Energy and Emissions Savings Potential of Renewable Thermal Technologies in Houston, Texas

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Abstract

Renewable Thermal Technologies (RTT), especially heat pumps paired with solar, have the potential to dramatically decrease energy consumption and by extension energy emissions. Using information from the Residential Energy Consumption Survey (RECs), Houston's Climate Action Plan, and our own report on Pathways for Reducing Energy Burdens in Harris County, the Texas Energy Poverty Research Institute (TEPRI) analyzed the residential energy consumption and carbon emission by end use and fuel type. From there, we investigated how much air-source heat pumps and ground-source heat pumps could lower both electricity and natural gas consumption and carbon emissions. Then, we investigated how much solar will be needed to completely decarbonize electricity under the current paradigm versus how much would be required under the proposed heat pump paradigm. We found that heat pumps can reduce total residential energy usage by up to 54%, reduce residential emissions by up to 53%, and virtually eliminate residential natural gas consumption and emissions. Furthermore, even with the increased demand for electricity from the heat pumps, electricity consumption also decreases by up to 38%, which reduces the amount of solar needed to decarbonize electricity by 38% as well. These results highlight the importance of increasing the adoption of these technologies by increasing awareness and expanding energy efficiency programs. We believe that existing efficiency programs can be an effective vehicle for implementing these technologies. Furthermore, increasing community and contractor engagement to tell consumers about the products and also teach contractors how to install them are needed. While the adoption of RTTs faces many obstacles, our report shows that the benefits are worth it.

Keywords:
Energy Poverty; Renewable Thermal Technologies; Heat Pumps; Energy Efficiency; Solar PV

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1. Introduction

The objective of this study is to evaluate the potential for renewable thermal technologies (RTTs) to reduce energy consumption and carbon emissions in Houston, Texas, and to determine how to ensure the financial and environmental benefits of deployment may be realized by low- to middle-income (LMI) communities. As energy technologies continue to evolve, there is a need for us to evaluate applications of those technologies in new and creative ways. Part of TEPRI's role is to evaluate the potential technologies that can reduce energy burdens and how to intentionally direct the benefits of the energy transition, like fewer emissions, toward LMI communities. In our Pathways paper [16], heat pumps were identified as having the potential for significant reductions in energy burden. So in this paper, we examine the category heat pumps fall under, RTTs.

RTTs, including heat pumps, thermal storage, and solar thermal heating, offer potential financial and environmental benefits to our society but face unique challenges to deployment in low-income households [29]. Households who make 0-80% of the area median income (AMI) represent 41% of the Texas population. This segment faces clean energy participation barriers including limited access to capital, low credit scores, poor quality of housing stock, and lower rates of home ownership. In addition, low-income energy consumers spend a disproportionate amount of household income (three times greater) on energy, which is referred to as the energy burden. On average, Texas low-income households spend 10% of their annual income on home energy costs, compared with 2% for their non-low-income counterparts [14]. Reductions in energy burdens through RTTs can provide significant financial, environmental, and quality of life benefits to low-income families.

In this study, using Houston as a case study, we investigate how RTTs can reduce energy usage and carbon emissions, because of their efficiencies, by calculating the potential energy and emission savings if every household in Houston transitioned from the typical heating and cooling technologies to more efficient air and ground sources heat pumps. We rely upon public data sources on population, technical specifications of heating and cooling equipment, and empirically backed assumptions. This study adds to the literature by examining the potential energy savings and emissions benefits of RTTs in a specific locality, which has its own unique energy usage patterns and a recently ratified climate action plan, investigates how these technologies fit in that localities existing energy efficiency programming framework, and summarizes how these technologies and programs would reduce overall energy poverty. We find that this hypothetical transition would result in up to 58% and 44% residential energy and emission savings, respectively. We believe that these incredible savings further highlight the need for the existing programs to be fine tuned so that these technologies adoption rates are increased and so LMI households can benefit from them as well.

2. Background

2.1. Energy Burden and the Energy Affordability Gap

Energy affects every part of a household, and in general, the vast majority of energy is used to heat and cool homes. Energy poverty is a condition faced by many Americans in which the cost to purchase enough energy to maintain a healthy lifestyle creates a significant economic burden [15]. Energy burden is defined as the portion of the total household income that is used for residential energy costs, expressed as a percentage. A household is said to have a high energy burden if the annual costs of energy exceeds 6% of the household's income [17]. Energy burden is often used to indicate whether a household is under financial stress in a specific geographically confined region. The Energy Affordability Gap (EAG) further crystallizes energy poverty and is defined as the annual cost of home energy for a household above 6% of that household's annual income [14]. Our goal with this paper is to find ways to reduce the energy burden of low- to moderate-income (LMI) households so that the EAG is zero.

2.2. Energy Use by Fuel Used and End Use

Three main energy end uses drive most of the residential energy demand in Texas: space heating, space cooling, and water heating [38]. Space heating represents the largest residential energy usage at 22 %, water heating the next highest at 19%, and space cooling at 18%. In the United States, most heaters (space and water) use natural gas and the remainder use a bit of petroleum and wood but mostly electricity. In Texas, which has less heating demand than most of the United States, a little less than half of houses use electricity for heat and a similar fraction use natural gas. Therefore, electrifying space and water heating would help decarbonize residential energy use even before realizing any efficiency gains electrification could bring.

The 2015 Residential Energy Consumption Survey (RECS, [7]) provides the number of houses that use a certain fuel and have certain end uses. The 2009 RECS data [39] provided this information for Texas, but the 2015 data is currently not represented by state, so we will use the 2015 data for West South Central region as a proxy. According to the 2015 RECS data, all homes in the region use electricity (13.8 million housing units) and 46% (6.4 million housing units) use natural gas. 63% and 58% (8.8 and 8.0 million housing units) use electricity for space and water heating respectively and 39% (5.4 million housing units) use natural gas for space and water heating. Note a small portion of houses also use propane and fuel oil, but the percentage is small enough that we ignore those fuels in this study. 95% (13.1 million housing units) of the households in the region use electricity for air conditioning.

Households in the West South Central region use 981 trillion BTU of energy, 673 (69%) and 275 (28%) trillion BTU of electricity and natural gas respectively. 29% (284 trillion BTU) of the energy is used for space heating, 18% (173 trillion BTU) for water heating, 18% (179 trillion BTU) for air conditioning, 3.8% (38 trillion BTU) for refrigerators, and 31% (307 trillion BTU) for everything else.

2.3. Carbon Emissions

According to the Climate Action Plan created by [4], in the baseline year 2014 Houston emitted 34,316,303 metric tonnes of carbon dioxide equivalent (CO2e) and 14.9 metric tonnes of CO2e per capita per year. 16.874 MMtCO2e are produced to provide energy to buildings. 83% of those emissions (14 MMtCO2e) come from the over 26 million megawatt hours of electricity that were consumed. The other 17% (2.87 MMtCO2e) comes from natural gas heating for buildings and industry. Commercial, institutional, and municipal buildings account for 60% of building emissions (10.13 MMtCO2e), followed by 33% (5.57 MMtCO2e) from residential buildings and 7% (1.18 MMtCO2e) from industrial operations.

2.4. Renewable Thermal Technologies

This subsection provides background information on RTTs, especially heat pumps, and their functions, applications, and benefits. This brief review will not evaluate every RTT and the many roles they may play. Instead, we focus on the RTTs which are strong candidates for widespread adoption in Houston.

2.4.1. Heat Pumps

Heat Pumps are a heating and cooling technology that use electricity to move heat from outside to an indoor space and vice versa using a refrigeration cycle. Heat pumps take low grade heat from the air, the ground, a body of water, or even waste heat and convert it to usable heat for building occupants [36]. The heat sink or source, depending on mode, influences the efficiency of the heat pump. In general, air source heat pumps (ASHP) are the least efficient because the temperature of the air fluctuates while ground source heat pumps (GSHP) are more efficient because those temperatures are relatively constant. Regardless, all heat pumps work in the same manner, in cooling mode heat pumps extract heat from indoors and reject it outside in a similar way as traditional AC units. In heating mode, heat pumps extract heat from outside and pump it inside. Both modes use electricity to power the fans, pumps, and compressors needed by the refrigeration cycle to transfer heat. Moreover, heat pumps can work in varied climates, are a mature technology, and depending on local heating fuel and electricity costs, are economically viable as well [27].

The ratio that measures the energy of the heat transferred from outside to inside (measured in BTUs) by the amount of electricity needed to do so (also measured in BTUs) is known as the coefficient of performance (COP). Because heat pumps move rather than generate heat, their COPs are generally well above 3. In contrast, electrical heaters have a maximum COP of 1 and fossil fuel heaters have a COP around 0.95. The ratio that measures the total heat removed from the conditioned space during the annual cooling seasons (measured in BTUs) divided by the total electricity consumed in the same season (measured in Watt-hours) is called the Seasonal Energy Efficiency Ratio or SEER rating. An Energy Star ASHP must have a SEER value above 15 compared to an Energy Star central AC unit which only has to be above 12.5 [9]. Energy Star GSHPs have even higher standard, they must be 45% more energy efficient than standard options which can correspond to a mandated EERs rating as high as 21.1 (which corresponds to an SEER rating of about 24.1) [8]. Note that the GSHPs have an EER rating rather than a SEER rating because the ground remains a stable temperature throughout the year and there is no need for seasonal adjustments.

Because of heat pumps efficiency and savings over the entire life-cycle, they have been studied and used extensively. One study states that heat pumps could help electrify the US building sector with minimum peak load increases [43]. A UK study notes that heat pumps' economical attractiveness is reduced by policies, but over the lifetime of the appliance, they still are cheaper overall [1]. Furthermore, heat pumps could be used to help temper the decreasing value of wind as wind integration increases, and together they could be a strong source for decarbonization [31].

Other studies look at how pilot programs and federal and state subsidies can be used to drive adoption. A study of a pilot program in the Northwest found that ductless heat pumps have the potential to save hundreds of megawatts and reduce the carbon intensity of buildings by 30% [33]. And another study found that federal and state subsidies make ground-sourced heat pumps economically viable [3].

In Leander, Texas, a suburb of Austin, hundreds of ground loop heat pumps are used in each school in the Leander Independent School District. Over the years, they have gained institutional knowledge that has lowered the cost of operation and installation so that the costs are comparable to non-GSHP systems and have solidified the already significant savings in both energy and maintenance costs [19].

Heat pumps can also be used to heat water. A desuperheater, a small heater exchange, can be attached to a space conditioning heat pump and use the super-heated gases from the compressor to heat water for free [37]. There are also heat pumps, specifically for water heating, that take the heat from the surrounding area and use it to heat water. These heat pump water heaters (HPWH) can provide up to 63% energy savings compared to a standard electric resistance water heater, although some efficiency may be lost in the winter due to their tendency to cool spaces they are in [44]. Regardless, since they are so much more efficient than other water heaters, [13] states that if all electric water heaters in the US were Energy Star certified HPWHs, the energy savings would be almost $12 billion per year and 140 billion pounds of GHG emissions would be prevented.

2.4.2. Other RTTs

Beyond heat pumps, there are other renewable thermal technologies that can also reduce heating and cooling loads. Active Solar thermal, combined heat and power (CHP) systems, and thermal storage are other renewable thermal technologies that could reduce emissions. However, they all have limitations based on cost (e.g. CHP and thermal storage) or can only be used to heat (solar thermal) [18]. Other technologies, like biomass heat, E-gases, and geothermal, can also be used and studies have shown they can fill in the gaps where heat pumps could not be used, which is especially important for cleaning up heating and cooling in Europe by 2040 [28].

2.5. Opportunities to Use Energy Technologies to Reduce Energy Burden

The Texas Energy Poverty Research Institute (TEPRI) led the Pathways for DERs to Reduce Energy Burdens initiative which developed a roadmap for cost-efficient, inclusive, and effective pathways for rooftop solar and energy efficiency deployment in residential buildings located in low-income census tracks — with the goal of reducing the energy burden of residents [16]. This paper expands on that work specifically focused on RTTs, which can fall under the umbrella of energy efficiency with appliances like heat pumps.

In the Pathways paper we used the Low-Income Energy Affordability Data (LEAD) tool, the RECS, and stakeholder data to investigate how DERs could reduce energy burden, and in this paper, we use and expand on these methods. Our utility partner in Houston, CenterPoint Energy Houston Electric, runs a number of programs aimed at reducing the cost and/or increasing adoption of DERs including RTTs. We believe that these programs can help increase the adoption of RTTs and the benefits that go along with them.

Geothermal Heat Pumps qualify for the investment tax credit which can reduce the cost for installation by as much as 30%. The geothermal heat pump must meet Energy Star program requirements where all Energy Star geothermal heat pumps are over 45% more energy efficient than standard options. [6]

2.5.1. Energy Efficiency Programs

There are a variety of Energy Efficiency programs that can benefit households in Harris County. The Weatherization Assistance Program (WAP) is a federal program that improves energy efficiency in low-income homes and reduces annual energy costs by an average of $283 per household a year (DOE 2019). In Texas, the Texas Department of Housing and Community Affairs (TDHCA) administers the Department of Energy (DOE) WAP and the Low-Income Home Energy Assistance Program (LIHEAP) WAP [34]. In 2018, 2,916 low-income households across all of Texas benefited from these programs with almost $24 million total expended with approximately $8,000 per house. Through Baker Ripley, Houston's WAP administrator, 277 Harris County households benefited from the program (95 through the DOE WAP and 182 through the LIHEAP WAP) [34].

At the state-level, the Public Utility Commission of Texas (PUCT) addresses energy efficiency through various goals. 20,827 low-income Texas households participated in their utility's hard-to-reach energy efficiency programs in 2018, at a total cost of almost $23 million. Harris County is in the service territory of CenterPoint Energy Houston Electric, the Investor Owned Utility (IOU) that manages and owns the transmission and distribution infrastructure in Harris County and the surrounding area. The PUCT requires that IOUs in competitive retail areas of the Electric Reliability Council of Texas (ERCOT) "acquire a 30% reduction in its annual growth in demand of residential and commercial customers." For low-income customers, PUCT says: "savings achieved through programs for hard-to-reach customers shall be no less than 5.0% of the utility's total demand reduction goal." 'Hard-to-Reach' customers are defined as households whose incomes are 200% or less of the Federal Poverty Line (FPL). In Harris County, 200% FPL accounts for 462,592 households compared to 604,573 using the 0-80% AMI range. Furthermore [24] has a website that details which products and programs can help a household increase its energy efficiency.

Despite the existence of this multitude of programs, heat pumps and other RTTs that could have an enormous impact on improving energy efficiency and reducing energy burden are rarely installed or even mentioned in these programs. This could be because of the Savings to Investment Ratio in the Technical Reference Manual (TRM), that utilities and contractors use to justify building design choices, is too low, lack of awareness, or technical difficulties with installation. Addressing these problems and concerns and allowing the many energy efficiency programs to use heat pumps to accomplish their goals could result in substantial long term energy and cost savings.

3. Methodology

This work extends on the work done by the RECS survey, Houston's Climate Action Plan, and our own Pathways work in a similar vein as [2] on heating use in Michigan. However, this paper focuses on how RTTs can improve efficiency, reduce energy and emissions, and by extension reduce energy poverty. Using information from the EIA, RECS, and Houston's Climate Action Plan we calculate how much energy is used by the residential households in Houston by end use and fuel type. Then using data from the DOE, Energy Star, and heat pump suppliers we calculate how much more efficient different types of heat pumps are compared to traditional air conditioning, space heating, and water heating appliances. Then, we calculate how much energy and by extension emissions would be saved by transitioning to the more efficient heat pumps. Lastly, we calculate how these energy savings would translate to energy burden reductions and by extension reduce energy poverty in Houston.

4. Calculations

In this section we explain how we calculated our results. Each subsection goes into detail on the sources, assumptions, and calculations made. All of our data is from publicly available sources and the methods are explained and justified below.

4.1. Carbon Emissions

In the baseline year 2014, Houston emitted 34,316,303 metric tonnes of carbon dioxide equivalent (CO2e) and 14.9 metric tonnes of CO2e per capita per year [4]. 16.874 MMtCO2e are produced to provide energy to buildings. 83% of those emissions (14 MMtCO2e) come from the over 26 million megawatt hours of electricity that were consumed. The other 17% (2.87 MMtCO2e) comes from natural gas heating for buildings and industry. Commercial, institutional, and municipal buildings account for 60% of building emissions (10.13 MMtCO2e), followed by 33% (5.57 MMtCO2e) from residential buildings and 7% (1.18 MMtCO2e) from industrial operations.

Houston produced 26 TWh of electricity and 33% of total energy (electricity and natural gas) is used by residential buildings, this gives us an energy usage lower bound of 8.58 TWh (26 TWh x 0.33). From the

RECS data, we know that 67% of the energy in the West South Central region comes from electricity. If this ratio holds for Houston, then we can estimate that the upper bound for residential energy use for Houston would be 12.8 TWh (8.58/0.67).

Armed with a lower and upper bound energy estimate, we can use the Texas generation information to calculate a carbon emissions rate and use that emissions rate to provide a reasonable estimate for total energy used. According to the [42] in 2019, Texas generated 483.2 TWh of electricity and produced 217.6 million tons of CO2 for a carbon intensity of 0.45 MMtCO2 / TWh.

Dividing the calculated carbon intensity of 0.45 MMtCO2e / TWh (0.99 lbCO2e / kWh) by the emissions from residential buildings (5.57 MMtCO2e) gives 12.4 TWh of energy usage for all residential buildings, which falls between our lower and upper range of 8.58 TWh and 12.8 TWh respectively. Furthermore, using the ratios from the 2015 RECS data, we can calculate the electricity and natural gas energy usages as 8.30 TWh (12.4 * 0.68) and 3.47 TWh (12.4 * 0.28) respectively. Multiplying these energy usages by the carbon intensity associated with Houston electricity production (0.45 MMtCO2 / TWh) and natural gas (0.41 MMtCO2 / TWh, [41]) gives us the emissions of 3.735 MMtCO2 and 1.42 MMtCO2 for electricity and natural gas respectively and a total of 5.16 MMtCO2 for residential buildings. These values are shown in the table below.

Table 1: CO2e Emissions by Fuel

	Emissions (MMtCO2e)	**Energy Used TWh**
Total	5.1577	11.77
Electricity	3.735	8.3
Natural Gas	1.4227	3.47

4.2. Efficiency Comparison of RTT Appliances vs. Others

To explore residential air conditioning, space heating, and water heating energy usage, we make assumptions about the type and characteristics of Houston residential dwellings and climate conditions. We assume that the average house in Houston has 1952 sq ft [20] and gets all of its heating and water heating from natural gas appliances. We assume that the natural gas heater has a AFUE of 90 which qualifies as a high-efficiency heating system [35] and the water heater has an energy factor of 0.70 which corresponds with an efficient Energy Star model [32]. We assume the average apartment in Houston has 880 sq ft [30] and gets all of its heating and water heating from electricity appliances. We assume that an electric furnace has an AFUE of 100 [5] and that water heater has an energy factor of 0.9 [32]. We assume that the average air conditioner has a SEER (Seasonal Energy Efficiency Ratio) value of 14, new standard for most of the US starting in 2023 and the current minimum for the Southern United States [40].

Based on the square footage assumptions and HVAC sizing calculators below, we calculated that the representative apartment needs a 1.5 ton (18,000 BTU) air conditioning unit and the representative house needs a 2.5 ton unit (30,000 BTU) [12] for the 3,355 cooling hours in Houston [21]. The average electric heater size for apartments would be a 30,000 BTU unit and a 60,000 BTU unit for the houses [26] with an average efficiency of 6.30 BTU/ heated square footage / heating degree day (6.075 cf of Natural Gas * 1.037 BTU / therm) [39] for the 1,265 heating degree days [21]. And the average water heater for the apartments would have a 4500 Watt element and use 30 gallons of hot water a day and the house's average water heater would have a 30,000 BTU gas rating and use 60 gallons of hot water a day [22, 25].

Using these values, we can calculate the amount of electricity each appliance uses. A 1.5 ton, 14 SEER air conditioning unit uses 1.29 kWh / cooling degree day (18000 BTU / 14 BTU / Watt-hour / 1000 Watt-hour / kWh) and a 2.5 ton, 14 SEER air conditioning unit uses 2.14 kWh / cooling degree day. Since Houston has an average of 3,355 cooling degree days, this corresponds to 4314 and 7189 kWh / yr for apartments and houses respectively.

The apartments 30,000 BTU, 100 AFUE electric furnace would use 2,055 kWh / yr or 7.0 MMBTU / yr [6.3 BTU / HDD / sq ft * 1265 heating degree days * 880 sq ft] and the houses' 60,000 BTU, 90 AFUE natural gas furnaces would 4,559 kWh / yr or 15.6 MMBTU / yr [6.3 BTU / HDD / sq ft * 1265 heating degree days * 1952 sq ft * 100 / 90].

The apartments 4500 Watt, 90% efficient water heater that heats 30 gallons a day would use 1070 kWh / yr [4500 Watts * 1 / 0.9 * 3.41214 BTU/Watt / (30 Gal * 300 BTU/Gal) * 1 kWh / 1000 Watts * 365 days]. The houses' 30,000 BTU, 70% efficient hot water heater would use 2751 kWh / yr [30,000 BTU * 1 / 0.7 / (60 gal * 300 BTU / Gal) * 365 days * 1 MMBTU / 1,000,000 BTU].

Figure 1 shows the calculated energy use for heating, cooling, and water heating appliances by technology and housing type.

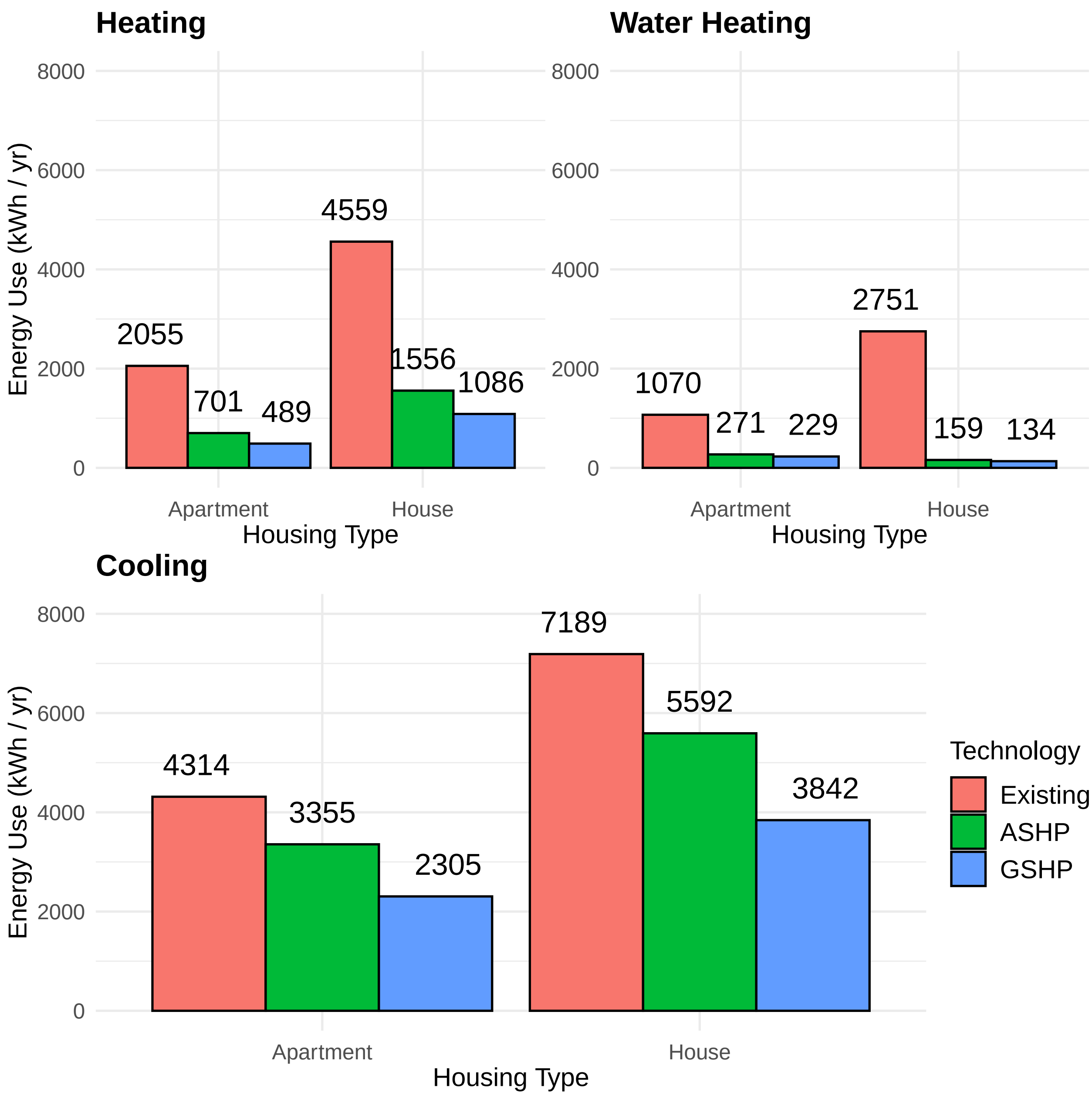

Fig. 1: Average Household Energy Use by End Use, Technology, and Housing Type

Table 2: Assumed Average Efficiencies of Households Appliances

Apartment Cooling		**Apartment Heating**		**Apartment Water Heater**	
1.5	Tons	30000	BTU	4500	Watts
18000	BTU	100	AFUE	0.9	Efficiency
14	SEER	7.0	MMBTU / yr	30	Gallons / day
4314	kWh / yr	2,055	kWh / yr	0.65	Hot Water Hours
				2.93	kWh / day
				1070	kWh / yr

House Cooling		**House Heating**		**House Water Heater**	
2.5	Tons	60000	BTU	30000	BTU
30000	BTU	90	AFUE	0.7	Efficiency
14	SEER	15.6	MMBTU / yr	60	Gallons / day
7189	kWh / yr	4,559	kWhe / yr	0.86	Hot Water Hours
				9.39	MMBTU/yr
				2751	kWh / yr

4.2.1. Air Source Heat Pump Technical Savings Potential

Air Source Heat Pumps are more efficient alternatives to both electric and natural gas heaters, hot water heaters, and air conditioners. We use one of the latest high efficient heat pump with a SEER of 18 and a HSPF of 10 which correlates to an efficiency of 293% (10 HSPF / 3.412 BTU / Watt) [10]. These savings reduce energy costs dramatically which also leads to reduced emissions.

The calculations for the energy use of the ASHP are very similar to those above. The only differences are the units for efficiency for the space and water heating portions. The efficiency metric for ASHP space heating is HSPF which can be converted to a unitless efficiency ratio by taking the HSPF number and dividing it by the the BTU to Watt conversion e.g. 10 HSPF / 3.41214 = 2.93 heating BTUs / BTU of energy input. The efficiency metric for a ASHP water heater are UEF which is simply the efficiency ratio e.g. A 3.55 UEF value is equal to 3.55 BTUs / BTU of energy input. The values and the percent energy savings compared to the existing appliances are shown in the tables X and XX below. Our results are even more optimistic than the energy savings numbers from [36] and [23] that note that heat pumps can save up to 50% of your energy costs.

4.2.2. Ground Source Heat Pump Savings Potential

Geothermal heat pumps are even more energy efficient than air source heat pumps, because they reject the heat to a moderate and relatively constant temperature underground. We took efficiency data from the latest Energy Star geothermal heat pumps and used them to parameterize efficiencies and calculate energy usage and savings [11]. We used the GSHP with an EER value of 22.8 which translates to a SEER value of 26.2 and a COP of 4.2. The only difference between these calculations and the ASHP calculations is the name of the efficiency metric (COP vs. EER). The COP is the efficiency ration so a COP of 4.2 means that you get 4.2 units of heat for every unit of energy input. The values and the percent energy saved are are shown in the table below. Our results show with the energy savings numbers from [36] that note that heat pumps can between 30% and 60% of your energy costs.

Solar Thermal and Solar Water Heaters are also an option, but we exclude them from this study because of their expense and lack of practicality in most situations.

4.3. Climate Mitigation Impact of RTTs

The climate mitigation calculations take the total emissions calculated above, the number of people in houses and apartments and the percentage of people in different AMI levels from our Pathway paper, and the

Table 3: Efficiencies of Energy Efficient ASHP Appliances for Apartments and Houses

Apartment Cooling		**Apartment Heating**		**Apartment Water Heater**	
1.5	Tons	30000	BTUe size	4500	Watts
18000	BTU	10	HSPF	3.55	UEF
18	SEER	7.0	MMBTU / yr	30	Gallons / day
3355	kWh / yr	701	kWh / yr	0.17	Hot Water Hours
22.2%	**Savings**	**65.9%**	**Savings**	0.74	kWh / day
				271	kWh / yr
				74.6%	**Savings**

House Cooling		**House Heating**		**House Water Heater**	
2.5	Tons	60000	BTU	30000	BTU
30000	BTU	10	HSPF	3.55	UEF
18	SEER	15.6	MMBTU / yr	60	Gallons / day
5592	kWh / yr	1,556	kWhe / yr	0.05	Hot Water Hours
22.2%	**Savings**	**65.9%**	**Savings**	0.54	MMBTU/yr
				159	kWh / yr
				94.2%	**Savings**

Table 4: Efficiencies of Energy Efficient GSHP Appliances for Apartments and Houses

Apartment Cooling		**Apartment Heating**		**Apartment Water Heater**	
1.5	Tons	30000	BTUe size	4500	Watts
18000	BTU	4.2	COP	4.2	COP
22.8	EER	7.0	MMBTU / yr	30	Gallons / day
26.2	SEERe	489	kWh / yr	0.59	Hot Water Hours
2305	**kWh / yr**	**76.2%**	**Savings**	2.64	kWh / day
46.6%	**Savings**			229	kWh / yr
				78.6%	**Savings**

House Cooling		**House Heating**		**House Water Heater**	
2.5	Tons	60000	BTU	30000	BTU
30000	BTU	4.2	COP	4.2	COP
22.8	EER	15.6	MMBTU / yr	60	Gallons / day
26.2	SEERe	1,086	kWhe / yr	0.18	Hot Water Hours
3842	**kWh / yr**	**76.2%**	**Savings**	1.93	MMBTU/yr
46.6%	**Savings**			134	kWh / yr
				95.1%	**Savings**

heat pump savings calculated below and synthesizes them into the following energy and emissions savings tables. It also calculates the needed solar capacity necessary to offset the HVAC energy use as well. The HVAC savings and needed solar capacity are shown in Figure 2 The information sources are listed below and the calculation tables derived from these tables are in the subsections below.

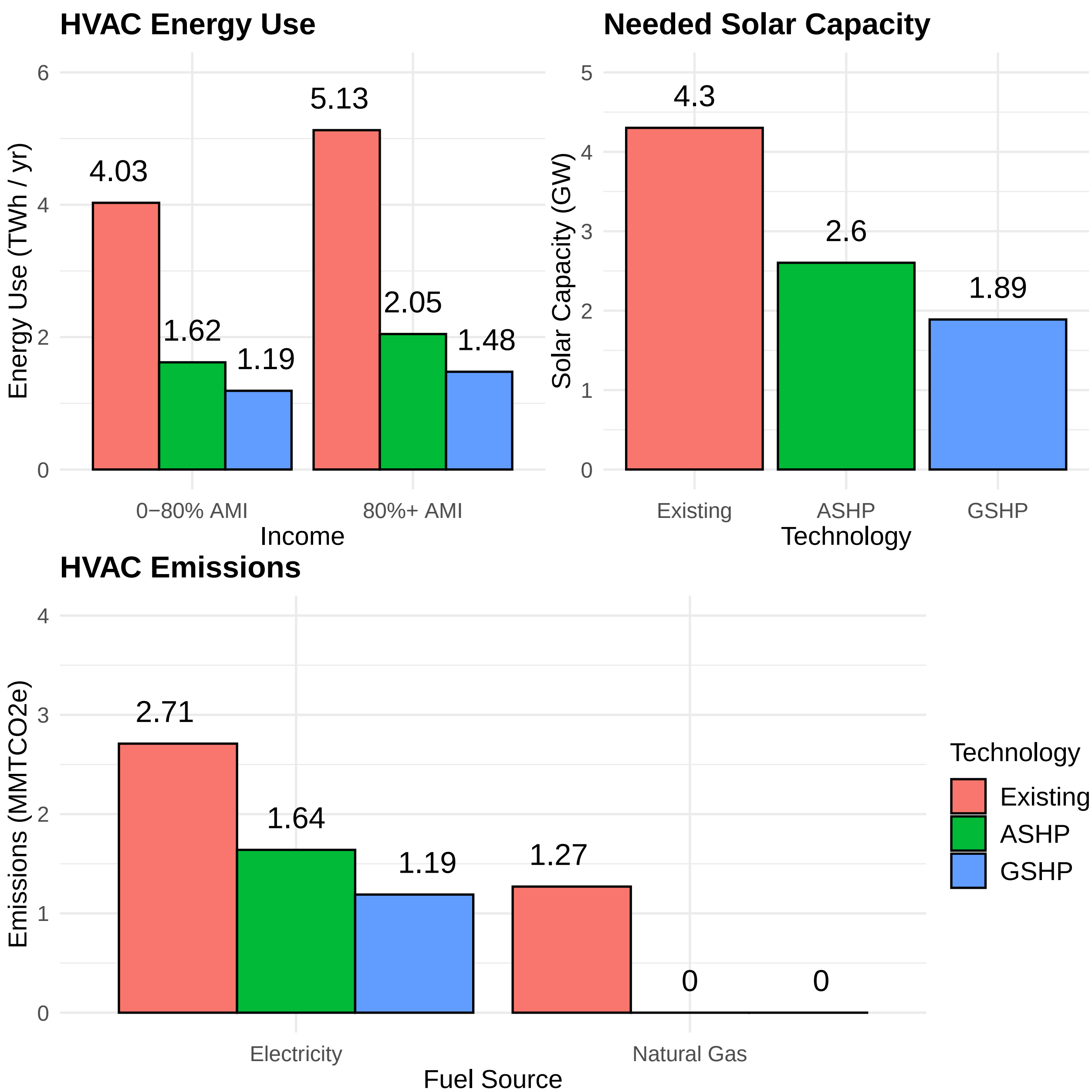

Fig. 2: HVAC Energy Use, Emissions, and Solar Capacity Needed to Offset HVAC Energy Use

4.3.1. Air Source Heat Pump Energy and Emissions Savings

The energy reductions produced by the heat pumps not only saves energy, reducing energy burden but also reduces emissions. For this analysis, we assume that all systems are replaced by these systems to give a maximum amount of RTT potential. The energy savings are divided into AMI level and building tenure and represent the energy savings from both electricity and natural gas in TWhe. Households 80% or less of the AMI save 2.4 TWhe. This amounts to a total emission savings of 1.04 MMtCO2e. Residential Air Source source heat pumps can provide 5.49 TWhe of savings, which totals out to 2.38 MMtCO2e emission savings a year. The results are shown in the tables below.

Table 5: Emission Savings by Adopting ASHPs

	Apartment TWh Savings	**House TWh Savings**	**Emission Savings MMtCO2**
0-80% AMI			
Air Cooling	0.15	0.14	0.13
Air Heating	0.56	0.66	0.52
Water Heating	0.56	0.34	0.39
80%+ AMI			
Air Cooling	0.19	0.17	0.16
Air Heating	0.72	0.85	0.67
Water Heating	0.72	0.43	0.50

4.3.2. Ground Source Heat Pump Energy and Emissions Savings

The energy reductions produced by the heat pumps save energy, reduce energy burden, and reduce emissions, and these effects are magnified for Ground Source Heat Pumps. For this analysis, we assume that all systems are replaced by these systems to give a maximum amount of RTT potential. The energy savings are divided into AMI level and building tenure and represent the energy savings from both electricity and natural gas in TWhe. Households 80% or less of the AMI save 2.85 TWhe / year. This amounts to a total emission savings of 1.24 MMtCO2e / year. Residential Ground Source Heat Pumps can provide 6.50 TWhe of savings per year which totals out to 2.82 MMtCO2e emission savings a year. The results are shown in the tables below.

Table 6: Emission Savings by Adopting GSHPs

	Apartment TWh Savings	**House TWh Savings**	**Emission Savings MMtCO2**
0-80% AMI			
Air Cooling	0.26	0.25	0.23
Air Heating	0.65	0.73	0.59
Water Heating	0.59	0.36	0.41
80%+ AMI			
Air Cooling	0.34	0.32	0.30
Air Heating	0.83	0.94	0.76
Water Heating	0.76	0.46	0.53

4.3.3. Solar Needed with RTTs

The massive energy savings available via heat pumps dramatically reduces energy consumption and by extension emissions, and those benefits could be compounded if they are coupled with clean energy sources like solar. Solar thermal technologies provide either active or passive heating that reduces the energy needed to heat a space or water. Solar PV provides local clean electricity that can be used to power the heat pumps making all heating and cooling needs completely emissions free and possibly cheaper as well.

For this report, we focus on Solar PV. While solar thermal has potential, it is generally expensive, has large space requirements, and generally needs to be coupled with other technologies, like heat pumps, reducing its impact. Solar PV, on the other hand, can be paired perfectly with heat pumps. The vast majority of all household's energy use is for heating and cooling their space and/or their water. Heat pumps dramatically reduce this demand, which also reduces the amount of Solar PV needed to power these devices. In the current paradigm, there is an electricity demand of 8.30 TWh, which would require 5.93 GW of solar to meet that. This amount equates to one million Houston area households to place 5.93 kW of solar on their roof (assuming 1400 kWh / kW of solar / year). If all cooling and heating needs were met by geothermal electricity demand drops to 5.11 TWh, even with the switch from natural gas heating to electric heating, which would only require 3.65 GW of solar. That amount equates to one million Houston households placing 4.32 kW of solar on their roof. At $3 / Watt for installed residential solar, the current scenario would require $17.79 billion the Ground Source Heat Pump scenario $10.95 billion saving $6.84 billion on the race to zero emissions.

Table 7: Solar Needed with Heat Pumps vs. Current Paradigm

	Emissions (MMtCO2e)	Energy Used TWh	Solar Needed (GW)	GHP Emissions	GHP TWh	GHP Solar Needed (GW)
Total	5.16	11.77	5.93	2.45	5.47	3.65
Electricity	3.74	8.30	5.93	2.30	5.11	3.65
Natural Gas	1.42	3.47		0.15	0.36	

5. Discussion and Conclusion

Renewable Thermal Technologies (RTT), especially heat pumps paired with solar, have the potential to dramatically decrease energy consumption and by extension energy emissions. Using information from the Residential Energy Consumption Survey (RECs), Houston's Climate Action Plan, and our own report on Pathways for Reducing Energy Burdens in Harris County, the Texas Energy Poverty Research Institute (TEPRI) analyzed the residential energy consumption and carbon emission by end use and fuel type. From there, we investigated how much air-source heat pumps and ground-source heat pumps could lower both electricity and natural gas consumption and carbon emissions. Then, we investigated how much solar will be needed to completely decarbonize electricity under the current paradigm versus how much would be required under the proposed heat pump paradigm.

5.1. Savings Potential

We found that heat pumps can reduce total residential energy usage by up to 58%, reduce residential emissions by up to 44%, and virtually eliminate residential natural gas consumption and emissions. Furthermore, even with the increased demand for electricity from the heat pumps, electricity consumption also decreases by up to 29%, which reduces the amount of solar needed to decarbonize electricity by almost 30%.

5.2. Implementation Strategies

5.2.1. Use Existing Energy Efficiency Programs

We believe that we can realize the massive benefits of RTTs by implementing them via existing efficiency programs and increasing awareness for community scale solutions. Houston's efficiency programs include upgrading heating equipment with heat pumps but its utilization is low. District ground loops are a new development that spreads the most expensive part of ground-source heat pump installation among a community. These efforts can be added to the cost of the house in a neighborhood or taken up by the city increasing odds of adoption.

5.2.2. District Ground Loop Pumps

Community investment significantly reduces individual costs by lowering barriers to entry, increasing economies of scale, and allowing for outside financing. Sharing the costs of installing the underground pipe loops for Ground Source Heat Pumps is the next area to witness this trend. By sharing the underground pipes among a group of houses or apartments, the upfront costs for Ground Source Heat Pumps decrease dramatically, and in some cases, the cost for the underground infrastructure can be either paid for by the developer and added to the cost of the house or paid for by the city. Then the homeowner or landlord would only have to pay for the heat pump itself and hook up to the communal underground pipes, dramatically lowering costs. This innovation could bring geothermal potential to the masses, lower energy bills across the country, and accelerate the adoption of renewables by lowering the amount that is required.

5.3. Limitations

While the data we used is verifiable and accurate, it is aggregate and disaggregating the data into representative households will have errors. Our assumptions regarding the efficiency of the appliances is conservative so our results might underestimate the potential savings. However, there is a possibility that they underestimate the average efficiency, in which case our savings will be overestimated. Furthermore, our calculations do not take into account the barriers, additional soft costs, or the installation costs preventing the installation of ASHP or GSHP. In other words, our savings are pure energy savings, and we do not take into account the costs (or savings) in dollars that might prevent a household from adopting heat pumps over traditional HVAC appliances, like the higher upfront costs.

5.4. Future Directions and Implications

Next steps would include creating programs to increase awareness of the potential of RTTs and to increase adoption among low-income communities. We believe that this study can be expanded to other jurisdictions, and we would find similar results. RTTs can be a tool for reducing energy consumption and by extension energy burden and for reducing the effects of climate change. Our goal is to study different areas and come up with overarching solutions that can be applied anywhere.

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