BITCOIN MINING HEAT REUSE

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Printed in the Czech Republic
ISBN 978-80-909253-2-8

BITCOIN MINING HEAT REUSE

This book was written by Tyler Stevens — a former rocket thermal engineer, owner of Exergy LLC, organizer of the Hashrate Heatpunks and co-founder of The Space. It explores the emerging industry of heating with bitcoin miners, aiming to educate individuals and professionals in both the bitcoin mining and heating sectors. This comprehensive guide examines why this technology matters, who can benefit from it, how to implement it, and provides insights into potential savings, challenges, and future trends.

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ACKNOWLEDGEMENTS

This book would not have been possible without the incredible support of the team at Braiins, who immediately embraced the vision for a book about bitcoin heating. A special thanks to Kristian Csepcsar and Martin Connor, whose eagerness to bring bitcoin mining heat reuse content to the masses was both motivating and inspiring. Your dedication to bitcoin education, openness to new ideas, and passion for advancing this industry are truly contagious.

To Rob Warren, thank you for encouraging me to take that leap of faith and attend my first mining conference, where I caught the spark to explore bitcoin heating. Your ability to simplify complex topics and your unwavering willingness to help others understand bitcoin mining have been invaluable.

To Wyatt O'Rourke, Zach Wischler, Dylan Seib, Mark Maraia, and my many close friends in the Denver bitcoin community, thank you for guiding me on my bitcoin journey. Your technical expertise, relentless drive, and commitment to building a strong community and innovative companies have profoundly influenced my life and career.

To the Hashrate Heatpunks - the pleb builders, educators, engineers, and doers who have taught me nearly everything I know about bitcoin heat reuse - thank you for your dedication to this emerging industry. Your generosity in sharing knowledge and your determination to shape the future inspire me daily.

Finally, to my parents, Rodney and Jill, and fiancée, Rachel: your unwavering support, patience, and encouragement through countless bitcoin conversations, late-night frustrations, and stressful moments have meant the world to me. I couldn't have done this without you. Thank you.

FOREWORD

Bitcoin Mining Heat Reuse: A "Double Spend" Solution

Believe it or not, you *can* double spend on bitcoin – with electricity. Every watt of power used to mine bitcoin can be **fully reused as heat**. This simple, earth-shattering fact is so underappreciated that many bitcoiners haven't even realized its significance. It's a testament to how early we are in understanding this technology's full potential.

Bitcoin has already achieved remarkable milestones. What began as a niche experiment embraced by a handful of visionaries has evolved into a global phenomenon – recognized as digital gold, a decentralized currency, and a tool for financial sovereignty. Its adoption has earned respect from mainstream financial institutions, governments, and individuals around the world.

As a former computer science professor and long-time bitcoiner, I've spent years teaching the principles of bitcoin to university students. Yet, it wasn't until later in my journey that I truly grasped the profound significance of mining. **Bitcoin mining beautifully intertwines MATTER, ENERGY, and INFORMATION.** This unique relationship elevates mining beyond simple computation, showcasing its role in converting raw energy into one of humanity's most secure and decentralized systems of truth.

The energy we consume today is only a fraction of what's available to us. The sun delivers an unfathomable surplus of energy to Earth, and with technological innovation, humanity will continue to unlock its potential. At its core, life's ultimate purpose is to use matter and energy to create and perpetuate information. Bitcoin mining embodies this principle in a profound way – transforming raw energy into digital records that secure and transmit value.

Bitcoin mining isn't just theoretical; it's deeply practical. It thrives under free-market principles, providing a perfect example of how capitalism drives innovation. By incentivizing the use of low-cost, otherwise wasted energy, mining offers grid stability, economic opportunity, and a path to rethink energy consumption altogether. Heat reuse takes these principles even further – turning every watt of mining energy into a dual-purpose tool for both securing the network and providing warmth. **Using electricity twice – reusing the heat after computation – makes bitcoin mining more efficient and valuable than ever.**

After computation, electrical energy is fully converted into heat energy. This heat can be reused, making it essentially free. The possibilities here are staggering, and while the industry is still in its infancy, the progress we've already made is extraordinary. Building on this momentum requires innovation, collaboration, and a willingness to reimagine what mining can achieve.

We created Fog Hashing in 2021 knowing that this double spend of electricity could revolutionize both the bitcoin mining and heating industries. While we're often seen as a liquid cooling company, one of our core strategies revolves around enabling waste heat reuse. There are countless ways to reuse heat produced from bitcoin miners – Tyler will show you throughout his book – and we are thrilled to be building solutions for people.

A bitcoin mining heat reuse setup exemplifies bitcoin's transformation of energy into digital information while releasing heat. Thousands of bitcoiners today pay heating bills while stacking sats from exchanges. There's nothing wrong with this, but bitcoiners are critical thinkers. They see value where others see waste. This book will open their eyes to the untapped potential of heat reuse - an opportunity to combine heating and sat stacking as one operation that extends beyond individual plebs to the industrial scale.

Even in its early stages, the pace of innovation in mining and heat reuse is unstoppable. Companies like Braiins, a pioneer in the bitcoin space, have published invaluable guides to make this technology accessible to all. Tyler, the author of this book, has poured immense effort into documenting these advancements. His work not only inspires but also provides a roadmap for integrating heat reuse into mining setups of all scales.

The best way to predict the future is to invent it, together.

Paul Jin Li
Founder & CEO, Fognitive | FogHashing
December 9, 2024 – Winnipeg, Canada
Block Height 874033

A HEATPUNK'S MANIFESTO

Energy consumption is essential for human prosperity. Energy consumption is not immoral. It reflects our ability to harness the inherent potential of the natural world to our benefit. No prosperous society exists without significant energy use, and nearly half of all energy consumption is dedicated to heating.

If someone desires to use energy how they see fit, they should have the right to do so, provided it does not infringe on others' rights to life, liberty, and private property. No use of energy is perfectly efficient – heat is always released. So who is to judge what is wasteful?

The emergence of bitcoin as a neutral and ethical monetary protocol introduces a new way to use energy via the mining proof-of-work mechanism. Miners consume electricity with the expectation of rewarded economic value. Heat is released as a side effect. The creation of this decentralized peer-to-peer electronic cash has incentivized a new industry of energy consumption and conversion to heat.

Bitcoin mining secures the most robust monetary system known to man, while hunting cheap and wasted energy through its hashing algorithm. Rather than viewing mining solely as a rewards-based system that aims to return more economic value than the cost of energy consumed, it should instead be recognized as a new tool for electrically powered heating infrastructure, which economically subsidizes one of the largest sectors of global energy consumption. Bitcoin miner exhaust heat is a product, not a problem.

Since energy and heat are required for human prosperity, we must ensure they are available in abundance. We must defend the ability to use energy however we desire. When we consume energy to mine bitcoin, there is nothing to criticize. We could be purposefully supporting a decentralized protocol, monetizing resources, or offsetting necessary heating costs. A bitcoin miner is not a bad use of energy. Moreover, a bitcoin heating system rewards heat consumption, reduces waste, and secures the neutral monetary network.

The incentives are linked. Mining energy costs can be subsidized through heat monetization, and heating costs can be subsidized with mining rewards. For bitcoin heating systems to exist, the bitcoin network must exist and remain robust against threats. Physical decentralization of bitcoin mining secures the network against centralized attacks, and global distribution of heating systems powered by bitcoin helps further decentralize the network.

The combination of economic, utilitarian and ideological incentives of bitcoin mining will drive hashrate distribution to the most diffuse locations: to the sources of energy production where cost is lowest, into millions of heating systems that can be subsidized by mining rewards, and into the hands of the most convicted, who will support the network regardless of the outcome.

We cannot expect individuals, governments, corporations or other faceless organizations to immediately embrace energy consumption for bitcoin mining. Little do they know, it is in their economic best interest to do so. They will learn. Heating applications of this new technology will allow individuals to protect their wealth, reduce waste, and create a more prosperous society for all. It is to their benefit to let us mine and consume energy at will.

Heatpunks deplore regulations on energy production and consumption. To attempt to hinder energy consumption used for mining is to fight against the laws of thermodynamics themselves. Energy is not just available to be used; it is meant to be. Bitcoin mining will hunt trapped and wasted energy. It will target heating applications that can benefit from its utility. It serves as a vehicle that transfers energy resources into heat, and rewards the driver with economic value. In the race of entropy generation, bitcoin mining leads the way.

Mining only extends as far as its value is recognized. Heatpunk systems add additional utility benefits to mining operations. Through aligned incentives, we, the Heatpunks, will infiltrate all nooks and crannies of the world, physically distributing hash power. Mining for heat as a desirable product adds a direct utility value to bitcoin network security. It reduces sensitivity to pure economic incentives. It becomes difficult to vilify, more widespread, harder to stop, and will accelerate adoption.

We, the Heatpunks, are dedicated to advancing systems that capture, repurpose and reuse bitcoin miner heat energy. We are reducing net costs and eliminating waste. We are setting the standard for conscientious energy consumption. We are the heating militia of the bitcoin network, driven by the innate human need for warmth. We are fortifying bitcoin's strength in this monetary revolution.

Heatpunks are builders, innovators, and bitcoiners. We are aligning incentives and following the natural laws of thermodynamics. We believe hashrate heating is key to a hyper-decentralized bitcoin network. Our systems and insights are available for all. Heating demand will not be stopped, and as such, neither will we.

We, the Heatpunks, seek your questions, concerns and expertise as we navigate this emerging industry. We hope to engage with you and integrate with all viable heating applications in good faith. We will not, however, stop mining for heat or reduce our energy consumption because you disagree with our methodology. Let us continue in peace and prosperity.

Keep building.

HEAT IS A PRODUCT, NOT A PROBLEM

WHAT IS BITCOIN MINING HEAT REUSE?

Bitcoin mining heat reuse is the implementation of methods to capture reuse, and integrate the otherwise wasted heat energy exhausted from bitcoin miners into useful applications.

Bitcoin is a decentralized monetary protocol, where peer-to-peer transactions are logged on a distributed ledger called the blockchain. For transactions to be added to the blockchain, they have to be settled by bitcoin miners. **Miners purposefully consume energy through a proof-of-work process, which gives them a chance to settle the next block of transactions and get rewarded with bitcoin in return**.

What does this have to do with heat?

Bitcoin miners are computers that consume electricity to compute logic. **During the process, the electric energy for computation is converted into heat energy**. Over each hardware transition of mining devices, the computational power (hashes/second), electrical power (watts), and mining efficiency (J/TH) increased exponentially.

ASIC miners are the current status quo, with modern machines pushing trillions of guesses per second (terahashes/second) in computation, while consuming thousands of watts of power.

Every watt of electrical power used for mining is converted into heat! For traditional mining operations focused solely on earning bitcoin, managing heat energy poses a significant challenge. Heat must be effectively dissipated to ensure the machines operate efficiently. Otherwise, the miners will shut down or potentially damage themselves. The industry standard has been to treat this heat energy as waste and release it into the environment. However, the **heat**

doesn't have to be discarded – it's a valuable resource that can be harnessed and reused for a variety of applications.

WHY DO IT?

If we switch our mindset about bitcoin mining heat exhaust from a problem to deal with, to a product to use, there are two things that become obvious:

1. **Heat consumers can use mining hardware as electric heaters that reward them with bitcoin in return.**

2. **Traditional mining operations can monetize their waste heat for additional revenue streams and improve their P&L.**

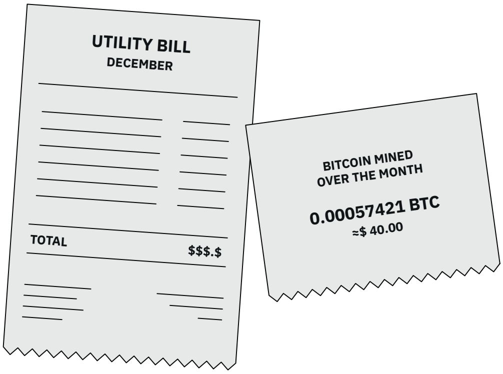
Both approaches are not only viable, but are actively being implemented today in homes, businesses and large mining operations. Let's walk through the incentives.

Saving on Heat

Heating bills are an unavoidable part of life for both consumers and businesses. We need warmth, and heating is required in various commercial applications. Despite its necessity, the cost of heat is often outside the control of the user.

Reusing bitcoin miner waste heat, which I'm coining ***Hashrate Heating***, offers a unique opportunity to flip this dynamic. Instead of paying for heat as a pure expense, these systems return bitcoin mining rewards while heating your home or business, turning heat consumption into revenue generation. **The more heat you need, the more power is used to mine bitcoin, increasing your rewards**.

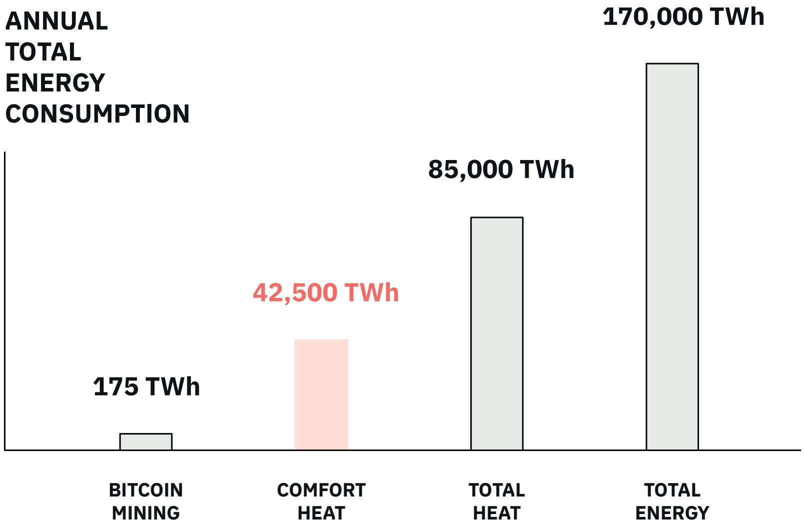
Depending on a handful of factors, bitcoin miner heating systems can significantly subsidize heating costs – potentially offsetting them fully or returning a profit on heat consumed. This creates a powerful economic incentive, making bitcoin mining an attractive solution for anyone looking to lower their heating costs.



Global Heat Demand

The potential market for hashrate heating is enormous, with an estimated 50% of all global energy consumption used for heating – nearly half of that dedicated specifically to space and water heating[1]. This works out to roughly 42,500 TWh (terawatt-hour) of energy used annually for comfort heating (space and water). **As of December 2024, the total bitcoin network uses around 175[2] TWh of annualized energy – nearly 250 times less than the energy consumed just to keep us warm**.

1 Data from https://www.iea.org/reports/renewables-2019/heat
2 Data from https://ccaf.io/cbnsi/cbeci



If just 1% of the energy used globally for comfort heating were converted to hashrate heating, it would add approximately 1800 EH/s to the bitcoin network, assuming an estimated current average miner efficiency of 27 J/TH. This is just under a 3x increase in the size of the network.

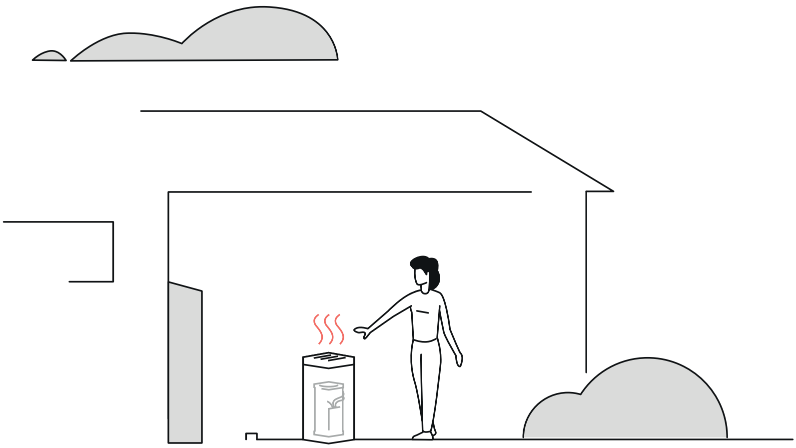
With only a tiny fraction of the global heating market converted to bitcoin miners, the total network hashrate could expand to multiple ZH/s (zettahash/second), without requiring any additional power dedicated solely to mining. The energy for this already exists and is currently powering traditional heating systems instead of mining bitcoin.

Of course, several variables influence the precise feasibility of bitcoin-powered heating systems, such as what type of heat you already have, energy costs, climate, and how much heat you need. That said, the potential for scaling hashrate into millions of residential and commercial heating applications is immense.

Utility Value of Mining

An under-recognized incentive to use bitcoin miners in heating applications is the direct utility value that it brings to the devices. For years, bitcoin proof-of-work has been wrongly vilified as harmful to the environment for its energy consumption.

If bitcoin miners are classified as electric heaters, all of a sudden they have a direct, observable use case and are needed everywhere.

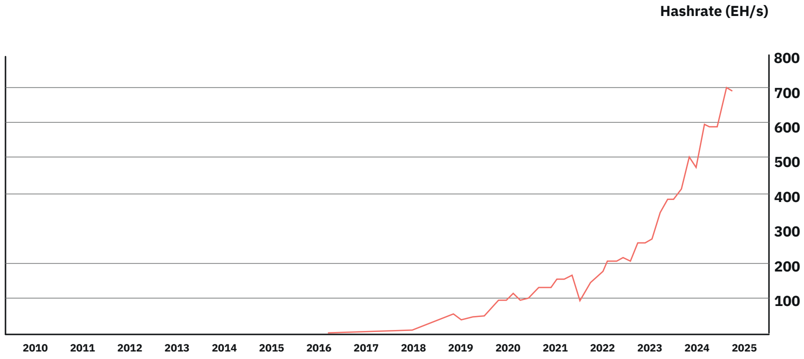


It's not worth trying to convince every mining critic of all its benefits. A more productive solution is to instead innovate further and devise solutions that showcase additional use cases for the technology.

As a result, mining for heat becomes much harder to criticize. **In a roundabout way, driven purely by economic incentives, hashrate heating will reduce bitcoin mining FUD.**

Strengthened Network

Every time more bitcoin miners come online, the total network hashrate (combined computing power of all miners) increases. This metric measures the total effort put towards finding the next block by guessing a specific number - called a nonce - that meets the network's difficulty target. In simple terms, it's a way of showing how much total computing power is securing the network at any given moment.

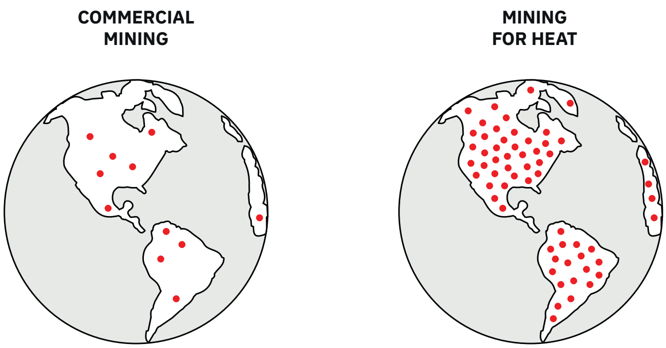


Hashrate Decentralization

For bitcoin to stay secure and robust, the network must remain online and be resilient against threats. Another way to increase resilience aside from adding more machines to the network is to physically hyper-decentralize hashrate by distributing bitcoin miners into as many locations as possible.

A roadblock to hashrate hyper-decentralization is the cost of electricity. In populated areas, energy prices tend to be higher, making it less profitable (or unprofitable) to mine bitcoin in these locations. As a result, most of the bitcoin mining hashrate has been **consolidated** into large operations that find extremely cheap power in rural areas or near the source of energy production. **Current operations, which see heat as a problem, inhibit physical hyper-decentralization of hashrate**. Fur thermore, regular mining operations must be enormous in scale to lock in power pricing deals, secure fiat financing, and maintain their overhead.

Integrating bitcoin mining hashrate into heating solutions will physically hyper-decentralize the bitcoin network through economic self interest. And more crucially, each home and business owner with hashrate heating acts as their own independent mining operation, with the ability to uniquely select different mining pools and block template construction structures to prevent digital centralization of pool power and transaction censorship risk. **Physical decentralization can aid digital decentralization**.



Non-KYC Sats

Hardcore bitcoiners will argue that the only proper way to acquire, hold and spend bitcoin is with coins that have not been tainted by know-your-customer (KYC) laws. These regulations require exchanges to gather sensitive consumer information that is linked to your coins forever.

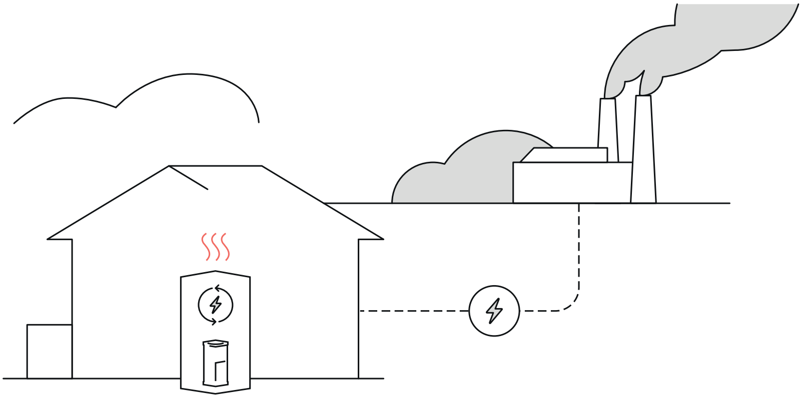
Bitcoin mined from your heating system is *completely private*. Newly minted bitcoin is directly issued to your wallet address of choice.

For those seeking to accumulate a steady stream of surveillance-free money, bitcoin heating systems provide an economically attractive and discreet method to do so – completely concealed within your heating bill.

Reduce Local Emissions

Bitcoin-powered heating systems can also be attractive to individuals who want to minimize the **local emissions** of hydrocarbons. From a fundamental perspective, hashrate powered heating systems are electrically resistive heaters. No fuel or emissions are released.

Even though converting electric energy into heat is almost perfectly efficient, this is typically an expensive method of providing warmth due to the high cost of electricity. It's often cheaper and more effective to use natural gas, or other fuels. Resistive heaters, however, are emission-free, which makes them ideal for ESG investors and carbon-conscious consumers, or anyone who wants to help keep the air around them as pure as possible.

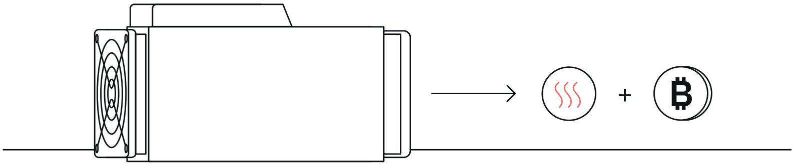


With bitcoin mining heat reuse, you can have the best of both worlds. An emission-free, electrically resistive heating system that's cost effective with net bitcoin rewards. No combustion byproducts are emitted into the atmosphere where the heat is used.

Increased System Efficiency

Overall system efficiency is another selling point of hashrate heating. For bitcoin heating systems or heat reuse in traditional mining operations, finding utility value for exhaust heat results in a more efficient use of total energy consumption.

Think about a bitcoin-powered heating setup. **Every bit of energy you buy is used for heating, *and* is also used to hash, rewarding you in return**. With traditional mining operations, heat reuse finds value in what would otherwise be waste, offering the potential to recoup additional revenue for something that was going to be discarded in the first place.

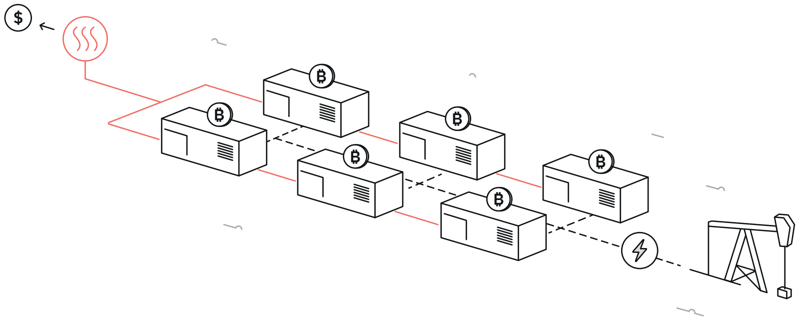


In either scenario, **repurposing hashrate heat results in more conscientious energy consumption**. You're doing more with each bit of energy purchased and consumed, ensuring you get the most out of it. Once again, bitcoiners are leading the way in energy efficiency and waste reduction.

Stability to Traditional Mining Economics

Heating systems aside, there is also an incentive for traditional mining operations to monetize or use their exhaust heat. Most large scale mining sites are wasting millions of watts (megawatts) of heat energy. This heat could be put to use or be purchased by other consumers.

By selling the heat to nearby demand or reusing the energy for industrial heating applications, mega-miners can introduce a new line item to their income statement. Heat monetization is stable and consistent. Traditional miners can bring added stability via heat energy revenue when bitcoin mining rewards are volatile – an inevitable reality as payouts transition from primarily block subsidy bitcoin – to transaction fee based.



Mining operations will have to get more creative. **Treating heat as a new type of block reward can give you a competitive edge**. At the end of the day, **it makes sense to monetize the consistent *physical* operation of the machines – the conversion of electricity into heat**.

THE INCENTIVES ARE ALIGNED

The alignment of economic, utilitarian, and ideological incentives makes bitcoin miner heat reuse inevitable. It is an attractive proposition to bitcoiners and non-bitcoiners alike. As more people recognize the benefits, implementations and technological advancements will accelerate, increasing bitcoin adoption and education as a result. Heat is not a problem for miners to manage, but a valuable product to take advantage of.

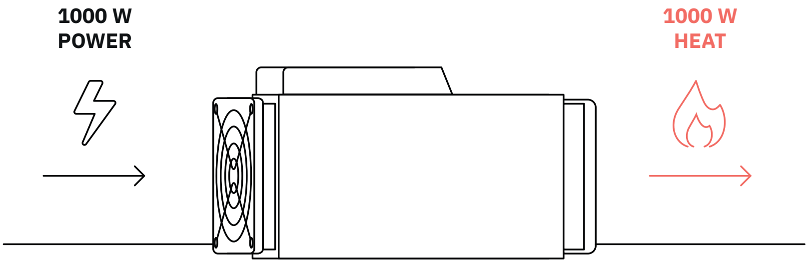
FRAMING THE FUNDAMENTALS

Since heat is a product, it has physical characteristics that can be measured, understood, and optimized using the laws of thermodynamics. But because this heat is often treated as waste, we often don't recognize its true value, or care to understand its definable strengths and limitations.

Below are two fundamental principles that will guide our understanding of how to capture, use, and quantify bitcoin-powered heat as a valuable resource.

The Heat isn't Going Anywhere

If you run a bitcoin miner using 1000 W of electric power, then 1000 W of heat power must be released from the machine. This energy cannot simply disappear. Whether you want it or not, it has to go somewhere.



This is dictated by the *First Law of Thermodynamics*: Energy cannot be created or destroyed, only transferred or transformed. Energy is always conserved.

This concept is non-negotiable. If you're mining bitcoin, you're generating heat.

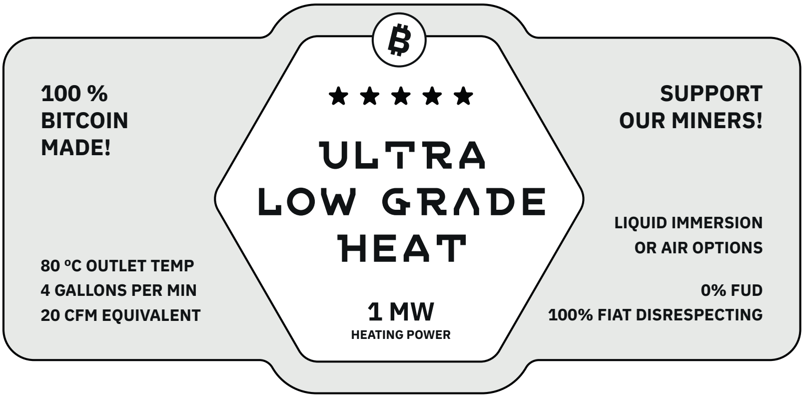
The Value of Heat is Measurable

To fully understand the true potential of hashrate heat, you need to measure its usefulness and utility, just like you would any other product.

The measurable value of heat is rooted in the *Second Law of Thermodynamics*: **Heat energy only flows from higher temperatures to**

lower temperatures, and its ability to do useful *work* is determined by the temperature difference between hot and cold. The hotter the heat and the more control you have over where it goes, the more utility you can extract from it.

Hashrate heat is not just a warm byproduct that can make a room feel cozy – it's an actual form of energy that can be quantified, harnessed, and applied to specific tasks like space heating, water heating, or industrial processes. Understanding how much heat you're producing, where it's going, and how useful it is will help you determine the best applications for a bitcoin-powered heating system.



The Technicals in More Detail

For those curious, *Appendix A* delves deeper into the first and second laws of thermodynamics, exploring the fundamentals of energy transfer and heat, all explained in the context of bitcoin mining. Similarly, *Appendix B* focuses on the principles of heat transfer for bitcoin miners, detailing how heat moves through different materials and environments.

But first, how did this all start,and who is it best suited for?

HASHRATE HEATING ACROSS DIFFERENT SCALES

Bitcoin heat reuse originated as small-scale systems in homes and small businesses. These early prototypes and proof-of-concepts were largely the work of bitcoin plebs and hobbyists experimenting with new ways to repurpose old miners to heat their environment, support the network, and save costs.

Later on, at the opposite end of the spectrum, some large-scale mining sites began to sell or repurpose their excess heat in district applications[3], showcasing mega-miner interest in the economic benefits of the technology at scale.

There is a substantial untapped middle ground for heat reuse between small-scale home setups and large-scale operations. **Mid-tier applications of hashrate heating in manufacturing plants, commercial businesses, and industrial facilities offer significant potential for utility cost savings and miner decentralization**. Millions of businesses that may not have cheap enough energy to mine profitably can still benefit from integrating these devices as heating systems.

The incentive to reduce utility costs is the largest driver for hashrate heating implementation. Depending on scale, the practicality, feasibility, and economic value proposition of bitcoin heating systems can vary dramatically.

3 District heating refers to a centralized system where heat is generated at a plant and distributed via insulated pipes to multiple buildings or facilities for space and water heating, making it an efficient solution for communities.

TIER 1: RESIDENTIAL & SMALL BUSINESSES

When thinking of a bitcoin-powered heating system, you likely imagine solutions such as space-heaters, ducted central air setups, hot water tanks, or home swimming pools. This is where most of the early experimentation and innovation in bitcoin heat reuse began. What these examples all have in common is their small scale. They all fall under the **Residential & Small Business Tier** of hashrate heating.

Residential & Small Business applications of hashrate heating systems often come with certain constraints and challenges that impact economic practicality and overall performance.

Mining Scale: Roughly 100 W - 100 kW

Heat Applications: Typically Home and Small Business Zone & Water Heating

Considerations:

- Consumer energy prices
- Complexity of integration (install difficulty)
- Industrial hardware and electrical requirements
- Upfront capital expenses
- Dependence on heating demand (intermittent usage)
- Limited maintenance, technician, and tradesmen understanding

This scale requires certain unique conditions like cheap energy access, high-power electrical infrastructure, or unique climates and applications for well-aligned economic incentives. It's still financially feasible for some, but is a more unique market.

TIER 2: INDUSTRIAL, MANUFACTURING & COMMERCIAL BUSINESSES

Medium to large-scale heat consumers are the most promising candidates for hashrate heating upgrades. The **Industrial, Manufacturing & Commercial Business Tier** represents the next level above residential and small business applications. This category includes facilities like large warehouses, apartment buildings, office spaces, and manufacturing plants, as well as industrial operations that require low-grade (warm, not hot) heat for production. These setups are significantly larger than home or small business systems, yet still smaller than mega-miners.

Integrating hashrate heating solutions into large heat consumers like these prompts different considerations and provides unique benefits that are unavailable to smaller-scale setups.

Mining Scale: Roughly 100 kW - 10 MW

Heat Applications: Typically Large Commercial Zone / Water Heating, Heat Consuming Industrial / Manufacturing Processes

Considerations:

- More favorable commercial energy prices
- Better suited for complex integrated heating systems
- Familiar with industrial hardware and electrical requirements
- Financing, access to capital, and tax write-offs or subsidies
- Higher potential for constant heat demand (more usage = faster payback)
- Maintenance staff and on-site technicians - complete understanding of installation, integration, and system management

There's great potential for symbiotic relationships between large heat consumers and bitcoin-powered heat producers. Financing, debt, and industrial demand are better suited for expensive and complex hashrate heating upgrades, resulting in even more optimal economic incentives and performance. It's the most well-rounded candidate for hashrate heating.

TIER 3: MEGA MINERS & POWER GENERATION

At the largest scale is the **Mega Miner & Power Generation Tier**. These operations are primarily focused on bitcoin mining or grid load balancing, and are profitable (for now) without needing to repurpose their exhaust heat thanks to cheap energy access. Any heat reuse or monetization at this level serves as an additional revenue stream or cost-saving measure. However, due to the vast amount of heat generated, on-site heat reuse is challenging. Thermodynamic cycles that turn excess heat back into electricity[4] have yet to be showcased for mega-miners. This prompts partnerships with large-scale industries nearby who will take the low-grade heat, but most large operations are in remote locations and far from heat consumers.

When successfully implemented, hashrate heat reuse at this scale can provide a competitive advantage. And with well-balanced energy prices and revenue from heating, the overall cost of mining can be significantly reduced, potentially resulting in net negative operational costs.

4 Thermodynamic cycles that turn excess heat into electricity are systems, such as the Rankine or Brayton cycles, that use heat to drive a special fluid through turbines or engines, converting heat energy into mechanical energy and ultimately electricity.

As block subsidies decrease, heat monetization becomes more attractive and possibly even necessary for these large-scale businesses to survive into the future. Yet, this scale still faces unique challenges and considerations that need to be addressed for successful deployment.

Mining Scale: Roughly 10 MW+

Heat Applications: Typically District Heating, Pre-heating, Large Industrial Heat Consumers & Thermodynamic Cycles

Considerations:

- Best locked-in energy prices near generation
- Complex industrial machinery is common
- Extremely familiar with mining hardware and electrical requirements
- Financing, access to capital, and tax write-offs
- Maximum uptime; requires a large constant heat demand
- Large miners typically in rural locations, far from reuse applications
- Higher temperatures needed for industrial use of waste heat
- Finding partners or nearby applications that need the heat at scale
- Maintenance staff and on-site technicians - complete understanding of installation, integration, and system management

High uptime and financial advantages make mega-miner heat reuse attractive. Certain challenges make it difficult to reuse bitcoin miner waste heat when you have so much of it. Scale and proximity constraints necessitate large heat demand for symbiotic relationships with nearby heat consumers.

COMPARING TIERS

To better understand how hashrate heat reuse generally varies across different scales, let's break down each tier using key criteria for comparison:

Energy Pricing

Energy costs vary significantly across the three tiers of hashrate heat reuse. Residential and small business consumers often face higher utility rates with limited negotiating power, making bitcoin-powered heating less competitive compared to cheaper options like natural gas.

In contrast, **industrial operations benefit from scale-based pricing, with energy costs decreasing as consumption increases**. Larger consumers can also secure stable rates through Power Purchase Agreements (PPAs) or access near-production-cost energy by operating close to energy sources or off-grid.

While pricing for hashrate heat reuse is generally more feasible at scale, smaller applications can still make sense if the power is priced fairly.

Levels of Integration and Infrastructure

As the number of bitcoin miners in a heat reuse system increases, so does the complexity of integrating them. The more miners you use, the greater the heat output and availability to distribute heat to multiple applications. This makes the integration process more involved for larger setups. Heat reuse systems present unique challenges and benefits depending on whether they're integrated into residential, industrial, or mega-mining applications.

At the **smallest scale**, hashrate-powered heating systems are often used for localized zone heating, taking the form of space heaters. These are simple to implement plug-and-play solutions, requiring no integration to existing infrastructure. This provides an ideal solution for consumers who want to warm specific areas of their homes or offices while minting satoshis.

However, integrating these systems into larger home or business networks, like replacing a central heating system, requires more substantial modifications. These could include upgrades to electrical systems to support the high power requirements of mining hardware, along with adjustments to HVAC[5] ducting or hydronic[6] plumbing to accommodate the cooling needs of the miners and heat distribution.

In integrated applications, the bitcoin miners act as the heating core in the system that converts electricity into warmth. But to replicate the performance of a furnace or water heater, the miner must be paired with other hardware to ensure the heat is effectively captured and distributed.

Keep in mind – bitcoin miners are industrial-grade electronics. They are not yet designed to perfectly integrate with off-the-shelf heating infrastructure found at your local hardware store. Additionally, since this is a new and evolving industry, there is limited contractor experience when it comes to designing, integrating, and servicing these solutions.

When it comes to **medium-scale** applications, such as manufacturing plants, industrial facilities, and commercial businesses, integration becomes more sophisticated. These types of operations, however, are familiar with the custom fabrication and system modification necessary for implementing commercial and industrial-grade heating systems. This experience makes them better suited for integrating industrial hashrate-powered heating hardware that is yet to be standardized.

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5 HVAC stands for Heating, Ventilation, and Air Conditioning. It refers to air-based systems designed to regulate indoor temperature, air quality, and comfort in residential, commercial, or industrial spaces.

6 Hydronic systems use water or other fluids as a medium to transfer heat through pipes, radiators, or underfloor systems, providing efficient liquid heating in integrated heating setups.

The scale and complexity of heat demand in these settings can be significant, which calls for more thoughtful design and comprehensive integration that balances both mining performance and heat delivery. The system might require more automation, monitoring, and control software to manage the miner's heat output and ensure it's efficiently distributed to more complex targeted applications. In these industrial settings, someone is often paid to understand, maintain, and oversee a system like this.

At the **largest scale**, the level of integration becomes the most complex. These setups likely require custom-built solutions and fabrication to channel vast amounts of heat over large distances for district heating or to power thermodynamic processes and complex machinery. The hardware needed to move heat on this scale involves industrial-grade heat exchangers, complex piping, large-scale fans, and custom control systems for managing heat distribution across multiple applications. Mega mining operations must integrate these systems into their broader business model, considering factors like uptime, continuous heat demand, and long-term maintenance. Here, integration is not only about hardware but also about coordination with local utilities, regulatory bodies, and large industrial partners who take the heat.

Despite these challenges, mega mining operations have staff that are extremely familiar with the hardware and systems required to manage heat at scale. They already have advanced cooling systems in place, and adding heat reuse capabilities could unlock significant revenue streams.

As you scale up from small residential applications to mega mining operations, the complexity of integrating hashrate-powered heating systems increases. The key to success lies in adapting the system to the scale, available infrastructure, and specific heat demands of the application. While residential and small business setups can benefit from simplicity and accessibility, industrial operations and mega-miners require more engineering, advanced infrastructure, or partnerships to maximize the value of the heat generated by bitcoin miners, while also benefiting from being more familiar with industrial hardware, custom system modification, and the miners themselves.

Economics and Financing

To no surprise, upfront costs play a big role in the feasibility of hashrate heating systems across different scales. Bitcoin miners are expensive devices – especially when compared to boilers and furnaces used most commonly for heating.

For residential and small business applications of hashrate heating, the initial capital expense may scare off end users at first. It is true – these systems can be quite expensive, especially if it's an upgrade to an already working system. **Unlike traditional heaters such as boilers and furnaces, however, these ones pay you back over time.** And they often have much faster returns on investment than you would think.

Consider an individual homeowner - spending thousands on a new or upgraded heating system is a big ask. Especially if that initial investment has to come out of savings that could otherwise purchase bitcoin. But hashrate heating systems do pay back over time - eventually covering their own cost. So if your current heating setup is broken or needs to be replaced anyway, then it makes even more sense to consider it.

What if you already have a working boiler in your basement? Is it worth spending extra money up front to swap in a few bitcoin miners? Maybe – the answer depends on a handful of factors, including demand and energy costs. **But most certainly, a smaller upfront cost is more favorable for quicker payback.**

Businesses, on the other hand, are less concerned with the initial capital expenses for a new heating system. They have the ability to write off expenses from their taxable income, effectively reducing total profits and the amount owed to the government during tax season. This also applies to large mining operations purchasing heat reuse infrastructure.

Financing is another variable to consider. Business owners can take out personal or business loans at low interest rates to spread out up-front costs. I think it's fair to say, however, the majority of individuals and small business owners prefer not to go this route (even though us bitcoiners know it's the smartest thing to do because debt makes sense when the interest rate is less than inflation). **Larger corporations and mining operations have access to cheaper debt and more favorable terms because of the scale of money they borrow and access to capital markets**.

Many **grants and subsidies** also exist in the name of emissions reduction and electric heating. If properly researched, businesses and individuals can apply to take advantage of government and private subsidies.

Another cost consideration is the ratio of revenue generating to non-revenue generating assets in the system. This key performance indicator uniquely applies to hashrate heating systems because they generate revenue in addition to heat. The heat delivery and control infrastructure does not pay you – only the bitcoin miners. Optimizing this ratio results in a faster return on investment.

$$Ratio_{Rev\ Gen\ Assets} = Cost_{Miners} / Cost_{Infrastructure}$$

Across the different hashrate heating tiers, the ratio of revenue generating to non-revenue generating assets is typically higher for large mega-mining operations. Then comes industrial operations, manufacturing plants and businesses. They also benefit from larger order quantity pricing, economies of scale, discounted wholesale infrastructure costs, and are also more likely to have existing high power infrastructure ready to go for mining hardware. Typically, home and small business hashrate heating systems have the worst ratio of revenue generating to non-generating assets – which indicates that more money must be spent on stuff that won't generate revenue in return.

These economic and financial considerations for hashrate heating solutions point to better deals for larger projects. The bigger and closer to the money printer you are, the better you have it. **Businesses and larger operations are also most interested in reducing their bottom line expenses, and are more willing to take on debt to do so**. The takeaway is that bitcoin heat reuse makes a lot of sense if you're a business that uses heat in large quantities. Yes, there *are* home owners and individuals out there where hashrate heating makes sense, but larger commercial operations are more often the best candidates.

Uptime and Duty Cycle

Bitcoin heating systems only mine bitcoin when they are turned on and delivering heat. As a result, mining subsidies increase with heat consumption. This means the more heat you use, the more bitcoin you will mine.

The duty cycle of a heating system refers to the percentage of time that the system is actively operating to provide heat, relative to the total time period being considered, or the fraction of power a miner runs at compared to its maximum output capacity.

For example, if a heating system is on for 15 minutes in an hour and off for the remaining 45 minutes, the time-based duty cycle is 25%. Or, if a miner runs at 1250 watts on average over a time period, and its maximum power rating is 5000 watts, then the power-based duty cycle is also 25%.

$$\textit{Duty Cycle}_{Time} = \textit{Time}_{ON} / \textit{Time}_{TOTAL}$$
$$\textit{Duty Cycle}_{Time} = 15\ \textit{min} / 60\ \textit{min} = 0.25 = 25\%$$

$$\textit{Duty Cycle}_{Power} = \textit{Power}_{Miner} / \textit{Power}_{Miner\ Max}$$
$$\textit{Duty Cycle}_{Power} = 1250\ \textit{watts} / 5000\ \textit{watts} = 0.25 = 25\%$$

As the scale of a hashrate increases with each tier, the heating duty cycle tends to increase. For residential and small business applications, the heating duty cycle is largely dependent on the climate for the system deployment. In colder climates, more heat is required for zone and water heating. In hotter climates or during warm seasons of the year, a bitcoin heating system may run rarely or not at all.

Industrial and manufacturing operations, on the other hand, are more likely to use heat in higher duty cycles. For example, as an input for their operations, independent of external weather factors. Food plants, distilleries, green houses, and countless other businesses require heat year-round as part of their operations. For this tier of hashrate heating, higher duty cycles result in more bitcoin rewards, thus faster payback.

For the largest tier of hashrate heat reuse, mega-mines operate with almost full uptime. Their duty cycle is near 100%. As a result, this scale of bitcoin heat monetization is offset with the most potential mining rewards, driving the incentive for heat reuse in these applications.

Hashrate heating systems that run more often will pay themselves off faster than systems that run intermittently. Given this fact and the benefits of their scale, industrial and manufacturing operations are the best suited for hashrate heating.

ONE FILTER FITS ALL?

Scale alone does not determine the economic feasibility of bitcoin heat reuse. Instead, it's a preliminary filter that helps identify where the technology might provide the most value and best return on investment across different tiers of integration.

So, how exactly do you find out if hashrate heating is for you?

WHAT MAKES AN IDEAL CANDIDATE?

The exact economic feasibility of bitcoin mining heat reuse depends on a broader set of variables that must align to make the system financially attractive.

THE HEAT AUDIT

The ultimate value proposition of bitcoin heat reuse systems is highly subjective. It depends on what the individual or business values most. It could be non-KYC sats, reduced emissions, or network security for example. **The strongest value proposition to integrate bitcoin heat reuse systems, however, is the economic incentive of reducing net heating costs with bitcoin mining rewards**. At the end of the day, everyone wants to save money and improve their bottom line.

By filtering hashrate heating applications exclusively to use cases where heating costs are sufficiently offset, we can identify the core criteria that determines feasibility and identify the target market.

All of the variables that must come together for well aligned incentives can be determined in an analysis which I've started to refer to as the ***Heat Audit***.

Existing Heating Method and Cost

Bitcoin miner heat exhaust is low-grade. This means it's best suited for heating applications, rather than used for *work* like boiling fluids or spinning turbines. **This makes hashrate heat great for human comfort and water heating**.

The most common energy sources for comfort and water heating are natural gas, propane, resistive electric heat, heat pumps, and heating oil or wood. The first key variable for assessing economic viability of hashrate heating is examining which of these existing heat sources and costs are going to be replaced or offset. Depending on the original energy source used for heating, the cost savings can vary substantially.

Natural Gas Heat

Globally, the most common heat energy source is natural gas. In the United States, natural gas is used for over 60% of heating needs[7]. Natural gas is common because it stores a lot of energy and is easy to transport over long distances through pipes. Converting its cost from a dollar-per-cubic-foot basis to dollar-per-kWh makes it easy to directly compare the energy price on a unit cost basis to electricity.

Natural gas is roughly 2-5 times cheaper than electricity in the US, coming in around $0.04/kWh equivalent, compared to an average electric cost of $0.13/kWh. This means it's typically unwise to replace a natural gas heating system with a normal resistive electric heater. **For a hashrate electric heater to economically out perform a natural gas heating system, the mining rewards would need to be large enough to offset a 2-5x increase in the heating utility bill when switching from gas to electric**.

As a result, it's extremely difficult for bitcoin-powered heating systems to compete with natural gas systems. If the use case application has access to cheap natural gas, it's likely not worth installing bitcoin-powered heaters.

Propane Heat

While less common than natural gas, propane is still widely used for heating around the world, particularly in rural areas or locations where natural gas infrastructure is not available. Propane holds even more energy than natural gas, and can be easily stored in tanks. This makes

7 Data from https://www.eia.gov/consumption/residential/

it more suitable for rural and remote applications, where natural gas lines have not been drilled for centralized distribution.

Propane, however, is much more expensive than natural gas. In the Americas, converting the price from dollar-per-gallon to dollar-per-kWh for comparison shows it typically costs 2-3x more than natural gas on a per unit energy basis, around $0.10/kWh. **This puts the cost of energy for propane heat in close range to electric resistive heat, which doesn't have to be stored in pressurized tanks or delivered monthly**.

When adding bitcoin mining revenue to your electric heat, the systems can often provide sufficient mining rewards to bring the net heating cost below that of propane. Bitcoin-powered heating systems also eliminate dependence on propane refills, delivery charges, and other associated costs. This makes rural heating applications with propane heat good candidates for bitcoin-powered heating system upgrades.

Resistive Electric Heat

Resistive Heating – baseboard heaters, space heaters, and electric furnaces for example – is more common in places where electricity is relatively affordable or where there is no access to gas or fuel infrastructure. **A bitcoin miner is already a resistive electric heater that performs logic operations while the electric energy is converted into heat**. The upgrade from traditional electric heat to bitcoin electric heat has no impact on your utility bill. It's only upside, and the sats are essentially free.

An electrically resistive heater is a bitcoin miner with zero hashrate, and a bitcoin miner is an electrically resistive heater that pays you for securing the bitcoin network.

Electric heaters are dumb heaters. Bitcoin miners are smart heaters. **All electrically resistive heating infrastructure in the world should be replaced with hashrate heaters**.

Heat Pumps

Heat pumps are a growing method of comfort heating. They use a highly efficient heating technology that transfers heat from one place to another, rather than generating it from electricity or other fuels. They are effectively air conditioners that operate in reverse, and work by consuming electricity to pump a special fluid that **moves** heat from one place to another.

A traditional electric heater converts electrical energy directly into heat at 100% efficiency – so you get 1 kWh of heat for every 1 kWh of electricity consumed. A heat pump, on the other hand, moves heat from the outside air into your home or business by taking advantage of the energy in the ambient air, plus the energy supplied to spin the pump. Because it's moving heat rather than generating it, a heat pump can deliver 2.5 to 4 times as much heat as the electricity it consumes - called a coefficient of performance (COP).

$$COP_{heat\ pump} = 2.5\text{-}4$$

$$COP_{electric\ heat} = 1.0$$

This makes heat pumps 2.5-4 times more difficult to compete with for bitcoin-powered resistive heaters that convert electricity into heat and satoshis.

$10 worth of heat from a heat pump could cost upwards of $40 from an electric resistive heater for the same amount of warmth.

Heat pumps have their drawbacks, however. They perform worse the colder it gets outside (just like an air conditioner struggles on a very hot day). This is because there is less energy to move inside from the air outdoors. Around the freezing point of water, heat pumps begin to struggle and operate with similar efficiency to resistive heaters. **Wherever heat pumps are well suited, it may be difficult for bitcoin heaters to compete, but in extremely cold climates or at high altitude, hashrate heaters are the best electrically powered alternative**.

Heating Oil
Heating oil is also a common heat source in older developments like New England and Europe. Like propane, heating oil is energy-dense and stored in liquid form (similar to diesel fuel), making it well-suited for off-grid or rural heating where natural gas infrastructure is unavailable. However, heating oil tends to be 2-3x more expensive than natural gas and its price will fluctuate based on market conditions. On a dollar-per-kWh basis, prices average around $0.09/kWh equivalent in the Americas. While often slightly cheaper than propane on a per-unit energy basis, its costs are within close range of electric heating in many cases.

Similar costs between heating oil and electric heat presents the potential for hashrate heaters to offer an energy arbitrage opportunity, when factoring in bitcoin mining rewards. One of the drawbacks of heating oil, like propane, is that it requires on-site storage in tanks, meaning homes and businesses need to regularly refill their supply. It also burns less efficiently than propane or natural gas, resulting in less useful heat per gallon. Switching to bitcoin-powered heating can help reduce net heating expenses while providing greater ease of use.

Wood Heat
Wood is still used in many rural or off-grid homes, particularly where electricity or other fuels are expensive or unreliable. Interestingly, wood is still a cost-effective heat energy source. On a dollar-per-kWh equivalent cost, wood can undercut many common electric rates, coming in at around $0.06/kWh. When self-gathered, wood burning offers independence from energy prices and infrastructure, but it requires labor for sourcing and maintenance. Wood-burning systems, however, have lower efficiency than all other heating methods, and they produce more local carbon emissions.

When compared to bitcoin-mining heaters, wood heating has its challenges. **While wood is often cheaper than electric energy or even free in some areas, it doesn't offer the convenience of a ful-**

ly automated electric system powered by bitcoin. Wood storage also takes up a lot of space. The decision to switch from wood to bitcoin-powered heating depends on the availability of fairly priced electricity, the local cost of wood, and your preference for labor and maintenance.

Heating Method Takeaway

The existing heat source you have plays a significant role in the economic feasibility and convenience of integrating hashrate heating. Homeowners and businesses with access to cheap gas already have an efficient, low-cost heating solution. **For those without gas infrastructure, stored heating fuel alternatives can be more expensive or cumbersome, making them ideal candidates for bitcoin-powered heating systems. Those with electric heat are already paying the price of a bitcoin heating system, and are rewarded nothing in return.**

And remember, in traditional bitcoin mining operations, heat is a by-product and a problem. For them, there's no existing heat source to consider. Selling excess heat simply adds revenue to their business.

Electric Pricing Variables

When you switch to a bitcoin-powered heating system, the cost of heat energy shifts to your electric bill. For on-grid applications, your electric utility provider largely determines this cost.

Utility Rate

The cost of electricity is the most critical factor in determining whether a bitcoin heating system will save you money. It serves as a baseline for calculating the cost of bitcoin-powered heat before factoring in any mining reward subsidies. Globally, the average cost of electricity is around $0.16/kWh for residential consumers and $0.13/kWh for commercial users.

As we discussed with existing heat sources, you can convert the cost of other heating methods – such as natural gas – into a cost-per-kWh basis to directly assess them with your electric bill in an apples-to-apples comparison.

If your electric cost is equal to or cheaper than your existing heating cost on a $/kWh unit basis, then switching to hashrate heating is a no-brainer.

However, if your electricity is more expensive than your current heat source, the decision becomes far more complex. You might wonder, how much can bitcoin mining rewards offset the cost of electricity? Can it cut your net heating cost in half? Can bitcoin mining make electric heat competitive with your original heat source?

It depends. There isn't a straightforward answer. The amount a heating bill can be offset depends on several factors:

- **Electricity Rate:** The higher your rate, the harder it is for mining rewards to offset it.

- **Miner Hashrate and Efficiency:** Newer miners offset heating costs more effectively, but are more expensive to purchase.

- **Bitcoin Hashprice ($/TH/s/day):** Fluctuates based on the price of bitcoin, the block subsidy, on-chain transaction fees, and network difficulty.

While mining rewards can reduce your net cost, the exact percentage of savings is highly variable. In certain scenarios, mining rewards can fully offset heating bills. Typically, additional analysis is needed to determine whether hashrate heating will outperform other energy sources in your specific case.

Demand Charges, Dynamic Pricing and Load Management
With electric heat, understanding how electricity is priced is important. **Several factors can significantly impact your overall electricity**

costs, particularly for commercial applications who use heat more consistently and in larger quantities.

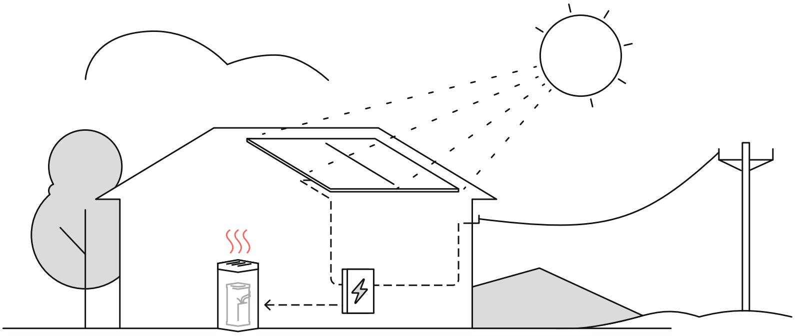
- **Demand Charges:** Commercial users often face penalties for their highest rate of peak power usage during a billing cycle, even if it's brief. Running bitcoin heaters instead of gas heaters could raise these peaks, but spreading power draw evenly throughout the day helps minimize the charges.

- **Dynamic Pricing:** Time-of-use (TOU) pricing means electricity costs vary by the time of day. Bitcoin heaters can be programmed to run during cheaper off-peak hours, optimizing costs and reducing heating expenses.

- **Load Management:** Utilities prefer steady, predictable energy loads, which are less stressful on the grid. A consistent bitcoin heating system may qualify for lower rates or incentives for maintaining stable energy demand.

Solar and Self-Generation
Solar panels or other forms of self-generation (like wind or hydro), can further reduce your electricity costs by using your own generated power for bitcoin mining and heating. This reduces dependence on grid electricity, lowering your average electric cost.

For example, if your standard electric rate is $0.10/kWh, but you generate part of your electricity from solar, your blended cost could drop to $0.07/kWh. This reduction makes bitcoin heating more financially attractive.



The more free or low-cost energy you generate, the less you rely on the grid, and the more competitive bitcoin-powered heating systems become.

Utility Relationships

Your relationship with your electric utility can also affect the feasibility of bitcoin-powered heating systems. In some cases, utilities are willing to offer lower rates if your energy usage increases significantly or if you provide benefits to the grid. Utilities may also offer incentives or rebates for energy efficiency measures or renewable energy adoption.

For instance, **switching from propane to electric heating via bitcoin miners may increase your electricity consumption enough to move you into a new pricing tier, where your rate per kWh decreases due to higher overall usage**. This often happens automatically, but it can also be triggered by reaching out to your utility provider.

Electric Pricing Takeaway

Understanding how electricity is priced is critical when evaluating the feasibility of bitcoin-powered heating systems. These factors can either support or hinder the economic viability of the system. Ultimately, each must be weighed together to determine if bitcoin heating is an attractive option for your specific application.

Duty Cycle Investigation

As we discussed with the different tiers of heat reuse, **the duty cycle of a hashrate heating system refers to the used percentage of maximum heating the bitcoin miners are capable of**. When it comes to bitcoin-powered heating systems, the duty cycle directly affects the system's *return on investment* (ROI).

ROI is a key performance indicator of the **Heat Audit** because hashrate heating systems will often replace existing heating systems that work perfectly fine. **The economic case has to be made to justify the hardware upgrade and installation costs**.

The percentage of your bill reduction – whether it's 30%, 70%, or even 100% – is determined by factors like bitcoin's hashprice, electricity cost, and the efficiency of your miner. These apply anytime the system is providing heat. **This bill reduction percentage remains in effect no matter how often the system runs – whether it's on for a few minutes or several hours a day**.

How quickly the system pays itself off, however, depends on how often it's running. If your duty cycle is high, it will generate more mining rewards, speeding up the payback period. **For certain applications, a hashrate heating system may technically reduce heating costs, but a slow ROI from infrequent usage and high upfront cost may make the solution less than ideal.**

Symbiotic Relationships

In many cases, the most suitable candidates for integrated bitcoin-powered heating systems are commercial operations and businesses that require heat for purposes beyond just keeping spaces warm in winter months. These businesses may use low-grade heat year-round as part of their core operating costs, whether for industrial processes, manufacturing operations, or other commercial activities. **This highlights the symbiotic partnership between frequent heat consumers and hashrate heat producers**. These consumers naturally have higher duty cycles, which makes bitcoin heating systems a more attractive and effective option.

What makes these symbiotic relationships so appealing is not just the more consistent heat demand, but also the strong financial incentive. **Businesses are typically more ROI-conscious than residential users**. If a company is considering investing in an upgraded heating system, it's crucial that the system not only cuts its heating costs but also is a worthwhile investment.

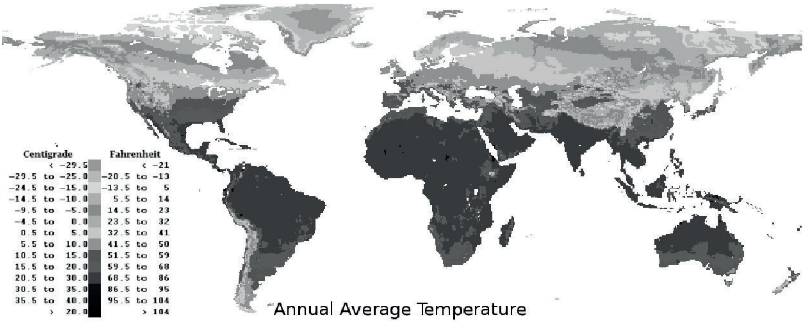
There must be a forecasted ROI to make the business case. They want to know how long it will take for the system to pay for itself, and once that threshold is crossed, the system starts generating profit. After all, bitcoin heaters don't just have the potential to reduce heating bills; they can also add a revenue stream to what would otherwise be a sunk cost.

In contrast, residential users may not place as much weight on the idea of ROI, as their heat demand is typically lower, more seasonal, and less tied to specific targeted use cases. It's still a useful metric worth considering for anyone looking to upgrade an existing heat source. But remember**, depending on the other factors, home heating can still have high-duty cycles**. The biggest driver of which is your climate and environment, which we'll talk about next.

How Climate and Environment Impact the Business Case

The climate and environment for a bitcoin heating deployment is important because it influences the duty cycle. In extremely cold locations or at high altitudes, heat is needed more consistently and in larger quantities. Extended heating seasons directly increase the system's duty cycle, which, in turn, results in a faster return on investment (ROI) for both residential and commercial hashrate heating. **In certain locations, climate can increase the heating duty cycle to such a degree that a typical residential heating system will run year round, mimicking a business that uses heat as part of its regular operations**.

In high-altitude or dry (low humidity) locations where the air is thinner and temperature drops quickly overnight, heating demands may stretch well into the warmer months, allowing the bitcoin miners to operate continuously for longer periods. This constant demand for heat gives hashrate heaters more uptime throughout the year, accelerating the system's ability to pay itself off via mining rewards.



In contrast, regions with mild climates or shorter winters may see lower duty cycles, as the system won't need to run as often. The overall bill reduction might still be substantial when the system is operating, but the payback period will take longer due to infrequent use.

Ultimately, the climate is the most important external factor for feasibility in most bitcoin heating systems.

Matching Hashrate and Heat Demand

Like we initially outlined with the different tiers, scale plays a big role in determining whether it makes financial sense for a particular application. Bitcoin miners are highly efficient, power-dense devices, but they can also be expensive to purchase and often require custom infrastructure upgrades.

Equally important to the quantity of total heating power required is the concept of matching hashrate power with heat demand.

Unlike traditional heating systems that can operate intermittently with high peak outputs on an extremely cold day, bitcoin miners like to run at a consistent rate, providing a steady stream of heat and sats. **Typical fuel-fired heating systems – like those running on**

natural gas – often have the capacity to deliver much higher peak heat outputs than is commonly used. They primarily run, however, in short bursts with low-duty cycles (your furnace/boiler turns on for 5 minutes, then off for 55 minutes each hour, for example). This allows them to cover a large range of heating needs.

A hashrate heater, on the other hand, operates best when running steadily and consistently. It's not designed to - nor economically wise to - run at 5% power, with a huge amount of headroom for a colder day. This makes it crucial to match your miner output with your average day-to-day heat needs as closely as possible. A heating system should be designed to best match mining power with the peak heat demand on the coldest and most stressed day of the year – known as a **design condition**.

If, for example, your peak heat demand is 7 kW on a very cold day in January, then a bitcoin-powered system should be sized to provide close to that amount, avoiding oversizing. **Adding more miners than what is typically required leads to idle machines sitting unused for most of the year, which is a significant waste of money, as they could be generating revenue if they were active**.

Two 3kW miners totalling 6kW are better than three that total 9kW of heating power. A slightly undersized hashrate heating system like this uses the miners more optimally and allows for the original heat source to top off the remaining heat required on the coldest day. The 9kW three miner system, on the other hand, is oversized. That third machine will only turn on during the most stressed days out of the year and destroy system ROI. **The hardware cost associated with designing to the coldest day may not be worth it**.

In some cases, it might even be more cost-effective to size the hashrate heating system to cover 80% of your heating needs during the season, then rely on a traditional backup system, like an existing propane heater, for the remaining coldest days of the year.

The goal is to balance and size the system so that your miners are working as close to full power, as much as possible. **Do not simply look at the heat output rating of your furnace and use that to calculate the number of bitcoin heaters you need**. That number represents the maximum heat load available if the furnace or boiler was running full-time at full power, which they don't do.

These concerns have less impact in climates or applications where there is a smaller variance between minimum and maximum heat load. If it's cold most of the year and stays cold around a relatively consistent temperature, your design condition shouldn't look that dissimilar from an average day. The same goes for targeted heating in a commercial or business application. If your load is consistent, then matching hashrate to heat demand is easier.

Keeping all of this in mind maximizes the main value proposition of bitcoin rewards and optimizes ROI, making sure you're getting the most out of every machine without overdoing the budget. But if you have extra capital, or want to ensure heating needs are met no matter what - there's no physical harm in having extra heating capacity.

Target Application

Not every heating application is a good candidate for a bitcoin-powered solution. While hashrate heaters offer unique benefits, they come with their own limitations. Certain use cases are better aligned with the capabilities of bitcoin heaters, while others may be impractical or inefficient. Understanding the target application is an important part of the **Heat Audit** to determine whether hashrate heating is the right solution for a given setup.

Temperature Requirements

Exact temperature requirements are important to consider when evaluating whether hashrate heating is suitable for a specific appli cation. Bitcoin miners generate low-grade (warm) heat – ideal for some heating applications, and not for others.

Most current miners can produce fluid outlet temperatures from 40°C - 70°C (104°F - 158°F) from the manufacturers, without overclocking[8]. This range is sufficient for comfort heating, warming water for standard residential and commercial use, or other low-to medium-temperature applications.

However, if the use case requires high-grade heat – for example, to heat fluids above 100°C (212°F) or run industrial processes like steam turbines – bitcoin miners are not yet suitable. For these high-temperature applications, combustion heating systems that can boil liquids are a better fit. **Of note, these same limitations apply to heat pumps and traditional electrically resistive heaters. There's a temperature output barrier between combustion fuel heat sources and electric heat**.

Specific Use Cases

Beyond temperature requirements, certain heating use cases may not align well with the capabilities of current bitcoin miners on the market. **Applications that rely on specific flow rates may find bitcoin-powered systems impractical or inefficient**. Target applications for hashrate heating are best suited when the heat demand is steady and the required amount of warm air or liquid falls within the operational capabilities of the available machines.

8 Overclocking refers to pushing mining hardware beyond its factory-set performance limits to increase hashrate. This results in higher bitcoin rewards at the cost of increased power consumption and more heat output. Underclocking, on the other hand, is when you lower your power consumption, and therefore hashrate to improve efficiency or reduce heating power.

BRINGING IT ALL TOGETHER: IDENTIFYING YOUR HEAT REUSE POTENTIAL

The **Heat Audit** framework serves as a general guide. What it points to is that while bitcoin heating can technically be integrated into any application – whether HVAC systems, hydronic heating, space heaters, or district heating – **it's the ideal alignment of specific factors that ultimately determines whether the system makes economic sense**.

If the analysis shows a strong mismatch in any of these variables, it might be best to stick with your current heating setup. The technology and value proposition are promising, but it's not a one-size-fits-all solution – and that's where a thorough, personalized assessment like the **Heat Audit** becomes important.

Let's see who has passed the **Heat Audit** with flying colors.

INVESTIGATING SUCCESSFUL CASE STUDIES

With the feasibility framework in place, it's time to take a look at applications that not only prove the effectiveness of this technology, but also showcase potential target markets and blueprints for scaling hashrate heating into more homes, businesses, and products.

SPACE HEATERS

Space heaters are straightforward, plug-and-play devices, ideal for localized zone heating. Designed to warm the air in a specific area, they're perfect for targeting cold spots in homes or offices. They're especially valuable for those without central heating or for anyone looking to cut costs by only warming spaces they're actively using. Bitcoin-powered space heaters take this a step further, not only warming the room but also mining satoshis. These devices plug directly into wall outlets, converting electricity into both heat and bitcoin – no modifications or additional integration required.

The hashrate heating movement began with bitcoin plebs retrofitting older mining hardware for space heating purposes. Today, companies have emerged that offer DIY solutions as well as fully integrated bitcoin space heater products, bringing this concept to a broader market.

What makes a bitcoin miner a suitable space heater ultimately comes down to making it a good "roommate". Traditional air-cooled miners tend to be loud, heavy, and power-hungry, which makes them less than ideal for home or office environments. Whether you want to build a DIY miner space heater or buy an off-the-shelf product, more options are becoming available.

DIY and Retrofitted Hashrate Space Heaters

As new, more powerful industrial miners enter the market, older machines struggle to stay profitable, especially as mining difficulty increases with more participants joining the network. For these outdated machines, mining operations face a choice: search for cheaper electricity, or junk them for more efficient models. **But some machines find a second life, repurposed as space heaters, since efficiency isn't as important when you also value the heat**.

Enter the bitcoin plebs and builders who started modifying older ASIC miners to turn them into cozy, efficient heaters. Through DIY projects, they found ways to make these machines suitable for the home, delivering both warmth and cost savings.

Common modifications for converting a bitcoin miner into a space heater include adding WiFi, fine-tuning power, replacing loud fans, tuning temperature limits, modifying the power supply, creating an appealing enclosure, and more.

Several companies and individuals have been instrumental in bringing bitcoin-powered space heaters to market, overcoming challenges and educating the public on this innovative technology. **CryptoCloaks** is well-known for their 3D-printed Bitcoin accessories and has created kits and tutorials to help users modify Bitmain Antminer S9 miners into space heaters, complete with custom 3D-printed enclosures for a polished, home-friendly look. **Altair Bitcoin Mining Solutions** and **D-Central Technologies** also contribute to this space. They offer a variety of retrofitted space heater products, with many of the essential adjustments already done. **Pivotal Pleb Tech** focuses on making industrial miners more accessible for home use with their Loki Kit. This innovative device connects to the control board of certain Bitmain ASIC miners, allowing them to run with different power supplies on standard 120V outlets, transforming new-generation miners into practical home space heaters rather than power-hungry industrial machines.

Commercially Available Hashrate Space Heaters

Building on the success of DIY and retrofitted hashrate heaters, some companies have taken the next step by developing fully integrated, user-friendly space heater products. Some of these products repurpose older or used mining chips and circuit boards from industrial machines, modifying them to make operation simpler and more accessible for home use, while other players have engineered mining hardware and circuit boards entirely from scratch. Designed specifically for space heating, these devices offer plug-and-play ease in more usable form factors, aiming to make bitcoin-powered heating suitable for a wider market and more mainstream adoption.

Unbound Networks

Unbound Networks is advancing bitcoin-powered space heating with a heavily refined device that reuses industrial miner hashboards, pre-modifying the machines for easy home use and quiet operation.

Heatbit

Heatbit takes a different approach, with hashrate space-heaters designed from the ground up for room heating and air purification. Their systems are vertically integrated at the chip level with a custom hashboard and remote management app that maximises simplicity. It's also the first hashrate heater that is UL safety certified, a small but significant benefit to this purpose-built, high power heating device that's meant to be kept in the home.

In my view, **this is the first step into the next phase of hashrate heating, where companies design dedicated heating appliances and infrastructure powered by bitcoin mining, free from the limitations and challenges described before with repurposed industrial mining equipment**.

POOLS AND HOT TUBS

Heated pools and hot tubs are another excellent application of bitcoin heat reuse, as they often require heating for extended periods throughout the year. They don't get extremely hot, and typically have their own isolated plumbing and heating systems. Furthermore, **many pools and hot tubs are already heated with resistive heat, stacking no sats for the same operating cost as a bitcoin heater.**

Much like space heaters, bitcoin enthusiasts have already begun modifying and integrating traditional mining hardware to heat pools and hot tubs by themselves with custom solutions. At the same time, companies are emerging that specialize in products specifically designed for hashrate-powered pool and hot tub heating, offering a more plug-and-play approach.

Custom Built Hashrate Heated Pools & Hot Tubs

There are many different ways to integrate a bitcoin-powered heating system into pools and hot tubs. By carefully selecting heat transfer hardware, control devices, and software, enthusiasts can create high-performance custom systems. With the right modifications, traditional industrial mining hardware can be repurposed, retrofitted, and integrated to provide effective heating for pools and hot tubs of all sizes.

To make these industrial miners suitable for pool and hot tub heating, a few key modifications are typically needed, just like with the space heaters mentioned above. Additionally, converting air-cooled miners to liquid cooling through immersion tanks or using hydro miners ensures the hashrate heat can be captured and delivered to the pool or hot tub effectively[9]. Finally, enclosing the system is recommended

9 Immersion tanks and hydro-cooling are liquid cooling techniques. Immersion involves submerging the hardware in a specialized non-conductive liquid to extract heat, while hydro-cooling circulates cool water through the miners, directly onto ASIC chips.

to protect it from weather and wear, ensuring that it can withstand outdoor elements and function reliably over time.

Here’s a great example of one of the early innovators:

Nakamoto Heating Solutions Hashtub

One company pushing the bitcoin-powered heating industry forward is Nakamoto Heating Solutions, founded by Michael Schmid (Schnitzel on X), who created the Hashtub. He’s developed a fully integrated and smart hot tub heating system powered by hashrate. This system includes plumbing and electrical components with adjustable valves, variable pump speeds, and relay power controls for the miners. Additionally, it features a Raspberry Pi microcomputer for seamless integration with Home Assistant (an open-source smart home OS), providing an interface for real-time monitoring of temperature and mining data, along with full customization and software automation controls. With only one miner, this system can bring a hot tub to operating temperature in just a few hours.

The HashTub can auto-regulate the temperature of the miners, ensuring they don’t overheat. Heat is delivered to the hot tub in bursts by cycling the miners on and off as needed. This maintains the water temperature within a range of just a few degrees, much like a conventional heating system.

Commercially Available Hashrate Pool Heaters

We are also starting to see commercial products available that have incorporated the same learnings and features from custom-built solutions into pool heating applications.

Constellation Heating

A Canadian company, Constellation Heating, has introduced the Star Heater, a fully thought-out, off-the-shelf solution designed specifically for heated pools and radiant flooring. This product is all about convenience, catering to those who want to harness bitcoin mining for heating but prefer to avoid the complexities of DIY setups with industrial miners, software customization, and intricate plumbing or engineering work.

The Star Heater comes as a complete package sized for home swimming pools, and features a user-friendly screen interface directly on the unit. Setup is easy – integrate it into the pool plumbing, plug it into power, connect it to the internet, and provide your bitcoin address to start hashing and heating. The system automatically self-regulates, preventing miner overheating and offers a seamless user experience.

Unlike traditional on-off heating systems, the Star Heater operates with a constant, adjustable heat load. Instead of delivering heat in bursts, it modulates the miner's power levels to better sustain the desired pool temperature, ensuring smooth and efficient operation.

RESIDENTIAL AND SMALL BUSINESS HEATING

Most heating systems are integrated into homes and businesses, and distribute heat to a handful of places and applications. As a result, integrated residential and small business heating systems are more complex than space or pool heating, yet are still a highly practical candidate for hashrate heat. Bitcoin miners must replace (or augment) a centralized heating element to offer the convenience of full zone heating and control.

This is typically achieved one of two ways: forced-air furnaces for air-based heat, or hydronic boiler systems that send liquid heat to radiators and other applications.

There are examples of enthusiasts and early adopters who have successfully integrated traditional mining hardware into their own homes and businesses with other infrastructure to complete custom hashrate heating setups, and now, centralized hashrate heating appliances and products are beginning to emerge.

Custom Built Hashrate Heating for Homes and Businesses

There are many ways to integrate common industrial bitcoin miners into heating systems for residential and small business settings, providing consistent, valuable heating. Custom solutions can be tailored to meet the specific heating needs of homes and businesses using traditional ASIC miners.

To adapt these industrial miners for integrated heating, the same key modifications are often required. WiFi compatibility offers convenience, while fine-tuning power settings enables more precise heating control. Form factors, noise, and compatibility concerns can be alleviated with the appropriate hardware customization.

Home Bitcoin Immersion Mining - Bob's House

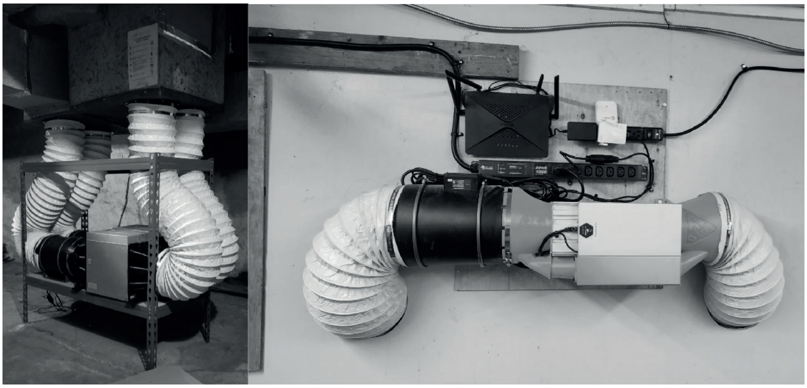
One of the most comprehensive and inspiring examples of a fully integrated hashrate heating system in a residential setting is Bob from the Home Bitcoin Immersion Mining (HBIM) YouTube channel. Bob has gone all-in, using bitcoin mining to power nearly every heating application in his home, including domestic hot water for taps and showers, his furnace for forced-air heating, radiators in the garage for a cozy workshop, and even his clothes dryer. His setup also includes an external cooling system, allowing him to continue mining even when heat isn't needed in the home. What sets Bob apart is his dedication to educating on every step of the engineering and design process. **His channel is the best-documented and most thorough resource available for anyone interested in creating a high-performance, immersion-cooled bitcoin heating system for the home**.

256 Heat - Toine's Solution Stackup

For a look at custom air-cooled hashrate heating systems in residential and small business applications, the projects from Toine of 256 Heat are excellent examples. Toine has continuously prototyped and refined his integrated air-cooled hashrate heating solutions for both home and business use, without the need for cooling oil or water.

These air systems are simpler to install and maintain, but they come with some trade-offs, such as noise levels, more limited heating capabilities, and lower mining power. Toine addresses many challenges with air-cooled hashrate heating via smart choices in hardware, including the use of a smart Wi-Fi PDU[10] for full remote power control, even when the user is away, as well as quiet fans and filters. Additionally, Toine's careful selection of components like ducts and dampers ensures effective heating performance, balancing the demands of mining and space heating.

10 A PDU (Power Distribution Unit) is a device that distributes electrical power to multiple components, like bitcoin miners, within a system. A smart PDU can remotely turn off connected devices.



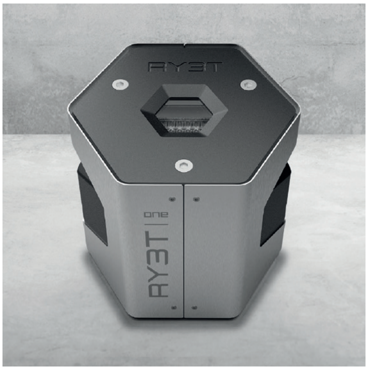
Commercially Available Home & Business Heaters

As with bitcoin-powered space and water heating solutions, specialized products for integrated home and small business heating are now emerging. These new heaters are designed to function like traditional furnaces, water heaters, or boilers, making them easy to install within existing heating systems. Currently, most of these plug-and-play solutions rely on retrofitted industrial bitcoin miners, modified for residential and commercial environments. However, fully integrated products with custom-designed hashboards and standardized form factors are likely on the horizon.

RY3T

In the European market, RY3T has introduced a bitcoin-powered boiler specifically designed for residential use. In Switzerland and many other European nations, hydronic (liquid-based) heating systems are common. The RY3T bitcoin boiler is a natural fit for integration into European home or small business heating systems, replacing traditional options that typically run on gas or other energy sources.

With RY3T's boiler, cold water goes in, then bitcoin and hot water come out. The design leverages the same principles and technology as other immersion systems, but it's sized to suit typical home heating needs and provides additional ease of use and safety features out of the box.



Hestia
The Canadian company Hestia Heating offers an air-based solution for integrating hashrate heating into home and small business systems. They've developed a forced-air furnace designed specifically to support certain industrial bitcoin miner models. Built with an optimized enclosure, airflow, fan speed, filtration, and power control panel, Hestia's system is tailored to fit seamlessly into most existing home and business furnace setups, providing an efficient bitcoin-powered alternative to traditional heating methods.

Businesses and Industrial Applications

Heat is an essential part of many businesses' operations, and consumption is a recurring operating expense. Some examples of businesses that can benefit from the synergy between their heat needs and the heat generated by bitcoin miners include breweries, distilleries, car washes, bathhouses, agricultural operations, and more. These use cases are ideal candidates for reducing operating costs while supporting the bitcoin network.

Traditional mining hardware can be integrated to these larger applications with the right infrastructure - while at the same time, specialized hashrate powered boilers and furnaces are starting to emerge for commercial use. No purpose-built heating devices at the chip level are on the market yet - although at this size, it makes more sense to use scalable solutions to meet a wide range of large heating needs.

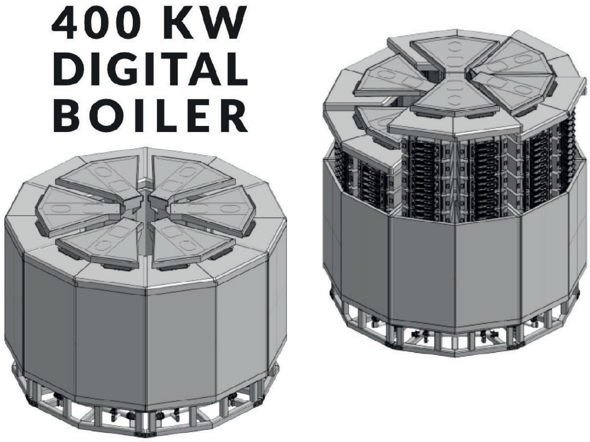
Commercial and Industrial Hashrate Heating Projects

Bitcoin mining heat can be captured through traditional mining hardware like all of the other examples and paired with specific heat transfer components, or through scalable hashrate heating products designed for large industrial operations.

Brewing and Distillation
Brewing and distillation showcase the opportunity for hashrate heating systems to integrate into operations with more consistent heat consumption. Here, bitcoin-powered heat-producing hardware is matched with an industrial process that consumes heat to produce a product. **Unlike space heating, the need for heat in brewing and distillation is independent of the climate or season and is instead a critical component of the manufacturing process**.

In brewing, heat is required for various stages such as mashing, boiling, sparging, and pasteurization, most of which fall within the temperature range that bitcoin miners can easily generate. Similarly, in distillation, heat is essential for both washing and the distillation process itself - all of which often demand high-duty cycles – making these businesses well-suited for substantial cost savings and fast ROIs.

The company **MintGreen** out of Canada has developed hashrate heating solutions for both Shelter Point Distillery and Container Brewing, and have recently released a bitcoin-powered “digital boiler” for business and industrial applications.



Greenhouses

Greenhouses are an example of a large heat consumer that is more closely linked to ambient environment conditions than operations like brewing and distillation. Depending on how cold the climate is, these applications can have widely varying duty cycles. In colder parts of the world, heat may be needed year-round to sustain plant growth.

These grow house rooms are often heated using a combination of hydronic and forced-air systems, both of which are great candidates for bitcoin-powered heat. Additionally, many greenhouse operators may appreciate the carbon-free nature of hashrate heating.

Bitcoin Bloem, a tulip farming company in the Netherlands, adopted hashrate heating by repurposing bitcoin miners to warm greenhouses[11]. This setup kept the greenhouse warm, reduced the farmer's reliance on natural gas, and provided bitcoin revenue throughout the process.

Car Washes, Concrete Mixing and the US Post Office

Commercial applications for bitcoin-powered heating extend to other unique industries that benefit from continuous heat. Car washes, for example, require a steady flow of warm water to remove dirt and grime effectively. Bitcoin miners, producing heat within the optimal temperature range, are an excellent solution.

In Challis, Idaho, **TC Car, RV, and Truck Wash** integrated industrial bitcoin miners into its water heating system using immersion tanks from **Fog Hashing**. The system, designed and implemented by hashrate heating engineer and founder of **Softwarm LLC**, Cade Peterson, demonstrates how bitcoin miners can be repurposed for commercial heating.

Softwarm has also brought hashrate heating to other industrial settings in their area, including construction sites, concrete mixing facilities, the Clayton Silver Bar and even the US Post Office in Clayton, Idaho - population: 7.

These applications leverage standard industrial mining hardware combined with heat-capture technology, like Fog Hashing's immersion tanks to deliver heat efficiently while stacking sats.

Bathhouses

In one of the world's largest cities, **Bathhouse NYC** integrated hashrate

11 Info from https://cointelegraph.com/news/flower-powered-bitcoin-miner-heats-greenhouses-in-the-netherlands

heating to supply the consistent, stable heat, essential for warming pools and hot tubs – the core offering of their business.

Initially, they relied on electric resistive heating, which consumes the same amount of energy as bitcoin miners but generates no revenue. After discovering the potential of bitcoin-powered heat, they researched mining devices, heat reuse, and worked closely with suppliers and contractors to make the switch.

Today, Bathhouse NYC has replaced its pool and hot tub heating with bitcoin-powered solutions, revolutionizing their business.

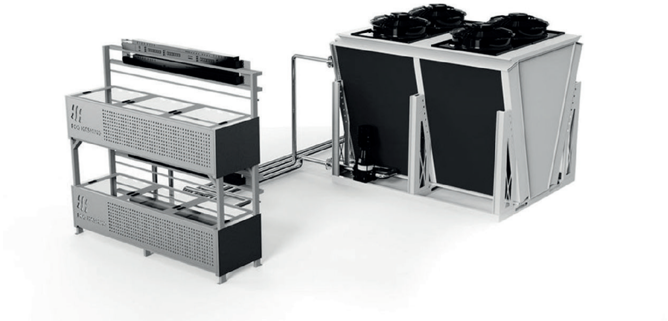
Products for Large Commercial & Industrial Hashrate Heating

The larger-scale heating applications mentioned above often require custom solutions, tailored to meet specific needs. Unlike residential applications that can use off-the-shelf appliances, these setups demand industrial-grade hardware and components. As a result, commercially available products for large-scale hashrate heating are less common, with many solutions custom-built based on each business's requirements. There are, however, companies focused on offering modular products for these applications that can be pieced together to meet any large heating needs.

Fog Hashing

Fog Hashing is one of the few companies offering these scalable hashrate heat capture products designed for larger applications. Their immersion oil tanks range from compact systems that can hold one or two industrial miners, suitable for home use, to expansive 24-miner tanks capable of capturing and repurposing substantial amounts of heat for commercial or industrial use. Additionally, Fog Hashing provides industrial heat transfer solutions that are built for hydro-cooled bitcoin miners.

These systems can be linked together to create a custom hashrate heating solution tailored to any commercial or industrial application. Fog Hashing's products come equipped with the necessary hardware and controls for high-performance, bitcoin-powered heating, regardless of size.



HeatCore

HeatCore exclusively specializes in hydro-cooled hashrate heating solutions for commercial and industrial applications. Unlike Fog Hashing, which also offers immersion heat transfer hardware, HeatCore is dedicated to delivering efficient, water-cooled systems designed to capture and repurpose the heat generated from bitcoin mining on a larger scale.

Like Fog Hashing, HeatCore's hydro-cooled systems are modular and can be inter-connected to accommodate various heating demands. Each unit is equipped with heat management features and precise controls - ready to integrate into any commercial or industrial application that needs heat.

DISTRICT HEATING & MEGA MINERS

District heating is a large-scale heating solution that provides heat to lots of consumers at once in applications like towns or university campuses. Here, a massive amount of heat generation is centralized and distributed over large distances to multiple use cases. Centralized heating is highly efficient and comes with a handful of other benefits, although it limits autonomy for the consumer.

In these systems, no heat generation is needed at the point of use. Hashrate heating systems can be scaled up (by adding more miners) to meet the high demand of district heating applications. Depending on conditions and climate goals, implementing hashrate heating can significantly reduce heating costs through mining subsidies while also eliminating heating carbon emissions for the entire district.

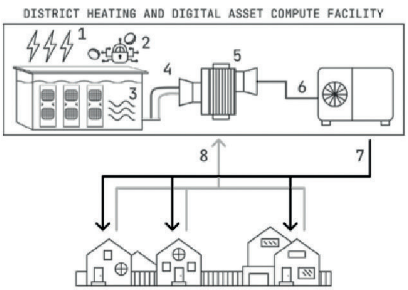
Because of the large scale of heat demand in district heating applications, these projects are a compelling candidate for partnerships between traditional mega-mining corporations and local cities, campuses, or resorts.

MARA Bitcoin District Heating in Finland

Mega-miner Marathon Digital Holdings launched a 2 megawatt hashrate heating pilot project in Finland[12]. The project uses excess heat from bitcoin mining to warm a community of 11,000 residents.

12 Info from https://bitcoinmagazine.com/business/marathon-uses-bitcoin-mining-to-heat-town-of-11000-in-finland?utm_source=chatgpt.com

By integrating hashrate with district heating, the town is able to produce reliable and consistent heating that meets demand, while saving costs through bitcoin rewards.



1. ELECTRICITY POWERS HYDRO-COOLED COMPUTING DEVICES
2. COMPUTING DEVICES PERFORM COMPUTATIONS TO GENERATE DIGITAL ASSETS AND SECURE NETWORKS
3. COMPUTING DEVICES CONVERT OVER 95% OF THE ELECTRICITY THEY USE INTO HEAT[45]
4. HEAT IS CAPTURED IN THE HYDRO COOLING SYSTEM LOOP, PREHEATING WATER FROM 55°C TO 75°C[46]
5. HEAT EXCHANGER TRANSFERS HEAT FROM HYDRO COOLING SYSTEM LOOP TO THE HEAT PUMP LOOP
6. HEAT PUMP INCREASES TEMPERATURE BY 5-25°C TO 80°C[47]
7. HOT WATER IS PUMPED UNDERGROUND TO NEARBY BUILDINGS
8. THE COOLED WATER IS RETURNED TO THE DISTRICT HEAT AND DAC FACILITY TO BE REHEATED AND RECIRCULATED

SOURCES: WILL SZAMOSSZEGI, HANNAH WRIGHT, MARATHON DIGITAL HOLDINGS

And like the commercial and industrial applications of hashrate powered heat, these large applications require custom engineering and sizing with modular industrial bitcoin heating hardware like the offerings from Fog Hashing, HeatCore, and others.

PROJECTS TO LOOK OUT FOR

As the technology matures, new projects will continue to push and redefine what's possible with hashrate-powered heating systems.

Having explored some proven examples of bitcoin heat reuse across a range of applications and scales, let's now list a few other ideal use cases.

- **Warehouses, Commercial Buildings, and Large Facilities:** From warehouses and industrial zones to hotels and offices - large facilities with centralized or zoned comfort heating systems can benefit from air or liquid-based hashrate heating.

- **Community Pools, Fish Farms and Desalination Plants:** Facilities requiring large volumes of low-grade heated water - such as public pools, fish farms, and desalination operations - are prime candidates for hashrate heating.

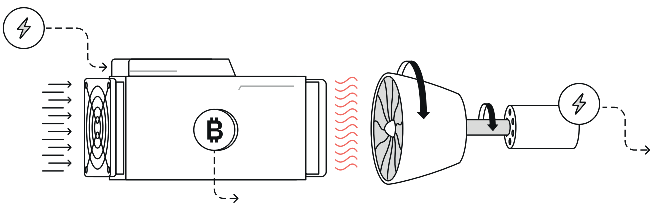
Work Applications in Thermodynamic Cycles

What all of the use cases above have in common is demand for low-grade heat. As a result, bitcoin miners are currently limited to comfort and select industrial heating applications. As the maximum output temperature from the bitcoin heating hardware increases, a whole new category of high-grade heating applications will become possible.

Heating in ***work*** applications, referred to as **thermodynamic cycles**, means using the heat to convert the energy back into other forms. Instead of simply supplying heat for warmth, the heat energy can be used in special industrial cycles to spin a turbine, power a generator, or even convert the heat energy into a cooling load for air conditioning!

Once miners are able to output high enough temperatures, we'll likely see integration into organic rankine cycles (convert heat into electricity), absorption chillers (heat-powered air conditioning), or preheating for other industrial processes - all of which will be especially interesting to mega-mining bitcoin operations.

Now that we've seen these things in practice, let's look at how they're controlled.



MANAGING AND CONTROLLING THE HEAT

The key to a successful bitcoin heating system is controlling both the amount of heat produced and where that heat goes. An important advantage of hashrate-powered heating systems is their potential for precise heat control and management, unlike traditional heating systems like furnaces or boilers. These systems are digital – they're computers that mine bitcoin – and because they use electricity to generate heat, they can be optimized specifically for high-performance and highly controllable heat.

BANG-BANG VS CONTINUOUS LOAD

This unique nature allows for a different control mechanism that modulates heat output by adjusting the power levels of the bitcoin miners themselves. However, it also presents challenges not seen in traditional heating systems, which primarily rely on straightforward on-off temperature control.

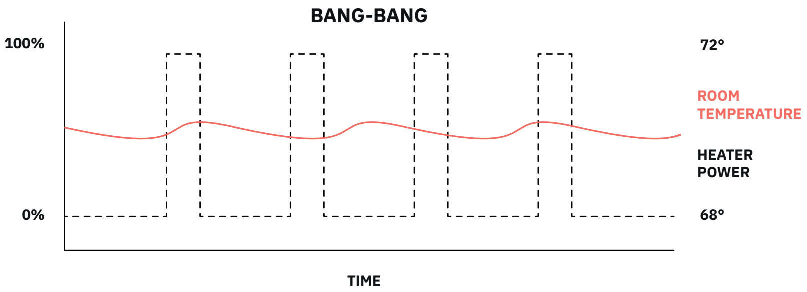
Bang-Bang

Most traditional heating systems – furnaces, boilers, water heaters, and some space heaters – use a type of control called "bang-bang" (or on-off) control, cycling the heater on and off to maintain a desired temperature.

Example:
You set your home thermostat to 70°F. When the temperature in the room falls below this target (typically with a buffer, say, at around 68°F), the furnace kicks on, delivering heat at full power until the temperature reaches or overshoots 70°F (often reaching up to 72°F). Then, the furnace shuts off entirely. This process repeats whenever the

temperature falls below the target, cycling on and off to maintain the room's desired temperature with some margin of error.

Bang-bang control systems provide maximum heat to reach the desired temperature, then shut off, waiting for the room to cool down before kicking on again. Many heating systems use this approach because partial power settings are not an option – you can't burn natural gas or propane at "half-power". The time the system is actively heating defines its "duty cycle" – the fraction of time it spends delivering heat.



While this approach works, it has downsides: it often overshoots and undershoots the target temperature, creating uncomfortable swings. Constant cycling by heating in bursts can also put additional wear and tear on the system over time.

However, a benefit of bang-bang control systems is that they can be built with higher maximum heating capacity without much additional cost.

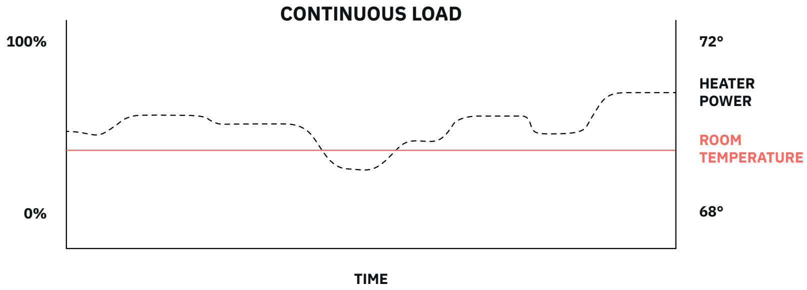
For example, a propane furnace can be designed to produce 500,000 BTU/hr as easily as 100,000 BTU/hr, by simply adjusting its duty cycle to deliver the right amount of heat. This means bang-bang systems are well-equipped to handle extreme cold snaps without extra cost.

Continuous Load

Bitcoin miners, in contrast, can operate continuously and precisely control heat output by adjusting the power they consume. **Since 100% of the mining power converts to heat, adjusting the miner's power directly changes the amount of heat produced, allowing for real-time adjustments based on heating needs**.

Example:
You set the thermostat to 70°F. With the right control software, a hashrate heater can provide exactly the amount of heating power needed to keep the room at this temperature. On a 30°F day, 1,500 watts (5,118 BTU/ hr) might be enough, while a colder day at 15°F might require 2,100 watts (7,165 BTU/hr). The miner can dynamically adjust its power in real time to maintain the set temperature with high accuracy and precision.

A hashrate heating system can continuously match its power consumption and heat output to the real-time demands of the space, making adjustments as external temperatures change or internal heat sources, like appliances turn on that could affect the room temperature.



One significant advantage of this control style is temperature stability. Rather than the temperature swings caused by on-off systems, well-designed hashrate heating systems maintain a stable target temperature, providing greater comfort and reliability – ideal for homes, offices, and applications needing precise temperature control.

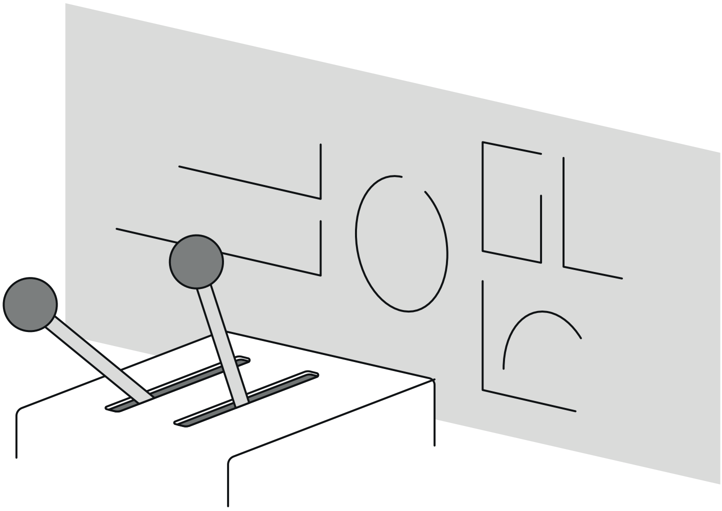
However, a drawback of this approach is limited “headroom” for total heating capacity, like we discussed with matching hashrate to heating demand. **Bitcoin miners are costly electronic devices, and tripling the capacity to handle extreme cold would require three times as many mining chips**. This makes extra hashrate heating capacity an expensive solution compared to bang-bang systems that easily handle extreme temperatures by simply increasing their duty cycle and burning more fuel. With hashrate heating, there’s a balance: additional headroom is costly and may not justify the investment if the excess capacity is rarely needed.

CONSISTENT HEAT, CONSISTENT BITCOIN

A bitcoin miner allows you to match heat demand to power output in a way traditional systems can’t. **When we talk about replacing traditional heating systems with bitcoin miners, it’s not just a change in how heat is generated. It’s a shift in how we manage and control that heat, creating opportunities for more efficiency, comfort, and best of all – revenue in the form of bitcoin rewards**.

TWO THINGS TO MANAGE

There are two things to manage in a bitcoin-powered heating system: the amount of heat and where the heat goes. Understanding how to control these aspects will help get the most out of your system. Both can be managed with software or analog controls, or a combination of the two, giving you flexibility in how you set things up.



The Amount of Heat

The first thing to manage is the amount of heat being produced. By adjusting the power used for mining, you can fine-tune exactly how much heat is generated.

This control is handled through software and firmware. With these tools and defined logic, you can adjust the power draw of a miner, either by overclocking or underclocking, to meet specific heating needs. For example, if it’s a particularly cold day and you need more heat, you can ramp up the miner’s power output and hashrate. On a milder day, you can dial it back to reduce hashing power and the amount of heat associated. This ability to dynamically control heat output gives bitcoin mining heaters a level of flexibility that traditional heating systems simply don’t have.

Where the Heat Goes

The second thing to manage is where the heat goes, and this can be done either through software-controlled systems or analog control

methods. In a bitcoin-powered heating system, you can direct the heat to different parts of your home or business based on your needs.

Electronic controls use software and microcontrollers to manage specific electronic devices that redirect heat. These smart components can be programmatically controlled, guiding the heat to the right areas based on desired settings and system setup. This can be combined with a smart home system for control from a panel or app to manage heating zones.

Alternatively, you can manage where the heat goes with analog solutions – parts that can dynamically adjust or turn on and off completely without designated software or code. These self-regulating components operate based on mechanical settings and specific calibration. For instance, a temperature regulating valve can modulate water temperature by mixing hot and cold streams without needing any electricity, directing the heat where it's needed based solely on the temperature flowing through the valve. This can be a good option for simpler setups or for projects that prefer not to rely on electronics.

And finally, there's always manual control, where the user must physically move levers to adjust valves and dampers that control heat direction.

CONSTANT MINING VS. ON-HEAT DEMAND MINING

Bitcoin miners are famous for running 24/7 to maximize profits and ROI. But as heating systems, we've talked about using them only when we need heat.

When integrating bitcoin miners into a heating system, you have two main options for how to use the miners: constant mining or on-heat demand mining. These approaches each offer different benefits, and the choice between them largely depends on electricity costs and what you want from the miners.

In constant mining systems, the bitcoin miner runs full-time (maximum uptime), generating heat continuously, regardless of your heating needs. Here, the heat produced is either reused when needed or rejected when it's not. **The key factor for constant mining is having electricity that is cheap enough to make full-time mining profitable**. Even when you don't need the heat, the system can still generate revenue through bitcoin mining, and you only divert the heat to useful applications as needed. This is a good solution to increase income for traditional bitcoin mining operations, who mine bitcoin for profit at scale, but can add additional revenue to their P&L by selling heat when it's in demand.

In on-heat demand mining, you only mine bitcoin when you need heat. This is simpler to implement and has been the main focus of the book. **Here, the miners are treated like traditional heating systems – turned on when there is a heat demand and turned off when there isn't**. While this is an easier setup, it either means you can't mine profitably, or are missing out on potential mining revenue.

Reject / Reuse

In a constant mining system, you're mining bitcoin full-time and have the ability to choose what to do with the heat, depending on whether it's needed or not. If it's winter and you need heat, the system redirects it to fit your needs. But in warmer months or periods where you don't need it, you can reject it outside, redirecting the excess heat into the environment.

This flexibility maximizes mining uptime. You're always generating bitcoin revenue, and the heat is free and readily available when it's needed.

To achieve this, you can use manual, analog or software-controlled solutions that redirect where the heat is sent. One path could be dedicated to reusing heat, while another is dedicated to rejecting heat. In certain scenarios, you may want to put some of the heat to use, maybe during a mildly cold fall day, but reject the majority of it. This is possible through careful system design and engineering with the right software logic and analog or digital heat transfer hardware.

Reject / Reuse hashrate heating systems are essentially bitcoin mining operations with an integrated heating solution baked in. The economic value proposition of these systems is very attractive if you have cheap enough power to justify it.

Hashing for Heat Only

Due to energy prices, most systems will opt for hashing for heat only. In these setups the miner is always a dual-purpose device, delivering high-performance heat while earning bitcoin.

For certain simple heating solutions like a bitcoin space heater, or a simple HVAC / hydronic system that sends heat from a central source to a single use case, dynamically managing where the heat goes might not even be required. All that's needed is to adjust how much heat the device produces, and fans or pumps can work to distribute the warmth around the room or heating network evenly.

These systems are easier to control because you don't need to manage the complexities of rejecting heat when it's not needed. The miner is off during the summer or when heating isn't necessary, and there's no concern about wasting energy or bitcoin mining potential. **If you need the added flexibility of controlling where the heat is reused, like specific rooms or targeted applications, additional design for more complex control is required**.

On-heat demand mining is ideal for most homes and businesses where heat is required seasonally or in specific periods, and where electricity prices might not justify full-time mining. Since you're using the miner primarily for heating, you only need to worry about controlling the heat you plan to use, and not any excess.

ANALOG VS SOFTWARE CONTROL

We've introduced both analog and software control. Each approach has its strengths, and combining the two can create a high-performance, reliable, and cost-effective system that efficiently controls heat output and distribution.

Analog Control

Analog control uses mechanical or electrical devices to manage heat output without the need for software. These systems, which have been staples in traditional heating setups for years, are known for their simplicity, reliability, and long-lasting durability. Analog controls provide effective and cost-efficient solutions that require minimal maintenance.

They are especially well-suited to situations requiring straightforward on-off control, though certain analog systems can still respond to and deliver gradual changes in temperature. While they lack the fine-tuning precision and customization of software controls, they provide a reliable, set-and-forget approach to heat management.

Software Control

Software control offers unmatched flexibility and precision for managing heat, allowing you to customize the behavior of your heating system based on real-time data and specific conditions. Unlike analog control, software control uses programmable settings and logic via written code to fine-tune heat output and efficiency.

With software, you can set specific conditions for different times of the day, seasons, or even fluctuating energy prices. It also allows for remote adjustments and real-time monitoring, meaning you can track performance and make updates as needed without being physically onsite.

Software control is ideal for users who want more granular adjustments, such as balancing heat across multiple zones or more accurately responding to external conditions. It provides a tailored heating experience, letting you adjust settings to meet comfort, efficiency, or operational goals – but requires software and devices to interpret code.

Combining The Two

A balanced approach often leverages both analog and software controls to optimize performance, safety, and cost-effectiveness. With software, you gain precise, data-driven control and flexibility – such as remote management, time-based adjustments, and responses to changing conditions. Meanwhile, analog components add a layer of reliability and simplicity, often acting as passive safety measures that can kick in if something goes wrong.

For example, you could set up analog relays to act as fail-safes, automatically cutting power if temperatures get too high, while the software takes care of everyday adjustments and overall heat regulation. This hybrid approach brings the best of both worlds – using analog's proven reliability as a safety net and software's customization for fine-tuned heat management.

Building Complexity in Control

One of the advantages of combining analog and software control is the flexibility to start simple and build complexity as needed. For basic heat reuse, an all-analog system can provide reliable control without digital configurations. The next level of complexity might incorporate basic firmware control, letting you tweak miner power settings and device temperature with minimal software involvement. For more advanced needs, you can add software-driven systems like Home Assistant on a microcontroller to create granular, smart control over the system. This layered approach allows you to balance flexibility with complexity, scaling the system as your needs grow or change.

IMPLEMENTATIONS OF HASHRATE HEATING CONTROL

So, what's the best way to control a hashrate heating system? Is there an ideal solution for simple space-heating setups? And aren't bitcoin miners designed to run at full power, and not adjust up and down for heating needs?

These are the right questions to be asking. **Heating with bitcoin miners is still an emerging industry and a new use case for this technology, and it's all unfolding in real-time**.

There's no single approach – it depends entirely on your heating requirements, budget, desired reliability, and any additional features like smart logic or remote management. Here are a few ways to do it.

Self-Regulating Miner Thermal Management

Current industrial bitcoin miners are designed to run at full power - so stock firmware on these devices usually offers minimal control for power adjustments.

One workaround to this limitation is using aftermarket firmware, which adds features not available in the manufacturer's stock operating system, enhancing control over the miner's settings and performance.

With custom firmware, like Braiins OS, miners can ramp their power from 100% throttle to very low levels, offering a broad range of heating capacity. Overclocking can push miners beyond factory power limits, increasing hashrate, bitcoin rewards, and heat output. For more refined control, features like Braiins' Autotuning feature optimizes the miner's efficiency at non-default power levels, allowing the hashrate heater to maximize rewards at any power and heat limit.

A standout feature in aftermarket firmware for heating control is self-regulating power based on temperature of the actual bitcoin miner itself. Firmware solutions like Braiins OS with Dynamic Performance Scaling (DPS) and others have made this possible. Dynamic Performance Scaling allows users to set temperature limits for the machine's internal temperature sensors. If they start to overheat, the miner automatically lowers its own power draw (and heat output) by a defined amount, preventing damage to internal electronics. After some time below the temperature target, the miner can then re-increase hashing power, like when it gets colder at night.

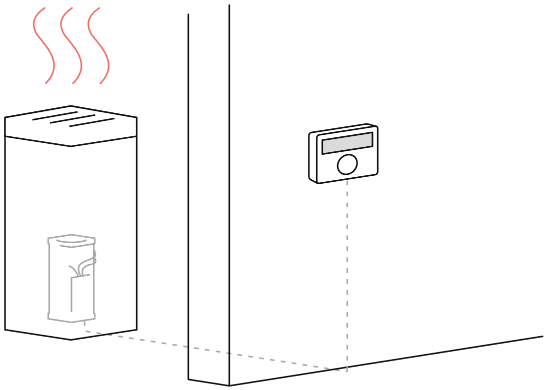
When calibrated and integrated into a hashrate heating system, this self-regulation does a good job of managing heat output and protecting the hardware. Best of all, it's achieved with custom firmware settings and on-device temperature sensors – no additional hardware or coding required.

External Temperature Sensor Miner Control

The limitation of self-regulating miner thermal management, like Braiins DPS, is that they automatically adjust bitcoin mining power based on temperature sensors within the device itself. The issue is, you likely don't care about the temperature inside your hashrate heater – you're focused on the actual temperature of your heating application, like rooms in a house.

While self-regulating miner temperature control offers a solid solution by providing basic heat management, overheating protection, and a no-fuss setup, it's clear that on-device temperature measurement isn't ideal for achieving finely tuned control in a bitcoin-powered heating system.

After all, a household thermostat doesn't measure the temperature inside the furnace or boiler, turning the heater on and off based on how close it is to overheating. Instead, the thermostat's sensor sits in the room or target application, gauging the temperature where you actually want the heat.



Fortunately, some innovative individuals and companies have developed solutions for this - linking external temperature sensors that can adjust bitcoin mining power based on temperature readings outside the device itself.

These solutions rely on communication between an external temperature sensor and microcontroller, and connect via API (application programming interface) to aftermarket firmware tools like Braiins OS. The Thermohashostat from **100AcresRanch**, for example, works with other aftermarket firmware, while devices like the **Heatmine** miner thermostat integrate with Braiins OS.

Maximum Analog Control

Full analog control is another approach to hashrate heating systems. When engineered correctly, analog systems can provide reliable heat management with minimal firmware adjustments and no need for software or smart devices.

The simplest analog system might use a bitcoin miner as a hashrate heater running at full power on stock firmware. The device could be turned on or off using a switch relay that controls power to the miner power supply. When powered on, the miner outputs maximum heat. Analog control of pumps or fans, connected to the miner's power circuit, ensures heat is transferred and delivered whenever the system is active. Temperature-regulating valves and similar components can then direct heat to where it's needed and prevent overheating, all without digital intervention.

Moving a small step beyond fully analog control, you could add custom firmware with self-regulating miner thermal management, like DPS on Braiins OS. This feature, combined with analog tools, will offer basic heating control while implementing self-regulation to the setup – preventing the ASIC chips from overheating and balancing heat delivery on warmer days with added failsafes.

For more robust systems, extra adjustments like manifolds or duct dampers can be implemented. When paired with analog temperature sensors and relay switches, you can create a system that automatically adjusts heat distribution to different applications or locations.

Maximum Software and Smart Control

The opposite of a primarily analog setup is full software control, where the entire heating system can be finely tuned, monitored remotely, and provide real-time data insights for precise heat management through smart devices.

In a typical smart hashrate heating system, the control process generally looks like this:

A bitcoin miner is equipped with Braiins OS, which enables power flexibility and other features. The miner connects to a microcontroller that allows remote adjustments. Software like Home Assistant can then link other smart devices together, enabling thermostatic control based on external temperature sensors and feedback from the home. A user-friendly interface ties everything together, with accessible controls like buttons, dials, and easy-to-change settings.

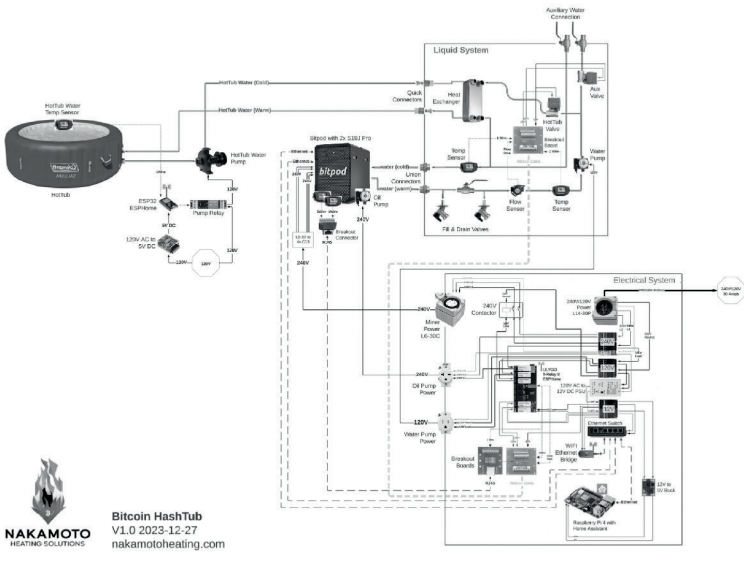
Integrated throughout the setup, sensors monitor parameters like temperature, pressure, and airflow. This allows the system to intelligently direct heat, adjusting room-to-room if there's a temperature difference, for example. Smart software control ensures that the heat is distributed efficiently and matches demand precisely.

For additional reliability, analog relays and switches are often included as safety backups. For example, they can cut power to the hashrate heater in the event of a pump failure or loss of pressure. These analog components provide peace of mind, even if your system is primarily controlled with smart devices.

Real-time data logs and performance tracking add significant value, especially for systems requiring stable temperatures over long periods, such as in industrial applications. This level of insight also helps with troubleshooting, allowing for quick diagnosis of issues in the heating system.

A standout example of a fully open-source smart control project is **Nakamoto Heating's "HashTub"** by Michael Schmid, mentioned in the last chapter. Michael provides a comprehensive parts list, schematics, and video documentation on his website, along with a GitHub repository for details.

Another useful smart control tool is the Wi-Fi-enabled Power Distribution Unit (PDU) from **Toine at 256 Heat** who designs the integrated air-based heating systems with repurposed industrial miners. This allows remote control over the power supply to the miner, supporting full system shutdown when heat isn't needed, rather than just putting the miner in a sleep state – which can still draw significant power on certain firmwares.



Bang-Bang Hashrate Heating

As we covered earlier, one of the strengths of hashrate heating systems is their ability to adjust heat output dynamically, unlike traditional on-off, or "bang-bang," heating systems. However, **it's entirely possible to control a bitcoin-powered heating system using a bang-bang approach, where the miners cycle on and off based on temperature needs**.

You can use a tool like the smart Wi-Fi PDU from 256 Heat, paired with a smart temperature sensor, to enable on-off control. With this control solution, the miner powers on when the room temperature drops below a certain threshold and shuts off when it reaches the target temperature, just like a standard home heating system.

Another innovative bang-bang control approach is possible with immersion-cooled hashrate heating setups, where the miner is submerged in a cooling oil bath. The immersion tank acts as a **thermal battery**, storing heat energy due to the high thermal mass of the liquid (just like a heavy cooking pan takes a long time to cool down). With a temperature sensor in the immersion tank itself, the system can monitor the oil bath's temperature and cycle the miner on or off accordingly. When the oil cools down sufficiently, the miners turn on to warm it back up; if the oil overheats, they switch off. This approach, designed by Heatpunk **Cody Harris**, leverages the heavy oil's heat storage capacity to maintain temperature without constant miner activity.

The unique feature here is that with immersion setups, heat is immediately available thanks to the stored energy in the oil tank. This "thermal battery" effect means you don't have to wait for miners to power up to get heat on demand, which can be especially advantageous for applications requiring rapid heat delivery.

BANG-BANG VS CONTINUOUS LOAD FOR HASHRATE HEATING

Bitcoin miners can adjust heating power dynamically or operate in a bang-bang manner, but which control method is better?

Most miners have a hashing efficiency “sweet spot,” often slightly below their rated power limit. Bang-bang control, cycling on and off at this level, might yield slightly better J/TH efficiency, generating more overall bitcoin for the same heat output. However, this approach can cause faster wear and tear on the hardware and larger temperature fluctuations.

This may not hold true forever, as miners improve at adjusting their power dynamically across a wide range, from minimal to full. If miners become capable of dynamic, real-time tuning to maximize efficiency at any power level – something companies like Auradine are pursuing with their latest models – then continuous control could become the standard for its more controllable heating performance.

Ultimately, it’s up to the user. Both methods provide similar bitcoin output over time unless the machine of choice has drastic efficiency swings at different power levels.

HASHRATE HEATING CONTROL TAKEAWAY

Control is a critical factor in hashrate heating systems, especially for integrated setups that need to efficiently deliver heat across various applications with high performance and responsiveness to user input and setpoints.

These digital devices introduce new heat management options that bring additional functionality and performance, at the cost of added complexity. There are many ways to control a hashrate heater, and the ideal solution depends on factors like reliability, budget, complexity, safety, and feature preferences.

As the field evolves, we may see even more control methods emerge or refinements to those described here.

What isn’t new is the plethora of hardware designed to move heat around.

PIECING TOGETHER THE HARDWARE

Effectively using the warmth from hashrate heaters requires more than just the bitcoin miners themselves. **To keep the miners running properly, heat must be efficiently extracted from the devices, and in most cases, additional hardware is needed to transfer that extracted heat to its intended application**.

THE BASICS OF ASICS

Any modern ASIC miner has four main hardware components, each with a specific job that ensures the machine can perform its primary duty with high performance and reliability.

These components include the **power supply unit (PSU)**, **control board**, **hashboard**, and **cooling system**. They work together to manage power, networking, and heat.

The other necessary hardware and infrastructure to effectively run a traditional bitcoin mining operation includes the following:

- **Transformer:** Adjusts grid power to the correct voltage and current for mining machines.

- **Electric Panels & Breakers:** Distribute power and protect circuits from overloads.

- **PDUs & Cables:** Distribute power to miners, often with usage monitoring.

- **Router, Switches & Cabling:** Connect miners to the bitcoin network for communication.

- **Cooling Systems:** Circulate air or coolant to keep miners at optimal temperatures.

For small-scale mining setups, some of the industrial-grade hardware, like transformers and PDUs, might not be necessary – provided you have the right power already on site.

These are the core essentials that have defined the bitcoin mining landscape so far, and they're required whether you plan to reuse heat or not.

But we're interested in actually reusing the heat energy, instead of letting it go to waste. So, how do we do that? What additional hardware is needed? Let's dive in and find out.

Stuff that Makes the Heat

First and foremost, it's important to keep reiterating that all the heat generated by a bitcoin miner comes from the power it consumes. Every watt of power that a miner uses needs to be dissipated as heat.

For example, if a bitcoin miner draws 3000 watts of power but only dissipates 2000 watts as heat, it retains 1000 watts of energy. This retained heat energy will cause the miner to heat up, potentially leading to hardware damage.

The miners themselves are the parts that generate the heat. Extensive engineering effort has gone into designing bitcoin mining hardware to ensure the power they consume is expelled as heat just as quickly as it's consumed. This process is often referred to as the "cooling system" or "cooling method" of the ASIC bitcoin miner.

There are three main ways to cool an ASIC miner:

- **Air cooling**: Fans or airflow are used to pull heat away from the machine.
- **Immersion cooling**: The miner is fully submerged in a special oil that absorbs the heat.
- **Hydro cooling**: Water or coolant mix flows directly over the ASIC chips to remove heat.

Stuff that Moves the Heat

The hardware needed to transfer heat from bitcoin miners to heating applications is already well-established, thanks to over a century of innovation in the heating industry.

Here's a quick overview:

For air systems, **fans** move air through the miners, while **ducting** and **manifolds** channel this heated air for delivery to rooms or other applications via **vents**. In liquid-cooled setups, **pumps** circulate water or oil through miners, **pipes** and **tubing** to transport heat to applications like **radiators**, **heat exchangers**, or **tanks**.

The components that move heat can vary greatly. For a space heater, a large, slow-moving fan on the device might be all that's needed to quietly circulate warm air in a room. However, in larger, more sophisticated setups, like those used in commercial buildings, a complex network of ductwork, plumbing, and other components may be required to distribute the heat across long distances.

The best way to understand how all of these components work together is to walk through the heat transfer process - from ASIC chips to the desired use case.

HOW MINERS GET RID OF HEAT

Bitcoin miners are some of the most power-dense electrical devices on the planet. They convert electric power into heat with high efficiency, in extremely compact form factors. These machines have become increasingly power-hungry over the years, and as a result, require high-performance cooling systems to evacuate heat energy.

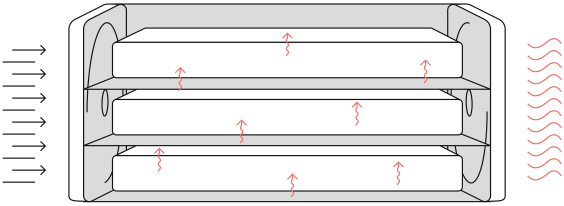
Air-Cooled Miners

Air-cooling is the simplest and most common way to keep a bitcoin miner from overheating – with no liquids involved. It works by moving cool air over special metal fins called **heat sinks**, which are attached to the **ASIC chips**. The heat sinks have a lot of surface area to help spread out the heat, making it easier for the air to absorb and carry it away. **Fans** push air through the miner and over the heat sinks, convectively[13] removing heat from the device.

From an operational perspective, air-cooled bitcoin miners are the most simple. Power is run through the ASIC chips to perform the hashing algorithm. The chips heat up as a result. Heat transfers conductively[14] from the ASIC chips to the heat sinks, where cool air is blown over them to push the heat out of the device.

So what are air-cooled hashrate heaters good for? **Well, they're great for heating up air, which can then be circulated to warm rooms and the air around you**.

13 Convection is the transfer of heat through the movement of fluids (liquids or gases) over a solid surface. See Appendix B for more details in the context of bitcoin mining.
14 Conduction is the transfer of heat through direct contact between solids. See Appendix B for more details in the context of bitcoin mining.

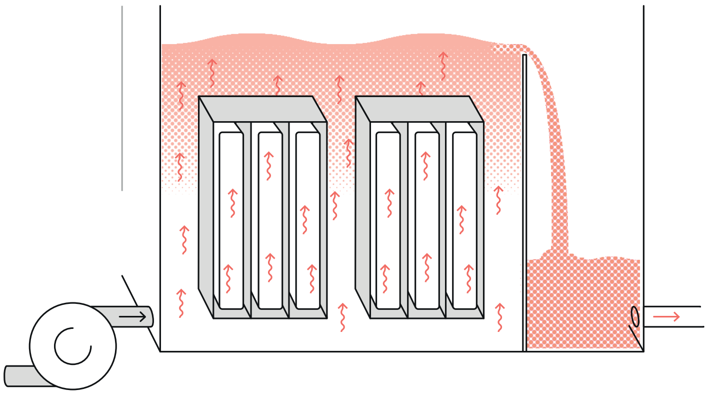


Immersion-Cooled Miners

Immersion-cooling works similarly to air cooling, but instead of using cool air to extract heat from the miners, a non-conductive, **dielectric oil** is used. This oil doesn't conduct electricity, so it won't short-circuit the device. It pulls heat away from the miner's internal hardware in the same way that air does, but the miners need to be fully submerged in a bath of this oil.

Inside, the mining hardware is the same. You can take an air-cooled ASIC miner, remove its fans (since pumps now move the oil instead of fans moving air), and submerge it in the tank for immersion cooling. Some manufacturers are even starting to make miners optimized specifically for immersion cooling.

Compared to air cooling, immersion cooling requires additional heat transfer hardware for the miners themselves. An **immersion tank** is required to contain the miners in the oil bath. The setup looks like a bathtub**:** cool immersion oil is pumped in from the bottom and flows up through the miner's **heat sinks**, absorbing heat via convection. **Oil pumps** are required to keep fluid circulating through the device and out of the tank to deliver the heat to other locations.



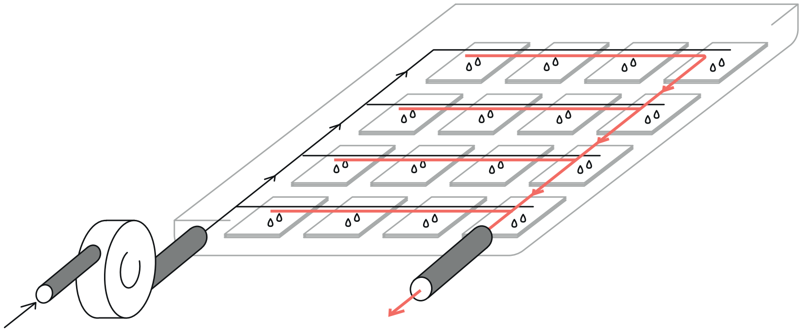
Immersion-cooling introduces the concept of using a liquid instead of gas to cool the miners, which comes with several benefits for heat reuse. **Liquids can hold much more heat energy than gasses like air**. **This is a better fit for higher-power miners, and is far more efficient when you need to move lots of heat over long distances or direct it to specific uses, like heating a pool or a hot water tank**.

Hydro-Cooled Miners

Hydro-cooling involves pumping water directly onto the ASIC chips themselves. Because unpurified water contains minerals, it is electrically conductive. Submerging the entire miner into a tank of water would short-circuit the electrical components. By exclusively directing the water onto the ASIC chips, short-circuiting is avoided, and only the ASIC chips that generate heat are cooled.

The key hardware component that directs the cooling fluid onto the ASIC chips is called a **water block**. It's designed with seals to prevent leaks onto other sensitive electrical components, which could cause shorts. Water, sometimes mixed with **antifreeze coolant** like ethylene glycol to prevent freezing, is pumped into the water block, where it directly interacts with the ASIC chips, removing heat through convection.

Because of the precise targeted cooling nature of hydro machines, more hardware components are needed like extra **tubing, fittings and seals**. A **water pump** must connect with these components to direct cooling to the miner and heat to other hardware that extracts it.



Like immersion cooling, hydro cooling uses liquid instead of air to cool the ASIC chips. **Liquids provide better cooling efficiency**, more precise heat transfer targeting for specific applications, and the ability to transfer heat over longer distances.

HOW TO MOVE THE HEAT AROUND

Once heat is removed from the bitcoin miners, it can be repurposed for heating applications. The hardware required to move that heat depends on the target use case and the cooling type of the bitcoin miners themselves.

Luckily, heat transfer infrastructure is well-established, reliable, and optimized. No new inventions are needed to unlock the potential of bitcoin heat reuse. The technology is already here, and the hardware that makes heat reuse possible is the *same* equipment used by bitcoin mining operations that currently discard the heat as waste!

Hardware to Move Heat in Air-Cooled Systems

Fans make air cooling an excellent method for heating the air directly around the bitcoin-miner, much like a regular space heater. If this is the intended use case, no additional hardware is needed.

However, out of the box, most industrial air-cooled bitcoin miners aren't designed to act as space heaters. They're built for large-scale mining operations, and as a result, there are some drawbacks if you want to use one in your living room or office cubicle for local heating.

One major concern is noise. The preinstalled small-diameter fans on air-cooled miners spin at high speeds to keep the machines cool, which can be quite loud. This isn't usually a problem for industrial mining operations in rural areas, but in air-cooled heating setups, it's disruptive. A common modification is to replace these fans with larger-diameter ones. **Larger fans** can push the same amount of air at lower speeds, resulting in good airflow and reduced noise.

But what if you want to use an air-cooled bitcoin heater for a more integrated heating system? In this case, the heat is no longer needed right at the location where it's generated; it must be transported somewhere else. In North America, air-based heating systems are commonly used to distribute heat throughout buildings. Traditionally, large furnaces burn fuel to heat air, which is then pushed through ductwork by a central blower fan to various rooms.

Hashrate heaters can be retrofitted into these systems, or new builds can be designed around them to use the heat effectively. The hardware used for air-based heating systems fall under the category of **HVAC (Heating Ventilation and Air Conditioning)** components. Here's how heat from a bitcoin miner can be transferred from a utility room to a different part of a building.

We've covered the first step: removing heat from the bitcoin miner to use it.

Now, how do you get this warm air into your ducts to distribute it around the building? Since most bitcoin miners aren't designed to slot into traditional air-based heating systems, you'll need some additional components. **Shroud adapters** are key here. These parts act as connectors, linking the inlet and outlet of hashrate heaters to air ducts (since the miner's fans aren't the same size as standard ducting).

Now that the warm air is in your building's **ductwork** (air pathways), it can be moved around to various locations.

Inline fans, which are installed directly inside the HVAC ducting, can be added to help boost air pressure and ensure the warmth continues moving through the ducts, even over longer distances.

With these main components, warm air from hashrate heaters can be distributed efficiently to various rooms and zones as needed. For more comprehensive information on this topic, I'd recommend researching HVAC systems, which have decades of engineering behind them. This will give you a deeper understanding of how air-based heating systems are designed and how to fine-tune your hashrate heater setup.

Hardware to Move Heat in Liquid-Cooled Systems

Liquid-cooled bitcoin miners offer higher performance than their air-cooled counterparts but come with added complexity. Since we live in an environment filled with air, moving heat in liquid form requires more specialized hardware to manage the heat transfer effectively.

Because of this, you won't typically find small, plug-and-play liquid-cooled bitcoin miners for localized room heating, like space heaters. **The real strength of liquid cooling lies in its ability to store and transfer much more heat energy than air, making it more efficient for moving heat over large distances, storing it in tanks, or targeting specific heating applications with more control**.

In immersion cooling, the hashrate heaters are fully submerged in a bath of special cooling oil. In hydro cooling, liquid is circulated directly inside the bitcoin mining devices, where it makes direct contact with the ASIC chips, which are the primary heat source. While there are key performance and hardware differences between the two methods, the basic principle is the same. Cool liquid (whether oil or water) is pumped through the miners, absorbing heat along the way. The result is hot liquid exiting the miners, ready to be put to use in your heating applications.

Once the hot liquid leaves the bitcoin-powered heaters, the next step is to transport it to where you intend to use it. But before doing that, there's an important factor to consider. In immersion setups, the non-conductive oil has a few downsides: it's expensive, prone to leaks, and difficult to clean up. You definitely don't want this oil spilling throughout your home or business, and buying large quantities to transport heat over long distances isn't practical.

Similarly, with hydro-cooled machines, it's not ideal to directly send the water used to cool the miners through your entire heating system or into your domestic tap for consumption. **Instead, it's better to isolate the miner cooling loop from the heating liquid loop used for heat reuse**. Using this **dual-loop** system also improves reliability and makes maintenance easier, since any issues or leaks in the heating infrastructure won't affect the miner's cooling system.

The key component that makes this separation possible is called a liquid-to-liquid **heat exchanger**. As the name suggests, this device transfers heat from one liquid to another without mixing them. This allows you to move heat from the immersion or water **cooling loop** into a separate liquid **heating loop** sent for your heating purposes.

To move this heated liquid efficiently, we rely on liquid **pumps** and plumbing through **pipes** and **tubing**. This type of system is well-established in an industry called **hydronics**. Hydronic systems are commonly used in residential, commercial, and industrial heating setups, and their principles are directly applicable to liquid-cooled hashrate heating systems.

A key consideration for liquid heating systems is that liquids, unlike gasses, are incompressible. If you compress air, its volume can shrink under pressure, but liquids cannot. When heated, liquids expand, and in a closed-loop (air-tight) system like a hydronic loop, this expansion has no place to go. Without a way to accommodate this, the rising pressure from the heated fluid could cause the system to explode – definitely not something you want.

To prevent this, an **expansion tank** is used. This tank provides a pocket of space where the liquid can safely expand as it heats up, acting as a buffer to maintain safe pressure levels within the loop. It's important to note that this isn't typically needed for the cooling oil side of an immersion system, since the immersion tanks are open to the air, allowing the oil to expand without building pressure.

These key components form the backbone of heat transfer systems for liquid-based hashrate heating.

For a deeper dive into liquid heat transfer systems, I recommend exploring the field of hydronics, which covers essential topics like pump sizing, piping materials, fluid dynamics, and heat exchanger efficiency.

CONTROL HARDWARE

A well designed control solution is part of any good heating system - bitcoin or not. And like the main heat transfer components outlined above, the hardware used for managing and controlling heat delivery is expansive and well established. Only with the advent of hashrate heating are some new devices coming to market that expand upon the unique features of bitcoin-powered heat.

The control hardware necessary to manage heat can be broken into three categories: components for **air-based systems**, **liquid-based systems**, and **automation tools**. Control can happen in various ways – sometimes through self-regulation with well-designed analog systems. Other times, more precise control is needed, requiring electronic systems that send commands to the hardware to regulate heat distribution. And sometimes, control remains manual, where a person adjusts settings physically.

Air System Control Hardware

The next step for air-based systems is controlling where the heat goes. In integrated systems, you'll likely want to heat multiple locations. To distribute the heat to various places, the warm air needs to be split into different pathways.

This is achieved using **duct splits**, like Y-ducts and **manifolds**, which divide the airflow into multiple sections of ductwork.

But what if you need more control? For example, maybe you only want to send warm air to your garage on weekends when you're working on your car, but don't want to waste heat there during the week. This is where dampers come in. **Dampers** are installed within the duct network and have adjustable blades that allow you to throttle airflow or completely shut it off to specific paths, giving precise control over where the heat goes.

Something that we want to prevent in air-based heating networks is air backtracking through the system. This is where **backdraft dampers** come in. These are essentially one-way valves for air, preventing air from flowing in the wrong direction when fans are off or pressure changes in the ducts.

These are just the key components - which can be controlled via manual, analog, or electronic input - to provide essential control in air-based heating systems. **They integrate smoothly with air-cooled bitcoin miners, requiring minimal hardware modifications to manage airflow effectively**. To complete a robust air-based hashrate heating system, make sure to research other HVAC essentials.

Liquid System Control Hardware

In hydronic heating systems, **valves** are the primary method of controlling the flow of liquid, functioning similarly to dampers in air systems. There are various types of valves – such as ball valves, butterfly valves, and more – each offering different advantages and suited for specific situations. Valves can be analog, providing self-regulated mechanical control, manual for fine-tuning or shutting off fluid for maintenance, or electronic for automated remote management.

Two essential valve types for hashrate-powered hydronic heating systems are mixing valves and electronic valves. **Mixing valves** have the unique ability to blend hot and cold water to reach a specific output temperature. This is an excellent analog solution for automatically directing fluid to different locations based on its temperature – no software or electronics required.

Electronic valves, on the other hand, offer more precision and remote control over the heated fluid's direction. Paired with temperature sensors and automation systems, they allow for smart logic, directing heat exactly where it's needed, when it's needed, based on a variety of inputs.

If the hot liquid needs to be diverted into different flow paths to deliver heat to various rooms or applications – such as sending some to your water tank, some to your heated driveway, and some to a radiator to warm your house – a device called a **hydronic manifold** is used. Hydronic manifolds split liquid flow into separate paths, enabling the heating of multiple applications simultaneously. This adds modularity and flexibility to the design of your heating system, for efficient heat distribution across different areas.

And just like backdraft dampers in air-based heating systems, hydronic systems use **check valves** to ensure the heated liquid flows in only one direction, preventing unwanted backflow. On the other hand, **pressure relief valves** are essential for protecting the system from overpressure, allowing excess liquid to escape if the pressure exceeds safe limits. Together, these components help the system operate smoothly and efficiently.

Using these core components, liquid-based hashrate heating systems can offer precise control over where heat is directed. But just like air-based systems, make sure to extensively research other hydronic hardware that is essential for a robust liquid hashrate heating solution.

Automation Control Hardware

A heating system needs a way to measure its surroundings to respond to requests, self-regulate, or adjust heat distribution automatically based on logical inputs and environmental conditions. **Switches** and **sensors** are critical here. Switches are binary devices, often analog, that operate with simple on/off signals when a set threshold is reached. Sensors, on the other hand, are typically digital and provide continuous, real-time data about variables like pressure, temperature, and flow rate. These core components, combined with hardware that responds to inputs, enable the system to make decisions as needed.

Monitoring Hardware
Switches and sensors play complementary roles in monitoring system conditions. **Temperature switches** (e.g., mechanical thermostats) can detect if the temperature in a room or heat exchanger crosses a preset threshold, triggering a relay to take action. Meanwhile, **temperature sensors** measure actual values continuously, allowing the system to adjust dynamically, such as ramping a pump speed or modulating a fan. For analog setups, **gauges** provide a visual way to monitor variables like temperature or pressure.

In both air and liquid-based heating systems, **airflow sensors** and **flow meters** play crucial roles in monitoring and regulating the movement of heated fluid to maintain performance. Airflow sensors measure the speed and volume of heated air in ducted systems, while flow meters track the rate of liquid circulation in hydronic systems. These devices ensure that air or liquid is moving efficiently and directed where it's needed. A flow meter, for example, might detect slowed flow rate - which could indicate a clog in the loop and trigger a pump shut-down to prevent damage.

Similarly, **pressure sensors and switches** monitor air ducts or hydronic loops, ensuring safe and efficient operation by identifying any pressure abnormalities - such as a leak that causes a pressure loss.

Decision-Making Hardware
What about the hardware that actually makes decisions and automatically regulates the heating system? In both analog and digital systems, there must be a way to take switch or sensor data and act on it, whether that means turning something on or off, or tweaking the system's behavior dynamically. This is where **relays** and **microcontrollers** come in, serving as the "decision-makers" of the system.

A **relay** is a simple electrical switch that controls mechanical devices like fans, pumps, or valves by turning them on or off. They can operate without any digital signals – making them perfect for analog setups. Relays are triggered by small electrical inputs from switches like mechanical thermostats or pressure switches. These switches provide direct electrical current to the relay, which then turns the device on or off, creating a mechanical, analog form of automation.

In an **analog logic circuit**, this simple on/off mechanism can define decisions without a computer. A thermostat connected to a relay can tell the system, “If the temperature is too high, turn the fan on,” or, “If the temperature drops below this point, turn the heater back on.” It’s a form of logic, but with structured electrical circuits instead of code.

Microcontrollers, on the other hand, operate on **digital logic (code)** and allow for more precise and flexible control. They’re tiny computers that can be programmed to handle complex inputs from multiple sensors and execute detailed control strategies. Microcontrollers, like the **Raspberry Pi,** read data from digital sensors – such as temperature, pressure, or flow sensors – and respond based on real-time data.

Unlike relays, which simply turn devices on or off, microcontrollers can make more advanced decisions. For instance, if the temperature sensor reads that a room is getting too hot, a microcontroller could lower the fan speed incrementally or slowly adjust the flow of heated water through a valve, rather than just turning the fan or valve fully on or off. This allows for granular control, making the system more efficient and responsive to changing conditions.

And because of their digital nature, microcontrollers can also integrate with broader smart home automation systems, offering remote control via apps or web interfaces. They can handle a lot more complexity, but they also require **code** and **software** to function.

User-Facing Hardware

That brings us to the user-facing hardware devices meant for changing settings, monitoring performance and adjusting things as needed. In analog systems, **mechanical thermostats** allow users to set a desired temperature mechanically. When the set temperature is reached, the thermostat sends a signal to the connected relay, which acts on the signal based on what's connected to it. In digital systems, **smart (wi-fi) thermostats** work in tandem with microcontrollers to communicate with electronic sensors, valves and other hardware that can dynamically adjust system behavior. For more advanced control, operators can use **control panels** to fine-tune settings. These panels allow adjustments such as directing heat to specific areas, creating schedules or even managing the heat output of the bitcoin miners themselves.

Sometimes paired with these systems are **smart PDUs** (Power Distribution Units), which provide full remote control over the power supplied to the hashrate heating devices themselves. This allows users to completely cut off power when heating isn't needed, reducing wasted energy and adding an extra layer of safety.

By combining analog hardware, smart devices and basic automation and control interfaces, users can achieve robust control and full system oversight, ensuring maximum efficiency.

HARDWARE TO DELIVER OR ELIMINATE HEAT

We've followed the heat from its generation during the mining process, through HVAC and hydronic components that move it, and explored how control hardware helps us manage where it's sent. Now, we'll look at how that heat is finally used – or, if necessary, eliminated from the system.

Delivering or Eliminating Heat In Air Systems

The hardware used for air-based heat delivery is no different than hardware used for heat rejection. It's either dumped somewhere you want it, or somewhere to get rid of it. Fans, ducts, and dampers control the movement up until this point.

But what kind of hardware actually delivers air-based heat? The answer is **vents**, which channel warm air into specific rooms or areas. To help smooth out heat delivery, air **diffusers** mix heated air with the surrounding environment, ensuring even distribution and reducing the intensity of direct airflow. If more precision is needed, **louvers** can regulate airflow at the end of ducts or exhaust systems, finalizing where and how much heat is delivered or rejected. Many are designed to prevent backdrafts and ensure airflow dumps only one way.

If excess heat needs to be removed or delivered more quickly, **exhaust fans** step in. Activated automatically when needed, these fans forcefully pull heated air out of the end of the system.

Delivering or Eliminating Heat in Liquid Systems

Liquid-based systems also use the same hardware for delivering and rejecting heat, but there are more options to choose from with more specific use cases. Here are some of the common options.

If you want to deliver heat from a hot liquid loop to another liquid application like a water tank, pool, or some other hydronic application, additional **heat exchangers** can be used to transfer energy between the two liquids. This separation is crucial for safety and system separation - an issue with one part of the setup won't impact the other parts of the heating loop. **Hydronic tubing** can also deliver heat directly, as seen in underfloor heating, baseboard systems, or even outdoor heated sidewalks, where the heat transfers to floors or the ground through a network of heated pipes.

Beyond delivery, heat exchangers can reject excess liquid heat to **thermal sinks** like streams, lakes, or oceans, where large volumes of heat can be safely absorbed by other liquid bodies.

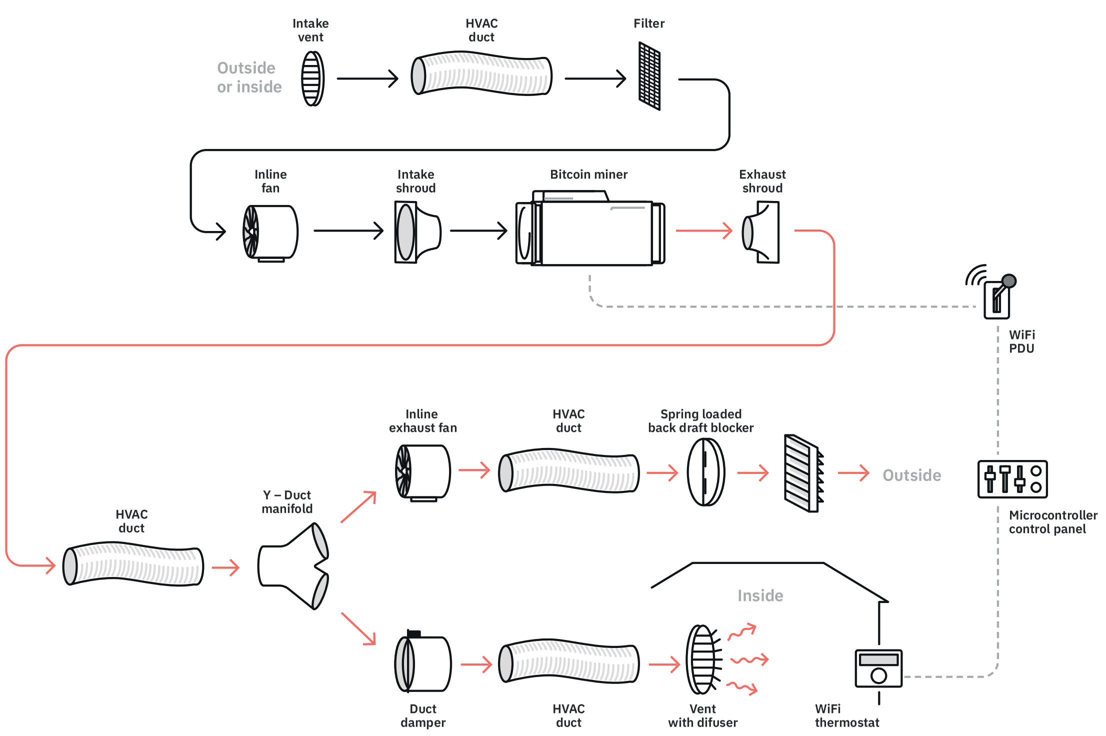
In some cases, you may want to convert liquid heat back into air heat for certain use cases. **Radiators** serve this purpose. They convert liquid heat to air heat (think heat sink, but extra large). This can be used to warm multiple rooms in apartment buildings, where warm liquid is sent throughout the building to different radiators that individually heat up the air in each zone. Conversely, outdoor radiators can reject excess heat into ambient air when liquid heat isn't needed elsewhere. To improve heat rejection, **dry coolers** (essentially large radiators with fans on them) enhance heat transfer by forcing air over the fins. Controlling the fan speed dynamically can fine tune how much heat is dumped outside.

Lastly, remember that in both air and liquid setups, rejecting excess heat only happens if more heat is generated than needed. For hashrate heating systems, this depends on the control model. Systems with high uptimes – due to cheap electricity or constant demand for mining – may produce more heat than is required. In these cases, excess heat must be "bled off" to prevent the miners from overheating. However, **in most hashrate heating systems - where mining operations are tied directly to heat demand - there should be no excess heat that needs to be rejected**.

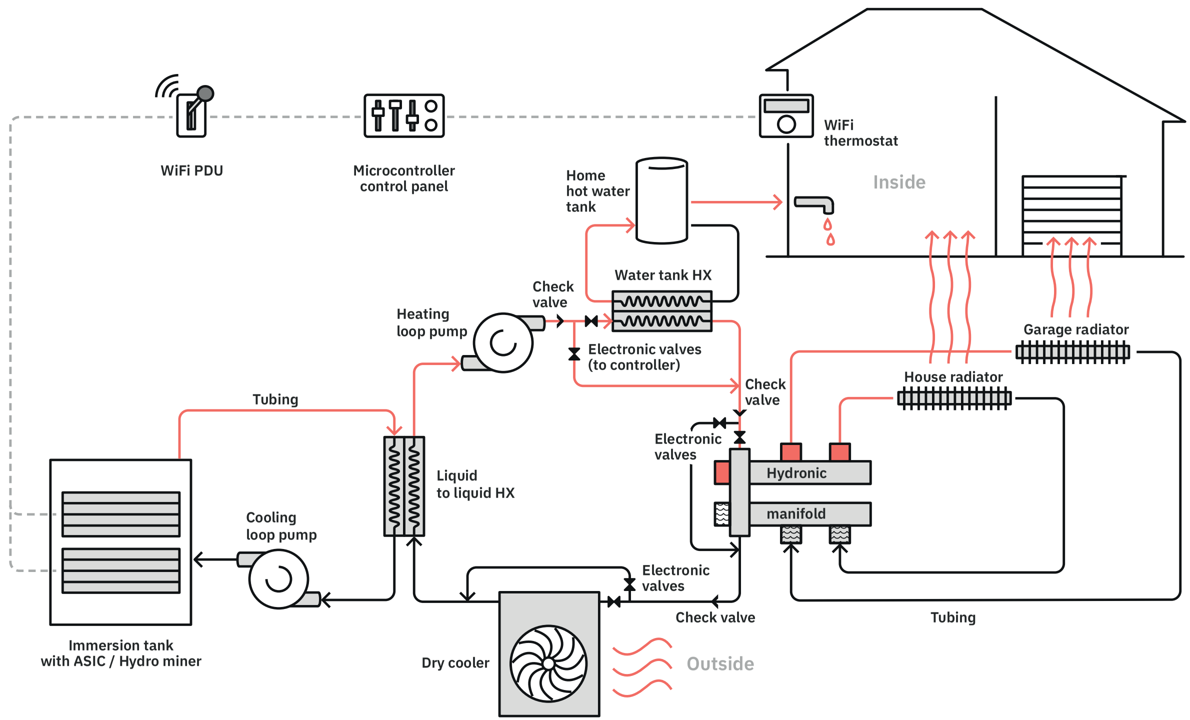
VISUALIZING THE SYSTEMS

That was a lot of hardware. To help connect the dots, take a look at the graphics below. They illustrate simplified possible system designs, showing how these components work together in both air-based and liquid-based hashrate heating setups.

Air-Based Hashrate Heating Ex



Liquid-Based Hashrate Heating Ex



SPECIAL CONSIDERATIONS

The hardware covered above highlights the core components of integrated air and liquid hashrate heating systems. However, it's far from an exhaustive list. Similarly, the example networks illustrated are just one way to approach system design - they're not the only path forward. Designing your own custom setup opens the door to endless possibilities, but it also comes with unique considerations that can make or break its success. Let's explore some of the key factors to keep in mind as you bring your system to life.

Air vs Immersion vs Hydro

So which cooling method is best? Like most things in bitcoin mining, it depends. There are trade-offs to each thanks to a combination of unique fluid properties and practical considerations.

Air Cooling Properties Compared to Liquids

Air is less effective than liquids for transferring heat over large distances or with small temperature gradients. This is because its low **density** and **specific heat capacity** (how much heat energy it holds) mean it carries less heat energy per volume or mass, requiring lots of airflow to transport heat. Additionally, air has low **thermal conductivity** (effectiveness at passing heat to other stuff), which makes it less efficient for transferring heat to surfaces. However, its high **diffusion** (mixing) efficiency helps distribute heat evenly, making air-cooled miners ideal for warming rooms or large zones.

Liquid Cooling Comparison – Immersion vs Hydro

Liquid cooling systems, like immersion and hydro, outperform air cooling in heat transfer due to the far superior physical properties of liquids. But the choice between these two liquid options is nuanced.

Immersion cooling submerges miners in dielectric oil, insulating hardware from dust and debris while leveraging the oil's high **spe-**

cific heat capacity and **thermal mass** to absorb and store heat. This helps stabilize temperatures, reducing wear and extending hardware lifespan. Thanks to full hardware submersion, immersion-cooling captures all heat from ASIC chips, power supplies, and control boards, making it ideal for applications where every watt of heat is valuable. However, it's not all upside. Oil's high **viscosity** (thickness) makes it less efficient for pumping and transferring heat over long distances compared to water. Maintenance can also be cumbersome, as miners must be thoroughly cleaned of oil for repairs, and immersion systems are notorious for eroding thermal paste between ASIC chips and heat sinks. Another major challenge for immersion hashrate heating is that most hydronic hardware - like pumps, valves, manifolds, and expansion tanks - is incompatible with dielectric oil. Components are more limited (thus more expensive) and must be carefully selected for compatibility.

Using water to directly target ASIC chips with hydro-cooling is more efficient at heat removal than immersion-cooling because there are no heat sinks in the way. Water's higher **density**, lower **viscosity**, and superior **thermal conductivity** allow it to transport more heat energy per unit volume and mass. This makes hydro setups ideal for applications requiring rapid heat transfer and distribution across longer distances. By targeting ASIC chips directly, hydro cooling offers precise temperature control with less fluid volume. However, the added complexity of tubing, seals, and water blocks add more potential points of failure, requiring careful management to prevent leaks or additional maintenance. Hydro systems are also more compact, avoiding the bulky tanks needed for immersion setups. However, hydro cooling doesn't capture heat from power supplies and control boards, focusing instead on chip-level cooling.

Who's the Winner?

Depends on what you're looking for. Immersion cooling systems are better suited for heat reuse setups that prioritize long-term reliability, temperature stability, full hardware encapsulation, and comprehensive heat capture. Hydro cooling, on the other hand, is better suited for heat reuse setups that prioritize more efficient heat transfer, higher heating fluid temperatures, more precise ASIC chip temperature control or direct compatibility with more hydronic hardware.

Picking out Parts – The Art of Component Sizing

While heating hardware is often designed for compatibility and interchangeability, building a bitcoin-powered heating system isn't as simple as snapping together Legos. Every component must be carefully selected to transfer the right amount of heat efficiently and reliably throughout the system.

This selection process is referred to as **sizing** the components. Much like assembling a high-performance PC, you wouldn't pair a top-tier processor with an underpowered graphics card - it's the same principle here. **Each part needs to work in harmony to ensure your miners continuously generate both BTC and BTU without bottlenecks or inefficiencies**.

BTU vs KWh - Comparing Apples to Apples

Before you can begin sizing components for your hashrate heating system, it's essential to make sure all units of measurement are comparable. Most bitcoin miners measure power and energy consumption in **kW** and **kWh** respectively, while heating infrastructure measures energy in **BTU** and heating power in **BTU/hr**. To properly select components, you'll need to convert the power consumption of your bitcoin miners into **BTU/hr** (heating power) for easy comparison with the other components in your system.

Quick conversion: *1 kW of power consumption equals roughly 3,412 BTU/hr of heat output.*

Every part of the system – air ducts, heat exchangers, radiators – must be able to handle the amount of heat your bitcoin miners are generating. If any component is undersized, the heat will become trapped in the system, which can lead to hardware failure.

And because a hashrate heater can run with continuous adjustable heating power instead of bang-bang control, you don't need to match the BTU/hr output of your original furnace directly. A furnace may be rated for high BTU/hr, but is designed to run intermittently, commonly delivering only a fraction of the total heating power it's capable of.

ASHRAE and Design Conditions

Sizing your hashrate heaters goes back to determining the "Design Condition," the most extreme scenarios your system will face. This defines the maximum heat output needed, the number of bitcoin miners, and the infrastructure required.

Once you know the BTU/hr (or kW) output needed, you must ensure the heat delivery or rejection hardware can handle that load. **Heat transfer efficiency depends on the temperature difference between the heat source and its surroundings - it's easier to move heat on cold days than warm ones**.

This is where **ASHRAE** (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) guidelines help by providing industry standards based on historical climate data, ensuring the entire system performs efficiently in both extreme cold and warm conditions.

For example, on the coldest day, heat transfer is straightforward, but during hotter periods, moving heat becomes more challenging. ASHRAE tools ensure your hardware is properly sized to handle these variations, keeping your system effective year-round. To optimize your system, size components to handle your worst-case design conditions; the coldest day when miners are running at full power to meet heating needs, and the hottest day when heat will transfer the least efficiently, but you still need it.

Heat Exchanger Sizing

In liquid hashrate heating systems, proper heat exchanger sizing is essential: an undersized heat exchanger limits heat transfer, creating inefficiencies, while an oversized heat exchanger adds unnecessary cost and complexity.

Heat exchanger size is determined by the flow rates and the temperature difference between the two loops. A larger temperature difference allows for more efficient heat transfer.

Pump Sizing

Proper pump sizing is essential in liquid-cooled systems to maintain efficient fluid circulation. Pumps operate along a “pump curve,” which shows the balance between flow rate and pressure head (how much force they can exert). Matching the pump’s capacity to your system’s resistance - factoring in pipe length, fittings, and elevation changes - is key.

An undersized pump won’t move liquid fast enough for effective heat transfer, while an oversized pump can cause excessive pressure, waste energy, or damage components. The goal is a pump that provides sufficient flow without unnecessary strain.

Radiator and Dry Cooler Sizing

The effectiveness of heat delivery or rejection for radiators and dry coolers depends on having enough surface area for efficient heat exchange. The faster you need to move heat, the larger the radiator or dry cooler must be, and the more fan and pump power it will require.

When using radiators to heat rooms, you’ll need to calculate the heat demand for the space and select a radiator with sufficient capacity. Similarly, dry coolers must be sized to handle heat rejection under the hottest design condition, ensuring they perform effectively even when it’s hardest to transfer heat.

Fan Sizing and CFM Matching

In air-based systems, fan sizing ensures the airflow (measured in cubic feet per minute, or CFM) matches the ductwork and heat distribution needs. An undersized fan won’t move enough air to heat the space effectively, while an oversized fan can waste energy and produce excessive noise. Larger ducts require fans with higher CFM ratings to maintain proper airflow and pressure.

Safety, Maintenance, and Reliability

Maintaining safety and reliability in hashrate heating systems requires specific hardware and consistent checkups - just like any other heating system. **Dust management** is crucial for air-cooled systems, where **intake filters** keep debris from damaging components and **exhaust filters** ensure clean indoor air is sent where you want to use it. Regular cleaning or replacing filters preserves performance.

Temperature consistency helps avoid **thermal stress**, particularly in air-cooled setups where rapid heating and cooling cycles can wear down electronic components. For liquid-cooled systems, **leak prevention** is key. Pressure test and inspect pipes, fittings, and tanks after installation. For immersion setups, containment is critical to avoid spills, given the high cost and messiness of immersion oil.

DON’T WORRY – THE EXPERTS ARE HERE

While everything in this chapter may sound daunting and confusing, it’s important to remember – **all of these hardware tools have existed outside of bitcoin mining for decades**. **The only new variables added are the bitcoin miners**. People know how this stuff works – so it’s worth working with professionals to select well established, reliable components that guarantee high performance and safe operation.

So much goes into selecting the right hardware for hashrate heating, but the right software can help your system thrive.

OPTIMIZING FIRMWARE & SOFTWARE

A well-engineered hashrate heating system can deliver consistent, comfortable, and reliable heat with properly sized hardware and analog control alone. Software, however, brings in what we might call “luxurious” features: remote control, data monitoring, customized performance, and automation.

Unlike traditional heating systems, where a thermostat connects directly to a furnace or boiler to turn heat on and off, **hashrate heating systems are quite literally computers (that only mine bitcoin) at their core**. They require several layers of communication between the user’s temperature setting and what’s delivered by the mining hardware. Each component needs to “talk” to one another, follow updates, and receive commands in specific ways, adding to the complexity but also enabling finer control.

THE LAYERS OF CODE

In a smart hashrate heating system that uses software control, the layers of code form a communication hierarchy that starts with the physical hardware and progresses up through various layers of software. Each layer serves a unique purpose and builds upon the one below it.

Layer 1: ASIC Miner Hardware

- **Purpose**: The core of the miner, consisting of boards, chips, and power supplies, defining its capabilities and limits.
- **Analogy**: Like a car engine that defines power, torque, and fuel economy, miner hardware defines power consumption, heat output, and mining efficiency.
- **Connection to Firmware**: Firmware interacts with hardware to manage processes like temperature, power levels, and system performance.

Layer 2: Firmware

- **Purpose**: The miner's operating system, managing processes, settings, and often featuring a web GUI for basic configuration.
- **Analogy**: Like a car's onboard computer that manages everything from fuel injection to engine temperature. Firmware handles settings that directly affect miner performance.
- **Connection to Hardware**: Translates hardware capabilities into controlled operations, optimizing hashrate, temperature, and power management.

Layer 3: Miner API (Application Programming Interface)

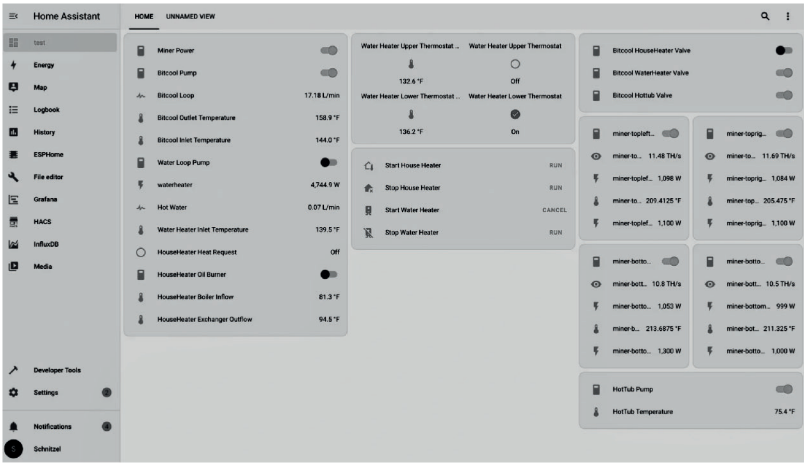
- **Purpose**: The API serves as an external access point for monitoring and adjusting firmware settings remotely, enabling outside interaction with the miner.
- **Analogy**: Like a remote control for a car, enabling you to start the engine or change settings from a smartphone.
- **Connection to Firmware**: Interfaces with firmware to execute remote commands, modify settings, and send performance data to external devices like microcontrollers.

Layer 4: Functionality Abstraction

- **Purpose**: Standardizes the functions of various miner types, translating different API commands into a unified set that's easier for an integrated system to manage. Functionality abstraction tools like *pyasic* or *Braiins Manager* simplify using miners from various manufacturers as a cohesive unit.
- **Analogy**: Like a universal translator, it lets miners of different types "speak" a common language, enabling centralized control.
- **Connection to API**: Uses the API to issue commands across a fleet of miners, ensuring consistent performance without needing device-specific code.

Layer 5: GUI (Graphical User Interface)

- **Purpose**: The GUI provides an easy-to-use interface, allowing users to access advanced functionalities through buttons, sliders, apps, and other tools. Open-source tools like *hass-miner* integrate with *Home Assistant OS* to make accessible smart control apps for hashrate heating systems.
- **Analogy**: Like a car dashboard, it displays controls and settings, enabling users to monitor and adjust performance without delving into complex systems.
- **Connection to Abstraction**: Interfaces with the abstraction layer (e.g., pyasic) to manage miner controls across models, presenting them as a unified system.



OPTIMIZING SOFTWARE AND FIRMWARE FOR HEAT REUSE APPLICATIONS

So how can some of these layers of code be optimized specifically for hashrate heating?

Stock vs. Aftermarket Firmware

Stock miner firmware lacks features and is often inefficient. Aftermarket firmware, like Braiins, replaces it, adding features such as autotuning and better efficiency, enabling more bitcoin rewards for the same energy and heat output. Think of it like a car engine tune: new software unlocks more performance without changing parts. **For hashrate heating, aftermarket firmware is essential, offering better control, efficiency, and temperature management - turning standard miners into effective heating devices**.

Temperature Targeting & Self Regulation

Firmware features like Braiins' DPS that enable self-regulating thermal management can be optimized to adjust power/heating levels more quickly and consistently. **Slow power ramp-ups after temperature-triggered power reductions don't work for heating systems that need steady, responsive heat**.

Power & Efficiency Tuning

Dynamic tuning ensures miners maintain efficiency at varying power levels. Some current miners require rebooting to re-tune, limiting adaptability. **Ideally, miners would tune once across all power levels, maximizing hashing performance and bitcoin rewards regardless of heating output. Better yet, miners could be designed to operate efficiently across all power levels from the start, eliminating the need for tuning altogether**. Moreover, scaling power down to near zero - perhaps by dynamically turning individual hashboards on and off to minimize efficiency loss - is key for a wide range of heating options.

Different Performance Modes: Efficiency vs Power

Pre-set modes in firmware for hashrate heating could address different priorities:

- **Max Heating Mode**: Prioritizes maximum heat output, using full power to quickly reach target temperatures.

- **Eco Mode**: Balances energy use and heating needs, ramping up and down efficiently to minimize costs.

- **Satoshi Mode**: Focuses on mining efficiency (J/TH), maximizing bitcoin rewards while meeting heating demands.

COMMUNICATION AND NETWORKING

Hashrate heaters require an internet connection to perform mining operations. This dependence on the internet presents a concern. Since miners need a connection to the bitcoin network to hash, what happens if your internet goes down? Do you lose heat along with it?

Fortunately, with Braiins OS, the answer is no. **By setting a secondary backup mining pool to drain://x, the miner can continue to operate and consume power even without internet access**. This allows the system to keep producing heat without interruption, regardless of connectivity.

A related concern is that **Hashrate heating systems rely on low latency data exchange to stay synced with the bitcoin network and mining pools.**

But what about rural areas, where hashrate heating is a great solution? Luckily, bitcoin mining has minimal bandwidth requirements. Even a Starlink satellite connection can handle it, making hashrate heating a practical option for remote locations.

MINING POOLS AND PAYOUTS

Joining a mining pool is essential for most hashrate heating systems, as solo mining requires significant hashrate to overcome long payout intervals. While large-scale applications, like district heating, might consider solo mining, most systems benefit from mining pools.

Mining pools enable many miners to collaborate on solving bitcoin blocks, splitting rewards among contributors. For hashrate heating, pools ensure steady payouts to help offset regular heating costs. Pool settings are configured in the miner's firmware and can be adjusted via the pool's website, offering flexibility in managing payouts and performance.

Here's what to keep in mind when it comes to selecting and configuring a pool:

Lightning Withdrawals

To collect rewards from a hashrate heating system, you'll need to provide a bitcoin address to the mining pool for payouts.

For most hashrate heating systems, Lightning Payouts (offered by pools like Braiins Pool) are essential. They use the layer 2 Lightning Network to enable instant, low-fee transactions, avoiding long waits to accumulate enough rewards for an on-chain payout and bypassing high transaction fees that could erode earnings.

Larger systems with substantial hashrate and higher payouts may not require Lightning withdrawals.

Locked Firmware and Pool Settings

Hashrate heating systems may require password protection on firmware pool settings to prevent unauthorized changes that

could disrupt system performance or reroute mining rewards. Pool accounts are linked to your bitcoin wallet and determine where the mining rewards are sent, which means security and control over these settings is critical.

Some miner firmware includes password-protected settings, allowing pool configurations to be locked once established. This ensures stable operation and safeguards the economic rewards of the system.

Sub Accounts

Mining pool sub-accounts can be a valuable tool for directing bitcoin heating system rewards to multiple wallet addresses. For example, a homeowner or commercial business might allocate a portion of the rewards to one wallet for saving and stacking sats, while sending the rest to another wallet for selling to offset heating costs.

Selecting a mining pool that supports sub-accounts and automatic reward splits adds flexibility and opens the door to more tailored approaches for managing hashrate heating system rewards.

WHY THIS MATTERS FOR HASHRATE HEATING SYSTEMS

While the flexibility, performance optimization, and fine-tuning options that come with software and aftermarket firmware are impressive, they do require extra layers of setup and understanding. Even if you opt for a fully analog hashrate heating system, firmware and software still come into play. Core functionality and settings – like power output and basic performance adjustments – are handled by firmware, so understanding these elements is essential for designing any well-rounded bitcoin heating system.

As the bitcoin heat reuse industry matures, I expect we'll see further innovations in software and miner firmware that improve performance, streamline setup, and enhance control options for heating applications.

Fortunately, many of the teams developing bitcoin mining firmware, including Braiins, actively listen to user feedback on issues and feature needs. Until then, it's promising to see open-source solutions like *pyasic* and *hass-miner* built on top that enable full digital control for smart hashrate heating.

At this point, we've explored why to do this, who's a good fit, and how to pull it off. Now let's talk about money.

ESTIMATING THE ECONOMIC OPPORTUNITY

While all the technical details are important, the main reason you're probably interested in bitcoin-powered heating systems is to save on heating expenses via bitcoin rewards. Why pay for *just* a heating bill when your heater could also mine bitcoin at the same time?

With thoughtful **thermo-economic analysis** (factoring heat energy consumption and linked costs), we can build off of the **Heat Audit** to forecast average expected mining revenue.

Let's take a look at the economic variables at play.

UNDERSTANDING KEY ECONOMIC VARIABLES

There are four key economic variables to a hashrate-powered heating system upgrade: Your **current heating operational costs**, the **upfront cost of upgrading to bitcoin-powered heat**, the **new heating system operational costs**, and the **bitcoin subsidy** that the hashrate heating system will provide.

Current Operational Expenses

Heat is a recurring expense in any home or business. Whether it's a monthly natural gas bill, annual propane tank refills, or another source, you're continually paying to keep the system operational. This existing recurring cost is referred to as an operational expense, or ***OPEX_original***

To fully understand your current heating OPEX, we need to identify three key things:

- **The quantity of energy you use** (kWh, BTU, MCF, Gallon, etc.)
- **The unit cost of that energy** ($/kWh, $/BTU, $/MCF, $/Gallon, etc.)
- **The relationship between heat usage and external factors** like weather or business operations.

In some cases, your energy bill might make this easy by isolating the heating portion – where you can find your heat *OPEX* by just looking at the bill. But sometimes, heating costs are blended with other energy uses in the bill, making it harder to pinpoint. Depending on your provider and billing structure, this information may be easy to extract, or you might need to do some further digging. **Knowing the exact amount of energy used for heat is key since we want to *replicate* it with hashrate heat**.

Once you know *how much energy* you're using for heat and the *cost per unit* of heat, you can calculate your current heating operational cost.

However, the real key to a solid thermo-economic analysis is understanding how your heat consumption changes based on external factors like the weather or how busy your business is[15].

Looking at a single month or year of data might not tell the full story. You want to account for variations in heat demand, like especially cold

15 There are various thermo-economic methods for estimating heat energy consumption based on external climate factors, including: Heating Degree Days (HDD), Duty Cycle & Load Analysis, Thermal Modeling, and Energy Metering. I encourage you to explore these approaches if you want a deeper understanding. A good rule of thumb is to use one miner per 1,000 sq/ft or 1,000 gallons as a general guideline, though factors like insulation, water temperature, and miner output temperature may affect this.

winters, so your analysis isn't skewed by an atypical season. Historical temperature data can give you this broader perspective, helping you size your system accurately and ensure you don't overpay for unnecessary extra heating capacity - but still have enough for the average winter.

$$\mathit{Energy}_{\mathit{Quantity,\ Heat}} = \textit{Unique. Influenced by external factors.}$$

The exact amount of heat energy needed depends on external factors like the weather or business cycles. Determining this relationship requires *separate* thermal analysis.

$$\mathit{OPEX}_{\mathit{original}} = \mathit{Energy}_{\mathit{Quantity,\ Heat}} * \mathit{Unit\ Cost}_{\mathit{Heat\ Energy}}$$

Example:

On average, 4.34 million BTUs of heat are required throughout January to keep a building at 65°F, based on the historical average ambient temperature over the past 20 years[16].

4.34 M BTU equates to roughly 51.6 gallons of propane, assuming a 92% heating efficiency (AFUE, which measures how efficiently the fuel is converted into usable heat).

$$\mathit{Energy}_{\mathit{Quantity,\ Heat}} = \textit{51.6 gallons (propane used for an average January)}$$

$$\mathit{OPEX}_{\mathit{Original}} = \textit{51.6 gallons * \$2.85/gallon = \$147.06 (spent for heat on average in January)}$$

16 To quickly estimate your original OPEX, you could just reference one isolated heating bill. But for a direct comparison with the upgraded system, it's crucial to evaluate costs for the same quantity of heat, as yearly needs can vary. By correlating average energy use with historical temperature or business data, we can better estimate average future heat demand and cost for a more accurate comparison.

Upgrade Capital Expenses

Switching to a bitcoin-powered heating system requires an upfront investment in the hashrate heater itself, supporting hardware, and the costs of installation. These initial expenses are known as capital expenditures or ***CAPEX***.

If the installation is cheap and easy, upgrading to a system that offsets costs by mining bitcoin is a no-brainer. But if the upgrade costs thousands more than a regular heater, it's natural to hesitate and question whether the investment is worth it.

We've stated several times that bitcoin miners are not cheap. They're highly efficient, power-dense devices that take years to develop and are continuously improved. Additionally, bitcoin miners don't operate with large amounts of heating headroom and low duty cycles like traditional furnaces or boilers - they prefer to run close to full power.

As a result, we want to size the system to use the *minimum* amount of bitcoin miners needed to sustain our heating needs. To do this, we need to know how much heating power is required - ensuring it's enough to meet the average winter, but not overkill for the fluke freeze once a decade. Getting this design condition right with *thermal analysis* and a more detailed **Heat Audit** investigation ensures you don't overspend on unnecessary heating capacity.

Once you know the heat output required, you can calculate how many bitcoin miners you'll need to meet that demand. From there, you can determine the additional components – such as ducts, pumps, tanks, and fittings – and build out a complete bill of materials (BOM).

A little research will give you an estimate for labor costs, completing your *CAPEX* calculation.

$$CAPEX = Cost_{Miners} + Cost_{Auxiliary\ Hardware} + Cost_{Labor}$$

Example:

Let's walk through the example business from earlier. Thermal analysis indicates they need one bitcoin miner, an immersion tank, and additional hardware to capture the heat from an air-cooled device and transfer it via liquid to the intended application. They also need to account for the labor costs involved in installing the system.

CAPEX = S19k Pro + Immersion Tank, Oil, Heat Exchanger + Labor
CAPEX = $1000 + $1000 + $1000 = $3000 (for the system upgrade)

Upgrade Operational Expenses

After we know how many bitcoin miners are required to meet the heating needs of your home or business, we can estimate the operating cost of the hashrate heating system upgrade, or ***OPEX_upgrade***.

Your previous heating system may have been powered by propane or natural gas, oil - but with a bitcoin-powered heating system, your heating expenses will now be part of your electricity bill. **Since electricity powers almost everything in homes and businesses, it won't be straightforward to isolate exactly how much of the new bill is due to heating alone**.

This is where having that predictive method to estimate heating costs based on external factors like temperature or business operations becomes crucial. Knowing the relationship between how much heat you use and external factors (like outside temperature) will allow us to estimate average future heating bills with the hashrate heating system. This isolates how much of your overall electric bill is now attributable to heating once the system is installed.

$$OPEX_{Upgrade} = Energy_{Quantity,\ Heat} * Unit\ Cost_{Electricity}$$

Example:
*We previously established that the business uses roughly **4.34 M BTU** (equivalent to 51.6 gallons of propane) of heat energy on average in January, based on historical temperature data over the past 20 years. By converting 4.34 M BTU to kilowatt-hours (kWh), we get **1271.4 kWh** of energy. With this energy estimate in the right units and the known electricity rate, we can now calculate the projected electric heating cost for January.*

$$OPEX_{Upgrade} = 1271.4\ kWh * \$0.13/kWh = \$165.28 \text{ (estimated for average January)}$$

This same method can be applied across every month or billing cycle to predict the recurring operational costs of the hashrate heating system, with confidence that the estimates will be close representatives of real bills, since they are based on historical weather data.

Now that we have a rough estimate of the new hashrate heating system's operational cost for each month, we can directly compare it to the original heating bill.

As you may have noticed, the new electric heating system is slightly *more* expensive to operate ($165.28 vs $147.06 for an average January) than the original propane heating system. However, they're quite close – *and we haven't even factored in the bitcoin mining rewards yet*.

Upgrade Bitcoin Subsidy

The last variable is to estimate how much bitcoin the system will mine to subsidize heating costs. This is the ***BTC_subsidy*** of the hashrate heating system upgrade.

To start, the miner's operating power will depend on the heat demand. It will dynamically adjust its power usage or kick on and off to match the amount of heat required at different times throughout the month.

So, how do we figure out how much work the miner does for the bitcoin network while it's heating your space?

This is where we calculate the ***average*** **duty cycle** of the miner for heating over the month. In this average monthly analysis, we can estimate it with the total energy used for heat, compared to the total mining energy *available* for heat if the miner was on all month at full power. From there, we can estimate how much the system will mine by calculating the miner's *average* hashrate over the same time period.

$$Duty\ Cycle_{Average,\ Energy} = Energy_{Miner\ used\ for\ heat} / Max\ Energy_{Miner\ at\ full\ power}$$

Once we have the *average* duty cycle for the month, we can multiply the total hashrate of all the miners in a hashrate heating system by the average duty cycle to get the ***average*** **hashrate** online for heating.

$$Hashrate_{Heat,\ Average} = (\Sigma_{Miners} Hashrate) * Duty\ Cycle_{Average,\ Energy}$$

Example:

In our example business, only 1 Bitmain S19k Pro miner is needed to supply sufficient heat, since 1 miner running at full power of 2.76 kW could generate 2053.4 kWh of total heat energy over the month. Here's a quick check.

$$2.76\ kW * 744\ hours\ in\ January = 2053.4\ kWh$$

Converting that energy to BTU, we see this is more than enough to replace the business's original heating need of 4.34 M BTU:

$$2053.4\ kWh = 7\ M\ BTU > 4.34\ M\ BTU$$

But since we don't need the total heating energy the miner is capable of, it won't run at full power all month. We estimate it will only need to run *at 62% power (or 62% of the time at full power) on average throughout the month to match the heating energy requirements[17]:*

$$Duty\ Cycle_{Average,\ Energy} = 1271.4\ kWh\ /\ 2053\ kWh = 0.62 = 62\%$$

Now we can estimate the actual hashrate for heating:

The S19k Pro has a total hashrate of 120 TH/s at full power, but because it's running at 62% of its total heating capacity for the month on average, the estimated average hashrate for heating is 74.4 TH/s.

$$Hashrate_{Heat,\ Average} = 120\ TH/s * 62\% = 74.4\ TH/s$$

This gives us the average hashing power used to heat the building throughout January. With this information, we can estimate the bitcoin rewards the system will generate to subsidize the heating costs for the month.

Revenue from hashrate heaters can be calculated using one of two metrics:

1. **Hashvalue**: This measures revenue in bitcoin terms (BTC/TH/s/day)

2. **Hashprice**: This measures revenue in fiat terms ($/TH/s/day)

Each metric has its benefits. For this analysis, we'll use hashprice, as it's measured in dollars, the same unit as our system *OPEX* and *CAPEX*. If you're interested in a deeper dive on these metrics, check out Braiins' *Bitcoin Mining Economics* Book.

17 This is a simplified method of estimating mining power over time. There will likely be times in January when the miner runs at full power to keep up with heating needs on particularly cold days. However, for the purpose of this economic analysis – which looks at the monthly energy bill as a whole – we can conservatively average the power consumption of the hashrate heater.

Hashprice is a way to estimate the daily revenue a hashrate heater generates for a given rate of computational work. In other words, it tells you how much money you earn per day for each TH/s of hashrate heating power online.

Hashprice takes into account four key factors:

- **Bitcoin Block Subsidy** (Decreases 50% after each halving)
- **Bitcoin Block Transaction Fees** (Based on network traffic)
- **Bitcoin Network Difficulty** (Competition from other miners)
- **Bitcoin Price** (Current value in fiat terms)

For these examples, we will use a moderately conservative bitcoin hashprice of **0.06 $/TH/s/day** - taken a few months after the fourth halving, but before the bull market is in full swing. Your analysis estimates may yield stronger or weaker results than what is shown here.

$$BTC_{Subsidy,\ FIAT} = Hashrate_{Heat,\ Average} * Days_{Heating} * Hashprice$$

Example:
For January, the average revenue estimate is:

$$BTC_{Subsidy}, FIAT = 74.4\ TH/s * 31\ days * \$0.06/TH/s/day = \$138.38$$

Now that we've estimated how much bitcoin revenue the hashrate heater will generate in January, let's walk through the numbers side by side. It looks pretty enticing.

Estimated Hashrate Heating Upgrade Economics - Average January		
Variable	Amount	Comment
$OPEX_{Original}$ *(Propane)*	$147.06	Average January Heating Cost with Original Propane Fuel
$OPEX_{Upgrade}$ *(Electric)*	$165.28	Average January Heating Cost with Upgrade Electric Heat
$BTC_{Subsidy, FIAT}$	$138.38	Average Estimated January Bitcoin Reward Value with Fixed Hashprice
$Cost_{Heat, NET}$	$26.90	Average NET January Heating Cost after Bitcoin Subsidy
$Savings_{Heat}$	$120.16 (82%)	Average January Heating Cost Savings Compared to Propane System

CALCULATING ROI

Once we've modeled the full year, we can move on to the final step: calculating the return on investment, or **ROI**. This will give us the complete picture of how worthwhile the upgrade is and how many years it will take to pay itself off.

To calculate ROI, we need to know the total bitcoin subsidies earned or the total saved through net heat cost reductions over a full year. **Without going into each month's details, the business example we've been following results in $550.86 saved over the year if the sats were immediately put towards heating expenses (with less savings**

in summer when less heat is needed). Another way to look at it is a total bitcoin revenue of $635.09, *assuming a constant* hashprice.

This highlights two ways to approach ROI:

$$ROI_{NET} = CAPEX \,/\, \Sigma_{\,Year}\, Savings_{Heat}$$

This is the standard way to calculate ROI, where we focus on the net savings – how much you pocket after selling mined sats to help pay your heating bill. This approach is common for infrastructure upgrades.

$$ROI_{GROSS} = CAPEX \,/\, \Sigma_{\,Year}\, BTC_{Subsidy,\ FIAT}$$

This method factors in annual bitcoin revenue, treating it as part of your ROI. In this scenario, you'd pay the regular heating bill and stack all the bitcoin mined as extra income, counting that towards paying off the system upgrade. The bitcoin may also appreciate in price. **Keep in mind – since bitcoin's inception, no asset has outperformed it**. If you are ever concerned about bitcoin's short-term price, zoom out on the price graph you're looking at.

Both methods are valid, and which one you prefer to measure depends on your goals. Do you want to reduce your heating costs month to month, or are you stacking **sats** for the long haul?

Also worth noting, for any other type of heating system upgrade, only net *ROI* can be considered, since other heat sources don't directly pay you for heat consumption[18].

Example:

$$ROI_{NET} = \$3000 \,/\, \$550.86/yr = 5.4\ years$$

18 If you're already using electric heating, the economic calculation is even simpler. The operating cost of the hashrate heating system will be the same as your current electric heating, but with the added bonus of earning bitcoin. The only factors to consider are the upfront CAPEX and bitcoin subsidy of the new system.

$$ROI_{GROSS} = \$3000 \,/\, \$635.09/yr = 4.7\ years$$

Conservatism, Hashprice Variability, and Weather

After walking through the economic model that estimates monthly cost savings and ROI for a hashrate heating upgrade, you might be asking yourself a few important questions:

- How conservative is the model, really?
- How is it accurate if we assume a static bitcoin hashprice when it changes every day?
- What about extreme weather conditions? What if there's an unusually cold day that throws off the estimates? Can you really "average" heat and hashrate?

Conservatism

In short, **this high-level, averaged approach is conservative, practical, and good enough for decision-making**. It captures the key financial trends and insights while smoothing out the noise from daily volatility, which helps avoid getting bogged down in analysis paralysis. It's an accessible and appropriate method for small-to-medium businesses and residential users, or for anyone looking for a quick first-pass analysis to gauge the economic potential of hashrate heating.

Could the model be more precise? Absolutely. You could incorporate real-time hashprice fluctuations, hourly thermal modeling, or more accurate design condition estimations. I encourage anyone with the need or resources to explore these deeper.

But for most users, this method strikes a balance between simplicity and reliability, offering a solid understanding of whether a hashrate heating system makes financial sense.

With that in mind, let's explore why this model is conservative and how it could be improved if needed.

Hashprice

The model conservatively uses a near-historic low hash price, a few months after the halving event and in the early stages of the typical bull market phase that follows.

Historically, bitcoin's price has trended upward over any **four-year period** due to its fixed supply and increasing demand. This cyclical appreciation means that, with an ROI estimate of over four years (4.7 years *ROI_GROSS* and 5.4 years *ROI_NET* in our example), **you can reasonably expect your actual ROI to be faster if you hold onto some of the mined bitcoin rather than selling it immediately to subsidize heating costs**. Additionally, the model excludes potential increases in transaction fees, which will likely grow as the block subsidy continues to halve, becoming a larger part of miner revenue. Although increased network difficulty reduces bitcoin rewards per unit of work, it's easier for bitcoin's price to rise faster than sufficient hashrate is added to suppress hashprice growth.

To refine this model, you could consider the bitcoin market cycle timing when performing your analysis, adjusting the hash price down if a halving is near or averaging it over a four-year period to smooth out cycle effects. Factoring in modest assumptions for new hashrate brought online, bitcoin price growth and transaction fee trends could further improve the model, aligning it more closely with historical patterns while still maintaining conservatism.

External Variables and Weather Fluctuation

The model estimates heating needs based on monthly average energy consumption, smoothing out extreme temperature swings like an unusually cold day. This approach is conservative, allowing flexibility. For instance, if miners are predicted to run at 62% capacity in January, the remaining 38% capacity acts as a buffer for colder days or hours when full power is required. This prevents overestimating and overspending on rarely-used equipment.

To further ensure reliability, the model uses data from one of the coldest months over a 20-year period, providing a conservative baseline for heat-energy relationships. This adds a built-in margin to accommodate future variations without requiring complex adjustments.

For added safety, you could implement additional margin-of-safety and increase heat energy estimates by 10-50% or analyze daily or hourly temperature data for greater precision. However, this model strikes a balance - sizing systems to handle colder months without overspending on capacity needed only occasionally.

If you're upgrading, retaining your original heating system provides redundancy. For example, keeping a propane system as backup ensures there's no risk of under-heating, adding another layer of conservatism.

NEW BUILDS OR REPLACING BROKEN SYSTEMS

The value of switching to a hashrate heating system depends on your current setup. For an upgrade to a functional, newer system, ROI must be compelling - with the **Heat Audit** and **thermo-economic analysis** supporting significant savings. **If the ROI stretches beyond a decade or the savings are minimal, the upfront cost likely isn't worth it**.

For new builds or replacing outdated or broken systems, the calculus changes. Traditional systems are a sunk cost with no payback, but a hashrate heating system introduces mining revenue to offset heating expenses. Even with a slightly higher upfront cost, the long-term potential for savings makes it an attractive option.

MAKING THE UPGRADE LAST

Bitcoin rewards will naturally decrease over time due to the halving cycles every four years, reducing the number of satoshis earned per terahash. This decline, coupled with the rising network difficulty - averaging a 60% annual increase - means your system will earn fewer bitcoin-nominated rewards as more miners join the network. While your hashrate heating system will still generate value, its share of network rewards will shrink over time.

However, declining bitcoin subsidies don't necessarily translate to diminished returns in economic terms. **As nominal bitcoin rewards decrease, their fiat value may rise, potentially preserving or even increasing the dollar-equivalent subsidy from your system**.

Hashrate heating systems also outlast traditional mining setups since heat value reduces reliance on miner efficiency. Upgrades are less frequent and, when necessary, may only involve replacing miners while retaining the existing infrastructure. With continued bitcoin growth and ASIC advancements, future upgrades of the "miner heating element" can rejuvenate your system, extending its usefulness and payback potential for years to come.

OPPORTUNITY COST – MINE FOR HEAT OR BUY SATS INSTEAD?

Even with a quick ROI and significant heating cost offsets, upgrading to a hashrate heating system may not always be the best use of your capital - especially if you already have a functional heating system. **For hardcore bitcoiners, the opportunity cost of buying bitcoin directly is worth considering**. Bitcoin's halving cycles reduce supply and have historically preceded bull markets, potentially making direct purchases more profitable than investing in a heating system upgrade if timed appropriately.

This is particularly relevant for residential users who shoulder the upfront costs themselves. With limited financing and only modest savings projected, putting that capital into stacking sats might make more sense. **In contrast, business owners can use financial tools to spread out CAPEX over time to improve upgrade ROI. This reduces upfront risk and opportunity cost while still benefiting from bitcoin mining revenue**.

Ultimately, the decision comes down to personal priorities and careful assessment.

MY ECONOMICS AREN'T GREAT, BUT I WANT TO DO IT ANYWAY

Even if the financial outlook of a hashrate heating system - like a longer ROI, higher CAPEX, or moderate savings - doesn't seem ideal, there are still valid reasons to move forward.

For instance, energy costs might not directly affect you. If you own an apartment building where tenants pay their own heating bills, you could stack sats passively while they cover the energy usage, creating a strategic win-win setup.

You might also be motivated by bitcoin itself, willing to invest extra to add hashing power, secure the network, and stack non-KYC sats. This aligns with supporting decentralization, making the expense worthwhile for ideological reasons.

Environmental benefits are another draw. Hashrate heating systems are fully electric and can reduce local carbon emissions. For projects focused on sustainability, this could be a compelling alternative to traditional heaters or heat pumps.

Bitcoin-powered heating offers a range of benefits beyond pure economics. It’s up to you to weigh the options, but completing with a solid economic assessment is always wise.

This example analysis should have you excited – however, there are still some challenges to discuss.

CHALLENGES FOR ADOPTION

It's important to continue pushing the innovation needle forward with hashrate heating to showcase how this technology can benefit the average consumer, business owner, and larger mining operations.

From gaps in knowledge to hardware limitations, the path forward will require creative solutions to overcome various challenges.

TECHNICAL AND HARDWARE CHALLENGES

The early adopters of bitcoin heat reuse have identified several hardware barriers throughout development. Some are minor inconveniences, while others are larger roadblocks that slow adoption.

Closed-Source ASICs and Hardware

One of the biggest technical hurdles for hashrate heating systems is the closed-source nature of the leading miner manufacturers, Bitmain and MicroBT. These companies currently control the industry with over 80% of global market share, and have invested hundreds of millions of dollars in developing the most efficient bitcoin mining chips available. **Unfortunately, their advanced chips are only available in fully assembled mining machines, leaving little room for customization**.

By selling their ASIC mining chips exclusively in complete devices, they lock customers into their hardware constraints and design choices. **Leveraging massive order volumes, market dominance, and first-mover advantage, they control access to leading ASIC technology**. This approach limits flexibility for bitcoin heat reuse and impacts the broader network. For now, we're bound by how the largest miner manufacturers choose to operate.

Innovators looking to use efficient mining chips for heating systems are forced to use the hardware designed for regular mining operations, retrofit them, or disassemble the expensive, industrial-grade devices to get chip access. This process is time-consuming, inefficient, and costly.

In the broader tech industry, companies like Intel, AMD, and NVIDIA sell their computer chips and products directly to consumers and retail businesses, allowing for flexible integration into a wide range of applications. Yet, in bitcoin mining, the best mining chips remain locked into specific hardware. If you were to build a custom computer, you'd choose a CPU, GPU, motherboard, RAM, power supply, storage, case, and cooling solution all from different companies that specialize in each specific area. **Specialization results in more competition, lower prices, and better products for consumers and different use cases**.

The closed nature of current ASICs also mean limited documentation and support, which further hinders innovation, maintenance, and device longevity. Other companies and individuals must rely on their own ingenuity, as exemplified by **Skot9000** who started the open-source Bitaxe movement, which literally purchases complete miners and tears them apart to reverse engineer ASIC chips, and retrofit them onto open-source hashboards. **Obviously, this is not a scalable or sustainable solution**.

Imagine a hashrate heater, designed to slide right into a common residential furnace, or a device that sits atop a domestic water heater to preheat the tank, without significant overhaul or modification required to the existing system. Or perhaps a new form factor that isolates the high-temperature components away from sensitive control boards and power supplies to protect them from the heating core of the device - just like a normal furnace.

The opportunities and use cases become endless as soon as chips become accessible. Thankfully, companies like Block, Heatbit, and Futurebit are beginning to make strides in the right direction, with initiatives such as the Miner Development Kit (MDK), integrated space heater appliances, or custom home mining devices. The industry as a whole, however, still lags behind.

For hashrate heating to truly scale, manufacturers should grant open access or supply documentation and support to their hardware, allowing other companies and individual innovators to integrate them into custom solutions, much like the broader silicon chip industry does. Right now, there is little room for customization, repair, and innovation.

The current model is a significant barrier to the widespread adoption of bitcoin-powered heating systems and could be vastly improved.

Lack of Customization for Heat Reuse

Ideally, third parties could buy ASIC chips directly, enabling them to design miners that fit perfectly into heating systems. But an alternative solution is for leading miner manufacturers to offer custom bitcoin devices optimized for hashrate heating from the start.

The lack of options in bitcoin mining hardware presents a significant obstacle for integrating these systems into heating applications. **Most current miners are developed solely to maximize hashrate and power efficiency for mining in industrial business settings, not for heat reuse**.

Adjustments such as form factors that integrate seamlessly into heating appliances, reduced noise levels, higher temperature limits for enhanced heating performance, power requirements compatible with standard home and small business outlets, and more flexible heating control without the need for constant re-tuning would significantly advance the hashrate heating industry.

Without a shift in how ASICs are designed or made available, the bitcoin heating industry will remain limited by constraints in system design and overall accessibility.

For direct ASIC chip sales or the development of custom miners tailored for heating applications to become a reality, the bitcoin heating industry must highlight its massive total addressable market (**TAM**). Demonstrating this substantial financial opportunity and untapped customer base is key to gaining the attention of goliath chip designers.

INTEGRATION, CUSTOMER USABILITY, AND SCALING CHALLENGES

Anyone using a bitcoin-powered heating system right now is a guinea pig taking risks in the early days of an emerging industry.

The people choosing to do this now are often bitcoiners themselves, or know and trust a bitcoiner in their life. **To my knowledge, there are no examples of organic implementations of hashrate heating systems, where a no-coiner business owner hires a generic contractor, plumber, or HVAC technician to install a hashrate heating system**.

It's just too early and complex. Most people have no idea what a mining pool, immersion tank, or ASIC even is. They want a reliable and cost-effective heating system, and have no interest in figuring out what firmware, cooling solution, and mining hardware makes most sense for their heating needs.

A challenge that must be overcome to accelerate adoption is a simplification of the technology and integration steps to get a bitcoin heating system online. Simplification should also eliminate the need for wifi adapters, aftermarket fans, or other hardware modifications. **Maintenance technicians and tradesmen need reliable plug-and-play solutions with minimal customization and setup required to install and service with confidence and ease**.

And for the end user, the operation must be as easy as possible. No one can be expected to log in to their mining heater's IP address to adjust firmware settings or reboot a device. **The user and technician experience can't be more complicated than installing the machine, connecting it to the internet, and controlling it with an app or web interface**. Ideally, the settings can be set once, automated, and then forgotten about.

Lack of Technician Education and Certification

The lack of education, certification, and standards among tradesmen and hardware manufacturers is a significant barrier to the adoption of bitcoin-powered heating systems. **Currently, there's no clear pathway for qualified individuals to learn about, let alone work on, bitcoin-powered heating systems.**

In residential and small business settings, homeowners typically rely on service technicians for their home infrastructure. Commercial or industrial businesses, as well as large mining operations on the other hand, may employ full-time staff to handle maintenance and system oversight.

Heatpunks have learned to design and build these systems through countless hours of trial and error, retrofitting industrial miners with aftermarket firmware, control systems, and integrations. But scaling this knowledge globally requires a skilled network of electricians, plumbers, HVAC technicians, and contractors. **For these systems to become mainstream, qualified tradesmen will need to understand**

how to install, maintain, service, and repair heating systems powered by bitcoin miners.

From a fundamental perspective, the physics associated with bitcoin-powered heating systems are nothing new. They're just electric resistive heaters that provide issuance and settlement for the bitcoin network. What complicates them is the mining operation side - pools, payouts, networking, and firmware - making standard education and certification critical.

By developing this knowledge base, not only can more people adopt this technology, but tradesmen can also expand their service offerings, opening up new revenue streams as demand grows. Educational institutions and technical programs must create coursework and certification pathways to empower technicians with the skills needed to perform **Heat Audits**, install systems, and ensure long-term reliability. Only then can hashrate heating systems achieve widespread adoption.

Consumer Reluctance and Lack of Regulatory Framework

Most people have never heard of bitcoin (although that is rapidly changing), let alone thought about how it can be used for heating systems and appliances. Sadly, there's enough misleading FUD that effectively scares people away from bitcoin mining in general. On the other hand, however, most people don't know, or need to know how their heating systems work. **It's up to hardware manufacturers to demonstrate how homeowners, business owners, and technicians can benefit from bitcoin mining**. By establishing a trusted brand name, they can offer high-quality, innovative new products that use revolutionary technology to lower heating costs with bitcoin rewards.

From a regulatory perspective, traditional heating systems are subject to stringent safety and regulatory requirements, including energy efficiency standards (ENERGY STAR and UL certification for example). Bitcoin-powered heating systems, on the other hand, are completely unregulated at the moment and will likely need to meet certain requirements before achieving mainstream adoption. This includes ensuring that hashrate heaters are deemed safe and reliable as alternatives to traditional furnaces, boilers, or space heaters. These systems must be insurable by owners. People want to know if this new high-power device in their home is a fire risk or not. They want to feel confident it has the right measures in place and is designed with safety in mind.

Traditional heating systems have been optimized for more than a century to integrate seamlessly into homes and businesses, whereas bitcoin-powered heating systems are still in their infancy. There's lots of work to be done.

Industry Competition

Bitcoin-powered heating systems don't compete with regular mining rigs like those used in traditional operations. They're insensitive to hashing efficiency and can mine at economic loss – because heat is the primary output. **The real competition for hashrate heating is traditional heating hardware and appliances**. The heating industry has existed for decades, with countless iterations, improvements, and technological advancements. It's already highly efficient, reliable, and saturated by companies that have billions of dollars of experience and long histories of successful deployments.

Bitcoin mining as a whole is the wild west, and hashrate heating is the new frontier. This technology must compete against companies that have perfected their products through extensive R&D, strong supply chains, and a deep understanding of customer needs. **Hashrate heaters are innovative and the value proposition is strong, but they currently lack the decades of refinement that make traditional heating systems reliable, trusted, and tailored to user preferences**.

This highlights a specific challenge with market penetration and familiarity. Most consumers and heating technicians are familiar with traditional heating systems and trust established brands like Carrier or Bosch. Bitcoin-powered heating solutions, on the other hand, are niche and have limited market exposure.

For hashrate heating to truly scale and steal market share from these industry goliaths, the economic incentive must be sufficiently strong, and concerns over reliability, serviceability, and insurability must be squashed. Established heating infrastructure manufacturers have an enormous opportunity to enter this market and leverage their experience, brand recognition, and distribution networks to help make hashrate heating mainstream.

Challenges aside, what are some ways this could play out? What's next for the industry?

AREAS OF INNOVATION AND WHAT HAPPENS NEXT

While the industry still faces significant challenges, exciting developments are already beginning to take shape, signaling a shift in how we think about heating systems, energy efficiency, and bitcoin mining. As we close the book, we'll explore the trends and innovations that could drive this technology toward mass adoption and outline where to go from here.

INNOVATIONS IN THE NEAR FUTURE

There are a number of promising innovations on the horizon that are expected to gain traction in the near future. These innovations, though relatively straightforward compared to broader industry shifts, have the potential to greatly improve hashrate heating system performance.

Open-Source Control Boards and Firmware

A straightforward improvement for hashrate heating systems would be the development of open-source firmware or control boards. These advancements could unlock a wide range of possibilities for bitcoin-powered heating. Currently, both stock and aftermarket firmware lack specific features tailored for heat reuse, hindering adoption and innovation in the space.

Open-source firmware could lead to better temperature regulation and power adjustment for specific heating applications - while open-source control boards could eliminate the need for additional aftermarket microcontrollers, allowing miners to be remotely controlled directly. Integrating Wi-Fi chips, for example, would remove the need to route cables to your heating system, simplifying setup. This highlights how industrial mining manufacturers have yet to fully recognize and address the potential of bitcoin heat reuse.

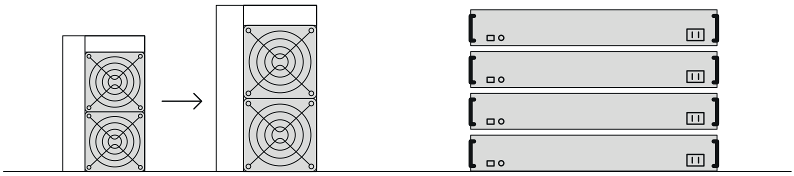
Standardized Form Factors

Over time, a somewhat uniform bitcoin miner shape has emerged, typically resembling two vertically stacked computer case fans with a power supply attached to the side. Despite this general design, the exact dimensions and footprints of these devices change frequently.

This constant shift in form factors is problematic, especially for hashrate heating systems where consumers expect their equipment to be easily upgradeable over time without needing to overhaul the entire infrastructure.

For effective upgradability and future-proofing, a standardized form factor is necessary. This will ensure that older systems can be easily upgraded or modified to support newer, more efficient hashrate heating systems.

On the positive side, hydro-cooled miners are leading by example. Modern hydro machines are increasingly adopting the standardized "U" form factor common in rack-mounted servers. This shift is significant, as it enables third-party heat transfer equipment and integration hardware from the high-performance computing industry to seamlessly work with bitcoin heat reuse systems. As a result, hashrate heaters can directly leverage the well-established hydro-cooling infrastructure already in place.



Overall, if bitcoin ASIC manufacturers aren't going to sell their chips directly to consumers or third parties, they should focus on standardizing the form factors of the complete mining devices they sell. Standardization is crucial not only for traditional bitcoin mining operations but also for homes, businesses, and commercial setups reusing waste heat.

Higher Operating Temperatures

Most bitcoin miners cap their device operating temperature around 80°C (176°F), a limit set by hardware manufacturers for internal electronics, not the outlet temperature of air, immersion fluid, or water used for cooling. Outlet fluid temperatures for heating from typical machines usually range between 40-70°C (104-158°F).

Interestingly, many ASIC chips are rated to operate at or above 100°C (212°F), the boiling point of water. **However, the hashboards, control boards, and other sensitive electronic components have lower temperature limits, which ultimately cap the device's peak output temperature**.

Higher chip temperatures result in higher fluid outlet temperatures for better heat reuse. With higher temperatures comes an increase in the usefulness and heat transfer efficiency of bitcoin- powered heating systems. Specifically, once hashrate heaters can reliably sustain chip temperatures that result in fluid outlet temperature of 100°C (212°F), the ability to boil liquids will be unlocked.

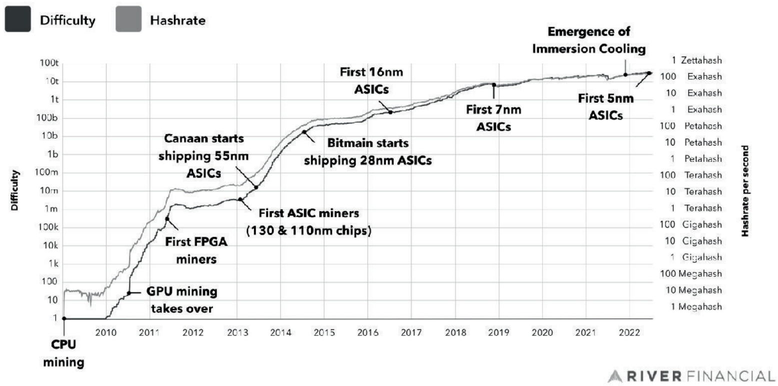
Once fluid boiling is achieved, industrial applications of hashrate heating go through the roof, with the ability to turn liquids into steam, which can then be used to spin turbines that generate motion or electricity. Effectively, once we crack fluid boiling, hashrate heaters can be used to turn heat back into electricity. From an efficiency standpoint, in heating systems, higher fluid outlet temperatures directly translate to increased efficiency in infrastructure such as boilers, where higher temperatures can significantly reduce the time and energy required to reach heating targets.

While it's generally understood that higher chip operating temperatures are less efficient for mining bitcoin, we must remember that bitcoin miners used for heat can take this loss. Because the heat is valuable in addition to the bitcoin mined, marginal improvements in hashing efficiency are less important.

Shift to Thermal Optimization over Hashing Efficiency

In these early days of bitcoin mining, nearly all focus has been spent on maximizing ASIC efficiency – more hashrate for the same power consumption. But that's starting to change.

Moore's Law predicts that these year-over-year efficiency gains will inevitably slow down. When that happens, mining efficiency improvements may become negligible. With a growing network hashrate, each miner's contribution to finding a block becomes smaller. Where does that leave room for improvement?



As J/TH efficiency plateaus, attention must shift to other areas like thermal optimization. **When efficiency gains taper off, the only way to get more hashrate in a single machine is to cram more power through the miner to increase hashrate**. This in turn, increases heat.

Managing higher power density means mastering heat dissipation to prevent hardware failure and maintain performance. This inevitable shift benefits the hashrate heating industry. **As manufacturers and mega-miners improve thermal management, those advancements will also enhance bitcoin-powered heating systems**.

Here are some of the ways we could see bitcoin miner manufacturers optimize for thermal efficiency and heat reuse:

- Increase chip and other electronic component max operating temperatures
- Isolate the power-hungry ASIC chips from other sensitive electronics
- Use materials that more efficiently transfer heat away from the ASIC chips
- Implement heat transfer principles like increased surface area and better fluid flow to optimize for thermal efficiency
- Shift away from air-cooled machines to more capable liquid cooling technologies

This shift in optimization from mining efficiency to heat management will indicate further maturation of the bitcoin mining and hashrate heating industries.

These optimizations aren't just beneficial for bitcoin-powered heating systems. They're also valuable for traditional mining businesses, where greater power density per machine means more hashrate in the same space. At the same time, improving thermal management helps mega-miners implement large-scale heat reuse strategies more effectively.

Collaboration and showing the benefits to all miners will be key. Through open-source initiatives, partnerships with new companies focused on bitcoin heat reuse, and the concerted efforts by dedicated chip architecture teams, it is possible to pool resources and expertise to develop miners optimized for both mining and thermal efficiency, which will benefit heat reuse applications and reliability at high temperatures.

TRENDS TO LOOKOUT FOR AND POSSIBLE PLAYBOOKS

With the advent of bitcoin-powered heating systems comes an exciting future for the industry. This new heating technology introduces the possibility for completely new business models that will force both the heating and mining industries to rethink what is possible.

What will the future look like in a decade or two? What will happen if heating systems begin to be replaced with mining hardware? Will total network hashrate and difficulty increases start to slow down? Or are we just getting started? And what about the current status quo? Are the mega miners doomed because of bitcoin heat reuse?

Business Model Evolution

The traditional business models of both bitcoin mining and heating are well-established. **For miners, it's simple: find cheap power, mine bitcoin profitably, sell sats to cover costs, and dump the heat**. Similarly, **the heating industry is built on a straightforward**

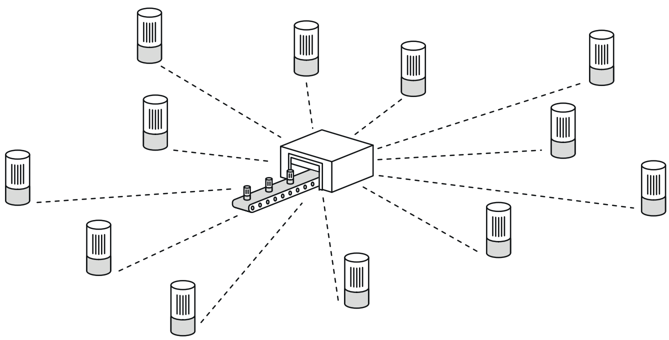
model: sell infrastructure for a profit and charge for labor to install and maintain it.

However, with hashrate heating, we can get more creative.

Decentralized Miners As Heating Appliance Manufacturers
Bitcoin-powered heating systems could transform common appliances like furnaces, boilers, and space heaters. **Unlike traditional heating hardware, which is sold at a profit, manufacturers could sell bitcoin-powered devices at or below production cost, profiting later from the bitcoin mining rewards the appliances generate**.

For example, a rural business owner might buy an electric boiler for a fraction of the cost of traditional systems. Marketed as a "smart boiler" powered by "high-performance computing", it requires only an internet connection and electricity to generate heat. **The bitcoin rewards are kept entirely by the manufacturer. Consumers wouldn't even need to know that bitcoin mining was the technology behind the product**.

This approach could potentially enable free or ultra-low-cost heating upgrades if expected bitcoin rewards cover the hardware costs, and the manufacturer doesn't have to pay for the energy. Over time, such devices could form a decentralized mining company embedded in everyday appliances around the world.



Infinite Sat-Split Model

Bitcoin's decentralized nature and the ability to easily split mining rewards creates new, flexible business models. One such model involves splitting mining rewards between different stakeholders. Here's a twist on the traditional heating system-technician relationship:

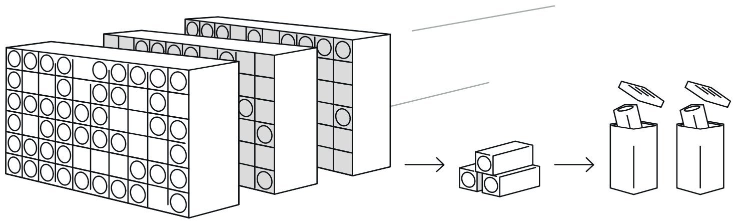
For instance, a homeowner installs a bitcoin-powered heating system but doesn't want to manage firmware, payouts, or maintenance. They hire a contractor to oversee the system, splitting rewards – 90% goes to the homeowner for heating cost subsidies, and 10% to the contractor for oversight. The contractor earns passive income while ensuring the system runs smoothly, incentivizing consistent performance.

This model flips traditional service incentives. Contractors benefit from keeping systems operational, not from costly repairs, making it a win-win for all parties. Reward splits can be tailored to cover labor costs and align with specific needs.

ASIC E-Waste Reduction with Used Hardware Market

Another intriguing business model involves mega miners partnering with heating appliance companies to repurpose older ASIC miner hardware. As mega miners upgrade to the latest chips to stay competitive, their older machines could be sold at a discount to heating manufacturers instead of becoming e-waste. This creates a win-win scenario for both industries.

Mega miners could use their hardware for a predetermined operational life – say, 30 months – before selling it to heating companies at pre-negotiated prices. This allows mining companies to fully depreciate their machines for tax benefits while guaranteeing to generate revenue from the sale. Meanwhile, heating appliance manufacturers gain access to affordable, functional ASICs that can be retrofitted into heating systems. While these devices may no longer be competitive in traditional mining operations, their heat output combined with a bitcoin subsidy make them perfectly fine for hashrate heating applications. And as a result, less miners go to the junkyard.



The primary challenge here lies in the reliance on industrial miner manufacturers, whose hardware must be retrofitted into heating appliances. As we've outlined, this dependency could limit integration and ease of use for plug-and-play solutions.

Increase in Hashrate Heating Market Share

Hashrate heating has the potential to redefine "normal" bitcoin mining. As this technology gains a foothold in the heating market, it could surpass traditional mining operations in scale, leveraging a global demand for comfort heat that dwarfs the energy consumption of the "regular" bitcoin mining network. The energy for heating is already in use and ripe for integration. One day, when people think of bitcoin mining, they might picture heating systems rather than industrial mega-miners.

Hashrate Plateau and Longer Useful Lives

We've established that as bitcoin adoption and mining technology expand, the network's total hashrate will grow, but each new miner's contribution will represent a smaller slice of the whole. Over time, this diminishing impact may cause a gradual plateau in year-over-year hashrate growth.

This slowdown creates advantages for hashrate heating systems. **Slower network growth means difficulty increases will ease, extending the profitability duration of mining hardware**. Plus, hashrate heaters already benefit from both heat output and bitcoin rewards so they're less impacted by efficiency gains or rising difficulty in the first place.

The result? Bitcoin heating systems can provide steady subsidies for longer, minimizing the need for frequent upgrades. **As network growth reaches a point of diminishing returns, hashrate heaters will thrive, offering stable rewards for longer**.

Death of the Mega Miners?

Will hashrate heating signal the end of mega miners? Probably not. Bitcoin mining thrives on finding cheap energy, and vast amounts of untapped, low-cost, off-grid resources remain available. This will sustain large-scale operations for the foreseeable future.

For on-grid mega miners, the challenge is more complex. Rising difficulty and shrinking block subsidies will push them to innovate. Many will adopt demand response for grid balancing, earning revenue for shutting off during peak demand. Others might mine for strategic national security, even at a loss.

Heat reuse is just another promising avenue. By integrating heat recovery, mega miners can adapt their models to remain competitive. **While I don't see hashrate heating replacing large-scale operations, it will drive innovation and open new opportunities for the industry**.

CONCLUSION: WHERE DOES THIS INDUSTRY GO FROM HERE?

The hashrate heating industry is just getting started. Bitcoin, already one of the most revolutionary technologies of our time, is poised to change not only the way we think about money but also how we heat our homes, businesses, and industrial processes. As we've seen throughout this book, the use cases are compelling, the challenges are real, and the opportunities are immense.

We are still early. Bitcoin is in its infancy compared to other technologies, and ASIC miners are even newer. The concept of hashrate heat reuse? Practically a newborn. Yet, like bitcoin itself, the trajectory is clear. Aligned incentives and collaboration between the established heating industry and the rapidly evolving world of bitcoin mining will drive this technology forward. This isn't just about efficiency **– it's about fundamentally rethinking how energy is used and monetized**.

The competition inherent in bitcoin mining will continue to push innovation, driving advancements in ASIC efficiency, thermal optimization, and heat reuse capabilities. These innovations will ripple across industries, unlocking new business models and applications that we can only begin to imagine.

A Call to Action: Be Part of the Heat Revolution

This book is not the end of the conversation – it's the beginning. The future of hashrate heating depends on all of us. Whether you're a curious bitcoiner, a business owner, an HVAC technician, an engineer, or someone who just loves the idea of a heater that makes money, there's a place for you in this movement. Here's how you can start:

- **For Bitcoiners:** Explore whether a hashrate heating system could make sense for your home or business. Advocate for products that integrate mining and heating. Become a Heatpunk by building and educating others.

- **For Tradespeople:** Learn about this technology. The heating and cooling industry is evolving, and skilled electricians, plumbers, and HVAC technicians will be critical in bringing these systems to life. Be the person who can confidently say, "Yes, I know how to install and service that."

- **For Businesses and Innovators:** The market is wide open for creative solutions. Develop products, launch pilot programs, and take risks. Whether you're a heating company, an ASIC manufacturer, or an entrepreneur with a vision, this industry is ripe for disruption.

- **For Mega Miners:** Don't fear heat reuse – embrace it. Leverage your experience and infrastructure to lead the way. Collaborate with nearby heat demand and symbiotic partnerships to strengthen your business.

The Dream: Hashing and Heating Become Synonymous

Bitcoin doesn't have to just be freedom money – and mining doesn't have to just hunt trapped or wasted energy. Thanks to Satoshi, it's now possible to monetize heat in a neutral and ethical way without counterparty risk. Heat is synonymous with hashrate. You can't have one without the other – thank the laws of physics. So let's strive for a future where electric heating infrastructure is converted to its maximum potential – delivering warmth while stacking sats and supporting the monetary revolution.

The Start of Something Hot

I hope that by the time you finish this book, it's already obsolete. That hashrate heating is so widely adopted that there's no need to explain it. A future where this technology is so normal, so integrated, and so obvious that no one needs to read about it – they just use it.

But perhaps the challenges described have not yet been solved, or new ones arose. If so, it's time to take action. Whether you're installing a bitcoin-powered heater, designing the next generation of ASICs, or just sharing what you've learned, you're part of a growing movement that's turning wasted energy into warmth, heat into money, and innovation into opportunity.

Let's build the future of heating, one hash at a time.

APPENDIX A: ENERGY & THERMODYNAMICS FOR BITCOINERS

It is important to note that everything discussed in this bitcoin heat reuse book is grounded in physics. This is what makes bitcoin the first thermodynamically sound money. Here's why that's true.

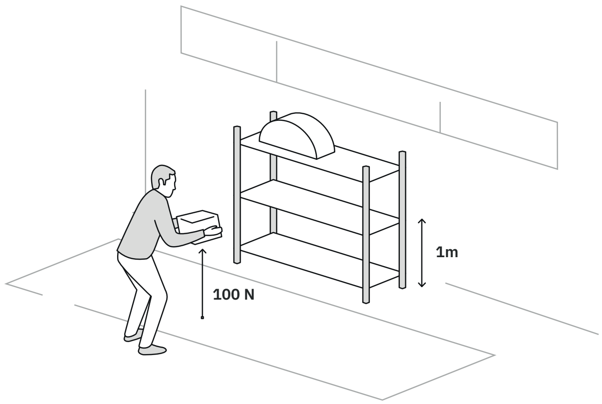
For rejecting or reusing bitcoin miner heat exhaust, a basic understanding of ***thermodynamics*** can effectively help manage mining operations and energy conversion. 'Thermodynamics' originates from the Greek terms *thermos* (heat) and *dynamis* (power). It refers to the study of energy transformations involving heat (thermal and heat are often interchangeable words in this field).

ENERGY & WORK

Energy is a property of matter that is not directly observable or tangible. It manifests in many different forms: kinetic, potential, chemical, electrical, nuclear, and thermal. Energy can be defined as "the capacity to do work". In physics, **work (*W*)** is defined as "the ability to exert a force over a distance". **The amount of work done is calculated by multiplying a force (*F*) over the distance (*d*) it was applied.**

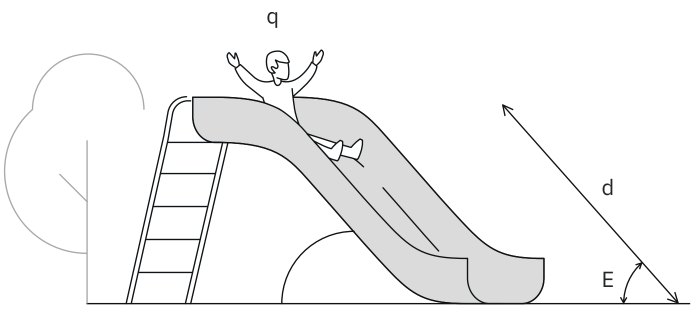
$$W = F * d$$

Let's first start with mechanical work energy. Imagine lifting a bitcoin miner to install onto some empty rack space. If you apply a force of 100 newtons (*N*) to lift the machine over a distance of 1 meter (*m*), the amount of *work* done is 100 newton-meter (*Nm*). Since energy is the capacity to do work, **the terms are interchangeable**. Therefore, 100 *Nm* of energy is required to lift the object. The unit of *work* or energy in the International Standard of Units (*SI*) is the joule (*J*), and 1 *Nm* is equal to 1 *J*. Thus, lifting the bitcoin miner requires 100 *J* of energy.



$100\ N * 1\ m = 100\ Nm$

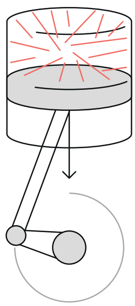
Electrical *work* involves moving an electric charge (*q*) through an electric field (*E*) over some distance (*d*). Electricity is invisible, so it can be hard to conceptualize. The best example I've found is the following: Think of the charge as a person going down a slide. The electric field is represented by the slope of the slide, where a larger electric field is analogous to a steeper slope. The distance that the charge travels is represented by the length of the slide. In this way, electrical *work* can be understood as the **force** exerted by the electric field on the charge multiplied by the **distance** the charge travels within the field.



$W = q * E * d$

Bitcoin mining requires electrical *work* to perform the logic operations of the SHA-256 hash functions, hence the appropriately named proof-of-work description for the process!

As it relates to bitcoin miner heat exhaust, you may wonder **how heat energy can do work**. When heat is added to a system, such as a gas, it increases the gas's pressure and volume, enabling it to do work. This occurs in combustion engines. **The *work* done on the system can be determined by measuring the pressure force (*P*) exerted by the gas over the change in volume (*ΔV*) - proportional to distance - of the piston chamber.**



$$W=P*\Delta V$$

The exact amount of *work* that can be performed by bitcoin miner heat energy is related to the temperature difference between the hot exhaust and the cold surroundings.

Because all of these forms of energy can be defined as the ability to do work, they share a common base unit, the Joule (*J*).

POWER

Power is a measure of energy usage over time, denoted joules per second (*J/s*), also known as the watt *W*. Power quantifies how quickly energy is consumed or generated. For example, if a device uses 1 joule of energy every second, its power consumption is 1 watt.

For bitcoin miners, power determines the **rate** at which energy is used to perform hash functions. **This is a critical metric for miners.** Higher power consumption generally means more computations per second, leading to higher hash rate, **and also more heat generation**.

Example:
A bitcoin miner drawing 3000 watts of electric power consumes 3000 joules of energy every second! Over an hour, this consumption amounts to 10.8 million joules (since 1 hour = 3600 seconds).

UNITS

In addition to the international standard units for energy and power, various other units are commonly used in different regions and applications.

Units of Energy

- **Joule (*J*)**: The standard SI (metric) unit of energy. It is defined as the amount of work done when a force of 1 Newton is applied over a 1 meter distance. $1\,J = 1\,N * 1\,m$

- **British Thermal Unit (*BTU*)**: Commonly used in the United States for heating and cooling systems. 1 *BTU* is the energy required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

- **Therm**: Used primarily in natural gas billing. 1 *Therm* = 100,000 *BTU*.

- **Watt-hour (*Wh*)**: Typically used for electrical energy storage, especially electronics and small battery capacity measurements.

- **Kilowatt-hour (*kWh*)**: 1 *kWh* = 1,000 *Wh*. Often used in electricity billing and large electric car battery sizing.

Units of Power

- **Watt (*W*)**: The standard SI (metric) unit of power. Defined as 1 *J* per second (*J/s*).

- **Kilowatt (*kW*)**: 1 *kW* = 1,000 *W*. Commonly used in electrical power applications.

- **Megawatt (*MW*)**: 1 *MW* = 1,000,000 *W*. Commonly used in industrial power consumption and generation.

- **Horsepower (*hp*)**: Used primarily in the automotive industry. 1 *hp* is approximately equal to 746 *W*.

- **BTU per hour (*BTU/h*)**: Used in heating and cooling applications to measure the heating power of HVAC or hydronic systems.

Common Units in Bitcoin Mining

During the mining process, **electric energy** (*J*) is continuously converted into **thermal heat energy** (*J*). Since both electricity and heat are forms of energy, they share the same unit of measurement. On a *rate basis*, **electrical power** (*W*) is converted into **thermal power, often referred to as a heat rate** (*W*).

While joules and watts are base units for measuring energy and power, other standard units are more commonly used due to practical considerations such as scale of consumption, measurement, and different applications. For electrical purposes, they are:

- **Electric Energy: Kilowatt-hour (*kWh*)** The kilowatt-hour (*kWh*) is the most common unit of *energy* measurement and *billing* worldwide. It is the standard used by electric utility companies for billing residential and commercial *energy* consumption.

- **Electric Power: Kilowatt (*kW*)** The kilowatt (*kW*) is the most common unit of *power* measurement worldwide. It is the standard unit used by most large equipment and high *power* machinery.

The difference between watts and watt-hours can be confusing at first. Watts measure power, which is the rate at which energy is used or generated. On the other hand, watt-hours measure the total amount of energy consumed or generated **in a time period**. Since one watt represents one joule per second, multiplying it by hours gives you joules, a direct measure of energy. This concept is best understood with an example.

Example:
If a bitcoin miner uses 3000 watt-hours (3 kWh) of energy over the course of 1 hour, then its constant power consumption is 3000 watts, or 3 kW. If that same machine is run over the course of 2 hours, then it consumes a total of 6000 watt-hours of energy, or 6 kWh.

$$3000\ Wh\ /\ 1\ h = 3000\ W$$
$$6000\ Wh\ /\ 2\ h = 3000\ W$$

When it comes to measuring energy consumption and power draw in the context of heating systems, the common units for electrical applications are not typically used. Instead, the most widely used units are:

- **Heat Energy: British Thermal Unit (*BTU*):** A commonly used unit for measuring energy, especially in heating and cooling systems in North America. 1 *kWh* = 3,412 *BTU*.

- **Heat Power: British Thermal Unit (*BTU/h*):** A common unit for measuring the power output or capacity of heating and cooling systems, indicating how much energy is transferred per hour. 1 *kW* = 3,412 *BTU/h*.

For bitcoin mining heat reuse systems, it's often necessary to convert between these common units of electrical and thermal *energy* and *power*. This is particularly important since most heating infrastructure is rated in *BTU/h*, while bitcoin mining hardware is rated in *kW*.

TEMPERATURE VS THERMAL ENERGY

Temperature is not a direct measure of energy. It is a measure of the ***average*** **kinetic energy of particles in a substance**. Molecules of a substance vibrate at the atomic scale, and **the average speed of their vibration defines temperature**. The faster particles of a substance move, the higher its temperature.

In bitcoin mining hardware, electrical *current* flows through the machine's circuitry. **Collisions and resistance at the atomic scale cause the internal components of the ASIC chips to vibrate, increasing their temperature**.

Thermal energy, on the other hand, represents the *total* kinetic energy of all the particles in a substance. This energy depends on three key factors: temperature, mass, and specific heat capacity.

- **Temperature (*T*):** The measure of the average kinetic energy of the particles in a substance. Higher temperatures mean more particle motion.

- **Mass (*m*):** The amount of substance. More mass means more particles, which contributes to greater total thermal energy.

- **Specific Heat Capacity (*c*):** This indicates how much heat energy is required to change the temperature of a unit mass of the substance by one degree Celsius. It can be thought of as how resistant a substance is to changing temperature.

Bitcoin mining hardware with more mass or substances with higher specific heat capacities require more energy to change temperature.

LAWS OF THERMODYNAMICS

Now that we have a grasp of the concepts of energy, work, power, and temperature, it's essential to understand the ***Laws of Thermodynamics***, which define the fundamental principles governing energy transfer and transformation. **These laws are useful for understanding the physical limits and maximum efficiency achievable for traditional bitcoin mining or heat reuse operations**.

1st Law

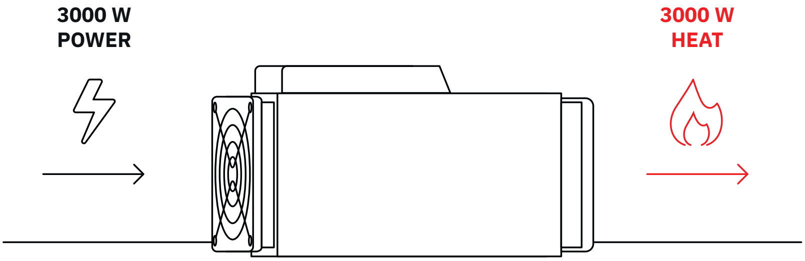
The First Law of Thermodynamics, also known as the Law of Energy Conservation, states that energy cannot be created or destroyed, only transformed from one form to another.

Electric energy consumed by bitcoin miners is used for computational work and converted into heat throughout the process. During this conversion of electricity to heat, **no energy is lost or destroyed**. Nor is any generated or added to the system.

Electric circuits are highly efficient at converting electric energy into heat. A negligible amount of the electric energy is converted into other forms, such as light, sound, and large-scale kinetic motion. If your hash boards start glowing, making noise or moving around, you've got a big problem on your hands!

The result is a near-perfect conversion of electricity to heat.

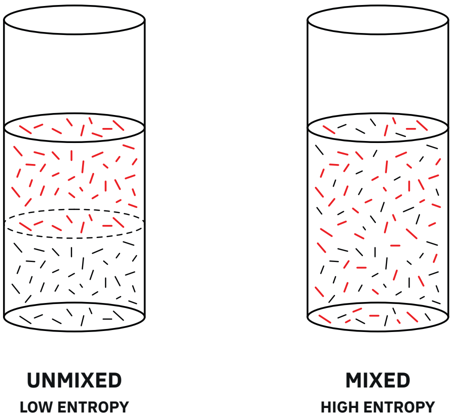
Example:
A 3000 W bitcoin miner exhausts approximately 3000 W of heat.



2nd Law

The Second Law of Thermodynamics states that for any energy transfer, the total entropy - a measure of disorder or randomness - of a system will always increase. This law defines a directional nature of all processes, indicating that energy transformations are inherently irreversible, and cannot be undone with perfect efficiency. It requires additional energy to undo things!

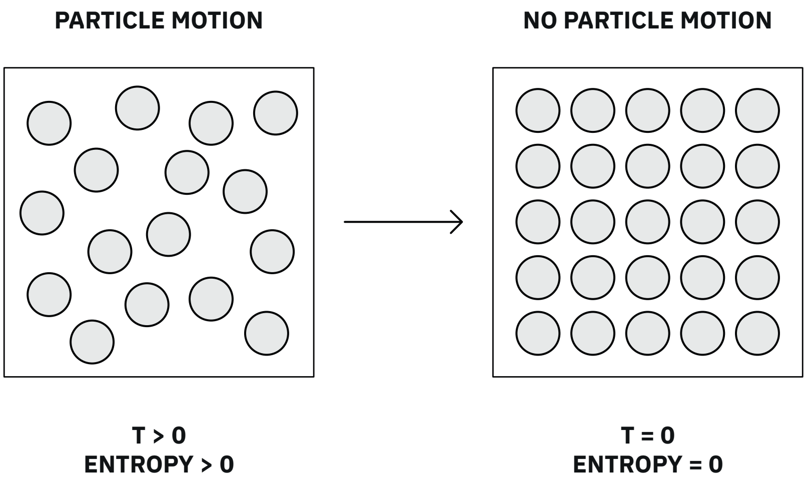
Consider mixing ethylene glycol into a water mixture to create a coolant with a lower freezing point. The process of separating the two substances, molecule by molecule, would require an impractical amount of energy and will not naturally undo itself. This illustrates an irreversible process where entropy is generated as the two substances mix.



As it relates to mining bitcoin, entropy is generated when electricity is converted into heat throughout hash operations. This conversion is an irreversible process, where the energy transfers from an ordered state to a less ordered state. The sum of **all heat energy cannot be perfectly captured and converted back into electricity**.

3rd Law

The Third Law of Thermodynamics defines absolute zero as the temperature at which the kinetic motion of particles approaches zero. Recall that temperature measures the average particle velocity of a substance. No particle motion represents the lowest possible temperature. **Absolute zero** is defined as -459.67°F, -273.15°C, or 0°K on the Kelvin scale (hence its purpose). At absolute zero, the entropy of a substance approaches zero, where there is no disorder or randomness.



Now, let's relate this to a bitcoin mining rig. Think of the miner as a machine that's constantly working to mine bitcoin. When the rig is powered on, it's using electricity and getting hot, like the particles in a substance that are moving around quickly when they're warm. But imagine slowly turning down the power to the mining rig. As you lower the power, the machine works less and less, cools down, and eventually, stops working entirely. This is like reaching absolute zero for the miner – there's no more hashrate, no heat generated, and everything is completely shut down. Just as absolute zero means no movement or heat in particles, a powered-off mining rig represents no work, no heat, and complete inactivity.

QUANTITY VS QUALITY

A more relatable way to think about the First and Second Laws of Thermodynamics is with the concept of energy **quantity** and **quality**. For a bitcoin mining operation, we can distinguish the two as follows.

Energy *quantity* refers to the total amount of energy in a system. From the first law, we know this must be conserved. It can neither be created nor destroyed. **The amount of electric energy consumed by the bitcoin miners is equal to the heat energy they output** (recall, electric circuits are nearly 100% efficient at converting electricity to heat). A one megawatt bitcoin mine must reject one-megawatt of heat. **The *quantity* is conserved.**

The *quality* of energy, however, is not conserved, and is governed by the Second Law of Thermodynamics. Energy quality is a measure of its usefulness for doing *work*. High-quality energy is organized (low entropy) and can be easily converted to perform work. Electricity is high-quality. It's very versatile – used to mine bitcoin, drive motors, power lights, and everything in between. On the other hand, thermal heat energy is much lower in quality than electric energy. Low-quality energy is disorganized (high entropy) and difficult to convert into useful work.

This is where the concept of **exergy** becomes essential. **Exergy quantifies the portion of energy that can be converted into useful work, considering both its quality and the surrounding environment**. While the total heat energy output (energy quantity) from a bitcoin miner is fixed and equal to its electrical energy input, the *exergy* of that heat depends on its temperature relative to its surroundings. Higher exhaust temperatures correspond to higher exergy, meaning the waste heat has greater potential for useful applications such as heating, boiling water, or even driving a heat engine.

Through the conversion of electricity to heat energy inside a bitcoin miner, *entropy increases* and *exergy decreases* as energy quality is diminished. Some of the capability for doing useful *work* is destroyed. But how much exactly?

The capacity for thermal energy to perform *work* is directly related to the temperature difference between a heat source and its surroundings. This is because thermal heat energy can only be transferred when there is a temperature difference between two substances. The mixing of a high-temperature substance with a lower-temperature substance increases entropy as it leads to a more disordered state and a more even distribution of the energy. The directional nature of the second law dictates that **heat energy will only transfer from hot to cold when there is a temperature difference**.

For bitcoin mining, the temperature difference between the exhaust fluid (air, immersion oil, water) and the ambient environment dictates *work* capacity. A larger temperature delta increases the potential of converting thermal energy into mechanical *work* or other useful forms. Thus, **higher temperatures have higher quality energy and are more capable of performing useful *work* (higher exergy).**

A system that converts heat energy back into useful *work* is called a **heat engine**. The theoretical maximum efficiency of a heat engine is defined by the Carnot efficiency:

$$\eta_{max} = 1 - (T_{cold,\ ambient\ temp} / T_{hot,\ fluid\ temp})$$

Here you can see the dependency of energy conversion efficiency on the temperature difference.

LOW GRADE HEAT

The output fluid temperatures from bitcoin miners typically range from 40-70°C. This range is commonly referred to as *low-grade heat*, since the thermal energy is relatively small compared to *high-grade heat* from sources like gas vapors, boilers, combustion and other industrial processes. Generally, temperatures below 150°C (302°F) are classified as low-grade. **Bitcoin miner heat exhaust falls into the specific category of *ultra low-grade* heat, with temperatures below 100°C** (212°F) – the boiling point of water.

High-quality heat energy is often used in processes such as heat engines or other thermodynamic cycles, where it is converted into useful *work*, such as motion or electricity. But we know these applications are limited by the temperature difference between the heat source and the surroundings. **Unfortunately for bitcoin miners, low-grade heat is extremely inefficient at converting into *work* compared to energy transfer from higher quality (temperature) heat sources**.

As a result, **bitcoin miners are generally not suitable for industrial processes where heat energy is converted back into useful work**. However, they can be effective for pre-heating if additional heat is supplied from an external source, like natural gas power generation, or can still make sense for work applications with low conversion efficiency if the energy is abundant and basically free, like from geothermal or other renewable sources.

HEAT FOR HEATING

So what can you do with the waste heat energy? Since it can't be destroyed and must be managed, it might as well put it to use! Because bitcoin miner heat exhaust is low-quality, however, the best application of hashrate heat is to use this waste energy directly for system heating, rather than convert the heat back into *work*.

Remember, we lose efficiency with each step of energy conversion. Using heat energy directly for heating applications, such as warming spaces or preheating fluids, takes advantage of its existing form without the efficiency losses associated with converting it back into higher-quality energy forms like electricity. **Bitcoin mining heat reuse is best suited for direct heating applications as a result**.

Bitcoiner miners already reduce waste by converting cheap and excess energy into economic value. Now, in heat reuse applications, miners serve an additional purpose by providing heat. Mining bitcoin is the most thermodynamically sound method for heating. Not a single joule of energy is put to waste. Instead, each one serves a dual purpose.

APPENDIX B: HOW BITCOIN MINERS MOVE HEAT AROUND

Miners produce an exorbitant amount of heat that cannot be destroyed. If this heat energy isn't reused, it is by definition wasted. Either way, it cannot be ignored. Managing bitcoin miner heat exhaust is key for optimizing both traditional operations and successful hashrate-powered heating systems. Understanding the basic physics of heat transfer provides the fundamentals for how to move heat around.

TRANSFERRING HEAT 101

Heat transfer is the process by which heat energy moves from one place to another due to a temperature difference. Heat only transfers from hot to cold, and the rate of thermal energy transferred depends on the temperature difference between the two objects.

There are three primary mechanisms of heat transfer:

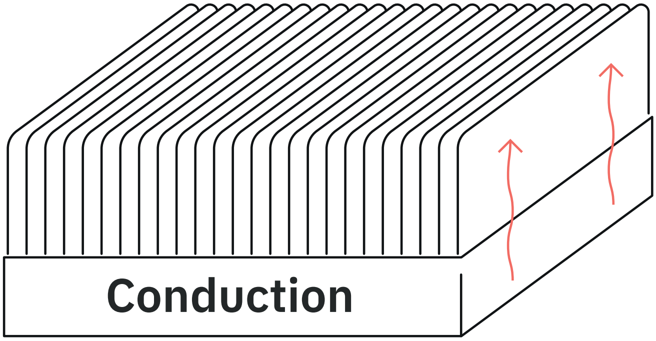
- Conduction
- Convection
- Radiation

Conduction

Conduction is the transfer of heat energy through a solid material or between objects in direct contact. This happens when molecules bump into one another and transfer their kinetic energy (remember, temperature is average atomic velocity).

Example:
The heat sinks attached to a hash-board increase in temperature via conductive heat transfer. The ASIC chips on the circuit board and the

heat sink are in contact with each other. Heat energy conducts from the chips to the heat sink, then continues conducting along the heat sink fins to distribute the energy.



The *rate* of conductive heat transfer is largely dependent on the material's **thermal conductivity, which is a measure of how easily heat energy can pass through it**. Materials with high conductivity, like metals, are efficient at transferring heat energy. Think about the heat sinks or aluminum chassis of a bitcoin miner – they are highly conductive and hot to the touch!

Conversely, **materials with low conductivity, like plastics, ceramics and fiberglass, act as good insulators**. Parts of bitcoin miners like the PCBs and fans are made of low conductivity materials with insulating properties, helping prevent unwanted heat transfer to these components.

Calculating Conduction

Each of the three mechanisms for transferring heat energy have equations that govern the *rate* of heat energy that is transferred. For conduction, it is defined by Fourier's Law:

$$\dot{Q}_{cond} = k * A * (\Delta T / L)$$

Where:

- **Conductive Heat Transfer Rate ($\dot{Q}_{cond}$):** = The rate of heat energy being transferred (W). This is the heating power measurement we care about.

- **Thermal Conductivity (k):** = How easily heat can transfer through a solid ($W/m°K$).

- **Cross-sectional Area (A):** = The area through which heat is being transferred (m^2).

- **Temperature Difference (ΔT):** = The temperature difference between the hot side and the cold side of the material ($°K$).

- **Material Thickness (L):** = The distance through the material in which the heat is being transferred (m).

Optimizing Conduction

For traditional bitcoin mining and heat reuse operations, we want to reject heat away from the machines and keep them cool. With energy quantity, we must specifically reject heat away at the same rate that the bitcoin miners consume electric power. **Recall: A machine drawing 3000 watts of electricity must constantly reject 3000 watts of heat to remain at a cool, steady temperature**.

How can we optimize conduction to our benefit? **We want the heat transfer rate away from the ASIC chips to be as high as possible**. Looking at the governing equation, there are a few options:

- **Choose materials with higher conductivity (k):** Material selection for heat sinks and other components that can conduct heat away from the ASIC chips at a faster rate prompt better heat rejection.

- **Increase the cross-sectional area through which heat is transferred (*A*):** ASIC chips or heat sinks that are physically larger can transfer heat more effectively.

- **Increase the temperature difference between the heat source and cold sink (ΔT):** Heat energy transfers more efficiently with larger temperature gradients. If heat is rejected away from the heat sinks more efficiently, keeping them colder, then heat will transfer at a faster rate from the ASIC chips to the heat sinks.

- **Decrease the distance of heat transfer (*L*):** The only term in the denominator. Decreasing the length over which heat is moved results in more heat transfer.

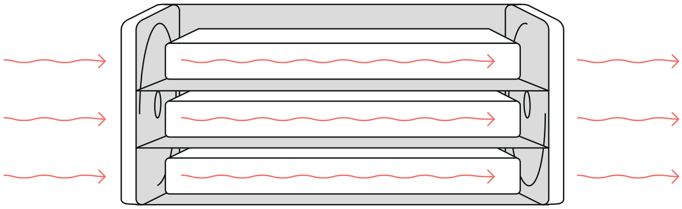
These same variables can be tuned in the opposite direction to minimize conductive heat transfer for an insulating effect.

Convection

Convection is the transfer of heat energy through the movement of fluids (gas or liquid). This process can be thought of as "carrying" the thermal energy from one place to another. It can happen in two ways. The first is *naturally*, where heat transfer is driven by buoyancy forces between hot and cold fluids (cold fluids sink, hot fluids rise). The other way is *forced*, driven by external sources like fans or pumps that are specifically designed to move the fluid.

Example:
To continue our bitcoin miner example, forced convective heat transfer occurs when cool fluids such as air, immersion oil or water are pushed through the machine. The cooling fluid comes into contact with a hot, solid surface area. Heat energy is convectively transferred from the hot mining hardware to the fluid, where it exhausts out of the back at a higher temperature than it entered. Cold fluid in, hot fluid out.

Convection



A driving factor of convective heat transfer is the **heat transfer coefficient (*h*), which represents how efficiently heat energy is transferred from a solid to a fluid, or vice versa.** This coefficient itself is influenced by several factors including the fluid conductivity, flow turbulence, velocity, and other variables. Fans and pumps that increase the fluid speed result in increased heat transfer coefficients. Hardware designs that break up laminar (smooth) fluid flow and facilitate turbulence also increase the coefficient.

Calculating Convection

The governing equation that defines the rate of convective heat transfer is defined by Newton's law of cooling:

$$\dot{Q}_{conv} = h * A * \Delta T$$

Where:

- **Convective Heat Transfer Rate ($\dot{Q}_{conv}$):** = The rate of heat energy being transferred (*W*). This is the value to be calculated.

- **Convective Heat Transfer Coefficient (*h*):** = This value defines how effectively heat is transferred between a solid and a fluid ($W/m^2\ °K$).

- **Solid Surface Area (*A*):** = The amount of solid surface area in contact with the fluid for heat transfer (m^2).

- **Temperature Difference (ΔT):** = Defined by the difference between the solid surface temperature and the fluid temperature far from the surface it's interacting with ($°K$).

Optimizing Convection

Convective cooling is crucial for managing and reusing heat in bitcoin mining operations. **All bitcoin mining machines rely on convective cooling, using air, immersion oil, or water**. Furthermore, nearly all low-grade heating applications for homes and businesses depend on warming air or water to maintain a comfortable environment.

To increase convective heat transfer and maximize machine cooling we can do the following:

- **Increase the convective heat transfer coefficient (h):** Choosing fluids with higher conductivity, increasing flow velocity or causing turbulence all increase the convective heat transfer coefficient. Resulting in more efficient heat transfer between the solid and fluid.

- **Increase the total amount of surface area interacting with the fluid (A):** This is the easiest way to increase convective heat transfer, and the exact purpose of a heat sink. Fins on ASIC heat sinks are designed to drastically increase the total surface area of hot material that interacts with the cool air or immersion fluid.

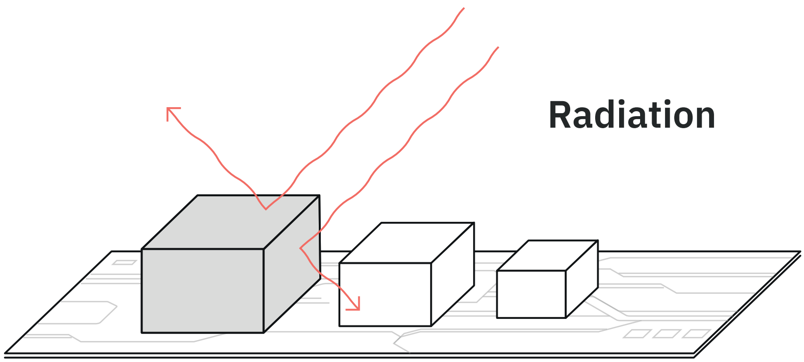
- **Increase the temperature difference between the solid surface and the cooling fluid (ΔT):** Maintaining a cooler fluid temperature or hotter solid temperature increases the gradient between the hot and cold substances. This results in more heat energy transfer. If the temperature difference is small, heat does not transfer efficiently.

As with conduction, these variables can be optimized in the other direction to minimize convective heat transfer between solids and fluids.

Radiation

Radiation is the transfer of heat energy through electromagnetic waves. It requires no medium or direct contact between objects (without fluids or solids). All substances with a temperature greater than absolute zero (-459.67° F, recall the Third Law of Thermodynamics) emit radiation. This thermal radiation energy can be absorbed, reflected or transmitted by other materials.

Example:
On Earth, we have an air medium all around us and are physically connected to the environment. Thus, radiation plays a small role in bitcoin miner heat management compared to conduction and convection, but we can still conceptualize its influence. Sensitive electronic components or cooling pipes and ducts can be wrapped in reflective shields. The reflective surface finish acts as a radiative barrier, deflecting radiation energy away from the components to keep them cool.



The rate of radiative heat transfer depends largely on a material's surface properties:

- **Emissivity (ε)**: How well a material emits thermal radiation. How good it is at releasing its thermal energy in the form of electromagnetic waves.

- **Absorptivity (α)**: The fraction of radiation a material absorbs. How good a material is at absorbing electromagnetic waves.

- **Reflectivity (ρ)**: The fraction of radiation a material reflects. How good a material is at reflecting electromagnetic waves.

- **Transmissivity (τ)**: The fraction of radiation that passes through a material. How good a material is at passing electromagnetic waves through itself.

Another key variable is the **view factor** (F_{ij}), which describes how well one component can "see" another for radiation purposes. **If a hot component can't directly see a cool component, it radiates less effectively to it**. Think of radiation as tracing straight lines between components. These lines are representative of electromagnetic waves that transfer radiative energy. If the line is obstructed, so is the radiation energy transfer.

In real-world applications, high-emissivity coatings and paints can be applied to heat sinks to improve radiative heat rejection to the surroundings. Conversely, reflective surfaces or those with low absorptivity are often used on outdoor equipment to minimize radiative heat transfer from the sun, keeping them cool to the touch.

Calculating Radiation

The Stefan-Boltzmann Law quantifies the rate of **energy radiated away from a surface**.

$$\dot{Q}_{rad} = \sigma * \varepsilon * A * T^4$$

- **Radiative Heat Transfer Rate ($\dot{Q}_{rad}$):** = The rate of radiation heat transfer to be calculated (*W*).
- **Stefan-Boltzmann Constant (σ):** = $5.67 * 10^{-8}$ $W/m^2\,°K^4$. Empirically determined constant.
- **Radiating Body Surface Area (A):** = Amount of surface area of a material with the capacity to radiate energy (m^2).
- **Material Emissivity (ε):** = How good the material is at rejecting its energy via electromagnetic waves (dimensionless, 0 to 1).
- **Temperature of the Surface (T):** = Absolute temperature of the surface (*K*).

To calculate the rate of radiative **energy absorbed by a surface**, we need to consider its absorptivity:

$$\dot{Q}_{abs} = \alpha * \dot{Q}_{rad} * A$$

- **Rate of Absorbed Radiation ($\dot{Q}_{abs}$):** = The rate of heat energy that a material absorbs from electromagnetic waves (*W*).
- **Material Absorptivity (α):** = How good a material is at absorbing electromagnetic waves (dimensionless, 0-1).
- **Exposed Surface Area (A):** = The amount of surface area of a material exposed to electromagnetic waves (m^2).

When calculating the rate of radiative heat transfer **between two surfaces** must consider their view factors:

$$\dot{\mathbf{Q}}_{rad,\,12} = \boldsymbol{\sigma} * \boldsymbol{\varepsilon}_1 * A_1 * F_{12} * (T_1^4 - T_2^4)$$

- **Radiative Transfer Rate Between two Materials ($\dot{Q}_{rad,\,12}$):** = The rate of heat energy transferred between object 1 and object 2 via electromagnetic waves (W) .

- **Stefan-Boltzmann Constant (σ):** = 5.67 * 10^{-8} $W/m^2\,°K^4$. Empirically determined constant.

- **Material 1 Emissivity (ε_1):** = How good the hotter material is at transferring its energy via electromagnetic waves (dimensionless, 0 to 1).

- **Radiating Body 1 Surface Area (A_1):** = Amount of surface area of hotter material 1 with the capacity to radiate energy (m^2).

- **View Factor Between Materials (F_{12}):** = Calculated based on geometry and relative orientation between the two surfaces (dimensionless, 0 to 1).

- **Temperature Difference (ΔT^4):** = Defined by the absolute temperature gradient between the radiating surface 1 and the absorbing surface 2 (°K).

Optimizing Radiation

While radiative heat transfer is not a primary concern for bitcoin mining operations and heat reuse systems, managing it can still provide a performance edge over competing setups. **Effective radiative thermal protection can be particularly useful in deployment locations with large amounts of sunshine**. In extremely hot climates, high-emissivity coatings on heat sinks and other hardware can enhance radiative heat rejection, boosting overall cooling efficiency beyond what is achieved through conduction or convection alone.

To increase radiative heat rejection to surroundings we could:

- **Increase the total surface area of hot components radiating**

energy to the surroundings (A): Increasing the amount of hot surface area exposed aids in radiative heat rejection.

- **Choose surface finishes with higher emissivity (ε)**: For hot components that we want to keep cool, choosing surface finishes that are better at radiating away heat energy improves cooling performance.

- **Increase the temperature difference (ΔT)**: A larger temperature gradient between a surface and its surroundings or to a cooler surface allows for more heat energy to transfer.

- **Increase the view factor from hot components to cool surroundings (F_{12})**: Increasing the view from hot components to cooler surroundings can enhance radiative heat transfer, allowing the hot components to shed heat more effectively.

To minimize radiative heat absorption we could:

- **Decrease the amount of exposed surface area (A)**: To keep a surface cool, we can limit radiative heat energy absorption by reducing the amount of surface area exposed to radiation.

- **Choose surface finishes with low absorptivity (α)**: Surfaces that absorb less radiative energy are well-suited for components intended to remain cool.

- **Decrease the view factor of cool components to radiation rays (F_{12})**: Reducing the view factor – how much of the hot surroundings are "seen" by the cool components – limits radiative heat transfer, helping minimize heat absorption.

As with conduction and convection, these variables can be tuned in the opposite manner to minimize radiative heat rejection or maximize radiative heat absorption.

HEAT TRANSFER TAKEAWAYS FOR BITCOIN MINERS

Bitcoin miners are power-dense. **Inadequate cooling can lead to poor performance, hardware damage, and sometimes catastrophic failure**. Understanding the three methods of heat energy transfer provides a crucial background for bitcoin mining system design and high performance. Teams building traditional mining operations can apply these principles throughout the design process and during management operations to ensure proper cooling of the hardware.

For bitcoin miner heating applications, these principles are even more important to understand. While adequately cooling high-powered electrical hardware is one challenge, effectively rejecting, capturing, and transferring that heat energy to a targeted application adds complexity.

Thanks for being curious!