From:	David Eagle <dme4truth@yahoo.com>
Sent:	Friday, October 14, 2022 4:51 PM
To:	DES SBCC
Subject:	Comments on SBCC's Proposal to Require Heat Pumps for heating air and water in new residential construction
Attachments:	Heat Pump Water Heater (HPWH) System-Wide Efficiency Comments to be Submitted.docx; Heat Pump Water Heater Analysis Including Incremental Effects 4 Submital.xlsx

External Email

Dear Sirs and Madams,

I have just conducted an analysis of the impact of Heat-Pump Hot Water Heaters (HPWH's) on the global-warming footprint of houses. Previous analyses have been over simplistic and thus have exaggerated the reduction on this footprint. My analysis takes into account the energy impacts of other systems in the house, in particular, the heating and A/C systems. I developed a spreadsheet that can handle different assumptions of the heating, A/C, and HPWH systems.

In conclusion, I find that HPWH's will increase the housing footprint if the house's heating system is only 100% efficient or less (e.g., gas or conventional electric). For the most realistic case, I do find the HPWH's will decrease the global-warming footprint but only by 10% to 16%, which is much less than the simplified analyses that preceded my analysis has led the SBCC to believe.

Please give my analysis some serious consideration. I am attaching both my written analysis and my spreadsheet. I am sorry, but I only began my analysis this week, and then today saw the deadline of 5pm approaching quickly so my paper or comments are less than perfectly written.

Sincerely,
David Eagle, Ph.D.

SBCC’s Proposed Requirement that

Heat-Pump Water Heaters (HPWH’s) be Required for all New Residential Construction

An Analysis by David Eagle, Ph.D.

Abstract: The proponents of requiring heat-pump water heaters (HPWH’s) have exaggerated the degree to which these HPWH’s will decrease housing carbon footprint. Analyses by those proponents are too simplified. Their analyses only focus on the water heater; they do not take into account the energy effects (and hence carbon effects) external to the water heater but part of the whole house system of heating and cooling. This paper analyzes the system-wide effect of HPWH’s taking into account effect of the HPWH on the heating and cooling of the whole house’s air. During the summer, the HPWH can be looked at as free because the use of the HPWH will reduce the energy needed to air condition a house by the same amount of energy used to run the HPWH (assuming the efficiencies of both the heat pump in the HPWH and the heat pump in the air conditioner are equally efficient. However, in the winter, the opposite is true. Because the HPWH cools the interior air of a house, that house’s heater will have to compensate by doing more heating. Since the heating season is much longer than the cooling season in the State of Washington, in some cases, the HPWH will actually increase the carbon footprint of a house, not decrease it. Even under the best of circumstances, this paper concludes that the best the HPWH can do is decrease the energy uses by slightly less than 50%. The use of the R134a refrigerant contributes 10,000 times as much to global warming as does a carbon molecule. Some researchers say we should subtract 22% from the efficiency of the HPWH to reflect the global warming impact of this refrigerant for HPWH’s. If we do so, then we are only getting a 28% reduction of the global-warming footprint by using HPWH even under the best circumstances.

Note: When I heard about the SBCC’s public hearings on this proposal, I started to work on the ideas behind this paper. While I have completed the analysis, I have not finished a polished paper. Today, I realized that the deadline for comments is today at 5pm. As a result, please do not expect an academic paper that is suitable for publication in a reputable journal. However, for the SBCC to ignore the points of analysis in this paper would be a travesty. Thus, I am doing the best I can to get this paper the best it can in the few hours that remain before the deadline.

Introduction

The argument for requiring HPWH to reduce the carbon footprint is as follows:

The COP efficiency of a HPWH is between 200% and 300%. If the COP efficiency is 200%, then to produce one heat-energy of hot water, the HPWH will only need to use half a unit of energy. On the other hand, the COP efficiency of a very high efficient gas or electric hot water is no more than 100%. Therefore, a HPHW with a COP efficiency of 200% will decrease our energy use in half. Even with a 22% increase in the global-warming impact from the heat-pump's refrigerant, that still is a 28% reduction in the carbon or global-warming footprint of heating water.

Some HPHW have a COP efficiency exceed 300%; which will result in even greater reductions in the global-warming impact from heating water. Thus, to heat water to included one heat-energy unit, the HPWH only needs to use 1/3 of an energy unit. Compared to high efficiency gas or electric hot water heaters of no greater than 100% efficiency, the HPWH will reduce the energy use 66.67%. Less the 22% for the global-warming effect of the refrigerant, the use of HPWH's will decrease the global-warming impact of hot water heaters by over 44%.

The above two analyses are too simplified because they focus only on the HPWH; they do not consider the impacts external to the HPHW on the overall house's heating and cooling needs. This paper's analyses include the external effects of a HPHW.

Generic Example 0:

Appliance A is 200% efficient at producing heat. This means that for each energy used at running appliance A, it will produce heat with an energy content of twice the energy used.

However, assume that as the result of running appliance A, appliance B will have to run more, using the same amount of energy that appliance A used. Hence, from a system-wide view, the energy used by the house as a result of running appliance A is not just the one unit of energy to run A, but it also includes the one unit of energy that appliance B has to use as a result of running appliance A. Thus, the system-wide efficiency of running appliance A is 100%, not 200%. Appliance A does produce two heat-energy units, but to do so the incremental energy used is two. Two divided by two is 100%.

Then appliance A is has a system-wide efficiency of 100%, not 200%. The energy use caused by appliance A running will be the energy use by appliance as well as the additional energy used by appliance B (as a result of appliance A running)

Sometimes the external effects may actually increase the overall system efficiency of an appliance.

Heat Pump Water Heater (HPWH) Example #1 - Summer:

Heat Pump Water Heater (HPWH) has a COP of 2. (This paper will later deal with higher COP ratings.)

Suppose the whole house includes an air conditioner with an efficiency rating of 2, with this efficiency rating meaning that the air conditioner will remove heat having the energy content equal to twice the energy required to run the air conditioner. We assume that the air conditioner expels to the outside air both the heat that it removes from the air and the heat that is generated from running the air conditioner.

During the summer when the house needs the air conditioner running, not only will the heat pump water heater heat the water with twice the energy the heater uses to run, but it will also reduce the air conditioning needs. To be precise, since the heat pump water heater will take twice as much heat energy out of the air as the heat pump will use, that means the air conditioner will no longer need to remove that heat energy from the air. Since the air conditioner has an efficiency of 2, that means its energy requirements will decline by one heat-energy unit, which equals half the heat energy removed by the heat pump water heater. The energy not used by the air conditioner will equal the energy used by the heat-pump water heater.

The system-wide efficiency of the heat-pump water heater is actually infinite, not just 200%. If we define the energy used by the HPWH to be 1, then running the HPWH removes 2 units of heat energy from the air and puts it into the water, plus it results with the air conditioner reducing its energy consumption by 1 energy unit. Thus, the incremental energy used by the HPWH is 0, +1 for the energy used by the HPWH plus -1 for the less energy used by the air conditioner. Two divided by 0 is infinite. In other words, the hot water from the HPWH in the summer is free.

Heat Pump Water Heater Example #1 - Winter:

In winter, the system-wide effects of the HPWH will be the opposite. Since the HPWH is basically an air conditioner in the house, it will cool the air. In the winter, the overall house will need to be heated, not cooled. Hence, f the HPWH cools the air, the furnace will have to run more to offset this cooling of the air. For this example, assume either a very high efficiency gas furnace or an electric furnace or heater. In either case, assume the furnace is 100% efficient, meaning it will create heat equal to the energy (gas or electricity) used.

Now let's determine the system-wide efficiency of the HPWH. For one unit of energy used to run it, the HPWH will remove two units of heat-energy from the air. However, the furnace will then have to run more to heat the air to compensate for those two heat-energy units removed from the air. Since the HPWH removes two units of heat-energy from the indoor air, the furnace will have to put two units of heat-energy back into the indoor air. With an efficiency of 100%, the furnace will have to use two units of energy to produce these two units of heat-energy into the indoor air. Therefore, systemwide, the incremental energy used to produce two heat-energy units of water is the 1 unit for the HPWH plus the 2 units for the furnace, which equals 3 units of energy to produce the two heat-energy units of water. The system-wide efficiency of the HPWH during winter is therefore 66.67%, which is much less than a high-efficiency gas hot water heater or an electric hot water heater that would have between a 90% and 100% efficiency.

Heating, Cooling, and Neutral Seasons in the State of Washington

Based on my own personal experience at heating and cooling in a well insulated house, I defined the heating, cooling, and neutral seasons as the following:

Heating Season: When the average highs during a particular time of year is less than 70° F.

Cooling Season: When the average highs during a particular time of year exceeds 80° F.

Neutral Season (neither heating nor cooling): When the average highs during a particular year is between 70° F and 80° F.

During the neutral season, opening and closing shades, opening and closing windows during particular times of the day, I assume can be used to keep the house's indoor air temperature comfortable.

I used the sources in the footnotes to determine these seasons for two cities in the State of Washington – Spokane[1] on the east side of the state and Seattle[2] on the west side of the state. For Spokane, I determined the heating season is 7.5 months, the neutral season is 1.25 months, and the cooling season is 2.75 months. For Seattle, the heating season is 8.75 months, the neutral season is 2.25 months, and the cooling season is 1 month.

I developed a spreadsheet to take into account the system-wide energy effects of a HPWH under different assumptions of the efficiency of the air conditioning (A/C), the heating system, and the HPWH. For the HPWH, the COP efficiency is well defined and is what I think we should use. For the A/C and heating systems, there are a variety of efficiency ratings that can be confusing. For this paper's Excel spreadsheet, the efficiency ratings for the A/C and heating system are operationally defined to be very similar to the COP efficiency rating. For the A/C, the rating is heat-energy units of air cooled divided by the energy units used to run the A/C. For the heater, the rating is heat-energy units created divided by the energy units used to run the heater. How these ratings for the A/C and heater compare to the efficiency rates actually quoted by the manufactures is an issue I did not have time to resolve, but given my definitions, I believe that most informed readers will be able to work with my definitions of their efficiencies.

[1] https://weatherspark.com/y/2022/Average-Weather-in-Spokane-Washington-United-States-Year-Round

[2] https://weatherspark.com/s/913/1/Average-Summer-Weather-in-Seattle-Washington-United-States#Figures-Temperature

I will discuss several examples. The first example is good to show that whether or not a HPWH can reduce a hot water heater really depends a great deal on what type of heat is being used. If the heater is a high efficiency gas or electric heater with an efficiency of 100%, the HPWH will actually increase the carbon footprint compared to a high efficiency gas or electric water heater having a 100% efficiency.

Case 1: A/C and HPWH efficiencies of 200%. Heater efficiency of 100%.

Heating Season: To produce 1 heat-energy unit of hot water, the HPWH itself will use ½ units of energy. However, because the HPWH cools the indoor air by 1 heat-energy unit to produce that heat-energy unit of hot water, the heater will have to heat that air back up to room temperature. Since the heater is 100%, it will need to use 1 energy unit to create 1 heat-energy unit of warmer air. That the energy used will be 0.5 energy units for the HPWH itself plus 1 energy unit for the heater or 1.5 energy units.

Neutral Season: To produce 1 heat-energy unit of hot water, the HPWH itself will use ½ units of energy. Because neither the heater nor A/C will be used in this season regardless whether or not the HPWH is running, there are no external energy effects of running the HPWH.

Cooling Season: To produce 1 heat-energy unit of hot water, the HPWH itself will use ½ units of energy. Doing so cools the air, so the A/C will not need to cool this 1 heat-energy unit; thus the energy used by the A/C will decrease by 0.5 units. Thus, the system-wide incremental energy used by the HPWH is 0, which equals the 0.5 energy units used by HPWH less the 0.5 energy units saved because the A/C decreased its energy use by 0.5 units.

Spokane: To produce 1 energy-unit of hot water each month or 12 energy units for the year, the annual energy used by the HPWH including external energy costs was 13.375 units. This equaled 8.5*1.5+1.25*0.5+2.25*0. Dividing the 13.375 units of energy used by the 12 heat-energy units of hot water produced equals 1.1146. This means that the HPWH required 11.46% more energy than the heat-energy units of hot water it produced. A 100% efficient gas or electric hot water heater would have used the energy as the heat-energy units of hot water they would have produced. Hence, the HPWH in this case actually increases energy use. If we add the 22% factor to reflect the global warming of the refrigerant, this means that the HPWH would have increased its global-warming footprint by 33.46%.

Seattle: The situation is even worse in Seattle than in Spokane. To produce 1 heat-energy units of hot water each month or 12 heat-energy units for the year, the annual energy used by the HPWH including external energy costs was 14.25. This equaled 8.75*1.5+2.25*0.5+1*0. Dividing the 14.25 units of energy used by the 12 heat-energy units of hot water produced equals 1.1875. This means that the HPWH required 18.75% more energy than the heat-energy units of hot water it produced, 18.75% more energy than a 100% efficient gas or electric hot water heater would have required. If we add the 22% factor to reflect the global warming of the refrigerant, this means that the HPWH would have increased its global-warming footprint by 40.75%.

Case 2: A/C and HPWH efficiencies of 200%. Heater efficiency of 100%.

Spokane: To produce 1 energy-unit of hot water each month or 12 energy units for the year, the annual energy used by the HPWH including external energy costs was 11.75 units. This equaled 8.5*1.33+1.25*0.33+2.25*0. Dividing the 11.75 units of energy used by the 12 heat-energy units of hot water produced equals 0.98. This means that the HPWH required 2% less energy than the heat-energy units of hot water it produced. A 100% efficient gas or electric hot water heater would have used the same energy as the heat-energy units of hot water they would have produced. Hence, the HPWH in this case decreased energy use by 2% relative to a 100% efficient gas or electric hot water heater. If we add the 22% factor to reflect the global warming of the refrigerant, this means that the HPWH would have increased its global-warming footprint by 19.92%.

Seattle: To produce 1 heat-energy units of hot water each month or 12 heat-energy units for the year, the annual energy used by the HPWH including external energy costs was 12.42. This equaled 8.75*1.33+2.25*0.33+1*0. Dividing the 12.42 units of energy used by the 12 heat-energy units of hot water produced equals 1.035. This means that the HPWH required 3.5% more energy than the heat-energy units of hot water it produced, 3.5% more energy than a 100% efficient gas or electric hot water heater would have required. If we add the 22% factor to reflect the global warming of the refrigerant, this means that the HPWH would have increased its global-warming footprint by 25.47%.

In summary, based on the analyses of Cases 1 and 2 for both Spokane and Seattle, the use of a HPHW when the furnace system is less than or equal to 100% efficient (e.g., a gas or electric heating system), will actually increase the carbon footprint of generating hot water, not decrease it.

Cases with Mini-splits for heating:

The SBCC's proposal if that heat-pumps be used for both heating of air and hot water. Thus, while cases 1 and 2 could be used for the support of SBCC banning HPWH's to be installed when the heating systems are gas or conventional electric, we need to consider examples more relevant to the SBCC's current proposal. Below are such cases:

Case 3: The efficiencies of the HPWH, the A/C, and the heater are all 200%.

In Spokane, the energy costs will be reduced by 23.96%. If we combined this the 22% factor for the global-warming caused by the refrigerant, we conclude that the use of a HPWH when the heating system is also a heat pump such as a mini-split, we conclude that the HPWH will reduce its global-warming footprint by 1.96%.

In Seattle, the energy costs will be reduced by 17.71%. When we combine this with the 22% refrigerant factor, we conclude that the use of a HPWH will increase the hot-water global-warming footprint by 4.29%.

In conclusions, if the efficiencies are 200% for all three appliances, the use of a HPWH will very slightly decrease or even increase the hot-water global-warming footprint.

Many models of heat pumps have theoretical efficiencies in the 300%. However, an article[3] in 2015 studied several homes built with mini-spits with theoretical efficiencies in the 300% range, but whose actual efficiency averaged 200% or less. One factor that does affect the efficiency is temperature. The next two cases I looked at had a COP efficiency of 300% for the HPHW and A/C, but 200% for the heater.

Case 4: The efficiencies of the A/C and HPHW is 3, but the efficiency of the heater is 200% to be consistent with the referenced article.

In Spokane, the HPWH reduced energy use by 37.5%. Offsetting with the 22% refrigerant factor, gives a reduction of 15.5% in the global warming footprint of the HPWH.

In Seattle, the HPWH reduced energy use by 32.99%. Offsetting with the 22% refrigerant factor gives a reduction of 10.99% in the global-warming footprint of the HPWH.

While many could argue that Case 4 is the most realistic of the cases as applied to the SBCC's proposal, a global warming footprint reduction of between 10% and 16% is much lower than what the SBCC though those reductions would be when they came up with this proposal.

While I think case 4 is the most realistic of all the cases this paper considers, it is only fair if this analysis be applied to the case where all three efficiencies are 300%. Case 5 below does just that.

Case 5: The efficiencies of the A/C, the heater, and the HPHW are 300%.

In Spokane, the HPHW reduced system-wide energy use by 49.31%. Offsetting with the 22% refrigerant factor gives a global-warming footprint reduction of 27.31%.

[3] https://www.nrel.gov/docs/fy15osti/63913.pdf

In Seattle, the PHWH reduced system-wide energy use by 45.14%. Offsetting with the 22% refrigerant factor gives a reduction of 23.14% in the global-warming footprint of hot water.

The deadline for the SBCC's comments is approaching so I will just summarize my findings.

Conclusion: The analyses used to generate the SBCC's proposal are overly simplistic ignoring energy effects on other appliances in the house. As a result, those simplified analyses exaggerated the potential of HPWH's to reduce the global-warming footprint of houses. This paper presents an analysis that takes into account the external effects of the HPWH, in particular on the heating system and on the A/C system. When HPWH's are used in houses with 100% efficient furnanes and heaters, the HPWH will actually significantly increase the houses global-warming footprint. When the HPWH is used in conjunction with a mini-split or heat-pump system, the HPWH can reduce the global-warming footprint by between 10% and 16%, which is substantially lower than that claimed by the overly simplistic analyses that preceded this analysis.

heat pump references: heat loss formula

average high and low temps.

average heat pump efficiency

New Article!

Note: My Analysis starts or

https://www.greenbuildingadvisor.com/article/ductless-minisplits-may-not-be-as-efficient-as-

"A recent monitoring study of ductless minisplits installed in seven New England homes found

The research was conducted by James Williamson and Robb Aldrich from the Consortium of A

https://www.nrel.gov/docs/fy15osti/63913.pdf

COP between 1.1 and 2.4

average COP

Table 1. Monthly COP Summary

Month	Site 1	Site 2	Site 4	Site 5	Site 8
Nov-13	1.3				
Dec-13	1.6		2.3		
Jan-14	1.4	2	2.4		
Feb-14	1.6	1.9	2.2	1.8	
Mar-14	1.8	2	2.3	1.7	2.2
Apr-14	2.2	1.9	3.1		2.5
Overall	1.6	2	2.3	1.7	2.3

Now Research on Heat Pump Water Heater Efficiencies

My Analysis:

A/C UEF	2	A/C system efficiency
UEF	1	heating system
COP	2	heat pump hot water heater

	(highs<70) heating season	70<highs<80 neutral season	highs>80 A/C season		
Spokane	8.5	1.25	2.25	12	total months
Benefits	1	1	1	1	per month
costs:					
Water Heater itself	0.5	0.5	0.5		
Incremental Heating	1				
Incremental A/C			-0.5	13.375	
net costs	1.5	0.5	0	1.114583	per month
Seattle	8.75	2.25	1	12	total months
Benefits	1	1	1	1	per month
costs:					
W/H itself	0.5	0.5	0.5		
Incremental Heating	1				
Incremental A/C			-0.5	14.25	
net costs	1.5	0.5	0	1.1875	per month

https://www.e-education.psu.edu/egee102/node/2057
https://www.currentresults.com/Weather/Washington/Places/spokane-temperatures-by-month-average.php
https://weatherspark.com/y/2022/Average-Weather-in-Spokane-Washington-United-States-Year-Round
https://weatherspark.com/s/913/1/Average-Summer-Weather-in-Seattle-Washington-United-States#Figures-T
https://learnmetrics.com/heat-pump-efficiency-vs-temperature-graph/

ı line 61

-we-thought

that these heating appliances had lower airflow rates and lower coefficients of performance (COPs) than expec

dvanced Residential Buildings (CARB) in Norwalk, Connecticut. The study was funded by the U.S. Department of

Site 9	Site 10	
1	1.8	
1.3	2.4	
1.1	2.1	1.871429

A/C UEF	2	A/C system
UEF	1	heating syst
COP	2	heat pump

Spokane An increase of 11.46% in electricit
22% increase in carbon footprint l
net change in carbon footprint =

A/C UEF	2	A/C system
UEF	2	heating syst
COP	2	heat pump

11.46% An increase of 11.46% in electricity costs

22% refrigerant factor
33.46%

18.75% An increase of 18.75% in electricity costs

22%
40.75%

Spokane A reduction of 23.96% in electrici
22% increase in carbon footprint l
net change in carbon footprint =

A/C UEF	2	A/C system
UEF	1	heating syst
COP	2	heat pump

Spokane An increase of 11.46% in electricit
22% increase in carbon footprint l
net change in carbon footprint =

A/C UEF	2	A/C system
UEF	0.65	heating syst
COP	2	heat pump

Spokane An increase of 49.6% in electricity
22% increase in carbon footprint l
net change in carbon footprint =

A/C UEF	3	A/C system
UEF	1	heating syst
COP	2	heat pump

Spokane An increase of 14.58% in electricit
22% increase in carbon footprint l
net change in carbon footprint =

A/C UEF	3	A/C system
UEF	3	heating syst
COP	2	heat pump

Spokane A reduction of 32.64% in electrici
22% increase in carbon footprint l
net change in carbon footprint =

A/C UEF	2	A/C system
UEF	2	heating syst
COP	3	heat pump

Spokane A reduction of 40.63% in electrici
22% increase in carbon footprint l
net change in carbon footprint =

A/C UEF	3	A/C system
UEF	3	heating syst

		COP	3	heat pump
	Spokane	A reduction of 49.31% in electrici		
		22% increase in carbon footprint l		
		net change in carbon footprint =		
Example 1 Corrected		A/C UEF	3	A/C system
		UEF	1	heating syst
		COP	3.45	heat pump
	Spokane	A reduction of 6.43% in electricity		
		22% increase in carbon footprint l		
		net change in carbon footprint =		
		A/C UEF	3	A/C system
		UEF	2	heating syst
		COP	3.45	heat pump
Most optimistic	Spokane	A reduction of 41.85% in electrici		
		22% increase in carbon footprint l		
		net change in carbon footprint =		

	standard	heat pump
Elec. Costs/Month	$30	$17.45
Elec. Costs/Year	$359	$208.76
savings per year		$150.24
lifetime savings		$1,502.42
payback		4.33

		A/C UEF	3	A/C system
		UEF	2	heating syst
		COP	3.45	heat pump
More realistic:	Spokane	A reduction of 37.5% in electricity		
		22% increase in carbon footprint l		
		net change in carbon footprint =		

	standard	heat pump
Elec. Costs/Month	$30	$18.75
Elec. Costs/Year	$359	$224.38
savings per year		$134.63
lifetime savings		$1,346.25
payback		4.83

A/C UEF	3	A/C system
UEF	2	heating syst
COP	3.45	heat pump

Temperature

cted. The average COP of these air-source heat pumps ranged from 1.1 at the house with the least-eff

f Energy's Building America program. The researchers' report, "Field Performance of Inverter-Driven H

efficiency		A/C UEF	2	A/C system efficiency
tem		UEF	1	heating system
hot water heater		COP	2	heat pump hot water heater
ty costs	Seattle	An increase of 18.75% in electricity costs		
b/c refrigerant		22% increase in carbon footprint b/c refrigerant		
33.46% decrease		net change in carbon footprint =	40.75%	

efficiency	A/C UEF	2	A/C system efficiency
tem	UEF	2	heating system
hot water heater	COP	2	heat pump hot water heater

ty costs			Seattle	A reduction of 17.71% in electricity costs		
b/c refrigerant				22% increase in carbon footprint b/c refrigera increase		
	-1.96%	decrease		net change in carbon footprint =	4.29%	
efficiency				A/C UEF	2	A/C system efficiency
tem				UEF	1	heating system
hot water heater				COP	2	heat pump hot water heater
:y costs			Seattle	An increase of 18.75% in electricity costs		
b/c refrigerant				22% increase in carbon footprint b/c refrigera increase		
	33.46%	increase		net change in carbon footprint =	40.75%	
efficiency				A/C UEF	2	A/C system efficiency
tem				UEF	0.65	heating system
hot water heater				COP	2	heat pump hot water heater
' costs			Seattle	An increase of 58.01% in electricity costs		
b/c refrigerant				22% increase in carbon footprint b/c refrigera increase		
	71.60%	increase		net change in carbon footprint =	80.01%	
efficiency				A/C UEF	3	A/C system efficiency
tem				UEF	2	heating system
hot water heater				COP	2	heat pump hot water heater
:y costs			Seattle	A reduction of 16.32% in electricity costs		
b/c refrigerant				22% increase in carbon footprint b/c refrigera increase		
	36.58%	increase		net change in carbon footprint =	5.68%	
efficiency				A/C UEF	3	A/C system efficiency
tem				UEF	3	heating system
hot water heater				COP	2	heat pump hot water heater
ty costs			Seattle	A reduction of 28.47% in electricity costs		
b/c refrigerant				22% increase in carbon footprint b/c refrigera decrease		
	-10.64%	decrease		net change in carbon footprint =	-6.47%	
efficiency				A/C UEF	2	A/C system efficiency
tem				UEF	2	heating system
hot water heater				COP	3	heat pump hot water heater
ty costs			Seattle	A reduction of 45.14% in electricity costs		
b/c refrigerant				22% increase in carbon footprint b/c refrigera decrease		
	-18.63%	decrease		net change in carbon footprint =	-12.38%	
efficiency				A/C UEF	3	A/C system efficiency
tem				UEF	3	heating system

hot water heater COP 3 heat pump hot water heater

ty costs Seattle A reduction of 45.14% in electricity costs
b/c refrigerant 22% increase in carbon footprint b/c refrigera decrease
-27.31% decrease net change in carbon footprint = -23.14%

efficiency A/C UEF 3 A/C system efficiency
tem UEF 1 heating system
hot water heater COP 3.45 heat pump hot water heater

y costs Seattle A reduction of .88% in electricity costs
b/c refrigerant 22% increase in carbon footprint b/c refrigera increase
15.57% increase net change in carbon footprint = 21.12%

efficiency A/C UEF 3 A/C system efficiency
tem UEF 2 heating system
hot water heater COP 3.45 heat pump hot water heater

ty costs Seattle A reduction of 37.33% in electricity costs
b/c refrigerant 22% increase in carbon footprint b/c refrigera decrease
-19.85% decrease net change in carbon footprint = -15.33%

	Elec. Costs/Month	$30	$18.80
	Elec. Costs/Year	$359	$224.99
	savings per year		$134.01
	lifetime savings		$1,340.15
years	payback		4.85 years

efficiency A/C UEF 3 A/C system efficiency
tem UEF 2 heating system
hot water heater COP 3.45 heat pump hot water heater

y costs Seattle A reduction of 32.99% in electricity costs
b/c refrigerant 22% increase in carbon footprint b/c refrigera decrease
-15.50% decrease net change in carbon footprint = -10.99%

	Elec. Costs/Month	$30	$20.10
	Elec. Costs/Year	$359	$240.57
	savings per year		$118.43
	lifetime savings		$1,184.34
years	payback		5.49 years

efficiency A/C UEF 3 A/C system efficiency
tem UEF 2 heating system
hot water heater COP 3.45 heat pump hot water heater

2.5	2.6	0	2.5
2.5	2.6	1	2.52
2.5	2.6	2	2.54
2.5	2.6	4	2.58
2.5	2.6		
2.6	2.9	3	2.56
2.6	2.9	0	2.6
2.6	2.9	1	2.66
2.6	2.9	2	2.72
2.6	2.9	3	2.78
2.9	3.1	4	2.84
2.9	3.1	0	2.9
2.9	3.1	1	2.94
2.9	3.1	2	2.98
2.9	3.1	3	3.02
3.1	3.3	4	3.06
3.1	3.3	0	3.1
3.1	3.3	1	3.14
3.1	3.3	2	3.18
3.1	3.3	3	3.22
3.3	3.7	4	3.26
3.3	3.7	0	3.3
3.3	3.7	1	3.38
3.3	3.7	2	3.46
3.3	3.7	3	3.54
3.7	3.9	4	3.62
3.7	3.9	0	3.7
3.7	3.9	1	3.74
3.7	3.9	2	3.78
3.7	3.9	3	3.82
3.9	4.1	4	3.86
3.9	4.1	0	3.9
3.9	4.1	1	3.94
3.9	4.1	2	3.98
3.9	4.1	3	4.02
4.1	4.3	4	4.06
4.1	4.3	0	4.1
4.1	4.3	1	4.14
4.1	4.3	2	4.18
4.1	4.3	3	4.22
2.2	2.3	4	4.26
		0	2.2