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Sustainability Research Institute

Building Heat Decarbonization

Practical pathways for decarbonizing the heating of buildings by 2050.

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In this white paper, *Building Heat Decarbonization*, we explore in detail the issue of decarbonizing building heating systems globally, which represents around $3GtCO_2$/y, and some of the key debates and roadblocks which impede the ramp up of greener heating solutions.

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Executive summary

Decarbonizing hard-to-abate sectors of the global economy can only happen if decarbonization comes at a net benefit to society. Greener technologies need to be provided at a fraction of their costs to incentivize consumers to uptake them at mass. One area of rich debate is over the cost-competitiveness of installing greener heating solutions for the built environment. Such heating systems exist; however, they are commonly held to cost more than traditional, carbon-intensive fossil fuel heating options.

This paper explores the conditions under which consumers would be motivated to uptake greener building heating alternatives. To do this, the cost-competitiveness of electrified heating solutions are assessed against their fossil fuel counterparts, under different scenarios, taking into account: varying taxation policies, electricity costs, and upfront cost and technology improvements in heat pumps.

The impacts of these different scenarios in both new buildings and retrofits, for commercial and residential buildings, are evaluated. The cost-competitiveness of installing 'reversible' heating solutions, which also provide cooling functions, is also assessed. Results are modeled for 19 key regions, across North America, Europe, and Asia, using BloombergNEF's Heating Unit Economics Calculator.

The paper's **main findings** highlight that:

- Under current market conditions, **oil heating** is seldom cost-competitive with electrified alternatives in **residential new builds and retrofits**. Furthermore, electrified heating solutions are likely to become even more compelling in the future.
- In **commercial buildings**, there is a strong case for installing electric systems, over **gas systems**, based on current circumstances, in many of the 19 regions modeled. When this is not the case, there are clear policy pathways under which the electrification of heating becomes economically feasible.
- Deploying electric solutions, over **gas systems**, also makes sense today in **residential new builds** in many regions. **For residential retrofits** – if relative savings on cooling from deploying reversible heat pumps are accounted for – electric alternatives become economically very viable under current conditions.
- There is clear trend suggesting that electrified heating solutions will become more competitive in the mid-term future, following improvements in heat pumps and possible lower electricity costs, and that this will play a critical role helping the building sector to decarbonize.

This thus suggests that the current heating debate is largely misconstrued and that multiple decarbonization pathways – which would be to the economic benefit of building occupants – exist for building heating systems.

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Introduction

Mitigating climate change requires all CO_2 emissions to be zeroed by 2050. There is thus a need to transform consumer demand to incentivize consumers to rapidly uptake greener technologies and services. This is particularly pertinent for the building sector. The heating of residential and commercial buildings alone accounts for around 20% of global final energy consumption and 10% of global energy-related CO_2 emissions.[1] Without the installation of decarbonized, efficient heating systems this has the potential to worsen as global heating demand, which is projected to increase by 15% by 2040, grows.[2] To successfully achieve net-zero there is the need to abate a huge amount of emissions from buildings.

Fortunately, the technology exists today to do this. A major contributor to heating-related CO_2 emissions is the heavy use of fossil fuels.[3] Replacing fossil fuel systems with electrified heating solutions has the potential to drastically reduce CO_2 emissions. On average, electrified heating solutions have much higher efficiency levels than fossil fuel heating systems meaning that less energy is required to achieve the same heat output. For example, as Figure 1 highlights, electric heat pumps are approximately 3-5 times more energy-efficient than equivalent performing gas and oil systems providing scope for huge emissions savings.[4] Furthermore, in contrast to fossil fuel systems, electrified heating systems generate no emissions at their end-use. Thus, if the electricity consumed by electric heating systems is generated using decarbonized sources, such as renewable energy, electrified heating systems are zero-carbon. Despite this, only around 5% of buildings' heating is currently electrified, with fossil fuels instead used for the majority of heating.[5]

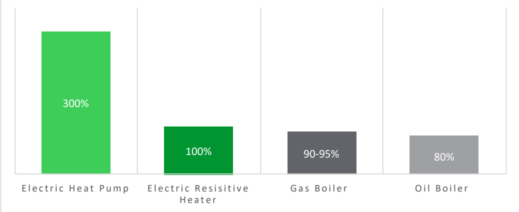

Figure 1: Average Efficiency levels of major heating systems

Source: Energy Transitions Commission (2020), Schneider Electric Research.

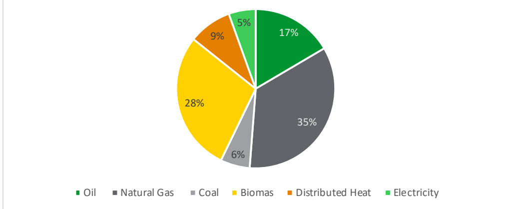

Figure 2: Global Heating Consumption in Buildings by Fuel Source

Source: © OECD/IEA (2010), Schneider Electric Research.

The widespread implementation of electrified heating systems, including retrofits in buildings with existing fossil fuel systems, is therefore widely accepted as pivotal for decarbonizing buildings' heating.[6] For instance, analysis from the Energy Transitions Commission suggests that as much as 80-90% of heating systems will need to be electrified by 2050 to successfully mitigate the worst effects of climate change.[7] Thereby, a major issue is that the rate of installation of modern electrified heating solutions remains slow.[8]

1 © OECD/IEA (2021). Global Energy Review: CO_2 Emissions in 2020; Schneider Electric Research.
2 Schneider Electric Research.
3 © OECD/IEA (2020). Tracking Report: Heating.
4 Energy Transitions Commission (2020). Mission Possible: Sectorial Focus Building Heating; Schneider Electric Research.
5 Schneider Electric Research. The efficiency of heat pumps specifically is typically called 'coefficient of performance' (COP).
6 Energy Transitions Commission (2020).
7 *Ibid.*
8 © OECD/IEA (2020). Tracking Report: Heat Pumps.

An often-cited issue with the decarbonization of buildings' heating is its assumed cost. To facilitate widespread consumer adoption, greener heating solutions will need to be cost-competitive with other alternative heating systems. However, the installation of electrified heating solutions is generally held to cost the consumer more. For example, in the United Kingdom, it is estimated that switching from natural gas to electric heating could increase consumers' annual bills by 15-20%.[9] Despite this, the specific conditions under which electrified heating systems are/become cost-competitive have seldom been modelled. This thus begs the question: are electrified heating solutions really more expensive than fossil fuel heating systems, and if so, what would it take for them to become cheaper?

To answer this, Schneider Electric has researched and modeled the competitiveness of electrified heating solutions in comparison to fossil fuel heating systems across 2,280 calculations. Its analysis shows that, contrary to conventional wisdom, the decarbonization of buildings is both economically feasible and can come at a competitive cost for building occupants. Furthermore, although selective policies will need to play a role in fostering decarbonization in the short-run, mid-term technology trends will likely help accelerate the rollout of decarbonized electrified heating solutions in the future. We thus believe this study to be a useful addition to the current building heating debate and to complement existing research on this highly complex topic.

[9] Energy Transitions Commission (2020).

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Methodology

This paper uses BloombergNEF's Heating Unit Economics Calculator to model the cost-competitiveness of *heat pumps* and *resistive electric heating* vs *oil* and *gas heating systems* from the consumers' standpoint. Oil and gas systems represent a large proportion of the heating systems which need to be replaced by electrified heating for a major decarbonization of heating to occur. Comparing the costs of these different technologies therefore provides insight into the circumstances under which a mass decarbonization of heating may be economically incentivized.

To do this, the cost-competitiveness of selected technologies in both new builds and retrofits for residential and commercial buildings are assessed. To model residential buildings, this paper uses data input from BloombergNEF's model for individual households. For commercial buildings, the heating of a 3,000 m^2 office and a 10,000 m^2 retail center have been evaluated. As the results for both these building archetypes are very similar, only the results for office buildings are shown in the main body of the paper. Detailed results for all archetypes modeled can be found in the annex sections.

This report also analyzes the impact of installing HVAC 'reversible' heat pumps, which provide cooling functions reducing the need for a building to install an independent air-conditioning (AC) unit. Assuming both heating and cooling functions are required, this in effect decreases the relative costs of purchasing a heat pump in the model, since a building faces the choice between installing a single heat pump system, or both AC and oil/gas heating systems.[10] As virtually all modern commercial buildings require cooling, this is accounted for in the modeling of the competitiveness of heat pumps for both new builds and retrofits. Given there is also growing demand for AC in residential buildings,[11] Schneider Electric has also analyzed the impact of this in residential retrofits of gas heating systems.

To assess the competitiveness of heating in new builds, the paper compares the operational costs (OpEx) of running electric and fossil fuel heating systems. An electrified heating solution is judged as more cost-competitive when the costs of running it are less than the costs of running a fossil fuel system. This is because the cost differences of installing different heating systems are negligible compared to the overall costs of constructing/purchasing a new build.[12]

For retrofits, the costs of installing and operating a new electrical heating solution against the same costs for a fossil fuel system are analyzed. A payback figure (in years) showing the time it would take for a consumer to break even following switching to using an electric heating system is provided. Paybacks of less than 10 years are assumed to indicate examples of when installing an electrified heating solution is cost-competitive.[13]

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[10] This is seldom accounted for when analyzing the relative cost of installing heat pump units.

[11] © OECD/IEA (2020). World Energy Outlook 2020.

[12] Currie & Brown (2019). A report for the Committee on Climate Change: The Costs and Benefits of Tighter Standards for New Buildings.

[13] Whilst this exact payback figure could be contested, we believe 10 years is an appropriate rough trigger point for a consumer to consider switching heating systems.

To provide a holistic analysis of the circumstances under which electrified heating solutions are cost-competitive globally, the price-competitiveness of these heating systems has been evaluated in 19 key geographies.[14] Relative factors such as: the weather and subsequent demand for heating, the cost of deploying selected technologies, current taxation costs, and electricity prices are accounted for in Schneider Electric's assessments. The regions modeled are:

- China: North Central; Eastern; South Central; Northeast; Northwest; Southern;
- Japan;
- Denmark;
- France;
- Germany;
- Italy;
- the Netherlands;
- Spain;
- the United Kingdom;
- Canada;
- the US: Midwest; Northeast; South; West.

These regions have been selected as they represent the majority of global building heating demand, accounting for approximately two-thirds of this figure in 2020.[15]

When analyzing the relative price competitiveness of selected heating systems under different scenarios several assumptions are considered. These are as follows:

i. **The Impact of Taxes**
The relative differences between fossil fuel and electricity taxation rates vary significantly between locations and can heavily distort the cost-competitiveness of electrified heating solutions. In the United Kingdom, for instance, electricity taxes are 16 times higher than the equivalent taxation of fossil fuels making the latter artificially more competitive.[16] The following is evaluated to adjust for this:
   - ***Electricity Tax Reform***. Schneider Electric has modeled the impact of a reform of electricity taxation policies, assuming that all electricity taxes are removed. It should be noted that electricity taxes are not input into the paper's assessments for China and Japan.
   - ***The Introduction of a Carbon Price***: on oil and gas of 65 USD/tCO_2.[17]

ii. **The impact of Lower Electricity Prices**
Electricity prices differ widely from one region to another. A cost convergence (before tax) towards 12c USD/kWh is modeled for all locations except for in China (where the electricity rate is already below this figure and no change is assumed) and the US (where it is assumed electricity prices drop to 9c USD/kWh).[18] This is applicable to both the residential and commercial sectors.

iii. **The Impact of a Disruption in Heat Pump Value Chains and Technologies**
The current costs of deploying heat pumps vary significantly. For instance, the upfront costs of purchasing residential heat pumps, across the geographies

[14] The paper uses the 19 key geographies defined in BloombergNEF's Heating Unit Economics Model.

[15] Schneider Electric Research.

[16] Eurostat (2020). Data for Households.

[17] This is based on BloombergNEF's assumed carbon tax rate.

[18] Though a theoretical sensitivity analysis, this could materialize through the greater penetration of decentralized renewable energies, particularly distributed energies.

evaluated in this paper, range from circa. 14,500 USD in Germany to 3,700 USD in China.[19] These costs, however, are expected to fall in the mid-term future as heat pumps increasingly penetrate the market.[20] In addition, there is also projected to be an increase in heat pumps' efficiency following technology improvements, in the coming decades. Consequently, the paper considers:

– ***A Radical Improvement to the Costs of Installing a Heat Pump***. For residential buildings, massive upfront installation cost differences suggest there is a significant reservoir for cost optimization. To reflect this, in residential buildings, it is assumed the upfront cost of purchasing a heat pump converge to around 4,000 USD in all regions except for China (where no change in costs is modeled). For commercial buildings, a 30% reduction in heat pump costs is assessed. This is to reflect the assumption that once heat pumps begin being installed at mass, their upfront costs are likely to decrease substantially facilitating further consumer uptake.
– ***An Improvement in Heat Pump Technology***. In both residential buildings and commercial buildings, an increase in the coefficient of performance (COP) levels of heat equivalent to BloombergNEF's 2050 forecasted rate is evaluated.

Based on these parameters, **12 scenarios are subsequently assessed**. These are outlined in the below table.

Scenario	Taxation Policies	Electricity Costs	Upfront Costs of Purchasing Electrified Heating Solutions
1	Current Circumstances	Current Circumstances	Current Circumstances
2	Electricity Tax Reform	Current Circumstances	Current Circumstances
3	Electricity Tax Reform and Carbon Price	Current Circumstances	Current Circumstances
4	Current Circumstances	Lower Electricity Prices	Current Circumstances
5	Electricity Tax Reform	Lower Electricity Prices	Current Circumstances
6	Electricity Tax Excluded and Carbon Price	Lower Electricity Prices	Current Circumstances
7	Current Circumstances	Current Circumstances	Radical Improvement to Heat Pumps
8	Electricity Tax Reform	Current Circumstances	Radical Improvement to Heat Pumps
9	Electricity Tax Reform and Carbon Price	Current Circumstances	Radical Improvement to Heat Pumps
10	Current Circumstances	Lower Electricity Prices	Radical Improvement to Heat Pumps
11	Electricity Tax Reform	Lower Electricity Prices	Radical Improvement to Heat Pumps
12	Electricity Tax Reform and Carbon Price	Lower Electricity Prices	Radical Improvement to Heat Pumps

[19] This is based on data from BloombergNEF.

[20] It is expected that with the deployment of heat pumps at mass, costs will go down following typical learning rates, further enhancing the competitiveness of these solutions. This trend has been witnessed with the uptake of other green technologies – most notably with wind and solar.

Table 2: Summary of Simulations Modeled					
Use Cases	Residential		Commercial (2 Building Archetypes)		Total number of calculations
	New build	Retrofit	New build	Retrofit	
Oil heating vs Heat Pumps	Modeled: 19 regions, 12 scenarios	Modeled: 19 regions, 12 scenarios	Not modeled as oil heating is seldom used in commercial buildings	Not modeled as oil heating is seldom used in commercial buildings	456
Oil heating vs Resistive electric heating	Modeled: 19 regions, 3 scenarios	Modeled: 19 regions, 3 scenarios			114
Natural gas heating vs Heat Pumps	Modeled: 19 regions, 12 scenarios	Modeled: 19 regions, 12 scenarios	Assumed all commercial buildings require both heating and cooling	Assumed all commercial buildings require both heating and cooling	456
Natural gas heating vs Heat Pumps, including needs for cooling	Similar as without cooling as no impact on OpEx	Modeled: 19 regions, 12 scenarios	Modelled: 19 regions, 12 scenarios	Modeled: 19 regions, 12 scenarios	1140
Natural gas heating vs Resistive electric heating	Modeled: 19 regions, 3 scenarios	Modeled: 19 regions, 3 scenarios	Not modeled	Not modeled	114
Total number of calculations	570	798	456	456	2280

Full details of the paper's methodology and the results of Schneider Electric's modeling can be found in the paper's annexes. The following sections outline the key findings of its research only. For the reader's convenience, sections are sub-divided to show results for electric vs oil/gas in new builds first, followed by in retrofits.

When visualizing results in graphs, areas where electrified heating solutions are judged to be cost-competitive with fossil fuel alternatives are shown in green and areas where they are not are shown in red.

Analysis Section One: Electric vs oil in residential buildings: transitioning to electrified heating solutions is a clear choice

1.1. Summary

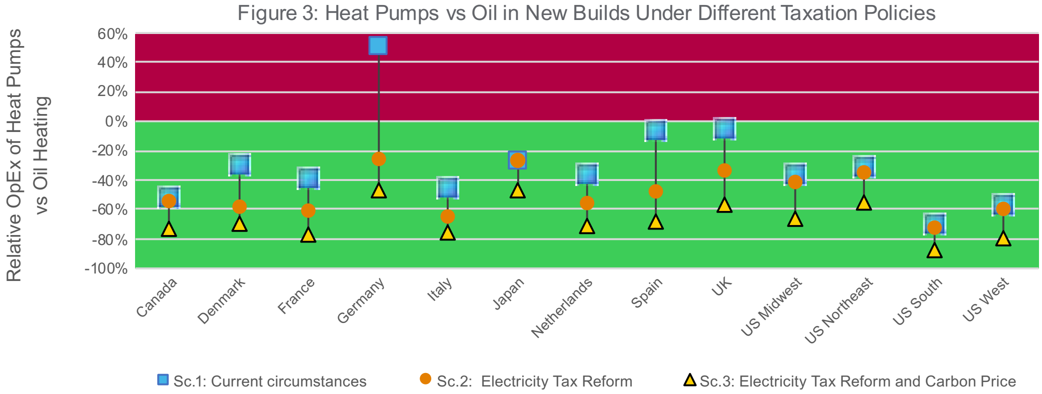
Oil heating is seldom competitive with electrified solutions. In **new builds**, there is a clear case for heat pumps which outperform oil in all regions except for Germany based on current conditions (Scenario 1). Resistive electric heating also largely outperforms oil heating systems, in terms of costs, especially following the introduction of greener taxation policies (Scenarios 2 & 3).

For **retrofits**, heat pumps again remain a natural choice in virtually all geographies, particularly following the removal of electricity taxes (Scenario 2). The case is weaker for resistive electric heating (Scenarios 1, 2 & 3). As oil heating is rarely used in commercial buildings, results have been modeled for residential buildings only. China is not included in this section's analysis due to oil heating seldom being used in its residential buildings.

1.2. Heat pumps in residential new builds: A clear winner

Installing heat pumps in new builds, over oil heating, is currently cost-effective for consumers in all assessed geographies, except for Germany due to its relatively high electricity taxes (Scenario 1). Furthermore – as Figure 3 illustrates – once electricity taxes are removed, it becomes cheaper for consumers to install heat pumps in Germany over oil heating as well (Scenario 2).

Figure 3: Heat Pumps vs Oil in New Builds Under Different Taxation Policies



1.3. Resistive electric heating in residential new builds: A natural choice in many regions provided taxation policies are reformed in line with decarbonization objectives

The installation of resistive electric heating, over oil systems, is already a natural choice in parts of North America (Scenario 1). Resistive electric heating becomes competitive in most of Europe too following electricity tax reforms (Scenario 2).

For Spain and the Northeast of America, the additional introduction of a carbon tax leads resistive electric heating's costs to be on par with that of oil systems (Scenario 3). Only in the UK, Germany and Japan does resistive electric heating fail to be competitive with oil heating in new builds. These results are shown in Figure 4.

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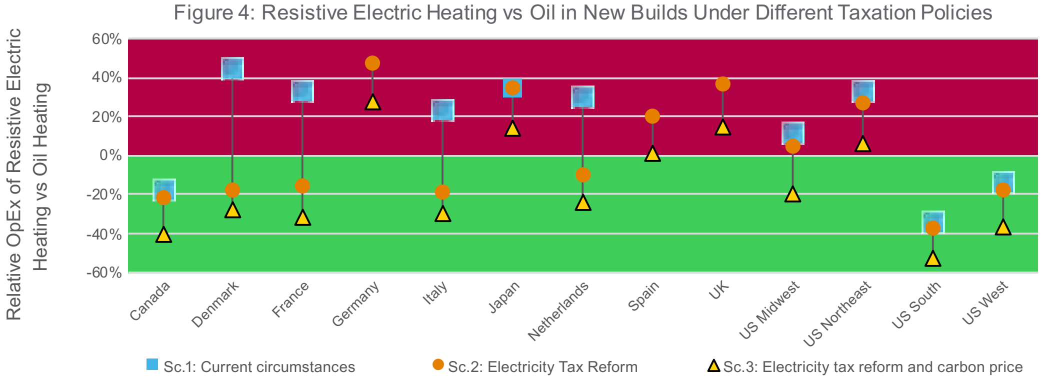
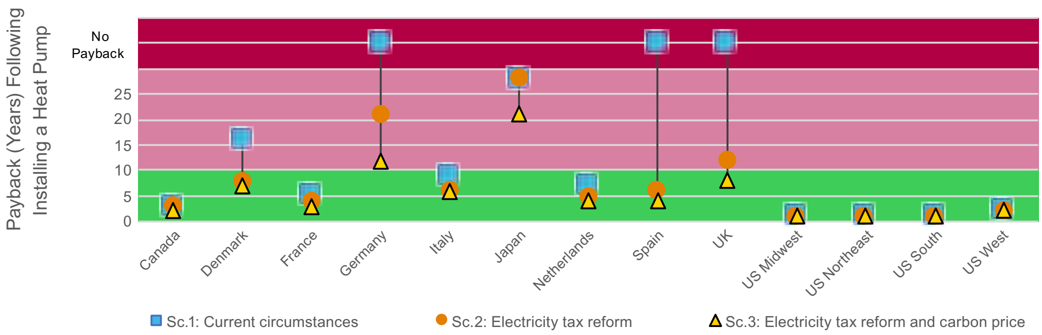
Figure 4: Resistive Electric Heating vs Oil in New Builds Under Different Taxation Policies



1.4. Heat pumps in residential retrofits: A natural choice in many regions, especially if taxation policies are reformed in line with decarbonization objectives

As Figure 5 demonstrates, retrofitting oil heating systems for heat pumps is a natural choice currently in North America and parts of Europe (Scenario 1). Long-payback periods make switching less clear cut for consumers in other selected locations under current conditions. The reform of electricity taxes alone overcomes this for all geographies except for Germany, Japan, and the UK (Scenario 2). Following the additional introduction of a carbon tax switching becomes viable in the UK; it remains unviable for Japan and Germany (Scenario 3).

Figure 5: Heat Pumps vs Oil in Retrofits Under Different Taxation Policies



1.5. Resistive electric heating in residential retrofits: A more complex picture

Replacing existing oil heating systems with resistive electric heating is a natural choice in parts of North America under current market conditions (Scenario 1). It also becomes rational in several European states following the reform of electricity taxation rates (Scenario 2).

For the American Midwest, it takes both the removal of electricity taxes and the introduction of a carbon price to make switching advantageous for the consumer from a cost perspective (Scenario 3). For Japan, Germany, Spain, and the UK, installing resistive electric heating remains more expensive even after greener tax reforms. Figure 6 illustrates these results.

Figure 6: Resistive Electric Heating vs Oil in Retrofits Under Different Taxation Policies

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Analysis Section Two: Electric vs gas in commercial buildings: selective policies make the transition to electric a no-brainer

2.1. Summary

The introduction of greener tax policies makes the installation of heat pumps, over gas heating systems, a clear choice for consumers in most regions for **new builds** (Scenarios 2 & 3). Lower electricity prices and progressive improvements in heat pump systems and costs also make heat pumps increasingly compelling for consumers (Scenarios 4, 6, 7 & 9).

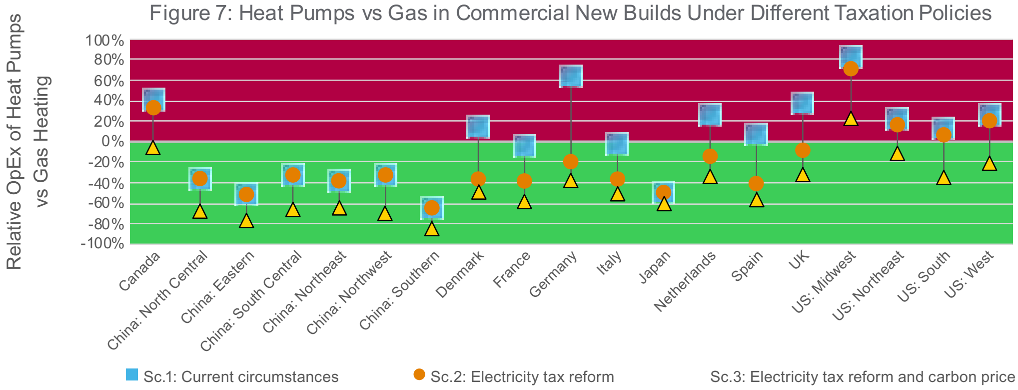
This trend is also reflected in **retrofits**, where selective taxation policies, cheaper electricity prices, or heat pump improvements make the installation of electric heating solutions economically competitive in most geographies (Scenarios 2, 3, 4, 6, 7 & 9). There is thus a clear case for the deployment of the technology over the mid-term future.

2.2. Heat pumps in new builds: A straightforward case everywhere, except select regions in North America

Figure 7 highlights that the installation of heat pumps, over gas systems, is a natural choice already in new builds in parts of Europe and all modeled areas of Asia (Scenario 1). Following the removal of electricity taxes, it also becomes cheaper to install heat pumps in all assessed European states (Scenario 2). Gas systems remain cheaper to operate in North America.

Introducing an additional carbon tax overcomes this, making electrified heating solutions more competitive in all selected geographies, except for the American Midwest (Scenario 3).

Figure 7: Heat Pumps vs Gas in Commercial New Builds Under Different Taxation Policies



As shown in Figure 8, lower electricity prices also make the installation of electrified heating solutions cheaper than gas heating systems in new builds for most regions (Scenario 4). Furthermore, the implementation of an additional carbon tax causes electrified heating solutions to be very competitive, from the consumers' standpoint, in all geographies (Scenario 6).

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Figure 8: Heat Pumps vs Gas in Commercial New Builds Following a Change in Electricity Prices

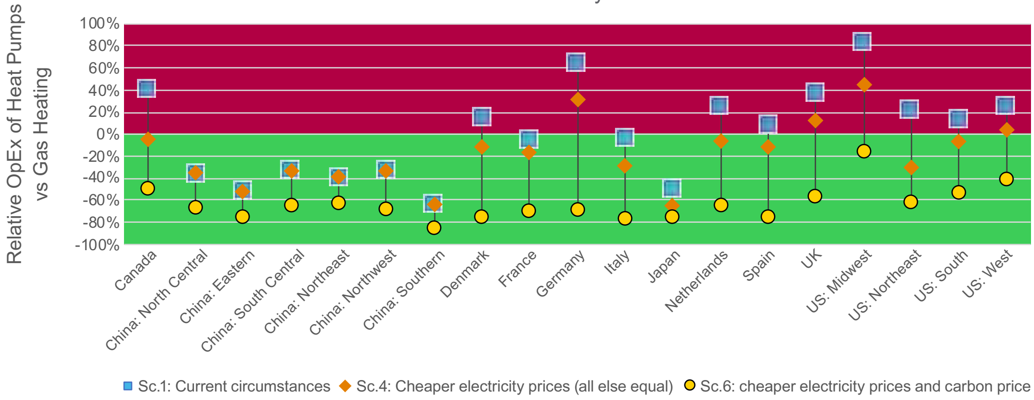
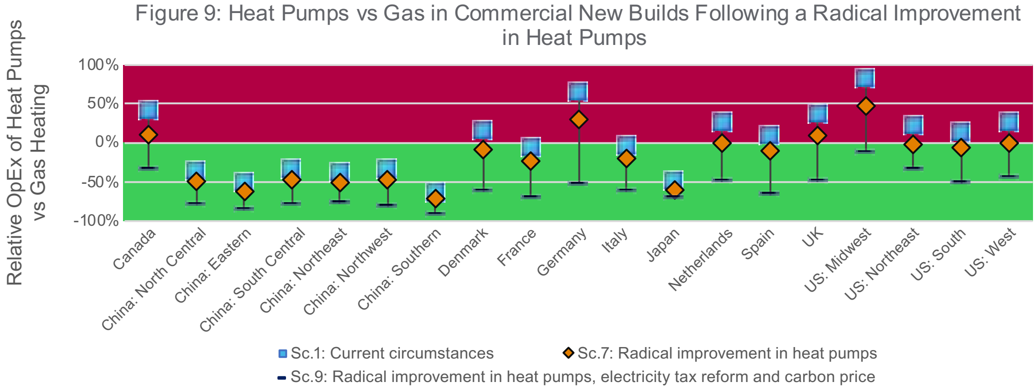


Figure 9 demonstrates that an improvement in heat pump costs – something likely in the mid-term future – leads heat pumps to become very viable economically (Scenario 7). Following this, the deployment of the technology becomes on par with or cheaper than gas heating systems in all evaluated locations except for Canada, Germany, the Midwest of America, and the UK (where it remains marginally more expensive). An additional carbon price leads heat pumps to be cost-competitive everywhere (Scenario 9).

Figure 9: Heat Pumps vs Gas in Commercial New Builds Following a Radical Improvement in Heat Pumps



2.3. Heat pumps in retrofits: A clear choice except in parts of the US and China

Under current conditions, replacing existing gas heating with heat pumps makes economic sense for consumers in parts of Asia and Europe (Scenario 1). The introduction of environmentally friendly taxation policies further makes the deployment of electrified heating solutions, in place of existing gas heating, cost-competitive in most commercial buildings as Figure 10 captures (Scenarios 2 & 3).

In Europe, electricity tax reform alone makes the retrofitting out of gas a logical consumer decision in all accessed states (Scenario 2). The additional implementation of a carbon price helps encourage switching from gas to electric, based on cost considerations, in Canada and parts of the US (Scenario 3).

Figure 10: Heat Pumps vs Gas in Commercial Retrofits Under Different Taxation Policies

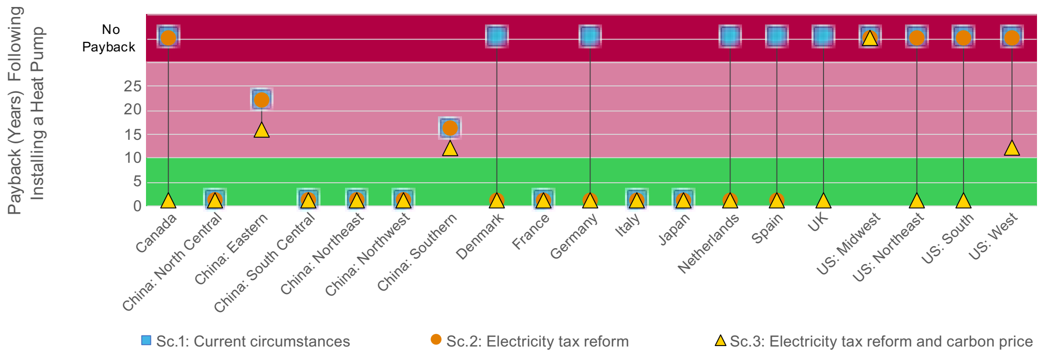
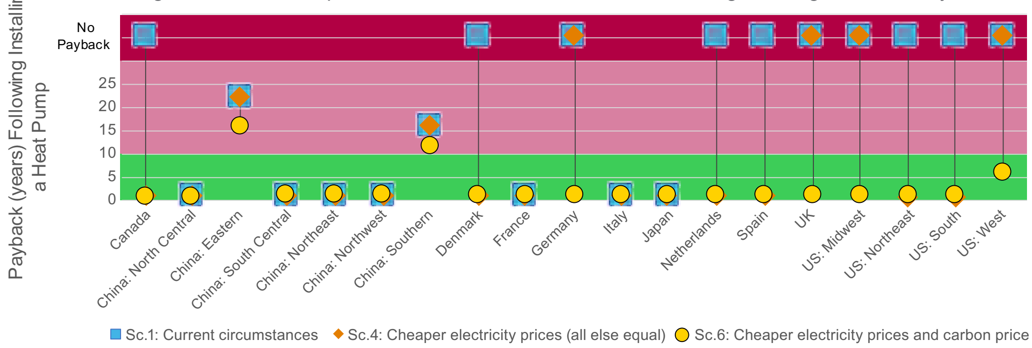


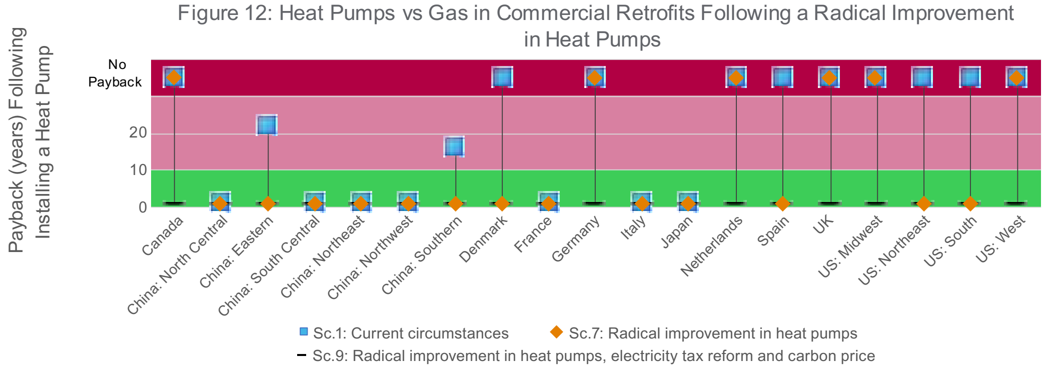
Figure 11 illustrates that lower electricity prices likewise economically incentivize switching for consumers in most regions (Scenario 4). For parts of the US, Germany, and the UK an additional carbon price is required to facilitate this change (Scenario 6).

Figure 11: Heat Pumps vs Gas in Commercial Retrofits Following a Change in Electricity Prices



As Figure 12 exemplifies, a radical reduction in heat pump costs – something that is likely as the heat pump market further develops – causes heat pumps to be economically competitive in additional parts of Europe, China, and the United States (Scenario 7). The picture is less favorable in Canada, Germany, the Netherlands, the UK and the Midwest and West of America, where additional reforms to taxation policies, including the introduction of a carbon price, are required (Scenario 9).

Figure 12: Heat Pumps vs Gas in Commercial Retrofits Following a Radical Improvement in Heat Pumps



Analysis Section Three: Electric vs gas in residential buildings: transitioning to electrified heating solutions is more compelling than we think

3.1. Summary

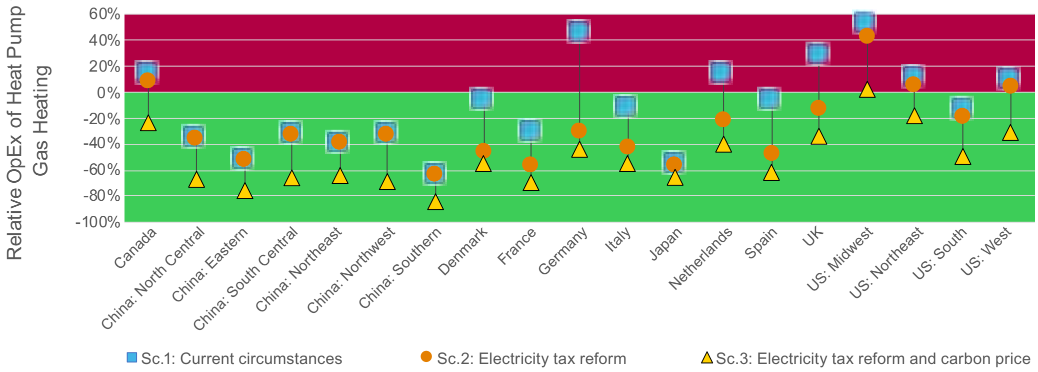
In residential **new builds** there is a strong economic case for the installation of heat pumps, over gas heating systems, especially following the removal of electricity tax distortions (Scenarios 2 & 3).

For residential **retrofits** – once the relative cost savings of installing reversible heat pumps are accounted for[21] – heat pumps again become economically very competitive with gas in most evaluated scenarios.

3.2. Heat pumps in new builds: A clear case (cooling not accounted for)[22]

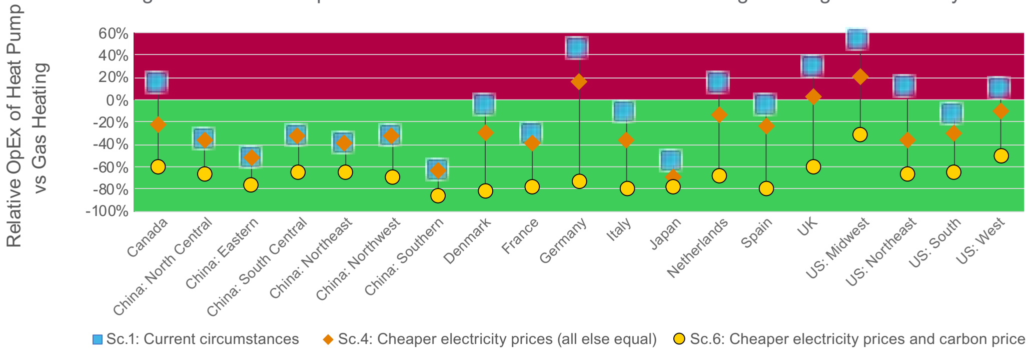
Figure 13 demonstrates that the installation of electrified heating solutions is currently cheaper than the installation of gas heating systems in new builds in many locations (Scenario 1). From a consumer standpoint, heat pumps are cost-competitive with natural gas in all geographies except for Germany, the Netherlands, the UK, and most parts of North America. The introduction of environmentally friendly taxation policies causes the deployment of electrified heating solutions to be cheaper than that of gas heating systems in residential new builds in most geographies globally (Scenarios 2 & 3).

Figure 13: Heat Pumps vs Gas in Residential New Builds Under Different Taxation Policies



Likewise, with lower electricity prices electrified heating solutions become cost-competitive in most regions (Scenario 4). The UK, the Midwest of the US and Germany require additional energy tax reforms for heat pumps to ultimately outperform gas heating in terms of costs in new builds (Scenario 6). This is shown in Figure 14.

Figure 14: Heat Pumps vs Gas in Residential New Builds Following a Change in Electricity Prices

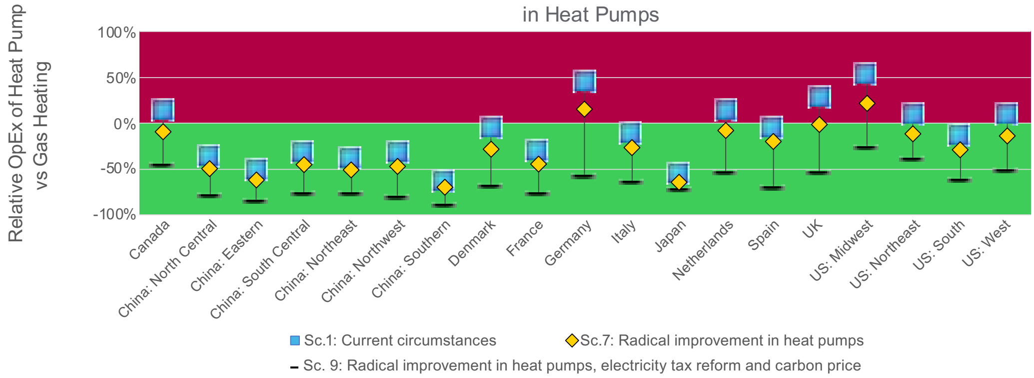


[21] Considering many regions of the world have both heating and cooling systems, there is a strong case for cooling to be accounted for when calculating the costs of installing reversible heat pumps. See Annex 1 for further details.

[22] The impact of installing reversible heat pumps is not evaluated in new builds as it is assumed to have no impact on the relative OpEx of heat pumps vs gas systems. Consequently the inclusion of 'cooling' does not impact the paper's results for new builds. See Annex 1 for more information.

Figure 15 demonstrates that a radical improvement in heat pumps leads them to be competitive in all locations evaluated except for Germany and the Midwest of America (Scenario 7). This therefore suggests there will be a strong case for the deployment of heat pumps – over gas systems in residential new builds – in the mid-term future. Electricity tax reform and the introduction of an additional carbon price makes heat pumps extremely attractive economically in all modeled geographies (Scenario 9).

Figure 15: Heat Pumps vs Gas in Residential New Builds Following a Radical Improvement in Heat Pumps

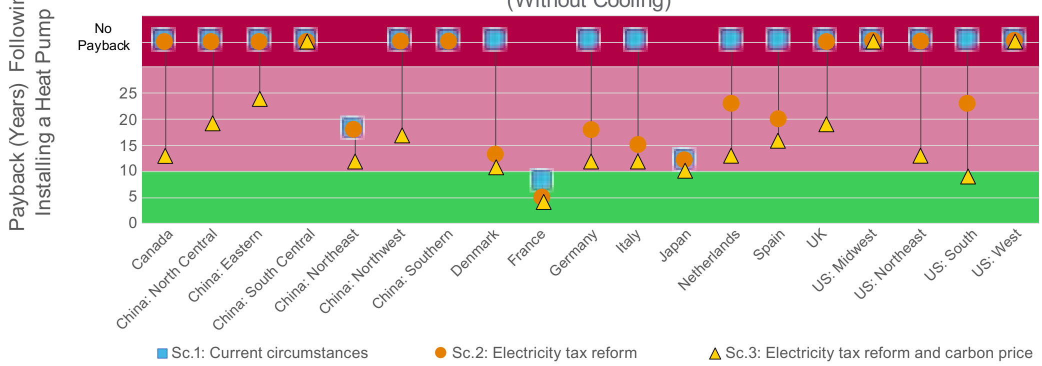


3.3. Heat pumps in retrofits: It depends on how we look at it

Replacing existing gas heating systems with electrified heating systems seldom appears economically justifiable due to the relatively high upfront costs of purchasing heat pump units. Without accounting for the relative costs saved through installing a reversible heat pump – even following the removal of electricity taxes and the implementation of a carbon tax – installing a heat pump appears economically rational only in France and the south of the US (see Figure 16; Scenarios 1, 2 & 3).

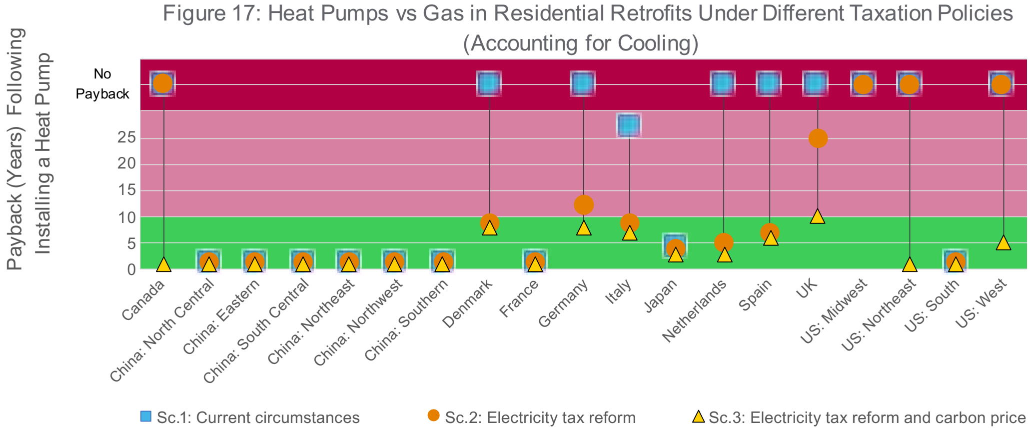
However, given a large share of residential buildings today require AC, and that demand for residential cooling is expected to rise dramatically over the coming decades,[23] it is also necessary to model the impact that deploying reversible heat pumps has on cost-competitiveness. Once this is accounted, it becomes evident that replacing existing gas heating for new reversible heat pumps is a very reasonable economic choice for consumers. Figures 16 and 17 illustrate the vast disparity in expected payback periods – when modeling the cost-competitiveness of heat pumps under equivalent policy scenarios (Scenarios 1, 2 & 3) – this causes.

Figure 16: Heat Pumps vs Gas in Residential Retrofits Under Different Taxation Policies (Without Cooling)



[23] © OECD/IEA (2020). World Energy Outlook 2020.

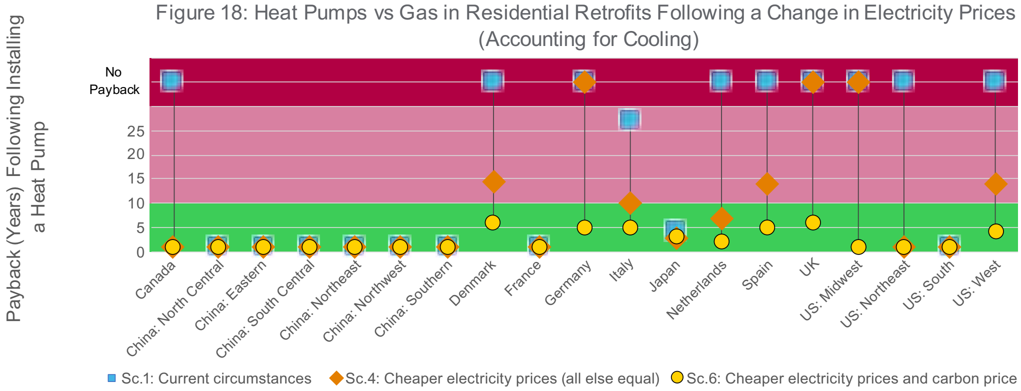
Figure 17: Heat Pumps vs Gas in Residential Retrofits Under Different Taxation Policies (Accounting for Cooling)



As shown above factoring in relative savings on cooling costs – from installing a reversible heat pump – highlights that retrofitting residential gas heating systems for electrified heating systems is already cost-effective in many locations including all of China, Japan, France, and parts of America (Scenario 1). Electricity tax reform makes switching competitive in all remaining regions except for Germany, the UK, and regions of the US (Scenario 2). Implementing an additional a carbon price leads switching to be economically enticing in all regions except for the Midwest of America (Scenario 3).

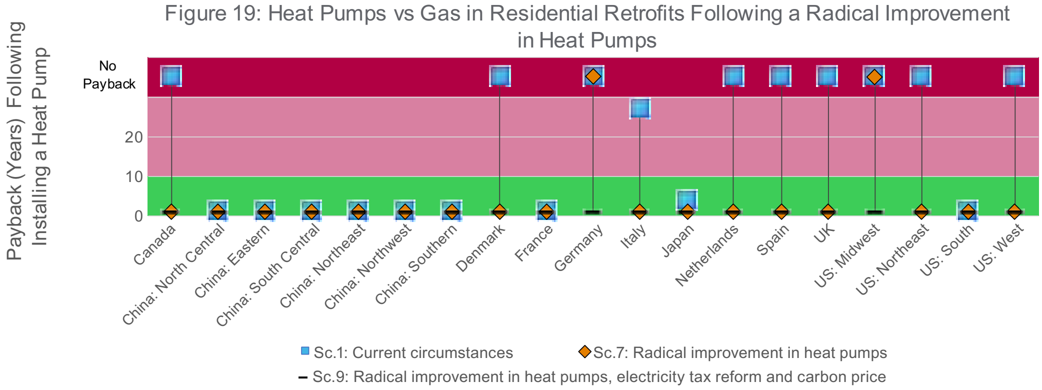
Lower electricity costs alone fail to cause switching to be viable in most geographies, with Italy the sole exception (Scenario 4). Figure 18 illustrates that, coupled with a carbon tax, cheaper electricity pricing causes electrified heating solutions to be cost-competitive in all regions (Scenario 6).

Figure 18: Heat Pumps vs Gas in Residential Retrofits Following a Change in Electricity Prices (Accounting for Cooling)



Finally, a radical improvement in the upfront cost of installing a heat-pump – a highly likely scenario in the mid-term as their market penetration grows – makes heat pumps highly viable in all assessed locations except for Germany and the Midwest of America (Scenario 7). The additional introduction of a carbon tax, shown in Figure 19, causes electrified heating solutions to be extremely cost-competitive in all modeled regions (Scenario 9).

Figure 19: Heat Pumps vs Gas in Residential Retrofits Following a Radical Improvement in Heat Pumps



Conclusion: The decarbonization of heating is more feasible than we think

Decarbonizing the global economy at pace requires green technologies which are economically competitive with their fossil fuel counterparts, to facilitate their rapid adoption by consumers. The heating of buildings is no exception. Environmentally friendly heating systems currently exist, however, their cost-competitiveness is often questioned. Evaluating the competitiveness of electrified heating solutions under different tax regimes, varying electricity prices, and following improvements to heat pumps demonstrates this consensus is debatable. Moreover, this picture further brightens once the relative cost savings of installing reversible heat pumps – with heating and cooling functions – is also included in modeling.

As demonstrated throughout this paper, there are many scenarios under which the decarbonization of heating is not only feasible but would also come at the economic benefit of residential and commercial building occupants, in both new builds and retrofits. This report thus adds to the global debate and highlights that there are multiple competitive pathways to decarbonize the global building stock.

Key takeaways:

- For oil heating:
  - Oil heating is economically less viable than electrified heating solutions – in both retrofits and new builds – especially once current electricity tax distortions are removed. Given its much worse environmental impacts, the displacement of oil heating for electric is therefore a no-brainer.
- For gas heating in commercial buildings:
  - The displacement of gas with electrified heating solutions already makes sense economically in Asia and parts of Europe.
  - Tax reforms in Europe and North America would further make the installation of heat pumps, over gas heating systems, economically competitive in both new builds and retrofits.
  - Lower electricity costs make heat pumps economically compelling for consumers.
  - Heat pumps become attractive for consumers following a decrease in their upfront costs. Given the growing rate of uptake of heat pumps, which will likely lead to cost decreases, it is expected that heat pumps will become increasingly competitive over the mid-term future.
- For gas heating in residential buildings:
  - In new builds there is a strong economic case for the installation of heat pumps, over gas heating systems, especially if supported by taxation reforms.
  - Switching is also largely economically competitive in retrofits once air-conditioning needs, largely forgotten in today's debate, are included in the equation.

The below table summarizes the paper's key findings for each region.

Table 4 highlights that, under current circumstances, there is already a compelling

Table 3: What does it take to decarbonize buildings

	Electric vs oil heating				Electric vs gas heating in commercial buildings		Electric vs gas heating in residential buildings		
	Heat pumps vs oil in new builds	Resistive electric heating vs oil in new builds	Heat pumps vs oil in retrofits	Resistive electric heating vs oil in retrofits	Heat pumps vs gas in new builds	Heat pumps vs gas in retrofits	Heat pumps vs gas in new builds	Heat pumps vs gas in retrofits without cooling	Heat pumps vs gas in retrofits with cooling
Canada	Competitive: -52% opex	Competitive: -18% opex	Competitive: payback of 3 years	Competitive: payback of 4 years	Electricity tax reform and introduction of carbon price needed	Electricity tax reform and introduction of carbon price needed	Electricity tax reform and introduction of carbon price needed	Radical improvement in heat pumps or lowered electricity prices needed	Electricity tax reform and introduction of carbon price needed
China: North Central	N/A	N/A	N/A	N/A	Competitive: -36% opex	Competitive: payback of 1 year	Competitive: -36% opex	Radical improvement in heat pumps or lowered electricity prices needed	Competitive: payback of 1 year
China: Eastern	N/A	N/A	N/A	N/A	Competitive: -52% opex	Radical improvement in heat pumps or lowered electricity prices needed	Competitive: -52% opex	Radical improvement in heat pumps or lowered electricity prices needed	Competitive: payback of 1 year
China: South Central	N/A	N/A	N/A	N/A	Competitive: -33% opex	Competitive: payback of 1 year	Competitive: -33% opex	Radical improvement in heat pumps or lowered electricity prices needed	Competitive: payback of 1 year
China: Northeast	N/A	N/A	N/A	N/A	Competitive: -39% opex	Competitive: payback of 1 year	Competitive: -39% opex	Radical improvement in heat pumps or lowered electricity prices needed	Competitive: payback of 1 year
China: Northwest	N/A	N/A	N/A	N/A	Competitive: -33% opex	Competitive: payback of 1 year	Competitive: -33% opex	Radical improvement in heat pumps or lowered electricity prices needed	Competitive: payback of 1 year
China: Southern	N/A	N/A	N/A	N/A	Competitive: -64% OpEx	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Competitive: -64% OpEx	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Competitive: Payback of 1 Year
Denmark	Competitive: -30% OpEx	Electricity Tax Reform Needed	Electricity Tax Reform Needed	Electricity Tax Reform Needed	Electricity Tax Reform Needed	Electricity Tax Reform Needed	Competitive: -6% OpEx	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Electricity Tax Reform Needed
France	Competitive: -39% OpEx	Electricity Tax Reform Needed	Competitive: Payback of 5 Years	Electricity Tax Reform Needed	Competitive: -5% OpEx	Competitive: Payback of 1 Year	Competitive: -31% OpEx	Competitive: Payback of 8 Years	Competitive: Payback of 1 Year
Germany	Electricity Tax Reform Needed	Disruption Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Disruption Needed	Electricity Tax Reform Needed	Electricity Tax Reform Needed	Electricity Tax Reform Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Electricity Tax Reform and Introduction of Carbon Price Needed
Italy	Competitive: -46% OpEx	Electricity Tax Reform Needed	Competitive: Payback of 9 Years	Electricity Tax Reform Needed	Competitive: -3% OpEx	Competitive: Payback of 1 Year	Competitive: -12% OpEx	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Electricity Tax Reform Needed
Japan	Competitive: -26% OpEx	Disruption Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Disruption Needed	Competitive: -50% OpEx	Competitive: Payback of 1 Year	Competitive: -56% OpEx	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Competitive: Payback of 4 Years
Netherlands	Competitive: -37% OpEx	Electricity Tax Reform Needed	Competitive: Payback of 7 Years	Electricity Tax Reform Needed	Electricity Tax Reform Needed	Electricity Tax Reform Needed	Electricity Tax Reform Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Electricity Tax Reform Needed
Spain	Competitive: -7% OpEx	Disruption Needed	Electricity Tax Reform Needed	Disruption Needed	Electricity Tax Reform Needed	Electricity Tax Reform Needed	Competitive: -6% OpEx	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Electricity Tax Reform Needed

Table 3: What does it take to decarbonize buildings									
	Electric vs oil heating				Electric vs gas heating in commercial buildings		Electric vs gas heating in residential buildings		
	Heat pumps vs oil in new builds	Resistive electric heating vs oil in new builds	Heat pumps vs oil in retrofits	Resistive electric heating vs oil in retrofits	Heat pumps vs gas in new builds	Heat pumps vs gas in retrofits	Heat pumps vs gas in new builds	Heat pumps vs gas in retrofits without cooling	Heat pumps vs gas in retrofits with cooling
United Kingdom	Competitive: -6% OpEx	Disruption Needed	Electricity Tax Reform and Introduction of Carbon Price Needed	Disruption Needed	Electricity Tax Reform Needed	Electricity Tax Reform Needed	Electricity Tax Reform Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Electricity Tax Reform and Introduction of Carbon Price Needed
US: Midwest	Competitive: -37% OpEx	Electricity Tax Reform and Introduction of Carbon Price Needed	Competitive: Payback of 1 Year	Electricity Tax Reform and Introduction of Carbon Price Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed
US: Northeast	Competitive: -32% OpEx	Disruption Needed	Competitive: Payback of 1 Year	Disruption Needed	Electricity Tax Reform and Introduction of Carbon Price Needed	Electricity Tax Reform and Introduction of Carbon Price Needed	Electricity Tax Reform and Introduction of Carbon Price Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Electricity Tax Reform and Introduction of Carbon Price Needed
US: South	Competitive: -71% OpEx	Competitive: -34% OpEx	Competitive: Payback of 1 Year	Competitive: Payback of 1 Year	Electricity Tax Reform and Introduction of Carbon Price Needed	Electricity Tax Reform and Introduction of Carbon Price Needed	Competitive: -14% OpEx	Electricity Tax Reform and Introduction of Carbon Price Needed	Competitive: Payback of 1 Year
US: West	Competitive: -57% OpEx	Competitive: -14% OpEx	Competitive: Payback of 2 Years	Competitive: Payback of 1 Year	Electricity Tax Reform and Introduction of Carbon Price Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Electricity Tax Reform and Introduction of Carbon Price Needed	Radical Improvement in Heat Pumps or Lowered Electricity Prices Needed	Electricity Tax Reform and Introduction of Carbon Price Needed

case for the electrification of heating in buildings in approximately half of the regions evaluated. This ratio goes up to circa. 90% when policies are adjusted in line with decarbonization objectives. Radical improvements in heat pump costs and technology also help to make the deployment of electrified heating compelling across all modeled geographies.

Table 4: Percentage Share of Regions Where the Installation of Decarbonized Electric Heating is Competitive Under Different Circumstances						
Circumstance	Electric vs Oil heating		Electric vs Gas Heating in Commercial Buildings		Electric vs Gas Heating in Residential Buildings	
	New Build	Retrofit	New Build	Retrofit	New Build	Retrofit (Including Cooling)
Current	92%	62%	47%	37%	63%	47%
Electricity Tax Reform	100%	77%	74%	63%	79%	68%
Electricity Tax Reform & Carbon price	100%	85%	95%	79%	95%	95%
Radical Improvements in Heat Pumps	100%	100%	100%	100%	100%	100%

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Looking forward

As shown in this paper, the replacement of fossil fuel heating with electrified heating solutions is already compelling in many regions or becomes so once taxation policies better reflect decarbonization objectives. Thus, there are clear paths forward for enabling the rapid adoption of competitive decarbonized solutions at mass.

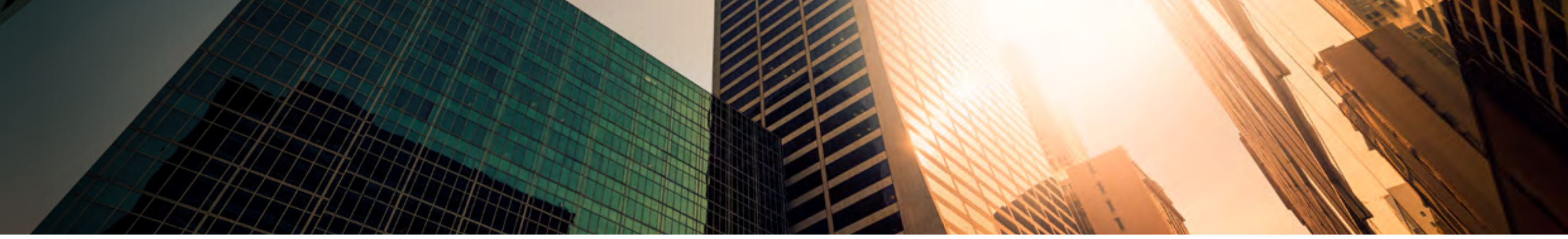
The current state of the union will also evolve inexorably. The greater penetration of decentralized energies (in particular, via an increase in distributed electricity generation and microgrids) is likely to lead to a relative decrease in average electricity costs, further strengthening the case for electrified heating solutions. The costs of purchasing a heat pump, and their performance levels, are also projected to improve, again significantly reinforcing the case for electrified heating systems.

Looking forward, the picture for the decarbonization of heating will thus further improve.

Policy recommendations

As the world races towards a net-zero economy by 2050, current policy frameworks must adapt to favor decarbonization. This report illustrates, if policies took stock of currently distorted taxation environments – that prevent a level playing field between decarbonized energy sources and fossil fuels – the economic case for consumers to switch to zero-carbon solutions would be highly compelling, fostering their rapid adoption. This therefore highlights 4 key recommendations for the future evolution of policy frameworks, broadly applicable to every region of the world:

- Remove oil heating. Oil heating is not economically competitive. Targeted policies should look to enhance the uptake of heat pump or resistive electric heating systems in the residential sector, possibly including upfront subsidies to foster rapid switching.
- Develop a vibrant market for all-electric buildings to accelerate learning rates, and competitiveness of decarbonized solutions. Including:
  - Drive all new build heating systems to be electric. There is a lack of economic rationale for expanding natural gas networks within a policy framework that favors decarbonization.
  - Create a sizeable retrofit market through large residential retrofit programs and a focus on government buildings.
  - Foster further innovation in heating systems and the development of a competitive ecosystem of actors.
- Continue the competitive decarbonization of the power system and promote a greater penetration of distributed generation (in particular rooftop solar). A competitive electricity price accelerates the case for heating electrification, and hence the decarbonization of the building stock.
- Align current energy tax regimes to advance decarbonization objectives, including realigning natural gas and electricity taxation rates, notably in regions with highly distorted systems.



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Annex 1 – Modeling details

Methodology

This paper uses BloombergNEF's Heating Unit Economics Calculator to run its simulations.

- 19 geographies from North America, East Asia, and Europe, are covered by its modeling.
- 3 different building archetypes are evaluated:
  - The paper models a standard individual household (BloombergNEF standard).
  - It also models 2 commercial building archetypes:
    1. A 3,000 m2 office building (5 floors)
    2. A 10,000 m2 retail center (1 floor)

Schneider Electric has evaluated the costs of heating for different models: the retrofitting of an existing (non-electric) installation and for a new build:

- For **new builds**, the differences in the upfront costs of installing different heating systems are not considered. This is as they are negligible in comparison to the total ownership costs of constructing/buying a building. The paper thus focuses only on differences in operating costs (differences in annual consumer bills).[24]
- For **retrofits**, the paper looks at paybacks over a 20-year period.
- Schneider Electric's analysis does not consider the maintenance costs of different solutions, which are assumed to have a negligible impact overall.
- Similar coefficients of performance (COP) levels are assumed across both new build and retrofits, although more efficient envelope designs (more likely in new builds) typically offer greater COP levels.

For heat pump systems, only standard Air-Sourced Heat Pump systems are modelled. There are a variety of other solutions available, notably Ground Sourced Heat Pumps which can provide greater benefits depending on their use case. Nonetheless, they are not accounted for in this analysis.

The paper also assumes the use of standard heating distribution systems, and does not explore in detail alternative heating solutions, such as radiant heating. Such systems could be the object of future research.

12 scenarios are assessed for each use case

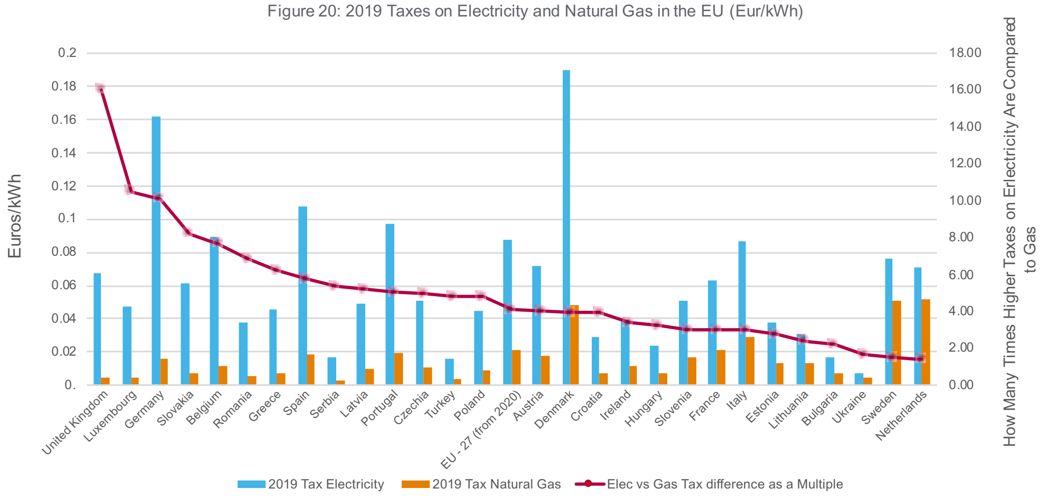
Schneider Electric has assessed scenarios pertaining to differing upfront costs (CapEx), performance levels, and fuel costs (oil, natural gas, and electricity).

Schneider Electric has modeled the impact of taxes:

- Current taxation rates in many regions – on electricity and fossil fuels – heavily favor the adoption of fossil fuel heating over electric heating. For example, see Figure 20 for an illustration of the impact of this in Europe.
- Schneider Electric has therefore evaluated the impact of excluding taxes on electricity (not available for China and Japan).
- It has also integrated a carbon price on oil and natural gas (using the standard model assumption of 65 USD/tCO_2).

[24] This is a widely endorsed method. See for example: Currie & Brown (2019). A Report for the Committee on Climate Change: The Costs and Benefits of Tighter Standards for New Buildings.

Figure 20: 2019 Taxes on Electricity and Natural Gas in the EU (Eur/kWh)



Source: Eurostat (2020), Schneider Electric Research.

The paper also considers the impact of a lower electricity price (based for instance on the competitive deployment of distributed energy provisions):

- Electricity prices differ widely from one region to another. It is assumed there is a cost convergence (before tax) towards 12c USD/kWh, except for in China (where the electricity price is below this figured and there is assumed to be no change) and the United States (where electricity is at this price currently and is assumed to decrease to 9c USD/kWh).
- On average, this corresponds to a 30% reduction in electricity prices across the assessed regions.

The paper evaluates the impact of a radical improvement in heat pump value chains and technologies:

- The upfront costs of heat pumps vary significantly from one region to another, mainly due to value chains' maturity.
- For residential buildings: costs vary from as low as 3,700 USD in China up to 14,500 USD in Germany. The paper assumes a convergence toward 4,000 USD in the upfront cost of purchasing a heat pump everywhere except for China (where current upfront costs are modelled). It also considers, in its scenarios, an increase in COP performance levels equivalent to BloombergNEF's 2050 forecast (a 20-25% improvement from current levels, ranging around 2.9).
- For commercial buildings: a 30% reduction in heat pump system costs, and a COP performance equivalent to BloombergNEF's 2050 forecast, is modelled.

2,280 calculations:

- These use cases and scenarios yield 2,280 calculations which help us to understand the dynamics of heat competitiveness across electrified (heat pumps and resistive electric heating), oil and natural gas heating systems.

Table 5: Summary of Simulations Modeled					
Use Cases	Residential		Commercial (2 Building Archetypes)		Total number of calculations
	New build	Retrofit	New build	Retrofit	
Oil heating vs Heat Pumps	Modeled: 19 regions, 12 scenarios	Modeled: 19 regions, 12 scenarios	Not modeled as oil heating is seldom used in commercial buildings	Not modeled as oil heating is seldom used in commercial buildings	456
Oil heating vs Resistive electric heating	Modeled: 19 regions, 3 scenarios	Modeled: 19 regions, 3 scenarios			114
Natural gas heating vs Heat Pumps	Modeled: 19 regions, 12 scenarios	Modeled: 19 regions, 12 scenarios	Assumed all commercial buildings require both heating and cooling	Assumed all commercial buildings require both heating and cooling	456
Natural gas heating vs Heat Pumps, including needs for cooling	Similar as without cooling as no impact on OpEx	Modeled: 19 regions, 12 scenarios	Modelled: 19 regions, 12 scenarios	Modeled: 19 regions, 12 scenarios	1140
Natural gas heating vs Resistive electric heating	Modeled: 19 regions, 3 scenarios	Modeled: 19 regions, 3 scenarios	Not modeled	Not modeled	114
Total number of calculations	570	798	456	456	2280

Focus on residential assumptions

The paper uses standard data inputs from BloombergNEF's Heating Unit Economics Calculator for individual households.

The specific case of resistive electric heating:

- The paper models the CapEx of installing a direct electric heating solution.
  - It is assumed there is the need to install one electric heater for 10 m² of surface.[25]
  - This is estimated to cost: 100/150/300 USD a piece (depending on heating intensity) and computed in the assessed region's local currency.
- The paper takes into account the inherent efficiency of zoned heating from direct electric heating.
  - It assumes a typical household is split in 10 zones (4 bedrooms; 1 living room; 1 kitchen; 2 bathrooms; 1 entry hall; and, corridors).
  - It is assumed that 6 of the zones operate for 4 hours a day (living areas) and 4 zones operate for 10 hours a day (bedrooms).
  - Schneider Electric has recomputed the associated "COP" to be input into its modeling at 1.4 (around 30% efficiency, consistent with other datapoints on room control systems, and references).[26]
- Unlike for other heating solutions, the paper only looks resistive electric heating's sensitivity to energy taxation policies (Scenarios 1, 2 & 3).

[25] ManoMano (2020). Electric Heater and Radiator Buying Guide.

[26] GreenAge (2015). Is Electric Heating expensive?

Cooling in Residential Buildings:

- At large, current analyses fail to integrate the need for cooling in most regions of the world. As the below table illustrates, cooling system penetration rates are all below current cooling needs, meaning many households can be expected to install cooling units in the future.

© OECD/IEA (2020)	Current need for cooling (% of households)	Current penetration
North America	56%	90%
Europe	80%	10-20%
China	80%	60%
Worldwide	**33%**	**20% ➔ could reach 60% by 2050**

- Since heat pumps can be reversible, they provide for both cooling and heating functions. For this paper's modeling, simulations have been run to also account for the growing penetration of 'reversible' heat pumps in residential buildings.
- When accounting for cooling in residential retrofits, this paper assumes a standard 3,000 USD AC unit is required in residential gas-heated buildings globally, for the purpose of calculating the relative upfront costs of heating systems.

Focus on commercial assumptions

Modeling

BloombergNEF's Heating Unit Economics Calculator reviews individual households only. Schneider Electric has modeled commercial buildings in the calculator, by leveraging the ASHRAE model to build commercial building archetypes.[27] The archetypes that have been built are:

- A 3,000 m2 office, moderately well insulated, with 5 floors.
- A 10,000 m2 retail center, with similar insulation characteristics, and only 1 floor.

Schneider Electric's modeling of an office

25	Roof R-Value
10.00	Wall R-Value
0.400	Window U-Value
0.4	Window Solar Heat Gain Coeffecient
40	Window-to-Wall Ratio [%]
150	People Density [square feet per person]
20	Ventilation [cubic feet per minute per person]
60	Weekly hours of occupancy
0.3	Infiltration Rate [air changes per hour]
1.2	Lighting Power Density [watts per square foot]
1.0	Plug Load Density [watts per square foot]
82	Heating Efficiency [%]
9.5	Air Conditioning Efficiency [EER]
0.10	Electricity Cost [$/kWh]
1.0	Natural Gas Cost [$/therm]
32,200	Total Building Area [square feet]
5	Number of Floors
1,700	Generation CO2 emitted [lbs/MWh]
11.8	On Site CO2 emitted [lbs/therm]

[27] ASHRAE (2020). Back of the Envelope Calculator.

Schneider Electric's modeling of a retail center

25	Roof R-Value
16.75	Wall R-Value
0.400	Window U-Value
0.4	Window Solar Heat Gain Coeffecient
0	Window-to-Wall Ratio [%]
300	People Density [square feet per person]
20	Ventilation [cubic feet per minute per person]
70	Weekly hours of occupancy
0.3	Infiltration Rate [air changes per hour]
1.2	Lighting Power Density [watts per square foot]
1.0	Plug Load Density [watts per square foot]
82	Heating Efficiency [%]
9.5	Air Conditioning Efficiency [EER]
0.10	Electricity Cost [$/kWh]
1.0	Natural Gas Cost [$/therm]
107,640	Total Building Area [square feet]
1	Number of Floors
1,700	Generation CO2 emitted [lbs/MWh]
11.8	On Site CO2 emitted [lbs/therm]

- Different weather patterns, from various locations, are assumed. The following locations are used as proxies to model weather patterns across the 19 assessed regions: New York City, Des Moines (Iowa), Houston (Texas), Los Angeles (California), Paris, Roma, Hong Kong.
- Schneider Electric has run the ASHRAE model – which yields energy demand, and heating/cooling loads – for the same building in different locations. It has also extensively crosschecked its results with other references. Its results prove globally consistent, albeit the ASHRAE model yields generally higher cooling loads and lower heating loads.[28] Thus, Schneider Electric's evaluations are rather conservative on the competitiveness of heat pumps as a result.

[28] EIA (2020). CEBS; Air Fixture (2020). How Do You Size A Commercial HVAC System?; Brummit (2020). What Size Boiler is Appropriate for My Business?; Carolina Comfort (2020). How Do You Size a Commercial HVAC System?; LBNL (1999). Commercial Heating and Cooling Analysis; Puravent (2020). Calculator Space Heating.

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3,000m2 office	Heat demand (kWh/y)	Heat demand (kWhm2//y)	"Heating need (kW)"	"Cooling need (kW)"
Canada	215,743	72	288	414
China - North Central	284,208	95	332	439
China - Eastern	23,242	8	112	421
China - South Central	78,077	26	212	468
China - Northeast	215,743	72	288	414
China - Northwest	284,208	95	332	439
China - Southern	23,242	8	112	421
Denmark	197,715	66	216	381
France	197,715	66	216	381
Germany	197,715	66	216	381
Italy	167,268	56	230	443
Japan	215,743	72	288	414
Netherlands	197,715	66	216	381
Spain	167,268	56	230	443
United Kingdom	197,715	66	216	381
U.S. Midwest	284,208	95	332	439
U.S. Northeast	215,743	72	288	414
U.S. South	78,077	26	212	468
U.S. West	82,328	27	132	359

10,000m2 Retail center	Heat demand (kWh/y)	Heat demand (kWhm2//y)	"Heating need (kW)"	"Cooling need (kW)"
Canada	421,735	42	535	551
China - North Central	531,341	53	614	650
China - Eastern	40,962	4	208	668
China - South Central	146,173	15	399	650
China - Northeast	421,735	42	535	551
China - Northwest	531,341	53	614	650
China - Southern	40,962	4	208	668
Denmark	376,427	38	403	491
France	376,427	38	403	491
Germany	376,427	38	403	491
Italy	302,954	30	432	629
Japan	421,735	42	535	551
Netherlands	376,427	38	403	491
Spain	302,954	30	432	629
United Kingdom	376,427	38	403	491
U.S. Midwest	531,341	53	614	650
U.S. Northeast	421,735	42	535	551
U.S. South	146,173	15	399	650
U.S. West	141,819	14	245	448

- This paper models the costs of HVAC:
  - The paper assumes these costs are similar (in USD) across regions, as the commercial market is more balanced across geographies than the residential market.
  - Even though the paper only looks at heating demand, Schneider Electric considers the upfront costs for both heating and cooling systems as commercial buildings generally require both systems.
    i. For buildings heated by natural gas, it is assumed both a gas system for heating and chillers for cooling are needed.
    ii. Heat pump systems are assumed to provide both heating and cooling functions meaning only one system is needed. The heat pump system required is assumed to be an air-source system as discussed previously.
  - The paper makes the following assumptions:
    i. For conventional heating solutions: a heating system at 200 USD/kW (integrating 75% efficiency for dimensioning) and a chiller at 510 USD/kW are used.
    ii. A Heat pump (reversible) system at 600 USD/kW is used.
    iii. This is based on multiple references and the assumption of a heat pump system at 600 USD/kW (conservative), an AC (chiller) system at 85% of that cost, and a conventional system at one-third the price of a heat pump.
- Schneider Electric has also assumed heat distribution systems remain largely similar (or at least that no upgrade of distribution systems occurs).
- Possible further cost variations – due to temperature requirements – are not factored into the paper's analysis.
- It is assumed there is enough electrical capacity (such as transformers). There are considerable uncertainties around these factors, but we believe our cost assumptions to be representative of the reality. Nonetheless, further studies on retrofits, in different configurations, should be undertaken to refine the paper's findings.
- Similar COP levels are assumed for the modeling of both residential and commercial buildings.
- The paper integrates fixed charges for gas heating. For office buildings, since energy demand typically remains below 300,000kWh/y, it is assumed these charges remain negligible. For its modeling of a retail center, Schneider Electric has added an extra 1,000 USD per year for Europe, Japan, and North America (excluding the South and West of the US) only.[29] This is found to have only a minor impact overall.
- This provides a value for heating demand and upfront costs for the 19 regions covered within BloombergNEF's model.
- The paper also runs a scenario with radical improvements in the upfront costs of purchasing a heat pump, assuming a 30% decline in the CapEx of heat pumps, and a COP performance equivalent to BloombergNEF's 2050 forecast.
- The same assumptions regarding fuel prices are used in both residential and commercial use cases.

[29] Ramsey (2020). Business Energy Standing Charges; Tarif Gaz (2020). A Quoi Correspondent Les Tarifs T1 T2 T3 Pour Le Gaz?; UK Power (2020). Average Business Energy Bills.

Annex 2 – Detailed results

How to interpret data tables' results

New builds (OpEx)

- For new build calculations, a figure is provided (as a percentage) which corresponds to the relative cost difference between the operating costs of a newly installed electrified heating solution and a fossil fuel system.
- **Positive percentage values**: Signify the amount by which the relative operating costs of running an electrified heating solution is higher than operating a fossil fuel alternative.
  - For example, an OpEx value of 50% signifies that operating an electrified heating solution is 50% more expensive than running a fossil fuel system for the relevant scenario.
- **Negative percentage values**: Signify the amount by which the relative operating costs of running an electrified heating solution are lower than operating a fossil fuel alternative.
  - For example, an OpEx value of -50% signifies operating an electrified heating solution is 50% cheaper than running a fossil fuel system for the relevant scenario.

Retrofits (Paybacks in years)

- Payback figures correspond to the number of years it takes to break even, in terms of total cost of ownerships, following installing an electrified heating solution vs a fossil fuel system.
- **Positive payback figures**: Arise when the cost-to-deploy (CapEx) of a heat pump or resistive electric heating system is higher than a fossil fuel alternative; however, its operating costs are lower, meaning the consumer makes savings in the operating phase.
  - For example, if an electrified heating solution is 1000 USD more expensive than a fossil fuel system to install, but 100 USD cheaper per annum to operate, this would correspond to a payback figure of 10 years. This is as it would take ten years (the equivalent to 1000 USD in relative savings in operating costs) for the consumer to break even following installing a heat pump in relative terms.
- **Negative years**: Arise when the initial deployment cost (CapEx) of installing an electrified heating solution is lower than retrofitting in a fossil fuel alternative, but the operating costs for the electrified heating solution are higher. In such instances, the number of years it would take for an electrified heating solution to become more costly to operate in terms of its total cost of ownership is provided as a 'negative payback' figure in a negative amount of years.
  - For example, if an electrified heating solution was 1000 USD cheaper than a fossil fuel system to install, but 100 USD more expensive per annum to operate, this would correspond to a payback figure of -10 years. This is as it would take ten years for the electrified heating solution to have the same total cost of ownership as a fossil fuel heating system, following which its total cost of ownership would surpass the total cost of ownership of the fossil fuel heating system.
  - For the readers convenience, such values are not shown in the main body of the paper, where instead 'no payback' is shown in their place.

Residential

Heat pumps vs Oil

Improvement in Heat Pumps	Current circumstances						Radical Improvement in Heat Pumps					
Electricity cost	Current Electricity Costs			Lower Electricity Costs (rooftop)			Current Electricity Costs			Lower Electricity Costs (rooftop)		
Tax	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price
Heat pumps vs oil	**Scenario**											
Opex (USD)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Canada	-52%	-54%	-73%	-67%	-69%	-89%	-61%	-63%	-83%	-74%	-75%	-95%
China - North Central	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
China - Eastern	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
China - South Central	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
China - Northeast	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
China - Northwest	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
China - Southern	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Denmark	-30%	-58%	-69%	-46%	-77%	-88%	-44%	-69%	-80%	-57%	-82%	-92%
France	-39%	-61%	-77%	-46%	-69%	-85%	-51%	-69%	-85%	-57%	-75%	-91%
Germany	52%	-26%	-47%	22%	-56%	-77%	21%	-41%	-62%	-2%	-65%	-86%
Italy	-46%	-64%	-76%	-60%	-79%	-90%	-55%	-70%	-82%	-67%	-82%	-94%
Japan	-26%	-26%	-46%	-48%	-48%	-68%	-41%	-41%	-61%	-58%	-58%	-79%
Netherlands	-37%	-56%	-70%	-53%	-72%	-86%	-49%	-65%	-79%	-62%	-78%	-91%
United Kingdom	-6%	-34%	-56%	-23%	-54%	-76%	-25%	-49%	-71%	-39%	-63%	-85%
U.S. Midwest	-37%	-41%	-65%	-50%	-54%	-78%	-50%	-53%	-77%	-60%	-63%	-87%
U.S. Northeast	-32%	-35%	-55%	-61%	-65%	-85%	-45%	-48%	-68%	-69%	-72%	-92%
U.S. South	-71%	-73%	-87%	-76%	-78%	-93%	-76%	-77%	-92%	-80%	-81%	-96%
U.S. West	-57%	-59%	-78%	-65%	-67%	-86%	-66%	-67%	-87%	-72%	-73%	-93%

Improvement in Heat Pumps	Current circumstances						Radical Improvement in Heat Pumps					
Electricity cost	Current Electricity Costs			Lower Electricity Costs (rooftop)			Current Electricity Costs			Lower Electricity Costs (rooftop)		
Tax	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price
Heat pumps vs oil	**Scenario**											
Payback (Y)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Canada	3	3	2	2	2	1	1	1	1	1	1	1
China - North Central	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
China - Eastern	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
China - South Central	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
China - Northeast	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
China - Northwest	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
China - Southern	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Denmark	16	8	7	10	6	6	1	1	1	1	1	1
France	5	4	3	5	3	3	1	1	1	1	1	1
Germany	50	21	12	50	11	8	1	1	1	1	1	1
Italy	9	6	6	7	5	5	2	2	1	2	1	1
Japan	28	28	21	31	31	22	13	13	9	10	10	7
Netherlands	7	5	4	5	4	3	1	1	1	1	1	1
Spain	33	6	4	10	4	4	1	1	1	1	1	1
United Kingdom	50	12	8	17	8	6	1	1	1	1	1	1
U.S. Midwest	1	1	1	1	1	1	1	1	1	1	1	1
U.S. Northeast	1	1	1	1	1	1	1	1	1	1	1	1
U.S. South	1	1	1	1	1	1	1	1	1	1	1	1
U.S. West	2	2	2	2	2	1	1	1	1	1	1	1

Heat pumps vs Gas

Improvement in Heat Pumps	Current circumstances						Radical Improvement in Heat Pumps					
Electricity cost	Current Electricity Costs			Lower Electricity Costs (rooftop)			Current Electricity Costs			Lower Electricity Costs (rooftop)		
Tax	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price
Heat pumps vs gas	**Scenario**											
Opex (USD)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Canada	14%	8%	-24%	-22%	-28%	-60%	-10%	-14%	-46%	-38%	-42%	-74%
China - North Central	-36%	-36%	-67%	-36%	-36%	-67%	-49%	-49%	-80%	-49%	-49%	-80%
China - Eastern	-52%	-52%	-76%	-52%	-52%	-76%	-62%	-62%	-86%	-62%	-62%	-86%
China - South Central	-33%	-33%	-65%	-33%	-33%	-65%	-46%	-46%	-78%	-46%	-46%	-78%
China - Northeast	-39%	-39%	-64%	-39%	-39%	-64%	-51%	-51%	-77%	-51%	-51%	-77%
China - Northwest	-33%	-33%	-69%	-33%	-33%	-69%	-47%	-47%	-82%	-47%	-47%	-82%
China - Southern	64%	64%	85%	64%	64%	85%	70%	70%	91%	70%	70%	91%
Denmark	-6%	-46%	-56%	-30%	-70%	-81%	-28%	-60%	-70%	-44%	-76%	-87%
France	-31%	-50%	-70%	-40%	-65%	-78%	-45%	-65%	-78%	-52%	-72%	-85%
Germany	45%	-30%	-44%	16%	-58%	-73%	16%	-44%	-58%	-7%	-66%	-81%
Italy	-12%	-42%	-56%	-36%	-66%	-79%	-27%	-52%	-65%	-46%	-71%	-85%
Japan	-56%	-56%	-65%	-69%	-69%	-78%	-65%	-65%	-74%	-75%	-75%	-84%
Netherlands	14%	-21%	-39%	-14%	-50%	-68%	-8%	-37%	-55%	-31%	-60%	-78%
United Kingdom	28%	-13%	-34%	2%	-38%	-60%	-1%	-33%	-54%	-18%	-51%	-72%
U.S. Midwest	52%	43%	2%	21%	12%	-30%	22%	15%	-27%	-3%	-11%	-52%
U.S. Northeast	10%	5%	-18%	-37%	-43%	-66%	-12%	-16%	-39%	-50%	-54%	-77%
U.S. South	-14%	-19%	-50%	-30%	-34%	-65%	-29%	-32%	-64%	-41%	-45%	-76%
U.S. West	9%	4%	-31%	-11%	-15%	-50%	-13%	-16%	-52%	-29%	-32%	-67%

Paybacks, without cooling

Improvement in Heat Pumps	Current circumstances						Radical Improvement in Heat Pumps					
Electricity cost	Current Electricity Costs			Lower Electricity Costs (rooftop)			Current Electricity Costs			Lower Electricity Costs (rooftop)		
Tax	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price
Heat pumps vs gas	**Scenario**											
Payback (Y)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Canada	50	50	13	13	11	6	8	6	3	3	3	1
China - North Central	34	34	19	34	34	19	26	26	16	26	26	16
China - Eastern	35	35	24	35	35	24	30	30	22	30	30	22
China - South Central	50	50	35	50	50	35	49	49	29	49	49	29
China - Northeast	18	18	12	18	18	12	14	14	10	14	14	10
China - Northwest	35	35	17	35	35	17	25	25	15	25	25	15
China - Southern	48	48	36	48	48	36	44	44	34	44	44	34
Denmark	50	13	11	19	9	8	3	1	1	2	1	1
France	8	5	4	7	5	4	1	1	1	1	1	1
Germany	50	18	12	50	10	8	1	1	1	1	1	1
Italy	50	15	12	18	10	9	7	4	4	5	3	3
Japan	12	12	10	10	10	9	1	1	1	1	1	1
Netherlands	50	23	13	33	10	8	1	1	1	1	1	1
Spain	50	20	16	41	15	13	10	4	4	6	4	3
United Kingdom	50	50	19	50	17	11	50	2	1	3	1	1
U.S. Midwest	50	50	50	50	50	16	50	1	1	1	1	1
U.S. Northeast	50	50	13	7	6	4	1	1	1	1	1	1
U.S. South	30	23	9	15	13	7	1	1	1	1	1	1
U.S. West	50	50	31	50	50	20	1	1	1	1	1	1

Paybacks, with cooling

Improvement in Heat Pumps	Current circumstances						Radical Improvement in Heat Pumps					
Electricity cost	Current Electricity Costs			Lower Electricity Costs (rooftop)			Current Electricity Costs			Lower Electricity Costs (rooftop)		
Tax	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price
Heat Pumps vs Gas	**Scenario, with Air Conditioning**											
Payback (Y)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Canada	-5	-8	1	1	1	1	1	1	1	1	1	1
China - North Central	1	1	1	1	1	1	1	1	1	1	1	1
China - Eastern	1	1	1	1	1	1	1	1	1	1	1	1
China - South Central	1	1	1	1	1	1	1	1	1	1	1	1
China - Northeast	1	1	1	1	1	1	1	1	1	1	1	1
China - Southern	1	1	1	1	1	1	1	1	1	1	1	1
Denmark	50	9	8	14	7	6	1	1	1	1	1	1
France	1	1	1	1	1	1	1	1	1	1	1	1
Germany	50	12	8	50	6	5	-37	1	1	1	1	1
Italy	27	9	7	10	6	5	1	1	1	1	1	1
Japan	4	4	3	3	3	3	1	1	1	1	1	1
Netherlands	50	5	3	7	3	2	1	1	1	1	1	1
Spain	50	7	6	14	5	5	1	1	1	1	1	1
United Kingdom	50	25	10	50	9	6	1	1	1	1	1	1
U.S. Midwest	-1	-2	-14	-2	-3	1	-24	-35	1	1	1	1
U.S. Northeast	-6	-11	1	1	1	1	1	1	1	1	1	1
U.S. South	1	1	1	1	1	1	1	1	1	1	1	1
U.S. West	50	50	5	14	10	4	1	1	1	1	1	1

Life Is On Schneider Electric

Resistive electric heating

Oil vs Natural gas	Resistive electric heating vs Oil heating						Resistive electric heating vs Natural gas heating					
New build vs Retrofit	New build			Retrofit			New build			Retrofit		
Tax	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price
Resistive electric heating	Scenario											
	1	2	3	1	2	3	1	2	3	1	2	3
Canada	-18%	-22%	-41%	4	3	2	93%	84%	52%	50	50	50
China - North Central	NA	NA	NA	NA	NA	NA	27%	27%	-4%	50	50	37
China - Eastern	NA	NA	NA	NA	NA	NA	5%	5%	-19%	50	50	11
China - South Central	NA	NA	NA	NA	NA	NA	44%	44%	12%	50	50	50
China - Northeast	NA	NA	NA	NA	NA	NA	-6%	-6%	-32%	13	13	3
China - Northwest	NA	NA	NA	NA	NA	NA	22%	22%	-14%	50	50	10
China - Southern	NA	NA	NA	NA	NA	NA	-16%	-16%	-37%	22	22	10
Denmark	44%	-18%	-28%	50	2	2	86%	6%	-4%	50	50	13
France	33%	-16%	-32%	-10	1	1	48%	-6%	-19%	-7	1	1
Germany	203%	47%	27%	-3	-9	-15	189%	41%	26%	-3	-10	-15
Italy	23%	-19%	-30%	50	2	2	100%	32%	18%	50	50	50
Japan	34%	34%	14%	-8	-8	-19	-5%	-5%	-14%	1	1	1
Netherlands	30%	-10%	-24%	-4	1	1	136%	63%	45%	-2	-3	-3
Spain	118%	20%	1%	-8	-43	-50	120%	21%	7%	-2	-9	-26
United Kingdom	101%	37%	15%	-2	-4	-8	167%	83%	61%	-1	-1	-2
U.S. Midwest	11%	5%	-19%	-16	-38	1	172%	155%	114%	50	50	50
U.S. Northeast	33%	27%	6%	-5	-6	-24	115%	105%	81%	50	50	50
U.S. South	-34%	-37%	-52%	1	1	1	96%	86%	55%	-6	-7	-10
U.S. West	-14%	-18%	-37%	1	1	1	118%	109%	74%	50	50	50

Commercial

Office building

Improvement in Heat Pumps	Current circumstances						Radical Improvement in Heat Pumps					
Electricity cost	Current Electricity Costs			Lower Electricity Costs (rooftop)			Current Electricity Costs			Lower Electricity Costs (rooftop)		
Tax	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price
Heat Pumps vs Gas	Scenario											
Opex (USD)	1	2	3	4	5	6	7	8	9	10	11	12
Canada	41%	34%	-6%	-4%	-10%	-50%	12%	7%	-33%	-23%	-28%	-68%
China - North Central	-36%	-36%	-67%	-36%	-36%	-67%	-49%	-49%	-80%	-49%	-49%	-80%
China - Eastern	-52%	-52%	-76%	-52%	-52%	-76%	-62%	-62%	-86%	-62%	-62%	-86%
China - South Central	-33%	-33%	-65%	-33%	-33%	-65%	-46%	-46%	-78%	-46%	-46%	-78%
China - Northeast	-39%	-39%	-64%	-39%	-39%	-64%	-51%	-51%	-77%	-51%	-51%	-77%
China - Northwest	-33%	-33%	-69%	-33%	-33%	-69%	-47%	-47%	-82%	-47%	-47%	-82%
China - Southern	-64%	-64%	-85%	-64%	-64%	-85%	-70%	-70%	-91%	-70%	-70%	-91%
Denmark	15%	-36%	-49%	-11%	-62%	-75%	-8%	-49%	-62%	-29%	-70%	-83%
France	-5%	-39%	-58%	-17%	-51%	-70%	-24%	-51%	-70%	-33%	-61%	-79%
Germany	64%	-20%	-37%	32%	-52%	-69%	31%	-36%	-53%	5%	-62%	-79%
Italy	-3%	-36%	-51%	-29%	-62%	-77%	-19%	-47%	-62%	-41%	-69%	-84%
Japan	-50%	-50%	-60%	-65%	-65%	-75%	-60%	-60%	-70%	-72%	-72%	-82%
Netherlands	26%	-13%	-33%	-6%	-45%	-65%	1%	-31%	-50%	-25%	-56%	-76%
Spain	8%	-40%	-57%	-11%	-60%	-76%	-10%	-50%	-67%	-26%	-66%	-83%
United Kingdom	37%	-7%	-31%	12%	-32%	-56%	10%	-26%	-50%	-10%	-46%	-69%
U.S. Midwest	83%	72%	23%	45%	34%	-15%	47%	38%	-12%	16%	8%	-42%
U.S. Northeast	22%	16%	-10%	-31%	-37%	-62%	-2%	-7%	-33%	-44%	-49%	-75%
U.S. South	13%	8%	-34%	-7%	-13%	-54%	-6%	-10%	-52%	-22%	-27%	-69%
U.S. West	26%	21%	-20%	4%	-1%	-42%	1%	-3%	-44%	-17%	-21%	-62%

Improvement in Heat Pumps	Current circumstances						Radical Improvement in Heat Pumps					
Electricity cost	Current Electricity Costs			Lower Electricity Costs (rooftop)			Current Electricity Costs			Lower Electricity Costs (rooftop)		
Tax	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price
Heat Pumps vs Gas	Scenario											
Payback (Y)	1	2	3	4	5	6	7	8	9	10	11	12
Canada	-8	-9	1	1	1	1	-50	-50	1	1	1	1
China - North Central	1	1	1	1	1	1	1	1	1	1	1	1
China - Eastern	22	22	16	22	22	16	1	1	1	1	1	1
China - South Central	1	1	1	1	1	1	1	1	1	1	1	1
China - Northeast	1	1	1	1	1	1	1	1	1	1	1	1
China - Northwest	1	1	1	1	1	1	1	1	1	1	1	1
China - Southern	16	16	12	16	16	12	1	1	1	1	1	1
Denmark	-4	1	1	1	1	1	1	1	1	1	1	1
France	1	1	1	1	1	1	1	1	1	1	1	1
Germany	-2	1	1	-3	1	1	-16	1	1	-50	1	1
Italy	1	1	1	1	1	1	1	1	1	1	1	1
Japan	1	1	1	1	1	1	1	1	1	1	1	1
Netherlands	-3	1	1	1	1	1	-50	1	1	1	1	1
Spain	-7	1	1	1	1	1	1	1	1	1	1	1
United Kingdom	-3	1	1	-7	1	1	-50	1	1	1	1	1
U.S. Midwest	-5	-6	-17	-9	-11	1	-31	-38	1	-50	-50	1
U.S. Northeast	-9	-12	1	1	1	1	1	1	1	1	1	1
U.S. South	-2	-2	1	1	1	1	1	1	1	1	1	1
U.S. West	50	50	12	50	50	6	-50	1	1	1	1	1

Retail center building

Improvement in Heat Pumps	Current circumstances						Radical improvement in Heat Pumps					
Electricity cost	Current Electricity Costs			Lower Electricity Costs (rooftop)			Current Electricity Costs			Lower Electricity Costs (rooftop)		
Tax	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price
Heat Pumps vs Gas	**Scenario**											
Opex (USD)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Canada	35%	28%	-12%	-9%	-16%	-57%	7%	1%	-39%	-29%	-35%	-75%
China - North Central	-36%	-36%	-67%	-36%	-36%	-67%	-49%	-49%	-80%	-49%	-49%	-80%
China - Eastern	-52%	-52%	-76%	-52%	-52%	-76%	-62%	-62%	-86%	-62%	-62%	-86%
China - South Central	-33%	-33%	-65%	-33%	-33%	-65%	-46%	-46%	-78%	-46%	-46%	-78%
China - Northeast	-39%	-39%	-64%	-39%	-39%	-64%	-51%	-51%	-77%	-51%	-51%	-77%
China - Northwest	-33%	-33%	-69%	-33%	-33%	-69%	-47%	-47%	-82%	-47%	-47%	-82%
China - Southern	-64%	-64%	-85%	-64%	-64%	-85%	-70%	-70%	-91%	-70%	-70%	-91%
Denmark	13%	-38%	-51%	-13%	-65%	-78%	-10%	-51%	-64%	-31%	-72%	-85%
France	-7%	-42%	-61%	-19%	-54%	-73%	-26%	-54%	-73%	-36%	-64%	-83%
Germany	61%	-23%	-40%	29%	-55%	-72%	28%	-39%	-56%	3%	-65%	-82%
Italy	-7%	-40%	-55%	-33%	-66%	-81%	-23%	-50%	-66%	-44%	-72%	-87%
Japan	-51%	-51%	-62%	-67%	-67%	-77%	-62%	-62%	-72%	-74%	-74%	-84%
Netherlands	22%	-17%	-37%	-9%	-48%	-68%	-3%	-34%	-54%	-28%	-60%	-79%
Spain	4%	-44%	-61%	-15%	-63%	-80%	-14%	-54%	-71%	-30%	-70%	-87%
United Kingdom	33%	-11%	-35%	8%	-36%	-60%	6%	-30%	-54%	-14%	-50%	-74%
U.S. Midwest	78%	67%	16%	39%	28%	-22%	41%	32%	-18%	10%	1%	-49%
U.S. Northeast	18%	12%	-14%	-35%	-41%	-67%	-6%	-11%	-37%	-49%	-54%	-79%
U.S. South	16%	10%	-33%	-5%	-11%	-53%	-4%	-8%	-51%	-21%	-26%	-68%
U.S. West	27%	22%	-19%	5%	-1%	-42%	2%	-2%	-43%	-16%	-20%	-62%

Improvement in Heat Pumps	Current circumstances						Radical improvement in Heat Pumps					
Electricity cost	Current Electricity Costs			Lower Electricity Costs (rooftop)			Current Electricity Costs			Lower Electricity Costs (rooftop)		
Tax	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price	Current circumstances	Electricity Tax Reform	Electricity Tax Reform and Carbon Price
Heat Pumps vs Gas	**Scenario**											
Payback (Y)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Canada	-13	-16	1	1	1	1	-50	-50	1	1	1	1
China - North Central	1	1	1	1	1	1	1	1	1	1	1	1
China - Eastern	15	15	11	15	15	11	1	1	1	1	1	1
China - South Central	1	1	1	1	1	1	1	1	1	1	1	1
China - Northeast	1	1	1	1	1	1	1	1	1	1	1	1
China - Northwest	1	1	1	1	1	1	1	1	1	1	1	1
China - Southern	11	11	9	11	11	9	1	1	1	1	1	1
Denmark	-8	1	1	1	1	1	1	1	1	1	1	1
France	1	1	1	1	1	1	1	1	1	1	1	1
Germany	-3	1	1	-5	1	1	-15	1	1	-50	1	1
Italy	1	1	1	1	1	1	1	1	1	1	1	1
Japan	1	1	1	1	1	1	1	1	1	1	1	1
Netherlands	-7	1	1	1	1	1	1	1	1	1	1	1
Spain	-30	1	1	1	1	1	1	1	1	1	1	1
United Kingdom	-6	1	1	-20	1	1	-50	1	1	1	1	1
U.S. Midwest	-7	-8	-29	-13	-17	1	-32	-41	1	-50	-50	1
U.S. Northeast	-16	-23	1	1	1	1	1	1	1	1	1	1
U.S. South	-31	-48	1	1	1	1	1	1	1	1	1	1
U.S. West	-8	-9	1	-43	1	1	-50	1	1	1	1	1

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