IMPERIAL

HeatNet
Task 4.1 Analysis of system configurations

Draft

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WP 4: Whole system benefits

Aim is analysis of HP peak demand contribution and derivation of diversity factors (T4.1)

Task 4.1 Analysis of system configurations (20 Dec 2024)
- Analysis of the peak demand contributions and maximum diversity factors from heat pump (HP) system configurations, both with and without HeatNet.

Task 4.2 Analysis of voltage-driven reinforcement (31 Jan 2025)
- Analysis of the reductions to voltage-driven reinforcement from using HeatNet across the three LV use cases and scaled for the UKPN and GB networks

Task 4.3 Review of alternative approaches (17 Feb 2025)
- Review and development of alternative approaches for integrating HeatNet technologies into distribution network planning

Task 4.4 Summary of the whole-system benefits (24 Feb 2025)
- Evaluation of the whole-system benefits of applying HeatNet, looking at competition with other flexibility technologies like demand response and battery storage.

Task 4.5 Whole-system evaluation of HeatNet (17 Mar 2025)
- Development of a cross-cutting report analysing the impact of the HeatNet method on the UKPN's distribution network and across the GB energy system under different future scenarios

D4.1.1 Review of alternative approaches (week 25)

D4.2.1 Whole System Evaluation of HeatNet (week 29)

Data Gap Analysis

Source: Passiv HeatNet discovery phase

Baseline annual half-hourly load profiles based on

- Normalised profile shapes
  - Four profile classes
  - 18 characteristic days
- Different peak demand

Heat pump annual half-hourly load profiles

- 20 archetype profiles
  - Four different HP nameplate rating 1.7, 2.7, 4 and 4.6 kWe
- Two simulated controls of HP: manufacturer (counterfactual) and optimised (HeatNet)
- Allocated to 172 domestic customers, repeating 8-9 times heat pump archetypes

Annual Peak Diversity

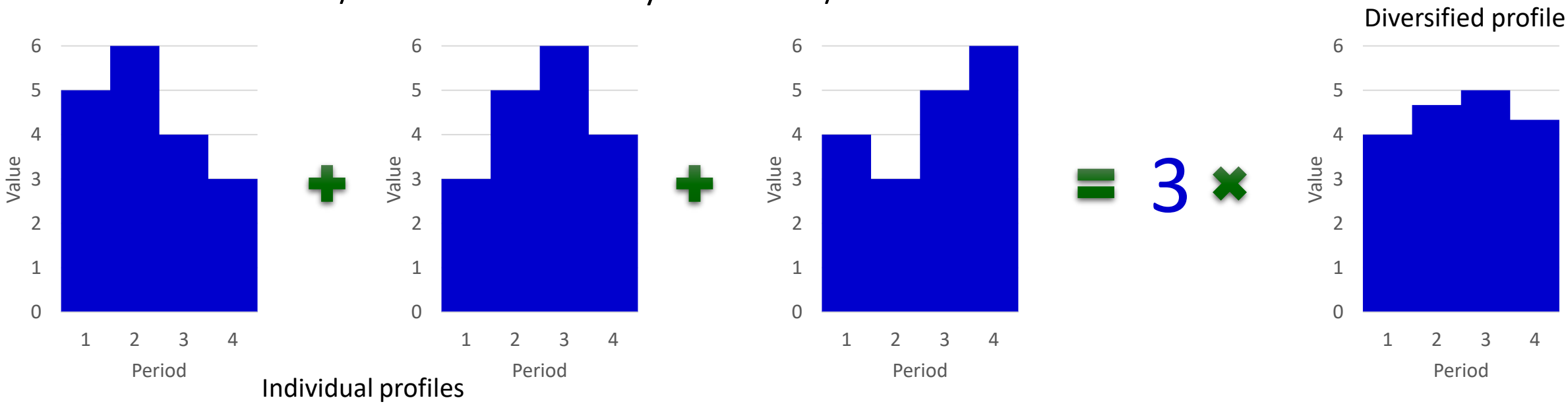
Coincidence factor: ratio of simultaneous peak of group of electrical appliances or consumers to sum of their individual peaks (≤ 1). Typically reducing in value by number of appliances or consumers reaching saturated value for ‘infinite’ number of appliances or consumers.

Diversity factor: reciprocal of coincidence factor (≥ 1)

In distribution network planning analyses, annual factors are used, including **After Diversity Maximum Demand** (ADMD)

Illustration

- Sum of individual peaks is 6+6+6=18 and simultaneous peak is 3x5=15, and ADMD is 5
- Coincidence factor is 15/18=0.83 and diversity factor is 18/15=1.2

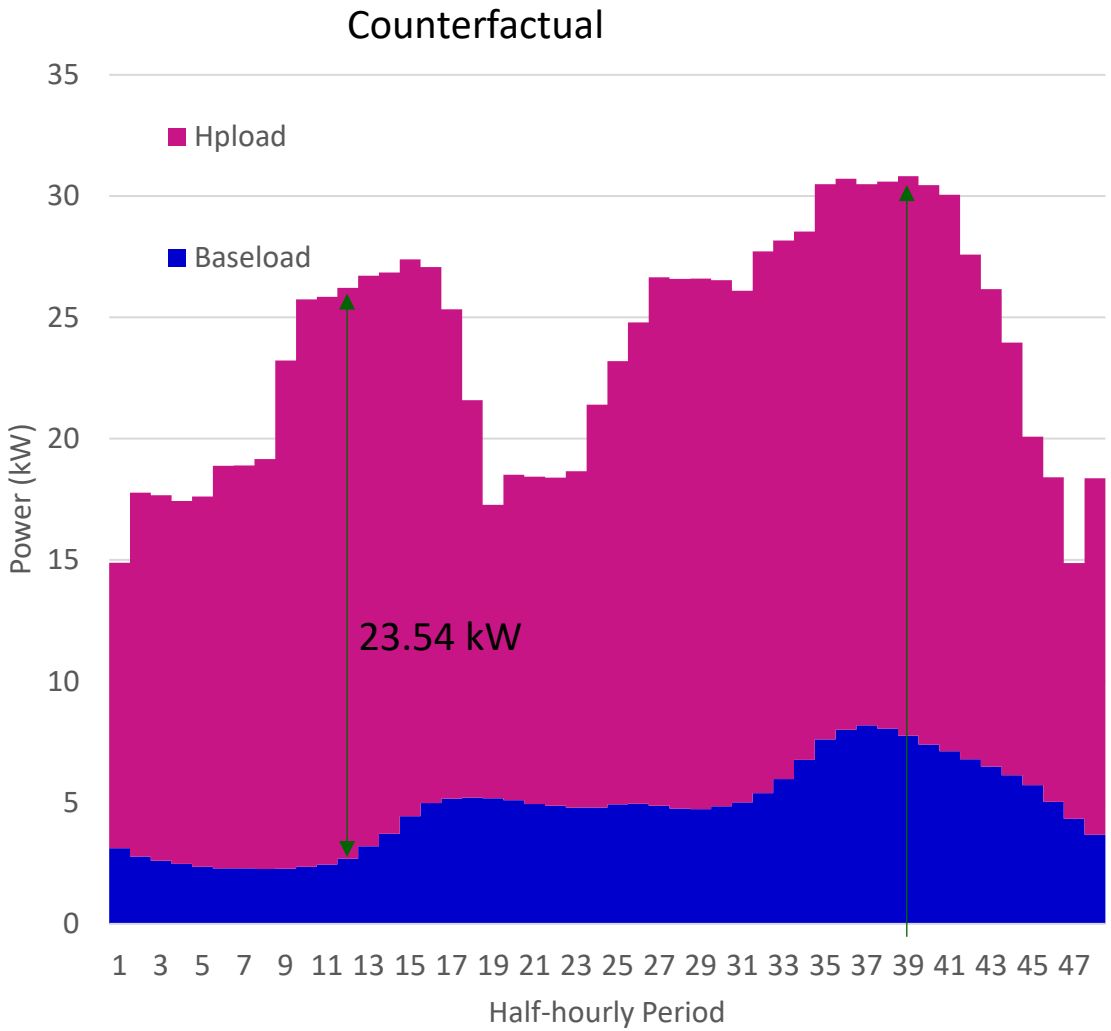


Coincidence Factor Calculation Algorithm

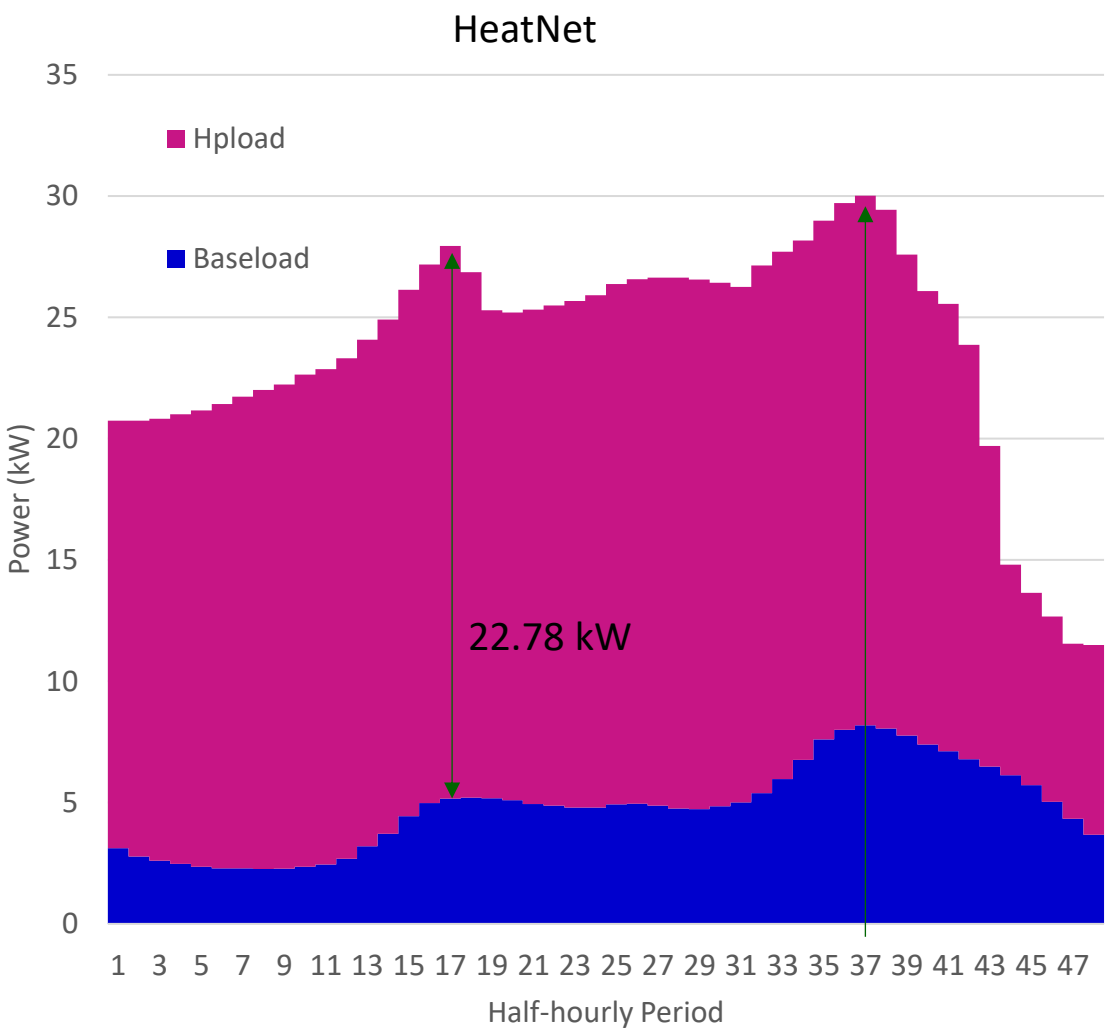
Monte Carlo Approach

- For desired number of customers/heat pumps, randomly select domestic customers
- For selected customers
  - Sum baseline profiles to obtain summary baseline annual profile
  - Sum HP profiles to obtain summary HP annual profile
  - Sum summary and HP annual profiles to obtain total annual profile
  - Sum HP electrical ratings to obtain total HP electrical rating
- Find total peak and binding period when total peak occurs
- For binding period find contribution of HP to total peak
- Divide contribution of HP to total peak with total HP electrical rating to obtain coincidence factor
- Repeat above 200 times to obtain statistics of coincidence factor
- Repeat above for different desired number of customers/heat pumps to obtain relationship between number of HPs and coincidence factor
- Repeat above for two simulated controls of HPs
- Repeat above for HP profiles only i.e. excluding baseline profiles

Example – Ten Customers and HPs – Electrical Power for Peak Day, 28 Feb



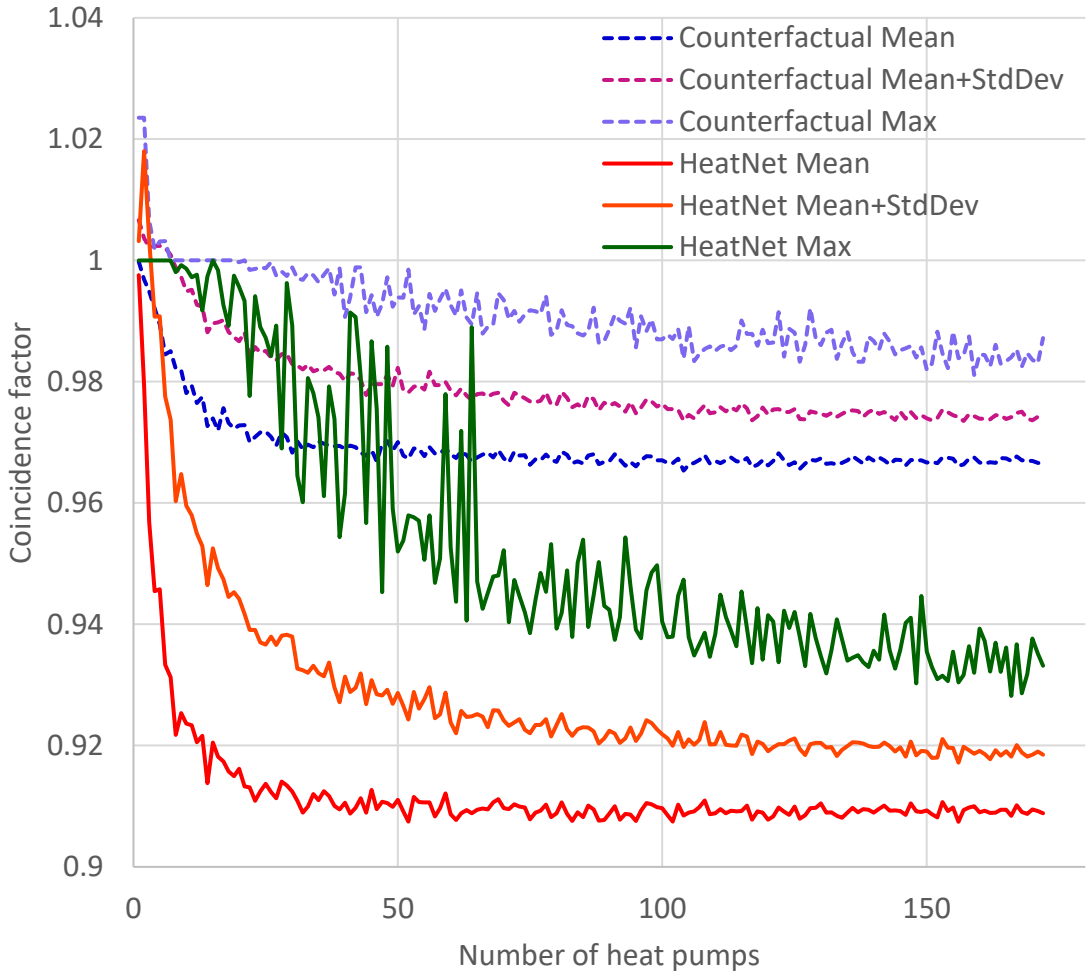
Peak 30.83 (=7.77+23.06) kW @ 19-19.30
Coincidence factor 0.977 (=23.06/23.6)
HP consumption 454.1 kWh, LF=80.2%



Peak 30.02 (=8.18+21.84) kW @ 18-18.30
Coincidence factor 0.925 (=21.84/23.6)
HP consumption 456.8 kWh (100.6%), LF=80.6%

Domestic Heat Pump Coincidence Factors

Monte Carlo calculation



Obtained Relatively high value for HP coincidence factors

- If homeowner installs higher rated HP, coincidence factor would be lower

Coincidence factors

Counterfactual

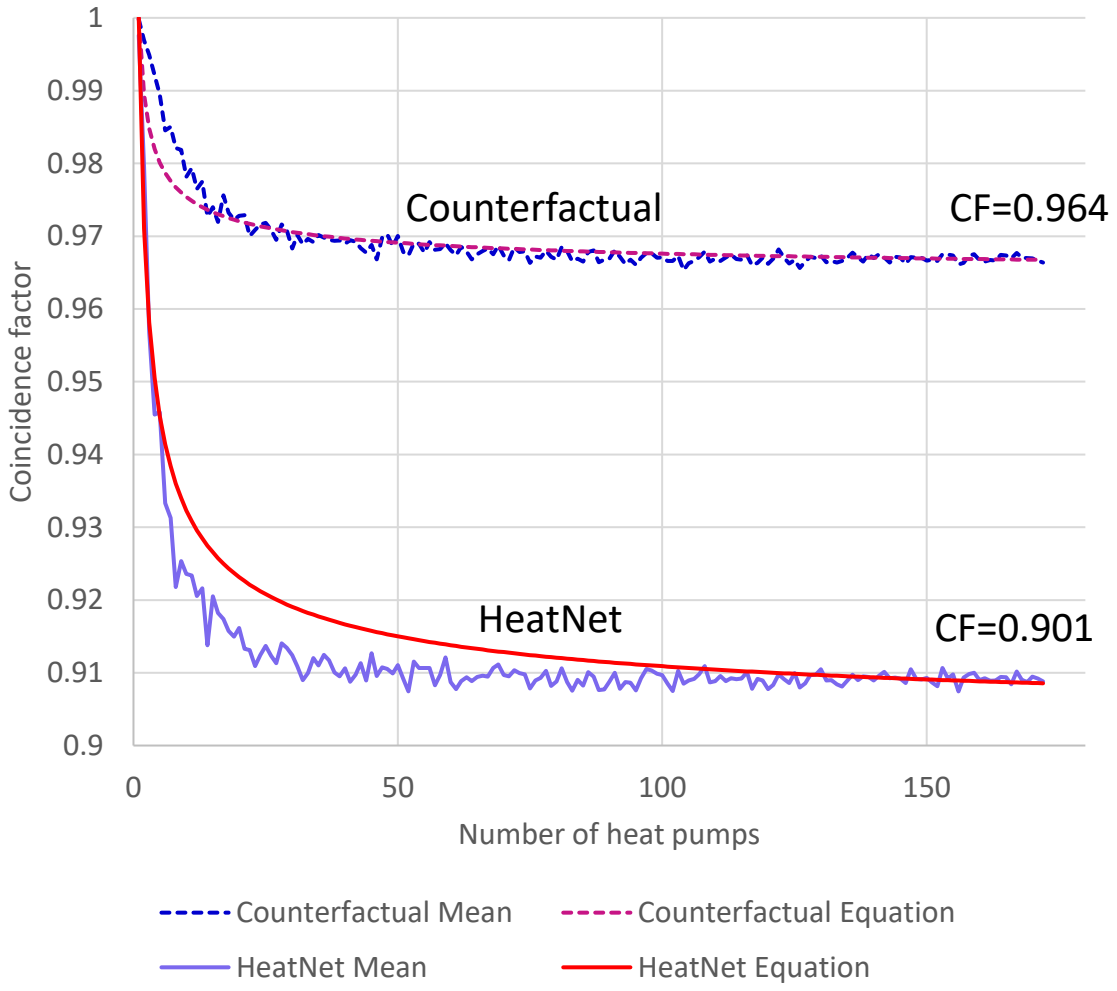
- Maximum value starts from value greater than one as occasionally for some heat pumps electrical power is greater than rated power and subsequently reduces linearly from 1 towards 0.98 as number of heat pumps increases
- Mean (average) value starts from 1 for one heat pump and reduces fast to about 0.97 for 20-ish heat pumps. Subsequently reduction is slow to about 0.966 for 172 heat pumps

HeatNet

- Observed high variability of maximum value starting from 1 and reducing towards 0.93 for 172 heat pumps. Potentially higher number of Monte Carlo samples could reduce variability.
- Mean (average) value starts from 1 and for 12 heat pumps reaches 0.92 and for about 40 heat pumps reaches 0.91 after which value is practically saturated
- HeatNet control of heat pumps reduces use of heat pumps during peak condition and hence coincidence factor is lower

Mathematical Equation of Domestic Heat Pump Coincidence Factors

Interpolation of observed coincidence factors with mathematical equation



Rusck's equation for coincidence factor

$$CF_n = CF + \frac{1 - CF}{\sqrt{n}}$$

where CF is coincidence factor for infinite number of similar electrical appliances or customer, and n is number of similar electrical appliances or customer

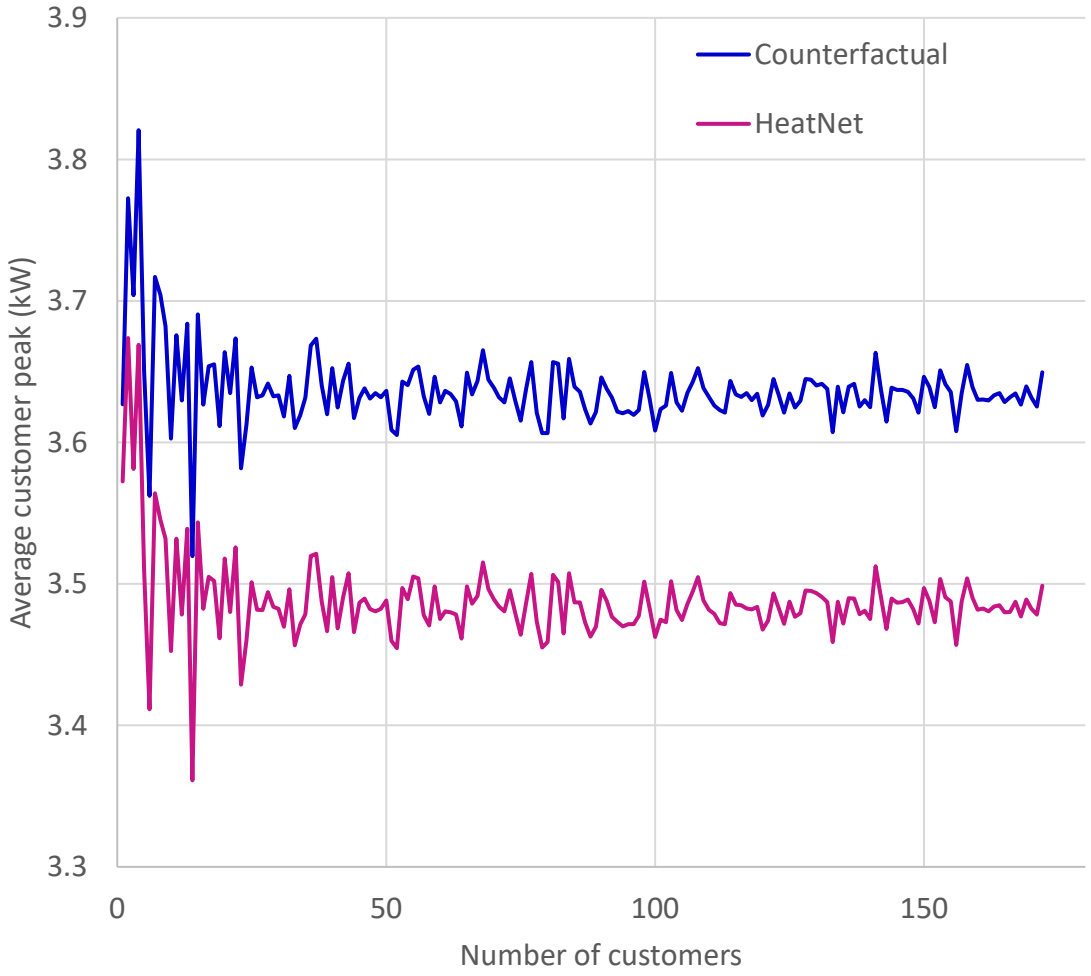
Maximum peak, P_n^{max}, of n similar electrical appliances or customer is

$$P_n^{max} = CF \cdot n \cdot P_1^{max}$$

where P_1^{max} is maximum peak single electrical appliance or customer, $P_1^{max} = \overline{P_1} + k \cdot \sigma_1$, where $\overline{P_1}$ is average peak and σ_1 is standard deviation of single electrical appliance or customer, and k is desired confidence level constant

Reference: S. Rusck, "The simultaneous demand in distribution network supplying domestic consumers," ESEA Journal, vol. 10, pp. 59–61, 1956.

Average Peak of Domestic Customer with Heat Pump



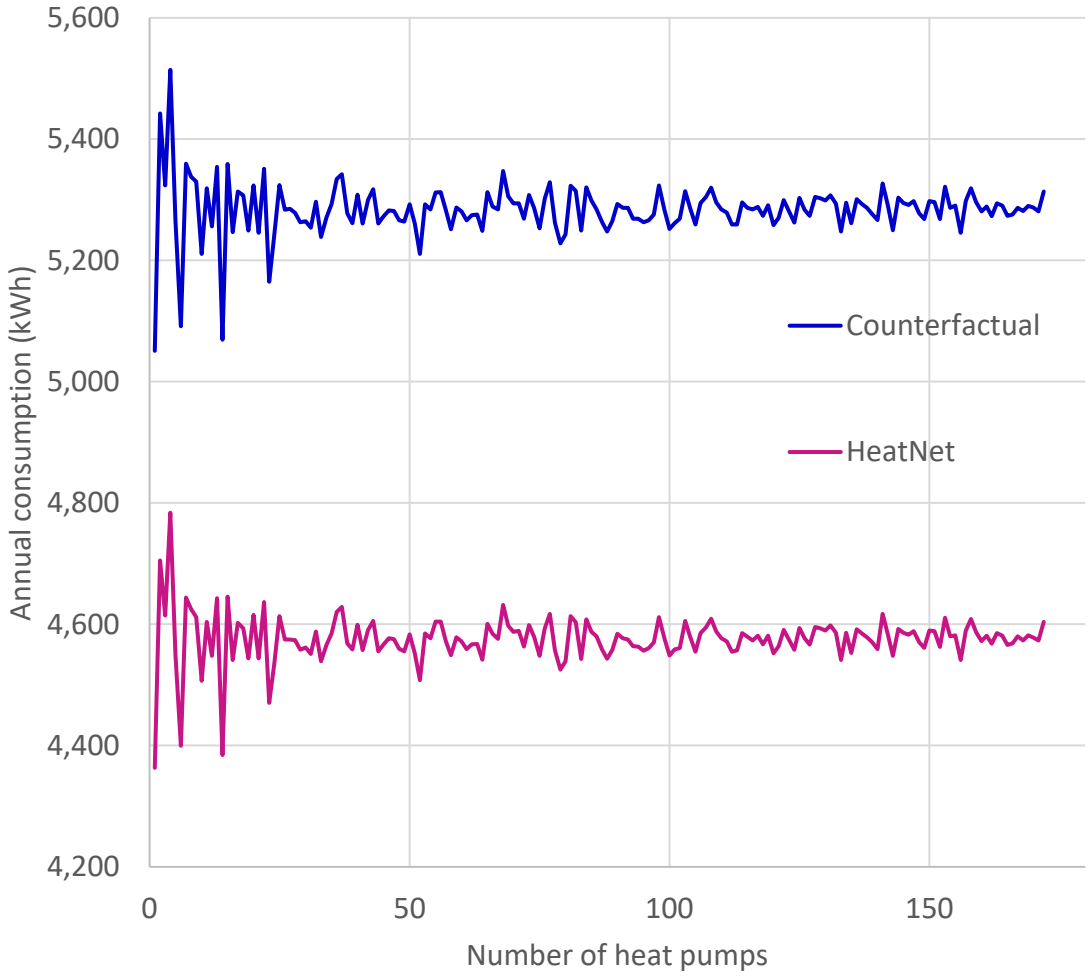
Typically, with increased numbers of customers the overall peak reduces with saturation value reached between 20-30 domestic customers

Average customer peak, for more than 40 customers is about

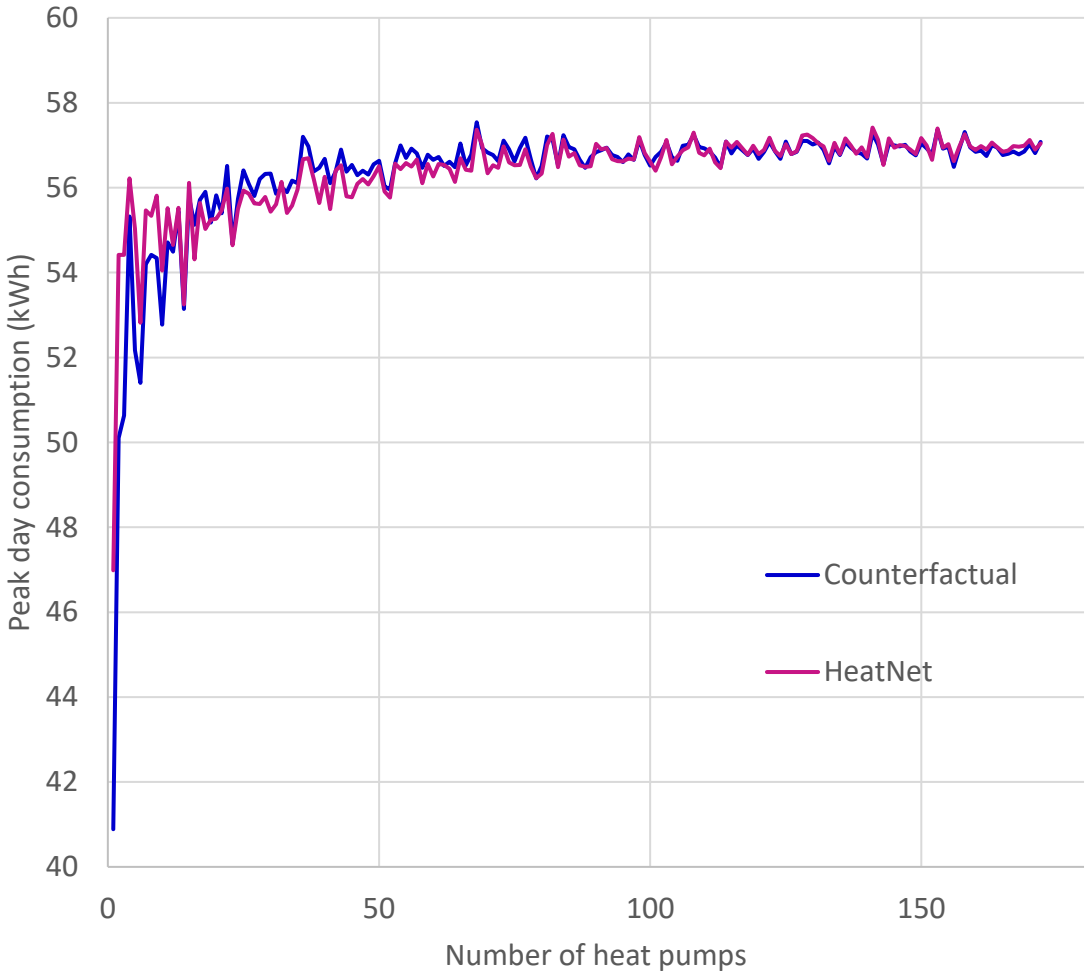
- In counterfactual 3.63 kW per customer
- In HeatNet 3.48 kW per customer
- Observed avearage customer peak reduction of about 4%

Average Heat Pump Energy Consumption

HeatNet reduces average annual consumption of heat pumps for about 13.5%.



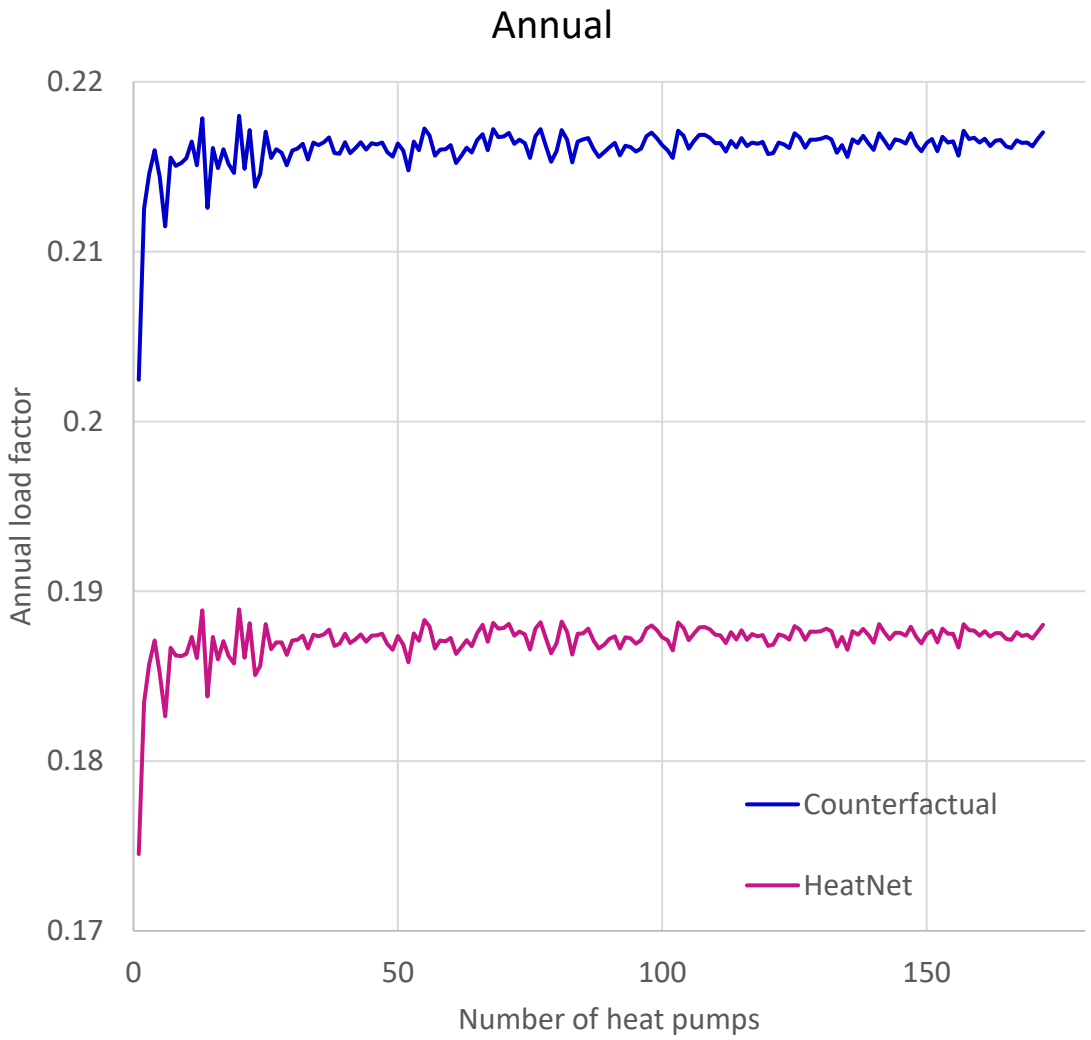
For fewer heat pumps, it is observed that HeatNet increases average daily consumption of heat pumps (testing with greater number of Monte Carlo samples is needed to confirm learning) but for greater number of heat pumps daily consumption is similar as in Counterfactual.

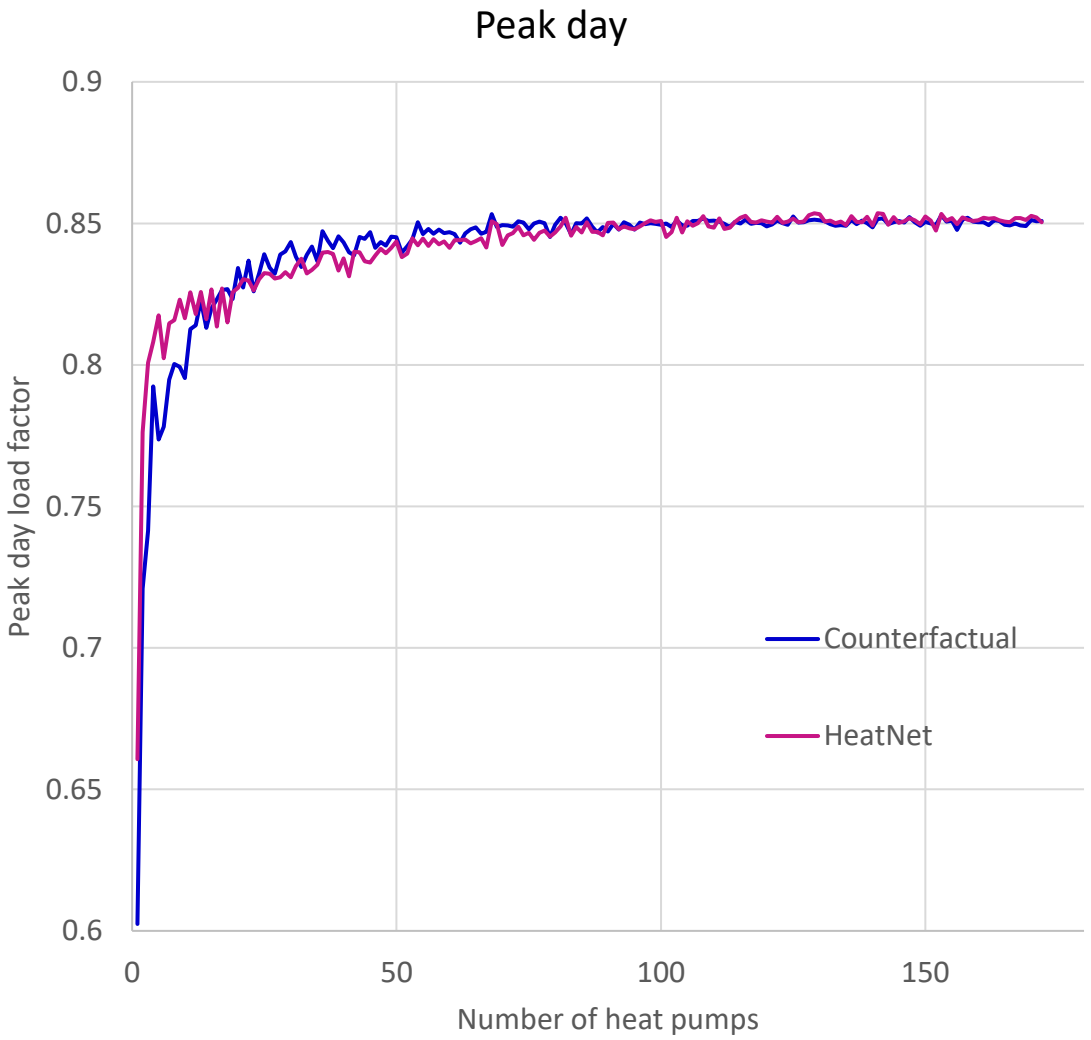


Average Heat Pump Load Factor

Load Factor values follows consumption trend

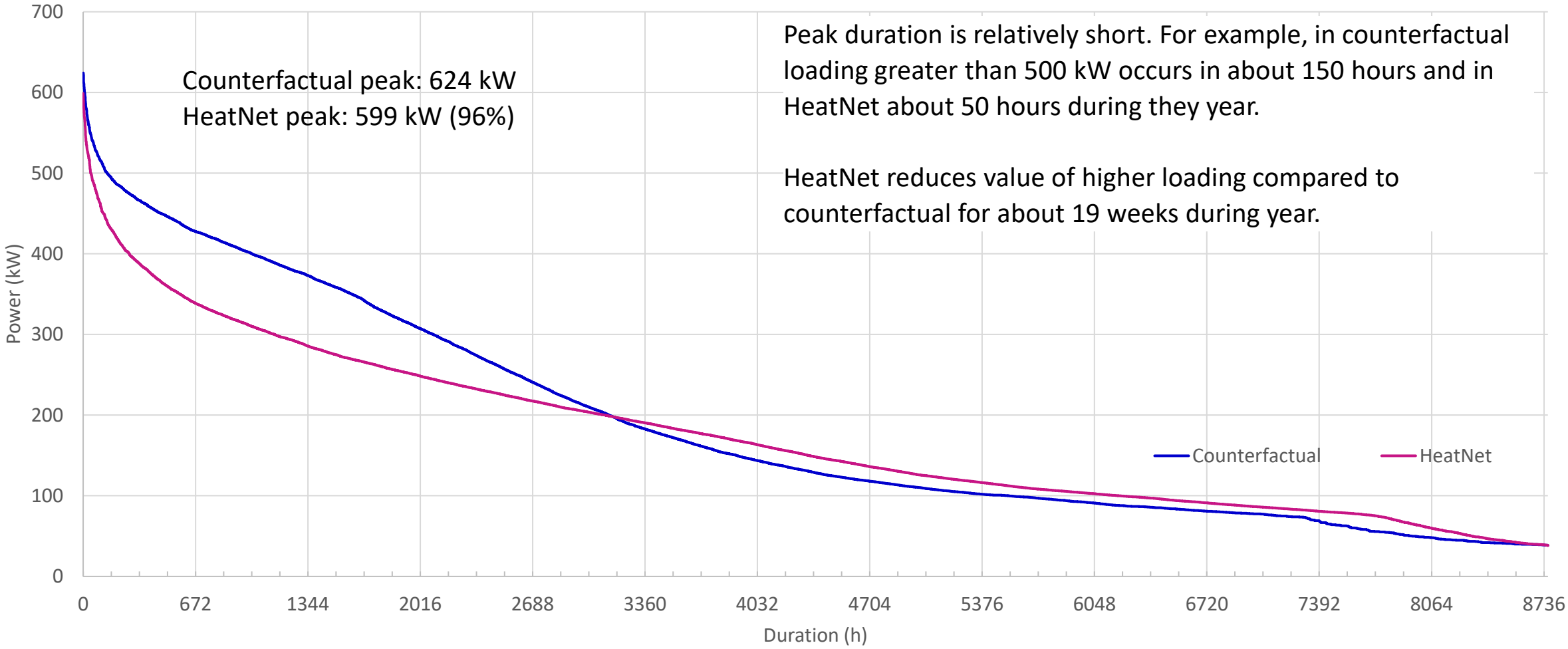
Heat pump peak day load factor, as expected, is significantly greater than annual load factor and for about 70 heat pumps saturates to about 85%.





Domestic Customers Load Duration Curves

Sum of all domestic baseload and heat pump load



Key observations

HeatNet reduces peak and from about 40 customers reduction is about 4%

HeatNet reduces annual heat pump consumption for about 13.5%

- Peak day consumption for about 70 or more heat pumps is same in both control scenarios
- For fewer than 20 heat pumps, number of Monte Carlo samples should be increased to test obtained observation that peak day consumption is greater in HeatNet control scenario
- Load factor follow similar trends

Reduction in domestic peak duration and reduction in higher power for about 19 weeks during year in HeatNet

Annual coincidence factor is relatively high and greater than 0.9 in HeatNet and 0.96 in counterfactual

- Coincidence factor could be approximated by Rusck's equation, $CF_n = CF + \frac{1-CF}{\sqrt{n}}$, using value for CF
  - Counterfactual: 0.964
  - HeatNet: 0.901