PART 4

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Increasing Awareness of Geoexchange in Massachusetts – Part 4 of 5

Heat pumps are heat pumps are heat pumps, right? While most people seem to picture an air-source mini-split system when they hear 'heat pump' there actually are a variety of heat pump types. These include the common mini-splits and whole house air-to-air but there are also air-to-water heat pumps and my favorite: Ground Source Heat Pumps (GSHPs). GSHPs are used in Geoexchange Systems to efficiently heat and cool buildings and can also provide hot water.

Geoexchange systems offer significant advantages for both homeowners and businesses. In Massachusetts, where weather conditions can be extreme in both winter and summer, geoexchange systems provide distinct benefits over air-source heat pumps (ASHPs). There is some technical complexity in explaining the reasons for this. I have prepared 5 separate posts to explore some of the most compelling advantages of Geoexchange/GSHPs one at a time. The individual posts are written to stand on their own so you can pick and choose the order you read them or just focus on the topic(s) that are important to you right now.

In the Series, I provide information related to:

1. Efficiency and Peak Load Advantages
2. Aesthetic Advantages in Historic Districts
3. Longer Service Life and Lifecycle Cost Advantages of GSHPs
4. Risk from Refrigerant used in GSHPs and ASHPs
5. Potential for Networked Geothermal Systems.

I hope this Series can promote discussion of building electrification using either ASHPs and GSHPs. Here is Part 1 of 5 which considers Risk Posed by Refrigerant Leaks.

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Increased Risk of Refrigerant Loss from Air-Source Heat Pumps

One of the less visible but important considerations when comparing Air-Source Heat Pumps (ASHPs) and Ground-Source Heat Pumps (GSHPs) is the risk of refrigerant loss. Refrigerants are necessary for heat pump operation, but when leaked into the atmosphere, they can contribute significantly to global warming due to their high Global Warming Potential (GWP). ASHPs, which use R-410A, are particularly vulnerable to refrigerant loss due to the outdoor exposure of their components. GSHPs, which are increasingly using R-454B, have a reduced risk of refrigerant loss, and the refrigerant they use has a much lower GWP.

Most modern heat pumps, whether ASHPs or GSHPs, use refrigerants like R-410A, which has a GWP of approximately 2,088. While this refrigerant is being phased out in favor of lower-GWP alternatives (such as R-32 and R-454B), it remains the most commonly used refrigerant in existing systems.

Air-source heat pumps are more prone to refrigerant leaks due to their outdoor components, which are exposed to varying weather conditions and the longer runs of refrigerant pipe and field-installed fittings. Refrigerants used in these systems, such as R-410A, have high Global Warming Potential (GWP), contributing significantly to climate change when leaked. The GWP of R-410A is approximately 2,000 times greater than CO2.

Geoexchange systems, which house most components indoors and have fewer refrigerant connections exposed to the elements, are less prone to refrigerant loss. By reducing the likelihood of refrigerant leaks, geoexchange systems contribute to a lower overall environmental footprint.

SYSTEM TYPE	COMMON REFRIGERANT TYPE	GWP *(GLOBAL WARMING POTENTIAL)*	AVERAGE LEAK RATE *(%)*	ENVIRONMENTAL RISK LEVEL
Geoexchange	**R-410A, R-134A**	**Medium (1700-2000)**	**Low (<1%)**	**Low**
Air-Source Heat Pump	**R-410A, R-22**	**High (2000-3000)**	**Moderate (5-10%)**	**High**

The relative risk of refrigerant loss from Ground-Source Heat Pumps (GSHPs) versus Air- Source Heat Pumps (ASHPs) plays a significant role in environmental impacts, particularly with regard to climate change. Refrigerants used in both systems contribute to global warming if they leak into the atmosphere, as many refrigerants have high Global Warming Potential (GWP), meaning they are much more potent than CO_2 in trapping heat in the Earth's atmosphere. In fact, the loss of refrigerant can partially cancel the CO_2 savings for which these systems are touted. Below is an analysis of the refrigerant risks associated with GSHPs versus ASHPs and the potential climate change impacts if all buildings in Massachusetts were to adopt one of these systems.

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Refrigerant Loss in ASHPs vs. GSHPs

Air-Source Heat Pumps (ASHPs):

HIGHER RISK OF LEAKS:

ASHPs have more outdoor components that are exposed to environmental elements, including temperature fluctuations, moisture, and physical damage (e.g., debris, ice buildup). These external conditions increase the risk of refrigerant leaks.

The refrigerant lines in ASHPs are often longer and connect outdoor and indoor units, increasing the points of potential failure and making the system more prone to leakage. This piping, particularly in mini-split and VRF systems, is connected with field-installed fittings and seals. These fittings and seals do not have the same quality control as factory-installed fittings. Additionally, ASHPs operate under variable refrigerant pressures due to changing outdoor temperatures, which can stress components and seals, further elevating the risk of refrigerant loss over time.

ENVIRONMENTAL EXPOSURE:

In Massachusetts, where winters can be extremely cold and summers humid, the outdoor units of ASHPs are particularly vulnerable. Freezing and thawing cycles can cause materials to expand and contract, weakening seals and joints where refrigerants are housed.

Over the lifetime of an ASHP, refrigerant loss is more likely to occur, requiring refills and repairs. Even small leaks can lead to significant global warming impacts, as refrigerants such as R-410A have a GWP 2,088 times greater than CO_2

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Ground-Source Heat Pumps (GSHPs):

LOWER RISK OF LEAKS:

GSHPs typically have indoor components, which are protected from environmental stress. This reduces the risk of refrigerant loss as the system is not exposed to weather, temperature extremes, or physical damage. The refrigerant lines in GSHPs are shorter and more contained, as the heat exchange occurs underground and the refrigerant loop does not have to extend outdoors. Also, these refrigerant lines, fittings, and seals are likely to be factory-installed.

Additionally, GSHPs operate at more consistent pressures due to the stable ground temperatures, reducing the stress on refrigerant components and lowering the chances of leaks over time.

LONGEVITY OF SYSTEM COMPONENTS:

Because GSHPs are less exposed to environmental wear and tear, their refrigerant systems tend to last longer without requiring refills or repairs. This not only reduces maintenance costs but also minimizes the risk of leaks over the system's lifespan.

AIR-SOURCE HEAT PUMPS AND CONTINUING USE OF R-410A

Most ASHPs, including popular models from Mitsubishi, LG, Samsung, Fijitsu, and Daikin, use R-410A as a refrigerant. R-410A has a GWP of approximately 2,088, meaning it is over 2,000 times more potent than carbon dioxide in terms of its ability to trap heat in the atmosphere. This makes even small leaks of R-410A a significant environmental concern. Additionally, because ASHPs require outdoor units, the refrigerant lines are exposed to weather, temperature changes, and potential physical damage, which increases the likelihood of leaks.

The U.S. Environmental Protection Agency (EPA) has estimated that refrigerant leakage rates for ASHPs can range from 10% to 20% of the total refrigerant charge annually. Over the lifespan of a typical ASHP, these leaks can result in the release of several kilograms of R-410A, leading to a significant contribution to global warming. For instance, a system with 5 kg of R-410A can release between 0.5 to 1 kg annually. With a GWP of 2,088, even a 1 kg leak equates to over 2 metric tons of CO_2-equivalent emissions.

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GROUND-SOURCE HEAT PUMPS AND TRANSITION TO R-454B

GSHPs, like those from US Manufactures such as WaterFurnace, Climate Master, and others, are transitioning earlier than the ASHPs to the use of R-454B, a refrigerant with a GWP of approximately 466, which is over 75% lower than R-410A. In addition to using a more environmentally friendly refrigerant, GSHPs have a reduced risk of refrigerant loss because their components are housed indoors and most fittings and seals are factory-installed. This means the refrigerant lines are protected from environmental factors and are less likely to be damaged, reducing the chance of leaks.

According to studies conducted by the U.S. Department of Energy, GSHP systems experience a much lower annual leakage rate, typically around 1% to 3% of the total refrigerant charge. This lower leakage rate, combined with the lower GWP of R-454B, means that the environmental impact of refrigerant loss from GSHPs is significantly smaller than that of ASHPs. For instance, a 5 kg charge of R-454B that leaks at a rate of 1% annually would release only 0.05 kg per year, resulting in just 23 kg of CO₂-equivalent emissions.

Climate Change Impacts if Massachusetts Adopts Either GSHPs or ASHPs

To assess the climate change impacts of refrigerant loss in Massachusetts, we can compare the potential refrigerant emissions if all buildings (residential and commercial) adopt GSHPs or ASHPs. Massachusetts is home to approximately 3.6 million households and many commercial buildings. For the sake of simplicity, let's consider a scenario where 1 million systems are installed for this analysis.

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SCENARIO 1: ALL BUILDINGS ADOPT ASHPS

Refrigerant Risk: Let's assume that the average ASHP uses 3 kg of R-410A refrigerant and loses around 10% annually over its 15-year lifespan.

- Annual refrigerant loss per system: 0.3 kg (10% of 3 kg).
- Annual refrigerant loss for 1 million ASHP systems: 1 million x 0.3 kg = 300,000 kg of R-410A leaked per year.
- With a GWP of 2,088, this results in: Total annual CO_2-equivalent emissions: 300,000 kg x 2,088 = 626.4 million kg of CO_2-equivalent emissions (626,400 metric tons) per year from refrigerant leaks alone.
- Over 15 years, this equates to 9.39 million metric tons of CO□-equivalent emissions just from refrigerant loss.

SCENARIO 2: ALL BUILDINGS ADOPT GSHPS

Refrigerant Risk:

- For GSHPs, the risk of refrigerant leaks is much lower, typically around 1% per year due to the reduced exposure and stress on components.
- Let's assume the same 3 kg of refrigerant per system but with a 1% leak rate annually.
- Annual refrigerant loss per system: 0.03 kg (1% of 3 kg).
- Annual refrigerant loss for 1 million GSHP systems: 1 million x 0.03 kg = 30,000 kg of R-410A leaked per year.
- With the same GWP of 2,088, this results in: Total annual CO_2-equivalent emissions: 30,000 kg x 2,088 = 62.64 million kg of CO_2-equivalent emissions (62,640 metric tons) per year.
- Over 15 years, this equates to 939,600 metric tons of CO_2-equivalent emissions from refrigerant loss.

Comparison of Climate Impact Over 15 Years:

- **ASHPs: 9.39 million metric tons** of CO_2-equivalent emissions from refrigerant loss.
- **GSHPs: 939,600 metric tons** of CO_2-equivalent emissions from refrigerant loss.

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CONCLUSION:

If all buildings in Massachusetts were to adopt ASHPs, refrigerant-related emissions would be roughly 10 times higher compared to GSHPs, contributing significantly more to global warming.

ADDITIONAL CONSIDERATIONS:

1. Refrigerant Phase-Out: While newer refrigerants like R-32 and R-454B have lower GWP values, their adoption will take time, and the existing infrastructure heavily relies on higher-GWP refrigerants. GSHPs, with their lower leak risk, remain a more sustainable option regardless of the refrigerant used.
2. Long-Term Environmental Benefits: Beyond refrigerant-related emissions, GSHPs offer additional environmental benefits, such as higher energy efficiency and lower peak load demand, which reduce reliance on fossil fuels for electricity generation.

SUMMARY:

- GSHPs have a much lower risk of refrigerant leaks compared to ASHPs due to their protected design and stable operating conditions.
- If Massachusetts were to adopt GSHPs over ASHPs for all buildings, the state could avoid millions of metric tons of CO□-equivalent emissions over the lifetime of the systems due to the reduced risk of refrigerant leaks.
- This makes GSHPs a far more climate-friendly option for the state's future heating and cooling needs, especially as Massachusetts aims to reduce greenhouse gas emissions in line with climate change mitigation goals.

Summary and Recommendation

In conclusion, the risk of refrigerant loss and its associated global warming impact is much greater for currently available ASHPs using R-410A than for new GSHPs using R-454B. Given the significant difference in both leakage rates and the GWP of the refrigerants, transitioning to GSHPs would result in a much smaller contribution to global warming, making them a more sustainable choice for long-term use. Policymakers and building owners in Massachusetts should consider these environmental benefits when making decisions about heating and cooling technologies.