Sustainability: What's That, and So What?

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ABSTRACT

In this paper I try to do two things. One is to describe what is really important to understand about sustainability. Two is to relate that understanding to homes. I've been working on understanding and applying sustainability to engineering education and buildings for over 25 years. In my book in progress on sustainability, three key ideas are identified: growth, happiness, and nature. An overarching concept is that of connectedness – to each other, to our communities, and to nature. The paper will explore these ideas, including how our current beliefs and expectations changed with time. You could say that sustainability is a projection of those changing beliefs into the future.

We already see sustainability beginning to be expressed in housing. New home size is leveling off. I expect a gradual decline in size, reflecting both a decline in materialism, and a rise in being more connected outside the home. Along with that, homogeneous suburbs will give way to diverse neighborhoods with more multifamily, multigenerational households. Walking and being outdoors will lead to more parks and greenways. There will be lots more home gardens, community gardens and neighborhood workshops.

On the technology side, buildings will be better insulated and more air-tight, with integrated energy recovery systems, and high-efficiency heat pumps, for space heating and water heating. The house systems will include the family's electric cars and bicycles. Houses will be built to utilize sunlight for light, heat, and electricity, and outside air for ventilation and cooling. Overall we'll live in homes and neighborhoods that better fit our changing norms and visions of happiness and sustainability.

WHAT IS SUSTAINABILITY?

Sustainability emerged in the late 1980s from two other movements – environmentalism and human rights. The classic definition from the U.N.:

> *Sustainable development … meets the needs of the present without compromising the ability of future generations to meet their own needs.*
> (World Commission on Environment and Development)

It combines the idea that every person has basic human rights and *needs* for human fulfillment, along with a recognition that our efforts to live decent lives today can compromise what is possible in the future. Though we often think of sustainability being all about the environment, it is a more holistic answer to the question of how can we all live decent lives here on Earth. It recognizes that a healthy planet is needed for decent lives, now and into the future.

HOW DID WE GET HERE?

There were three key changes that all began with the Scientific Revolution in the 1500's. Things were happening in 16th century Europe that were blowing peoples' minds. The Protestant Reformation was underway, taking power from the Catholic Church, and emphasizing the power of each person to interpret scripture. Then Copernicus claimed that the Earth and other planets orbited around the sun. Think about it. Your daily experience of the Sun moving around the Earth is now in conflict with this new philosophy called science.

As the life of the mind, exemplified by logic and reason, was elevated, the life of the body and its felt connections to the living world was diminished. Spirit was gradually withdrawn from the world, left to reside only in humans. We began to see the world as merely a giant storehouse of stuff there for our taking.

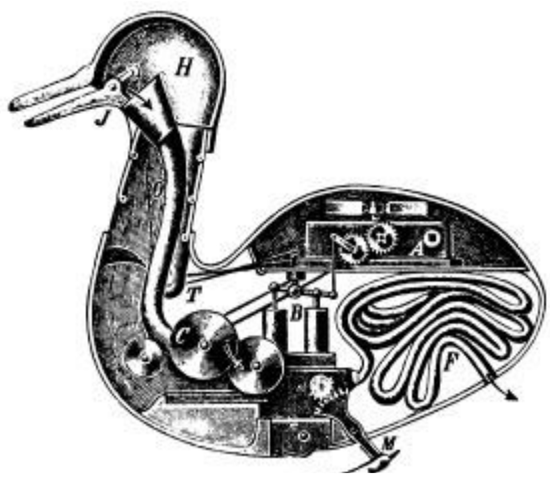

Figure 1 Descartes held that non-human animals could be reductively explained as automata (DesCartes).

Scientists were describing the creatures around us as nothing more than machines with feathery, furry, and scaly coats. The universe was just a gigantic machine, with its parts whirring around in space. The world became less meaningful as its life and spirit were withdrawn from human attention.

Then came another change that rocked the world – the idea of capitalism and its emphasis on material wealth and growth. When Adam Smith published *The Wealth of Nations* in 1776, the state controlled and regulated most of production and trade. With all of the respect that science and rational thought commanded at the time, Smith looked for basic rational principles of economics that were similar to scientific principles that were believed to govern and regulate the universe. His basic premise was that wealth was produced by land, labor, and capital, represented by the total output of goods and services. This concept of measuring wealth by total output, or production, came to be the standard we rely upon today, Gross Domestic Product (GDP).

Smith also proposed what has come to be known as the *virtuous cycle*. It is founded on the concept of *division of labor*. Instead of a worker making an entire product, a shoe for example, he only cuts the material. Another worker does the stitching, and another the sole, and so on. By each worker focusing on only one task, they can get really good at it, and do it fast. The result is that more shoes can be made by the same number of workers. Productivity increases and the increased profit can be reinvested in more productivity. It tends to ignore that a shoemaker's sense of accomplishment will be greatly diminished to be only a stitcher, or nailer. Now even people began to be treated like machines.

This system depends on growth and further productivity gains. Another fundamental change is that having more material goods and a less burdensome life became possible for a growing number of people. This shifted our attention from a good life after this one, to a good life right now. And it worked … for some of us.

It all literally picked up steam during the third key period in history, the Industrial Revolution. In the late 1700s and early 1800s in England, textile production that was typically done by craftspeople in their homes, was moved to factories and large weaving machines that could produce much more fabric per person. People began to move to the growing cities, further removing themselves from even domesticated animals. Yet for all of the growth and changes at the time, nobody could have imagined the next phase of the Scientific-Capitalistic-Industrial epoch.

The steam engine. Up until its development in the 1700s – for pumping water out of coal mines – the physical work of humanity was mainly provided by animals. That is the way it had been forever. Sure there were exceptions, like wind/water mills, and sailing ships, but the daily work to pull plows, harvest crops, and move about was animal power, including humans. The coal being mined at the time of the steam engine was used solely for burning to make heat for human comfort and for industry.

With the steam engine, we could now use heat from burning fuel to make work and power. The new coal-burning engines were put in factories, in ships, and then trains. Then came cars. Then electricity, delivering the awesome power to our homes.

Before engines and electricity, a horse was an important element of society. We even established the standard unit of power as a *horsepower*, meant to represent the rate a horse could work for some extended time. A horse is a powerful creature, especially when compared to us. A horsepower is equivalent to 746 Watts, or ¾ of a kilowatt. A human can steadily produce about 1/10 horsepower, or it takes 10 people to produce the daily work of one horse.

Look at what we are used to today. My electric leaf blower, plugged into an ordinary wall outlet, consumes 1,500 Watts of power. It is like having two healthy horses at my beck and call whenever I flip the switch. Two horses! My lawn mower is five-and-one-half horses. Even my small Kia Soul has 142 horses, and some would consider that not enough power. A 777 jet has a power equivalent to 220,000 horses. All in a culture that seldom experiences a living creature called a horse.

We think that is normal. What else do we think is normal after these three key periods in history?

- We need to have the power of hundreds of horses in order to be happy.
- We need growth in order to be happy.
- An easy life filled with conveniences is a normal aspiration.
- The other-than-human world is barely alive, spiritless, and mainly of value because of its use to humans.
- The benefits of modern society are worth the sacrifices.
- Sure there is still suffering, but that will be solved with more growth, and better technology.

SO WHAT'S WRONG?

This modern worldview does have its shimmer. If I'm in the lucky minority that has money and power, I'm materially well off. I have a nice house, at least one car, lots of gizmos and gadgets, good health insurance, and plenty of food. I may work long hours at a job that is not really fulfilling, but I justify it in the name of progress. To the average person in the wealthier countries, life is pretty good in these ways. Beyond stating the obvious about the majority of the world's people who are not materially well off, it's relevant to note that many of us who are materially well-off are less than satisfied. We have not found satisfying meaning in this convenient, well-stocked life. We're feeling a little duped. There's got to be more to life than maximization of personal preferences, and survival of the fittest.

But what also is wrong are the routine sacrifices we make of the more-than-human world: mountaintop removal, tar sands, climate change, eutrophication, species extinction, deforestation, etc. The best measure of all of those sacrifices is the ecological footprint [2]. Ecological footprint (EF) is a measure of the total bioproductive land and sea area that it takes to provide your resources and assimilate your wastes. In the United States, we typically have an EF that if everyone on Earth lived like us, it would take five planets.

Well that's a problem for a sustainable future.

About a year ago, I exchanged emails with an economist colleague who had published a report that claimed that the more money people make, the more satisfying is their life, and there is no evidence of satiation (Sacks). In other words, more money makes people happier, and this holds true for rich and poor. Their basic argument was that the best thing we can do regarding happiness is to continue to grow the economy.

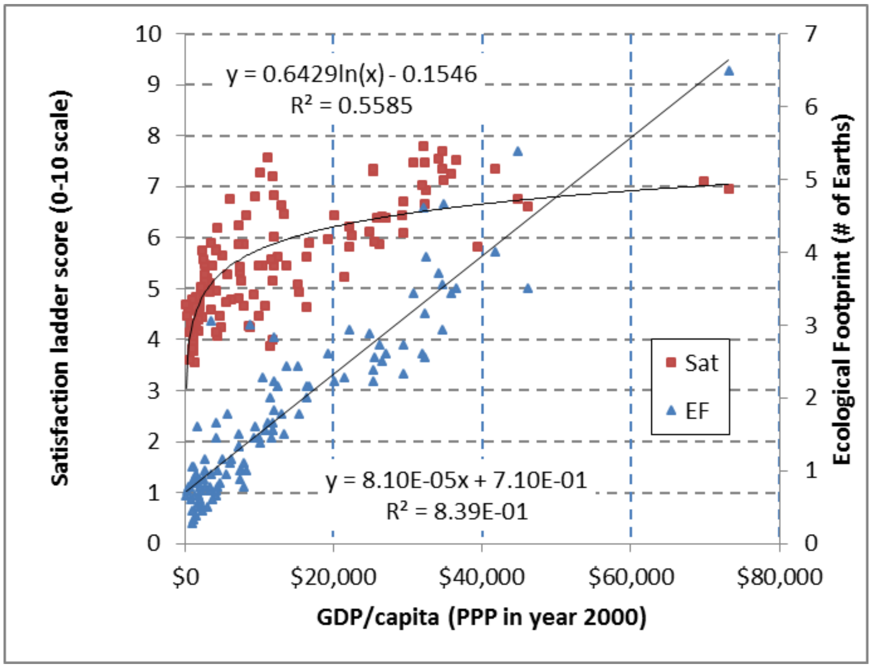

Figure 2 Country average life satisfaction and ecological footprint correlated to per capita GDP.

I took their dataset and added in data on EF and got the result shown in Figure 2. The left vertical axis is the "satisfaction ladder score," the most widely used indicator of life satisfaction (0 is the worst life imaginable and 10 the best). This is the data that Sacks had published.

The right vertical axis is EF. Anything above one is not sustainable. When I pointed out that while country-average life satisfaction goes up with income, so does EF. In fact, it crosses one planet at a GDP/capita of about $4,000. The response was that the authors had never heard of EF.

Before we leave this graph though, there's three more relevant observations. One is that while satisfaction does correlate with income, it only explains about 56% of the variation in life satisfaction. There's a lot of other factors, one of the most important being the number and quality of relationships. Sustainability brings our attention to human relationships, as well as the larger world.

Secondly, there is an interesting grouping of countries with relatively low incomes, ~$10,000, that have satisfaction levels at the same high level (6-8) as countries with 3-4 times the income. These countries are for the most part in Central and South America. Clearly there are cultural, ethnic, and/or geographical factors that influence satisfaction. One could argue that instead of increasing income in countries like the U.S. (GDP/capita of $42,000, ladder average of 7.35), we should decrease income to countries like Venezuela ($11,200, 7.58). But that ignores all of the other factors that affect satisfaction.

A third observation is that while satisfaction goes up a lot at low incomes, it tends to level off as income increases. In fact, the two countries with the highest incomes, Luxembourg and Qatar, have satisfaction scores that are lower than many of the other countries with lower incomes. How could the economists have said that there is no evidence of satiation? Because they plotted satisfaction versus the log of income; see Figure 3.

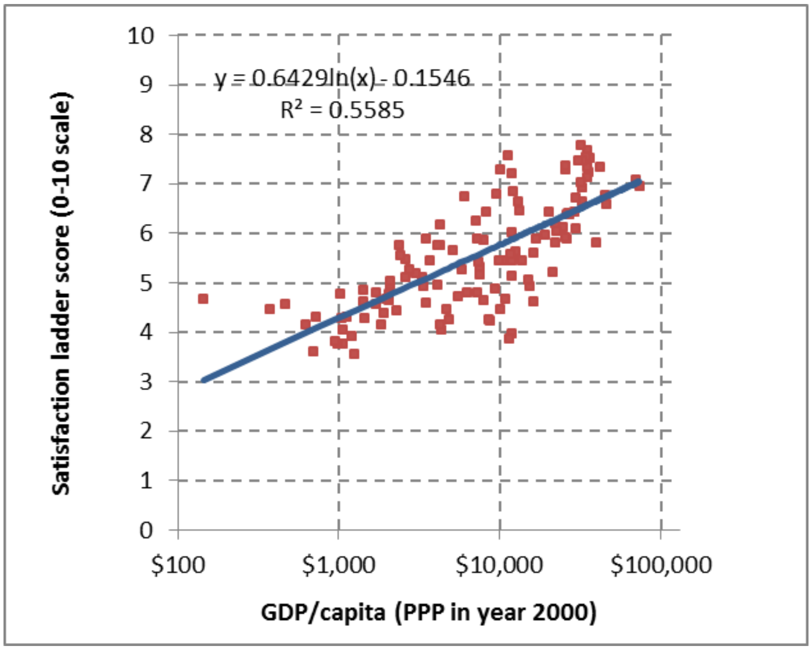

Figure 3 Country average satisfaction plotted versus log of income.

What changes here is that you don't see the leveling off. What the log plot does is make the data look like satisfaction just goes up and up with increasing income. It doesn't.

What it does say is that it takes ever increasing amounts of income to have a certain increase in satisfaction. As shown in Table 1, to go from 4 to 5 on the ladder score, the correlation equation says that income must go from $772 to $3,823, an increase of $3,051 and a factor of 4.9. To go from 5 to 6 requires an increase to $18,938, an increase of $15,115 and a factor of 4.9. Another way of saying that is that if a person making X amount a year wants to increase their life satisfaction by one ladder level, their income would have to increase by about a factor of nearly 5! That's pretty crazy, and a weak recommendation for making more money to be more satisfied with your life. Note that according to the correlation, to get to a ladder score of 9 would require an income of $2,300,000!

Table 1 Predicted ladder scores and associated income.

Ladder	GDP/capita
4	$772
5	$3,823
6	$18,938
7	$93,825
8	$464,840
9	$2,302,956
10	$11,409,535

Another way of looking at the correlation is suppose that someone made $500,000 a year. The same amount of increase in income that could raise that person's satisfaction, say one-tenth of a ladder level, could do the same for five people making $100,000.

Of course, while income does have some effect on life satisfaction, there is a lot more to it.

To conclude this section on what's wrong, we are exceeding the Earth's capacity to supply our resources and assimilate our wastes. The biocapacity of Earth is like our own household budget. If we spend more than our budget, we need to borrow but eventually need to live within our means. Right now, we're living on borrowed time. The global ecological footprint is now 1.6 Earths.

GETTING TO SUSTAINABILITY IN OUR HOMES

In the U.S., even if there was no growth in consumption, we need to reduce our environmental impact by a factor of 5. And we need to develop ways to ensure that every American has the capability to live a fulfilling life. Well that's a tall order. What might it mean for housing?

Sustainability draws our attention to the way one action affects another, and one technology connects to others. We begin to see that next to how many children we have, where and how we choose to live are the next biggest factors in our ecological impact. And where and how we live are also big factors in our happiness and life satisfaction.

> *Imagine. It's a beautiful July day in Pennsylvania in the year 2050 as I walk out into my yard to gather the wash from the clothesline. All around me the landscape flourishes. There's fruit on the peach and apple trees, and lots of little green walnuts on our young walnut tree. The sweet cherries are just finishing, but there's lots put away for the winter. After getting the wash, I pick as many juicy raspberries as I can on my way to move the "chicken tractor" to its new spot. But before moving it I gently retrieve 3 eggs from the nests. The four hens, Delores, Chickie-baby, Gaga, and Belle, are out in their yard pecking and scratching away …*

You're probably thinking: Hey, what does my yard and what's growing there have to do with housing and sustainability? Consider this. For the average American, what we eat and the way it's produced requires 7 units of fossil fuel energy for every 1 unit of food energy that we obtain from the food. And with more people and a worldwide increase in meat consumption, it's going to get worse globally.

Luckily here in Pennsylvania, we have a long tradition of growing and preserving food. Except for the chickens, that description of my yard describes the yards I knew growing up in Hanover in York County in the 1960s. Plus most of the alleys had mulberry bushes that were usually filled with sweet little berries for much of the summer.

The enlargement of home to include not just our house but also the yard where it lies, is a re-cognition of the interrelatedness of life, and a re-engagement with the processes of life. Sustainability has the greatest potential in our ability to see connections, and to see the bigger picture while also paying attention to the places we live.

It sounds like a step backward – the idea of growing food in our yards and preserving it for the winter. Why is that?

Part of our vision of material progress that we take for granted is that physical work is a burden, and that we should make life easier and more convenient. It sure is easier to just stop by the supermarket and buy a frozen dinner to microwave for dinner, than to plant a garden, care for it, clean the produce, preserve it, and then prepare it. Just like it's easier to just stuff wet clothes from the washing machine into a drying machine, turn it on, and pull out the warm clothes, than to carry the wet clothes outside, hang it on the line, and then gather it in when dry. And yes it's easier to turn the thermostat for heat than to chop wood, store it, bring it inside, light a fire, and keep it going. Easier yes. But what becomes of us humans if life was so easy?

I picture the people in the movie Wall-E who are very overweight and just float around in their levitating chairs watching a computer screen and drinking slushies. They live in space because they've destroyed life on Earth.

Part of the message of sustainability is that this disconnection from the living world that sustains us is how we became so unsustainable in the first place. The world matters. We are an integral part of that world, and we matter too.

In a similar way to including food when we think of where to live, we'll also pay more attention to transportation and services. For many, the idea of living someplace that requires driving a car will turn from an asset to a liability. So the old real estate adage of "location, location, location" may need another "location."

SELF-HEATED HOUSES

Here's a little secret that most of us in the high-performance home field know. A well-insulated, air-tight (with energy recovery), smaller home can pretty much heat itself. In Pennsylvania.

Note that I did not say that it does not use electricity. In fact, the increased electricity use for electrical devices, and its associated heat, is what has reduced the need for additional heat. Even with high insulation and air tightness, a home will still lose some heat in cold weather. A lot of that heat comes from all of the electrical uses around the house. Think about it. For most appliances that are not exhausted, all of the electricity that goes into them becomes heat inside the house. While thermal integrity has steadily increased over the last 40 years, there has been an increase in the number of electrical devices, and that translates to more heat.

Figure 4 shows a breakdown of the modeled electricity use in a 1,200 ft^2 high-efficiency ranch home in Philadelphia heated with a high-efficiency heat pump. The heating only accounted for 7% of the annual electric load. That's good news and bad. It's good because it means less fuel burned to heat the house, or less electricity used to run a heat pump. It's potentially bad for two bigger picture reasons. One is that at best, the heat given off by our electrical devices is 100% efficient. On the other hand, a high-efficiency heat pump can operate at an effective seasonal heating efficiency of

250%. I'd much rather heat with that heat pump than with my TV. But of course, the TV provides me some other service than simply heat (or does it?).

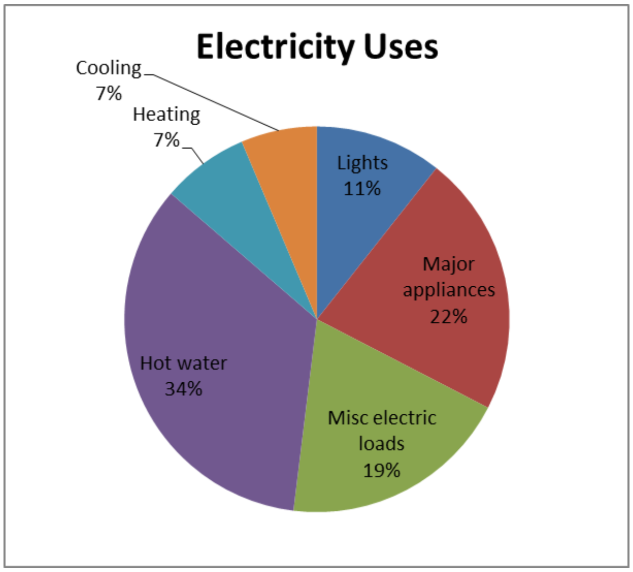

Figure 4 End uses of electricity in a small, high-performance home.

WATER HEATING

In a high-performance home, the energy required to heat water for use around the home is the largest heating load. We've got to be smarter about heating water than using electric resistance elements.

I started practicing engineering during the heyday of solar activity in the 1970s. One of the technologies promoted then, and just as relevant today, is solar water heaters. These thermal systems heat water, or antifreeze, in a collector outside, and then pump that fluid inside to be stored in a tank. The systems typically provide for 2/3 of the annual water heating needs. A typical family of four would need two collector panels, each about 4'x8'. Cost is about $5,000 to $8,000 and annual savings are about $200-$400 (compared to a conventional electric water heater).

A new player in water heating is the heat pump water heater (HPWH). Instead of electric resistance coils to heat the water, a heat pump is used. The heat pump obtains heat from the air surrounding it, so it cools the surroundings. In humid conditions, it also dehumidifies the surrounding air. This presents some interesting challenges in comparing it with a conventional electric (resistance) water heater, and with a solar water heater.

There's two basic places to put a HPWH, in the conditioned space, like an interior mechanical closet or in a conditioned basement, or in unconditioned space, like a basement. If you put it in conditioned space, then the heat it "pumps" into the water comes from the house heat system. So the overall efficiency depends on both the HPWH and the house heating system.

HPWH in Conditioned Space

For heat pumps, the common measure of efficiency is the COP, Coefficient of Performance. It is defined as the heating or cooling rate divided by the electrical power, and it is a dimensionless number – the same units are used for heating/cooling and electricity. The COP depends on the outdoor and indoor conditions, so for estimating seasonal performance, we use HSPF for heating, and SEER for cooling.

HSPF = heating seasonal performance factor = $COP_{avg,htg}$ (3.413 Btu/Whr)

SEER = seasonal energy efficiency ratio = $COP_{avg,clg}$ (3.413 Btu/Whr)

The HSPF for a heat pump is lower than the SEER because the temperature differences are greater in the heating season, e.g., 70-30=40 ^{o}F, than in the cooling season, e.g., 90-75=15 ^{o}F. Plus the heat pump must defrost when heating, and can use supplemental electric resistance heat in very cold weather. These days an efficient heat pump has an HSPF > 10 ($COP_{avg,htg}$ = 2.9) and SEER > 20 ($COP_{avg,clg}$ = 5.9).

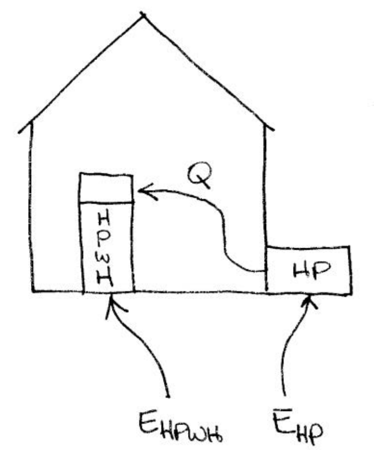

Figure 5 Schematic of house with a HPWH in conditioned space.

The easiest case to consider is a house with electric baseboard heat. A HPWH in this house, in the winter, will operate at an effective efficiency of 100%. As you can see in the diagram, the heat, Q, it pumps into the water was obtained from the baseboard (not heat pump in this case) at 100% efficiency, and the added heat from the compressor in the HPWH is also 100% efficient. So there is no difference – in the heating season – between a HPWH and a regular water heater, for a house with electric baseboard (or ceiling cable) heat. There is some cooling benefit in the cooling season.

Now when the house is heated with a heat pump, the thermodynamics works out to this:

$$COP_{TOTAL} = COP_{HPWH} [COP_{HP} / (COP_{HP} + COP_{HPWH} – 1)]$$

Let's say COP_{HPWH} = 3.0, then Figure 6 shows the overall system COP_{TOTAL}.

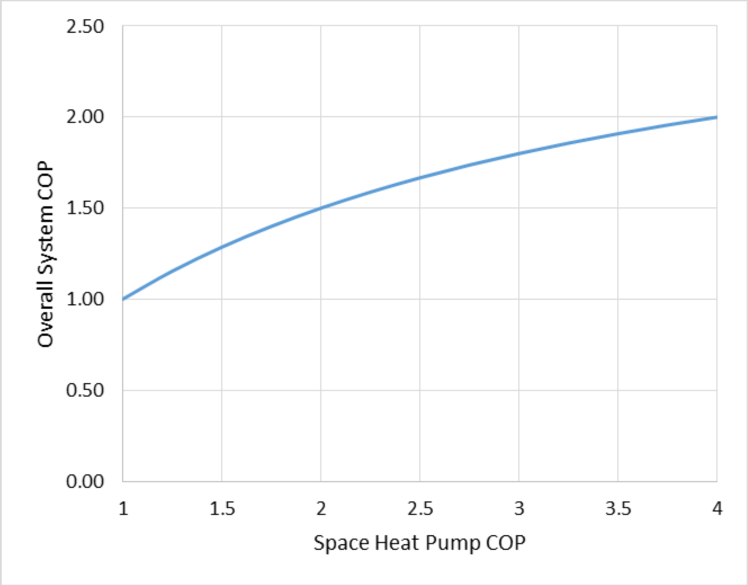

Figure 6 Overall COP for a HPWH with COP of 3 located in conditioned space.

The system efficiency is not as good as the HPWH itself, but it is still better than 1. Note too that even though the HPWH has a COP of 3.0, the overall system COP is no higher than 2.0, when the space heat HP has a COP of 4.0. For a seasonal COP of 2, the overall system COP is about 1.5.

HPWH in Unconditioned Space

What happens when the HPWH is in an unconditioned basement? Well there are two basic situations here. One is where the unconditioned basement is insulated from the conditioned part of the house, like with insulation in the basement ceiling. The other case is where there is no insulation between the basement and the upper floor.

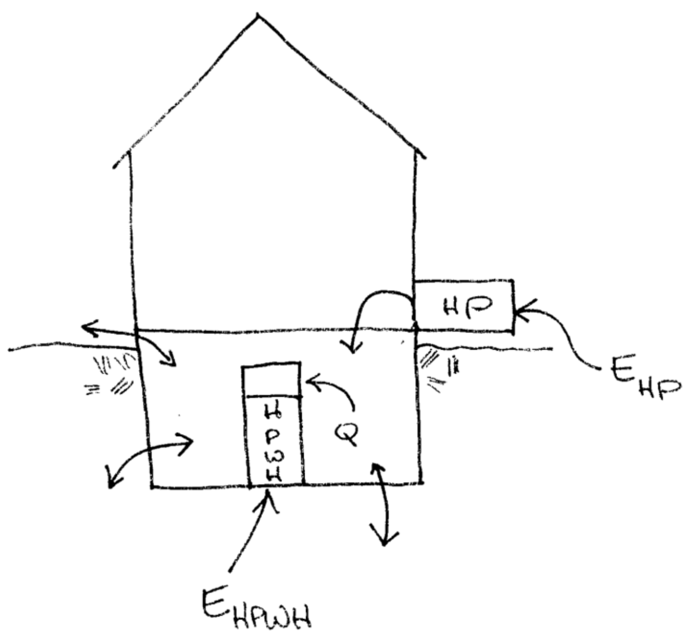

Figure 7 Schematic of a HPWH located in an unconditioned basement.

As you can see in Figure 7, the heat, Q, for heating the water comes from the basement air. That will end up reducing the temperature in the basement. The heat for the HPWH has to come from somewhere, so the basement air will be cooled, and that will draw heat both from the surrounding ground, and the conditioned spaces that are adjacent to the basement. When there is insulation present, the heat will be drawn more from the surrounding ground and the basement will get its coolest. There will be some additional heat that flows through the insulated floor. There is also a small amount of infiltration from outside.

When there is no insulation in the floor, the basement will not get as cool as heat will readily flow through the floor. But this reduced temperature will cause more heat to be needed than in the case of an insulated floor. Again, looking at the system effects is important to compare systems.

A year ago, two senior engineering students investigated the performance of HPWHs in unconditioned basements. They used a basic energy balance on a basement considering heat transfer from below-grade walls and floor, above grade walls and windows, the basement ceiling, and infiltration from outside. Here’s what they found the effect to be on basement temperatures. These results are not intended to represent all possible situations, and the real basement will have thermal mass effects both in the masonry walls and floor, as well as the earth it is in contact with. Yet these steady-state results do provide some indication of the effect on the overall efficiency.

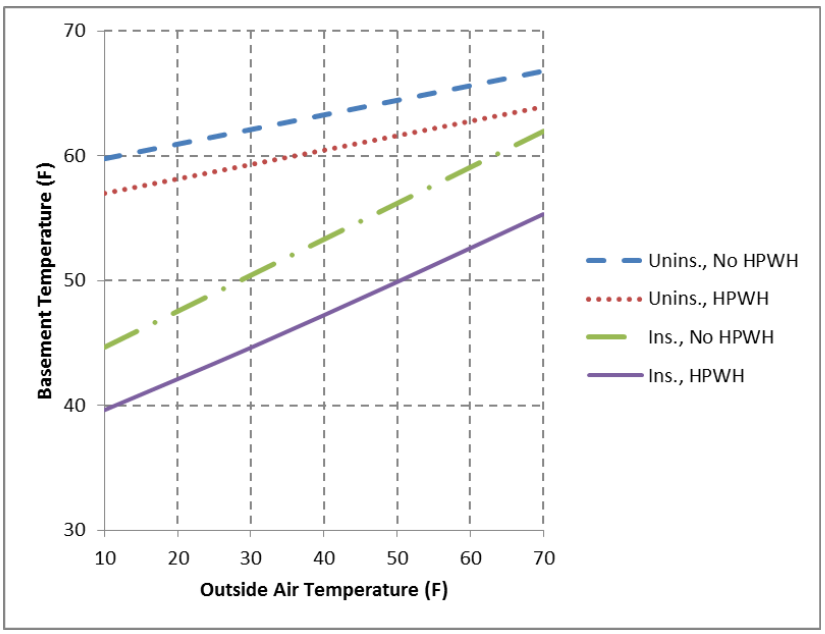

Figure 8 Unconditioned basement temperatures as affected by a HPWH.

Looking at the top two curves in Figure 8 for an uninsulated ceiling, you can see that the HPWH depresses the basement temperature by about 3 ^{o}F. That will result in an increased heat loss through the floor above on the order of 20% in winter, reducing the overall COP of the HPWH system.

Also for all cases, the steady-state basement temperature drops as the outside air temperature drops. This will reduce the HPWH efficiency in colder weather.

For the insulated ceiling cases, the basement is considerably colder. And the HPWH depresses the temperature 5-7 ^{o}F, about twice as much as for the uninsulated ceiling.

These temperatures were used with two types of space heating systems for the conditioned floor above, baseboard electric heat, and a high efficiency heat pump with a COP 0f 4.0 at 60 ^{o}F outside, and 2.0 at 20 ^{o}F. The COP characteristic for the

HPWH was obtained from one manufacturer's rated performance. It has a COP of 2.8 at 70 °F. The resulting overall system COP is plotted in Figure 9.

As we should expect, the lowest COP occurs when the basement ceiling is uninsulated and there is baseboard heat in the space above. A lot of the heat for the HPWH comes through the ceiling and the floor above. For this case, there is a slight improvement in COP over a conventional water heater (COP = 1), but only by about 25%.

If the basement ceiling is insulated with baseboard heat above, then there is marked improvement in COP, as less heat can come through the ceiling. Over the range of outside temperatures, COP is from 1.5 to 1.8 times conventional.

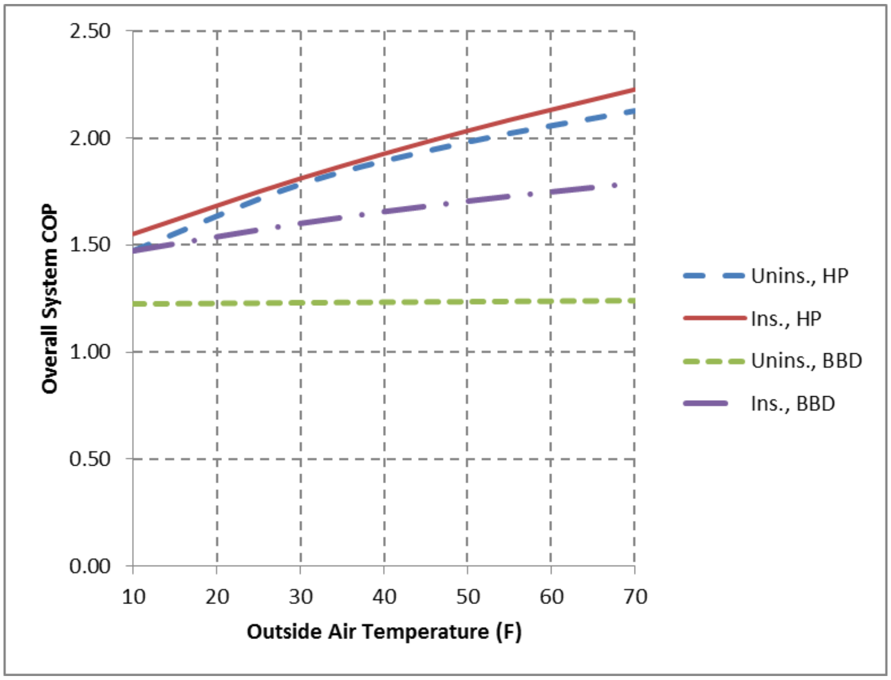

Figure 9 Overall efficiency of a HPWH located in an unconditioned basement.

When there is a heat pump in the conditioned space above, the highest HPWH efficiencies are obtained. Interestingly, there is little effect of the insulation in the floor. Here, the COP ranges from about 1.5 to 2.2 times conventional. Recall that the HPWH alone has a COP of 2.9 at room temperature. Also recall that for a high efficiency heat pump and the HPWH in conditioned space, the overall system COP was 2.0.

What about the cooling season? If the HPWH is in the conditioned space then it acts like a window air conditioner that dumps its heat into the water rather than the outside air. So if you need air conditioning, the HPWH provides a certain amount, and as a bonus heats your water too. If located in an unconditioned basement, it also helps to dehumidify the space.

By considering the HPWH as a system, we've learned this (for the heating season):

1. A HPWH is always equal to, or more, efficient than a conventional water heater with electric resistance elements.
2. How much more efficient depends. By itself, a HPWH has a COP of around 3. The specific model in this report had a COP of 2.9 at a surroundings temperature of 70 ^{o}F. It will not operate that efficiently though, because it draws heat from its surroundings. In the heating season, all or part of that heat comes from the house space heating system.

Table 2 Estimated system efficiency of a heat pump water heater in different circumstances.

Location	**Type of Space Heat**	**Basement ceiling**	**System COP**
Conditioned space	Electric resistance		**1.0**
	Heat pump		**1.5**
Unconditioned space	Electric resistance	Uninsulated ceiling	**1.3**
		Insulated ceiling	**1.7**
	Heat pump	Uninsulated ceiling	**1.9**
		Insulated ceiling	**1.9**

It is possible to compare HPWH with a solar water heater if we imagine that for the HPWH, we determine how big a solar electric array would have to be to provide the electricity that the HPWH system uses. Since the solar thermal water heater only provides about 2/3 of the annual needs, we'll have the HPWH system solar electric array sized to provide 2/3 of the annual needs. Then we're comparing apples with apples with solar as the source.

If we assume a typical new house with an efficient heat pump for space heat, then we'll assume the system COP is 2.0 (gives some credit to the cooling/dehumidifying benefit). A solar electric array size of 1,200 W would provide about 2/3 of the annual usage of a HPWH with a system COP of 2.0. At today's average installed cost of $5/W, that is about $6,000, plus about $600 extra for the HPWH, for a total of about $6,600. That's right in the ballpark of solar thermal system cost today. Solar electric costs will continue to come down so this system will look better and better down the road.

SMALLER HOUSES

In general, housing sizes have steadily increased, even though the number of people in each household has decreased; see Figure 10. Why? Is it growth for growth's sake, or do larger houses contribute to more fulfilling lives? This trend will surely reach a high point, and may be there already. Beyond a certain size, there is just too much house to clean, heat, and maintain. No matter what the Joneses are doing.

And even though our bigger houses may be the best insulated and tightly sealed ever, we still use more electricity than ever thanks to the many electrical devices in our homes, and a transition from fuel oil and natural gas to electric heat pumps. As shown in Figure 11, the significant increase in house size over the last 30 years has resulted in houses that use about 20% more energy than those built in the 1980s.

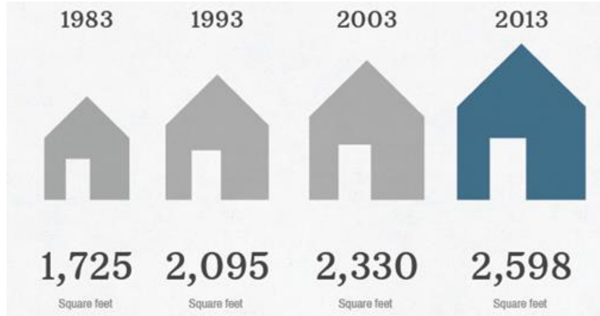

Figure 10 Average home size in the U.S.

One sign that our housing size expectations may be changing is the Tiny House movement. People are choosing to build and live in houses that are on the order of 500 square feet! In Portland, Oregon, one in ten new homes is less than 800 square feet. I love to watch this show on TV and observe both the ingenious ways of combining functions with compact furniture designs, and the change in lifestyle of the people who move into them.

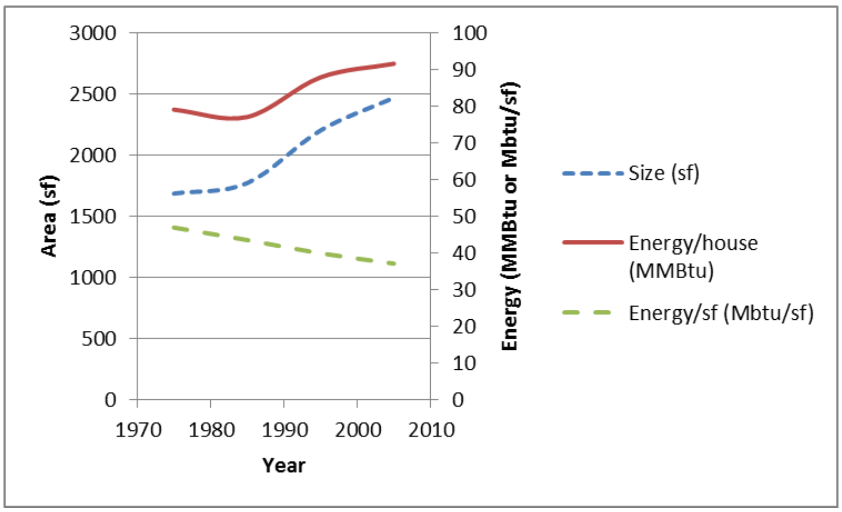

Figure 11 Trends in house size, energy efficiency, and overall energy use.

One of the biggest changes is that they spend more time outside their home. The money that they saved in the cost of their home allows the homeowners to invest in other ways to fulfill their lives: travel, education, gardening, cooking, less paid work, and more time with family. This is the human development side of sustainability.

Consider the bigger message here. People opting for smaller homes are living better, happier lives. They are reducing their negative impact on Earth too. From an economic standpoint they are paring down, what we might call *degrowth*.

In my book-in-progress, I imagine a time 50 years from now in the year 2066. As sustainability gets to be part of our way of life, our lives continue to change for the better. Suburbs like Park Forest here in State College, are rebuilt to better mirror our aspirations and human needs. Houses that are still in good shape are turned from 2,500 square foot, single-family homes into two to three-unit multifamily homes. Many of these units are multi-generational with grandparents, parents and an adult child and their family. Gradually, the average home size decreases to just around 1,000 square feet as shown in Figure 12.

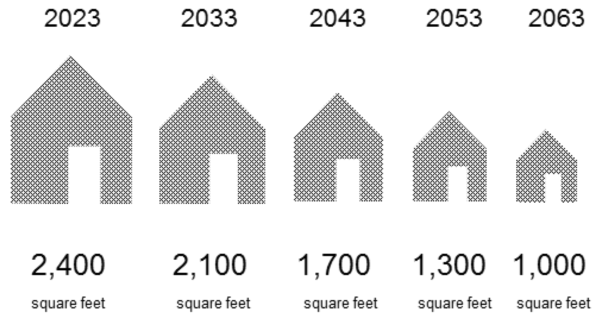

Figure 12 House size projection in a sustainable future.

Figure 13 Small house for added living space (http://www.medcottage.com/products.php)

Some small houses are added to yards where appropriate to add living options like this one already being offered today. This 299 square foot cottage is intended for accommodating an aging parent. It provides some independence while having them close by their families.

To help make smaller spaces more useable, companies will design and make multiple-use furnishings. There's pull-down beds, with desks when the bed is up. Expandable tables with chairs stored within. Architects and interior designers will use clever design to make the smaller spaces feel homey and comfortable.

Another big change imagined in 2050 is the greater prevalence of mixed-use of land. Now we have coffee shops, fix-it cooperatives, offices, micro-bakeries, tiny restaurants, and neighborhood gardens.

SMALLER REFRIGERATORS

Just like house size, I expect the size of our refrigerators to shrink. I did a survey of products in the internet and summarized their characteristics in Figure 14. One observation is that the largest one uses 2.4 times as much electricity as the smallest one shown. It's also interesting that the smallest unit is more expensive to purchase.

Figure 14 Range of refrigerator sizes in 2015.

CONCLUDING REMARKS

The triple play of the last 500 years of history – science, capitalism, and industrialization – has led to unprecedented material wealth, for some. Yet the very growth and consumption that fueled the economic success has also led to unprecedented environmental impact. The dream of sustainability challenges us to create a world where all people can live decent lives, and live within the planetary limits for a healthy Earth.

In the U.S., we need to build homes, neighborhoods, and communities that attend to the aims of sustainability. That will mean smaller, highly-efficient homes, more diverse neighborhoods, food-producing yards, and more time spent outside. Remember, we are talking about reducing our negative impact on Earth by a factor of 5. And that assumes no overall growth in income or consumption.

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