this article, we examine the impact of appliances on Equinox House. Energy requirements of high efficiency homes are dominated by humans and their activities rather than climate. Equinox House, for example, would only require one-third of its annual energy to maintain comfort conditions without people and their appliances. The operation of appliances and comfort conditioning systems are intertwined in high performance homes. Baking a turkey at Thanksgiving is sufficient to keep Equinox House comfortable for a day with freezing temperatures outside.

Photo 1 shows the kitchen in Equinox House. The kitchen has modern, custom Italian cabinetry with high quality appliances. Whether or not the style of the kitchen is appealing to one's taste is not important, but recognizing that a solar-powered house can have any and all of the modern conveniences one desires in a house is important. Luxury and sustainability are not mutually exclusive.

The appliance industry has improved its products for several decades, and many modern appliances offer consumers excellent quality coupled with high energy efficiency. The yellow energy tags placed on appliances in the United States and similar tags used in many countries around the world help inform consumers about the energy efficiency of each appliance. However, the yellow tag is only part of the story. A vented clothes dryer, for example, exhausts conditioned air out of the house while replacing it with unconditioned infiltration air.

Our October 2010 column discussed the annual energy requirements of Equinox House. With four occupants, the predicted energy requirement in central Illinois is 11,000 kWh. Without any human related loads, Equinox House requires 3,700 kWh of energy to maintain a comfortable room temperature and humidity. Supplying fresh air at ASHRAE Standard 62.2 recommended level for four occupants increases the energy load to 6,000 kWh per year based on conditioning of the fresh air. Energy recovery reduces the impact of fresh air substantially; however, we will leave the fresh air energy as-is for these discussions. The additional 5,000 kWh energy requirements are for major appliances (including water heating) and other electrical loads (television, computers, lights, hairdryers, etc.).

Three cities have been modeled and are discussed: Urbana, Ill.; Phoenix; and Fairbanks, Alaska. Urbana is a location

This is the eighth in a series of columns. Find previous columns at www.ashrae.org/ashraejournal.

that represents regions with significant summer air conditioning and winter heating loads. Phoenix and Fairbanks are used as extremes for cooling-dominated and heating-dominated climates. The house design model assumed for Phoenix and Fairbanks are similar to Equinox House except the Phoenix house design has more window overhang protection while Fairbanks does not have window overhang protection. The optimal wall and roof designs for Phoenix and Fairbanks would be different than the optimal choice for Illinois; however, we are keeping the basic house the same to understand the effect of appliances relative to climate.

Refrigerators

From the viewpoint of a house, refrigerators are heaters. Depending on the climate and time of year, heat from a refrigerator's operation may be either beneficial or not. A typical refrigerator has an annual energy use of 300 to 500 kWh, which is related to its size (volume), style (top-mount, side-by-side), component efficiency, use patterns, and features (through-the-door ice and water). The 22 ft^3 (622 L), counter depth, French door refrigerator in Equinox averages 28 kWh per month for an annual energy use of 340 kWh.

If we assume a yellow tag refrigerator has an annual energy load of 400 kWh, we find that the annual refrigerator energy impact for Urbana is 313 kWh. That is, the refrigerator's annual energy addition of 400 kWh to the interior of the house benefits its winter heating requirement more than it penalizes the air conditioning system during the summer cooling season. So, the real impact of the refrigerator on the house is 22% less than its nominal energy listing.

For Phoenix, the 400 kWh refrigerator results in 485 kWh of house energy load due to the extra air conditioning required to maintain comfort. The Fairbanks house realizes an energy load of 284 kWh due to the refrigerator operation because its heating effect is almost always beneficial. *Figure 1* shows the house energy with a refrigerator for the three locations relative to the house without people and with people (but no appliances). *Figure 2* shows the yellow tag refrigerator annual energy vs. the net house energy impact of a refrigerator for the three locations.

Dishwashers, Clothes Washers, and Cooking

Dishwashers, clothes washers and cooking appliances (microwave ovens, cooktops and ovens) are grouped together because they all add energy to a residence, in a similar manner to refrigerators.

Some of a dishwasher's operational energy remains in the house as an addition of heat and moisture, while a portion of the energy runs down the drain with the water. We will assume an annual dishwasher energy load of 300 kWh for a house based on a typical dishwasher, with the understanding that this may be discounted by the fraction of thermal energy that travels with the drain water. In addition, we will not address the moisture issue, although our simulation model does include moisture effects for the house.

Clothes washers follow dishwasher loads, with an assumed annual energy requirement of 300 kWh. This energy load assumes 600 laundry loads per year for a family of four. The energy does not include energy for hot water. We are using a cold water high efficiency (he) detergent in Equinox House, eliminating the need for hot laundry water.

Cooking energy is a fuzzy quantity, and has been continually decreasing over the past three decades to a level that is one-third of that in the 1970s. A U.S. Department of Energy report[1] indicates that 250 kWh for cooktop/oven use and 150 kWh for microwave oven use are reasonable estimates, for an annual total of 400 kWh for cooking. In Equinox House during December 2010, we used 73.6 kWh for cooking because of the holidays.

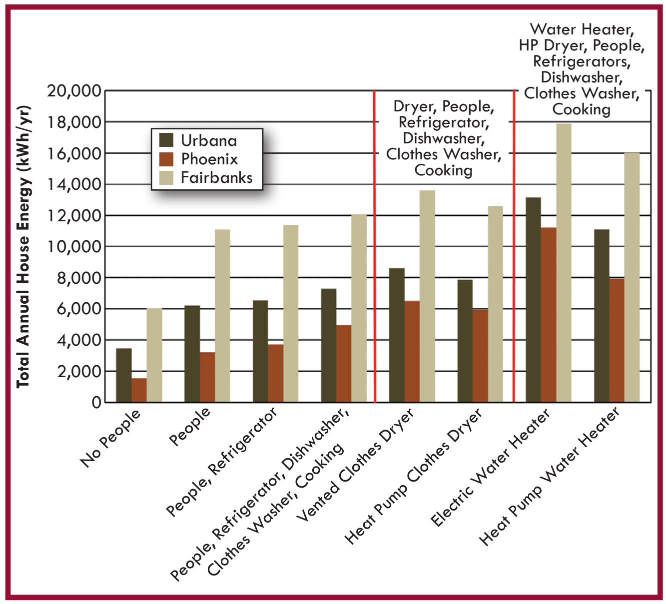

Figure 1: Annual house energy requirements due to people and appliances. The impacts of a vented, electric resistance clothes dryer and an electric resistance water heater are shown to the right of the red lines.

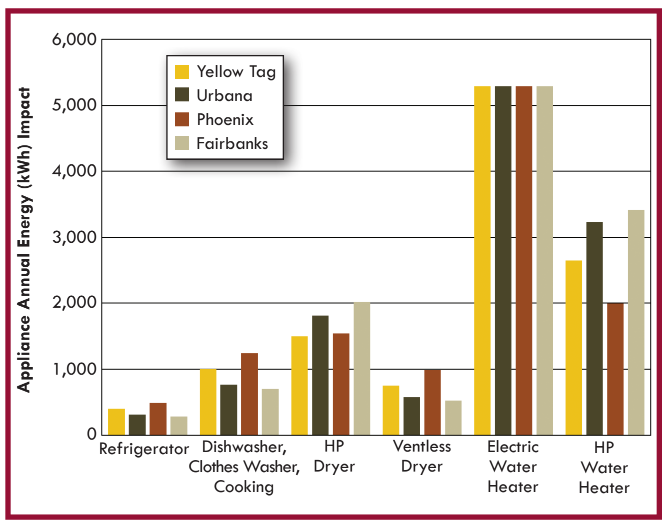

Figure 2: Appliance yellow tag annual energy versus net house annual energy for each appliance category for Urbana, Phoenix and Fairbanks.

Our January 2011 cooking energy was a more modest 24.7 kWh and is more representative of our wintertime cooking activities.

Combining dishwasher, clothes washer and cooking energies, we have 1,000 kWh of annual energy use. In a nearly proportional manner to the refrigerator load, this additional energy can be beneficial or detrimental. Equinox House has a net electric energy load of 780 kWh, or a decrease of 220 kWh from the 1,000 kWh appliance load. For Phoenix, additional air conditioning requires 245 kWh in addition to the 1,000 kWh load, while Fairbanks realizes 302 kWh less than the appliance load.

Clothes Dryers

Two classes of clothes dryers are the conventional vented dryer in which essentially all clothes dryer energy is exhausted from the house and the ventless, heat pump dryer in which all of the dryer energy stays in the house. A third category is the ventless, "condensing dryer," which is a less efficient version of the ventless heat pump dryer.

Photo 2 is a picture of the washer and dryer in Equinox House. The clothes washer is a modern, front loading, high efficiency unit with high spin speed. Our clothes dryer is a European ventless heat pump clothes dryer that uses 30% less energy than European "A" grade clothes dryers, which is approximately 50% more efficient than clothes dryers in the U.S. Continuing advances in Europe are pushing the envelope further with another 20% energy decrease (50% of European "A" grade) in the near future. Unfortunately, ventless, heat pump clothes dryers are not readily available in the United States due to the lack of clothes dryer ENERGY STAR appliance ratings. We acquired a European unit necessitating a power converter shown on top of the dryer. Eliminating the dryer vent saves construction costs, as well as cutting a hole in the wall.

Photo 2: High spin speed, water conserving clothes washer and ventless heat pump clothes dryer (the dryer is from Europe).

From our appliance research, we have found an average U.S. clothes dryer energy requirement of 2.5 kWh for a full load of cotton towels. For a family of four, 600 drying cycles are assumed, the same as used for clothes washing. A dryer cycling time of 0.5 hours per load is assumed with 5 kW of power, resulting in 1,500 kWh per year. Our clothes dryer ventilation studies have measured a vented dryer airflow of 58 L/s (120 cfm) during a drying cycle. We have added the dryer exhaust air to the house infiltration, resulting in an additional 310 kWh electrical energy required for additional summer and winter house conditioning in Urbana. For Phoenix, only 44 kWh of additional load is realized while Fairbanks has an additional comfort conditioning load of 518 kWh above the 1,500 kWh dryer energy.

Ventless dryers with heat pumps essentially remove water from clothing by temporarily vaporizing the water. Heat from the condenser coils vaporizes water in the clothing, which is then re-condensed in the evaporator, similar to a room dehumidifier. The energy used for the drying stays within the house, and no additional ventilation load is placed on the house. Based on the previous vented dryer assumptions, a ventless heat pump dryer that uses 50% less energy requires 750 kWh to operate over the course of a year, with the energy staying inside the house in the form of additional heat.

For Urbana, the net house energy due to clothes drying is 578 kWh compared to the 1,810 kWh required by the vented dryer. For Phoenix, the ventless heat pump dryer imposes an annual energy load of 986 kWh in comparison to a vented dryer's 1,544 kWh, while Fairbanks realizes 526 kWh of annual energy for the ventless dryer compared to 2,018 kWh for the vented dryer. *Figure 1* shows the progression of adding a vented electric dryer and a ventless heat pump clothes dryer to the house for the three locations. *Figure 2* displays the appliance energy impact for the ventless heat pump clothes dryer and the vented electric resistance clothes dryer relative to the nominal yellow tag values.

The energy difference between a ventless heat pump dryer and a vented electrical dryer is enormous. Electrical vehicles entering the market travel 4 miles per kWh (6.4 km per kWh), so the energy difference between a ventless heat pump clothes dryer and a vented electric resistance clothes dryer is equivalent to 2,000 to 4,000 miles (3200 to 6400 km) of driving.

Water Heating

Water heating is interesting because of its energy significance and the new heat pump water heating technology moving into the market. For a family of four, we will assume that 280 kg of hot water (approximately 80 gallons [303 L]) are required per day.

Electric resistance water heating has an annual energy load of 5,300 kWh per year based on the above assumptions. No allowance for storage tank losses is assumed for this discussion. Such losses may be either heat gains to the surrounding space, which may or may not impact the home energy depending on the location of the water heater. No distinctions are made between tankless ("instantaneous") and tank electric water heaters as the effects on the house are similar with regards to energy (but not in terms of power demand). Although some fraction of the energy in the hot water does transfer into the comfort space through both direct heating of the home and through water vaporization from showers and other uses, this amount will be neglected as well. All energy used for heating the water is assumed to go down the drain with the water.

Heat pump water heaters entering the market significantly reduce water heating energy requirements while also impacting the comfort conditioning of the house. We will assume that the heat pump water heater is located in the comfort space, although this may not always be true. *Photo 3* is the heat pump

Advertisement formerly in this space.

Photo 3: Heat pump water heater installed in Equinox House with additional tank insulation.

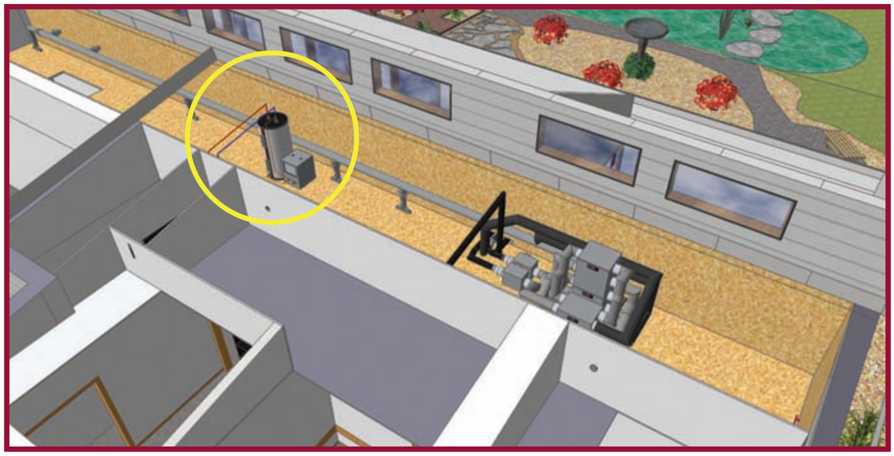

Figure 3: 3-D rendering of Equinox House showing location of the heat pump water heater in utility corridor located above the three bathrooms and laundry room. The fresh air heat pump/energy recovery comfort conditioning system is in the utility corridor.

water heater in Equinox House. *Figure 3* is a 3-D rendering of the heat pump water heater in the utility corridor (attic) that is part of the thermal and moisture envelope of the house. Assuming an average heat pump coefficient of performance (COP) of 2, the annual water heating electrical energy requirement is 2,650 kWh. The heat pump water heater's cooling effect on its surrounding ambient negatively impacts the house energy load during the heating season. The third section of *Figure 1* shows energy of the water heater added to the other internal energy loads including the heat pump dryer. The heat pump water heater added to Equinox House results in an additional annual energy load for Urbana to be 3,234 kWh and 3,418 kWh for Fairbanks. Phoenix nearly always benefits from the cooling impact of a heat pump water heater, with only 1,995 kWh of net house energy.

The impact of using an electric resistance water heater for all three locations is a fixed addition of 5,300 kWh to the house energy requirements, based on the water use assumptions above. *Figure 2* breaks down the yellow tag energy impact for both a heat pump water heater and electric resistance water heater.

We have neglected the dehumidification effect of the heat pump water heater. Our measurements in Equinox House indicate that with an interior relative humidity in the 40% to 60% range, we remove approximately 0.55 lb_m (0.25 kg_m) of water per shower (showers are the dominant hot water load as we use cold water clothes detergents, and the dishwasher heats its own water). The condensed water represents approximately 10% of the energy transferred from the surroundings to the water heater.

It might seem counterproductive to cool a house in the winter for northern locations, however, a heat pump water heater in combination with a home's heating system should be viewed as a "two-stage" system in which one system is designed to efficiently move energy from cold outdoor ambient to interior room ambient temperature conditions. The heat pump water heater is then able to efficiently "lift" room ambient temperature energy to the desired hot water temperature level. Another interesting aspect of a heat pump water heater is that the metabolic energy from a person over the course of a day is similar to the energy needed to heat one's daily shower water. The heat pump can be thought of as a means of redirecting the metabolism to a useful purpose before exhausting it down the drain. Finally, the 2,000 kWh difference between electric resistance water heating and heat pump water heating would provide the energy needed to drive an astounding 8,000 miles (12 800 km), and at a cost per mile that is significantly less than the cost per mile with gasoline.

Summary

Humans and their appliances dominate the energy requirements of high performance homes. Climate and the type of appliance are factors for determining the net effect on house energy requirements and can vary greatly from an appliance's government energy rating. Occupant behavior is also an important factor, which widely varies between households. Despite this variation, the trends in house energy impacts of appliances hold true.

References

1. DOE. 2005. Technical Support Document: "Chapter 6: Energy and Water Use Determination." The Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

2. Europe's Energy Portal. Accessed March 2011. "The EU Energy Label." www.energy.eu/focus/energy-label.php.

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