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HeatNet Alpha

D2.2.1 HeatNet scenario modelling



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Introduction



- The HeatNet project set out to explore the potential for smart controls to reduce the impact of heat decarbonisation on LV networks, enabling more heat pumps to be deployed without network reinforcement.
 - Previously, in the discovery phase, we constructed a crude network model of the Baldwin's Hill sub-network, using cable information and property metadata output from AmberTree's DPlan software to estimate voltage drop (VD).
 - Additional electrical demand from installing heat pumps onto the network was simulated for a whole year (including a very cold winter period).
 - We evaluated the impact of the install ordering of heat pumps in different scenarios (with and without both smart controls and network coordination).
 - This work package aims to expand this to different network types, and integrate with a voltage drop matrix exported directly from DPlan.
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Network modelling



- UKPN chose a range of network examples at different substations across 3 LV network types (rural, semi-urban new build, urban).
 - UKPN model their networks using AmberTree's DPlan software. AmberTree have added functionality to export a voltage drop matrix for each of these example networks.
 - AmberTree provided exports for each of the networks listed, containing the voltage drop matrices, and various metadata (ADMDs, initial voltages at each node, and information about buildings and clients).
 - This was then processed for use in Passiv's coordination algorithms.
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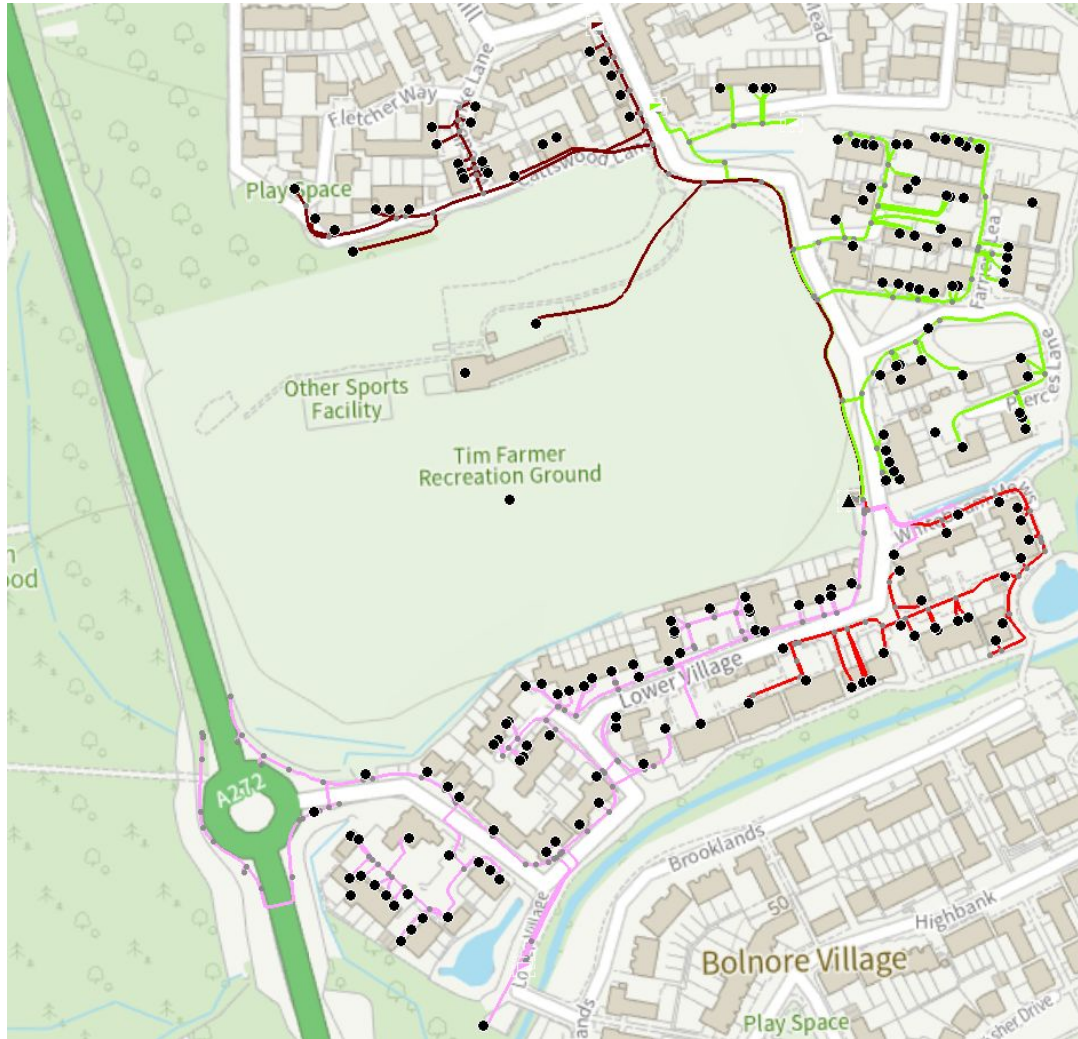


Network modelling: networks selected

Passiv requested network examples of 3 different types (rural, semi-urban and urban). The following list of network examples was provided by UKPN:

Network ID	Reference Name*	Type	Clients (Domestic)	Location
SPENS 361939 [SPN]	Rural0	Rural	63 (52)	Stelling Minnis, Kent
SPENS 363442 [SPN]	Rural1	Rural	54 (46)	Stelling Minnis, Kent
SPENS 444132 [SPN]	Rural2	Rural	70 (51)	Framfield, East Sussex
SPENS 444720 [SPN]	Rural3	Rural	112 (91)	Blackboys, East Sussex
SPENS 511500 [SPN]	NewBuild	Semi-urban (new build)	234 (214)	Haywards Heath, West Sussex
TC 91143 [LPN]	Urban0	Urban	262 (244)	Brixton, London
TC 90638 [LPN]	Urban1	Urban	86 (77)	Brixton, London
TC 91045 [LPN]	Urban2	Urban	385 (356)	Brixton, London
TC 90496 [LPN]	Urban3	Urban	278 (263)	Brixton, London
TC 94401 [LPN]	Urban4	Urban	444 (428)	Brixton, London

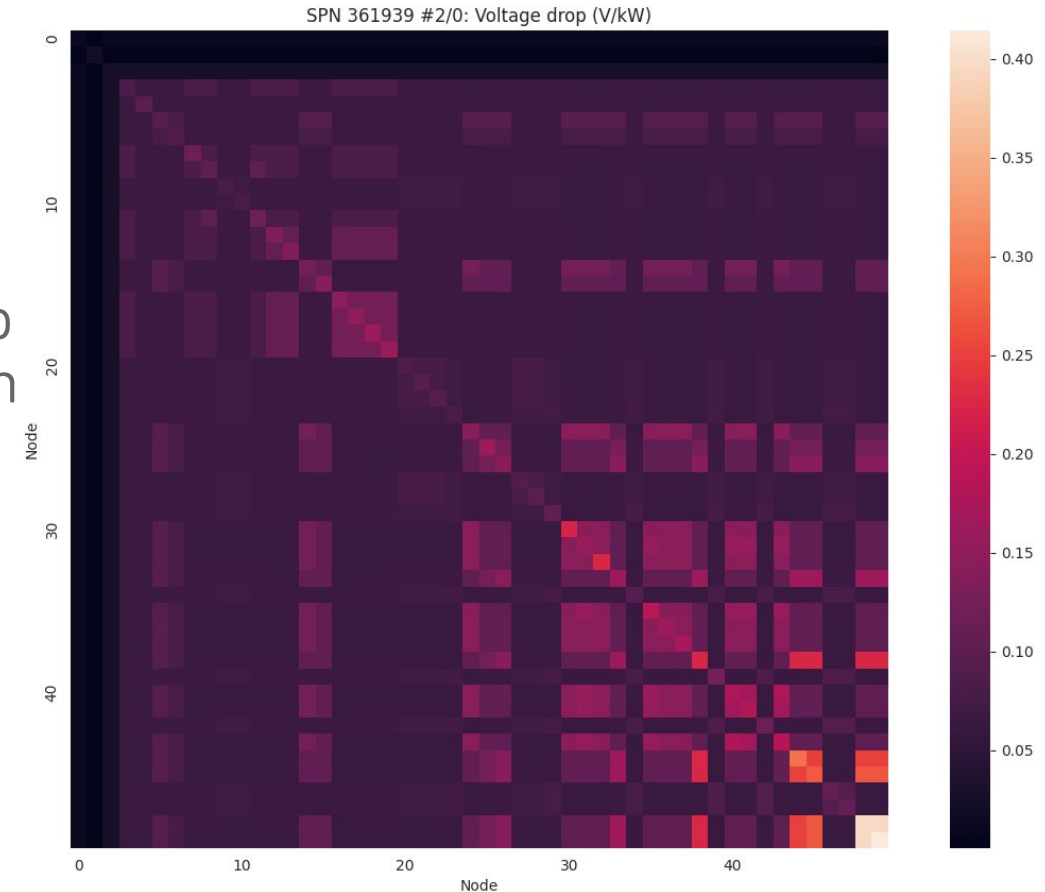
** For ease, we refer to networks by their reference name for the rest of the presentation.*



This map shows the network layout for network NewBuild.

- The transformer is shown by the triangle, nodes are shown as circles.
- In this instance all clients are domestic, except for one sports pavilion.
- The estate was constructed ~10 years ago and is believed to be almost entirely gas heated.

- We were provided with a voltage drop matrix by AmberTree, which linked every node on each network.
- Each row of the matrix represented the voltage drop (V) at one node on the network, due to a load (kW) on each of the other nodes of the network. Multiplying the matrix by a vector of loads at each **node** gives a vector of voltage drops for each **node**.
- This used information about the network present in AmberTree's DPlan tool.
- We processed this matrix to make it suitable for use by Passiv's coordination algorithms (see following slide for details).

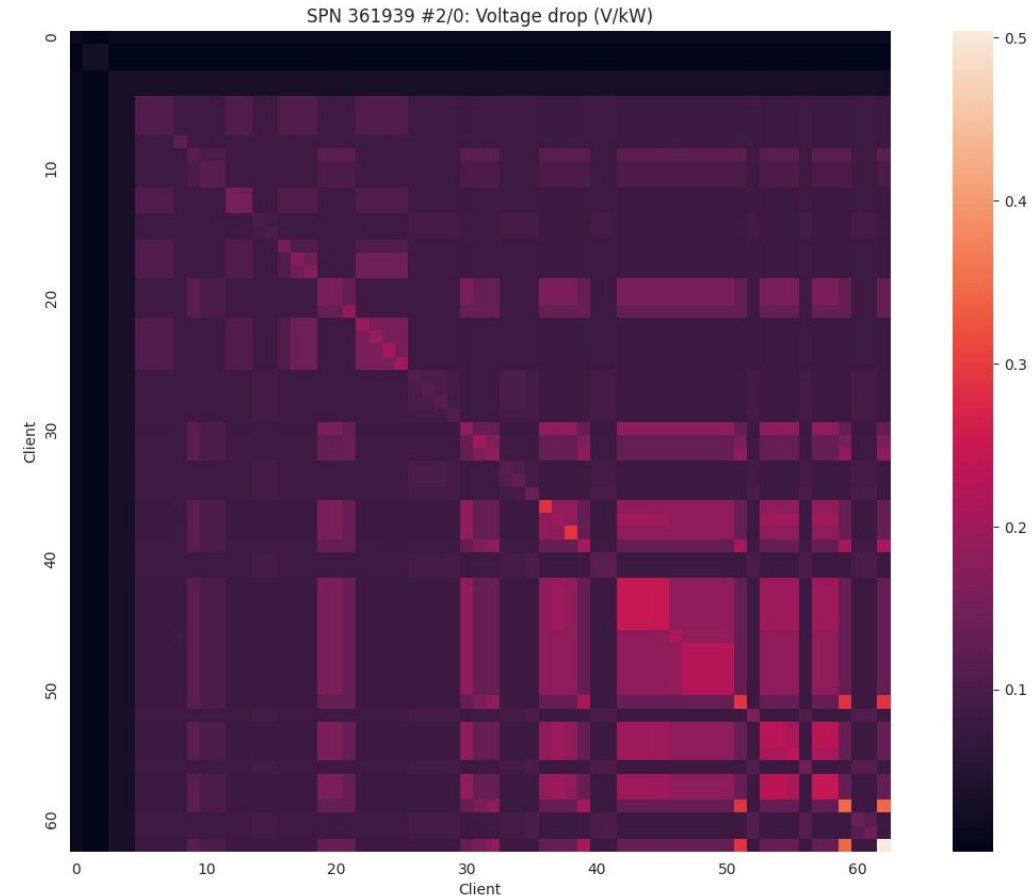


Example 'node' voltage drop matrix for Rural0 network.

- In reality, voltage drops will vary depending on the phase which each client is connected to.
- Phase information is possible to add to DPlan, but is often incomplete.
- Repair work could cause a change in the phase which a client is connected to, so this information could also be out of date.
- DPlan makes approximations of initial voltage at each node using the phase information available.
- This could be compared to the voltage drops calculated using the matrix and the ADMD loads provided, and used to calculate a **imbalance factor** for each network modelled.
- This provides an estimate of how imbalanced each network is on average. This is an approximation, as in reality the imbalance would vary by node as a result of the local network topology.
- This imbalance factor can vary between 1 and 6 (1 being a perfectly balanced network, and 6 being as imbalanced as possible).
- The imbalance factors were used to scale the voltage drop matrix for use in our coordination algorithms.

Name	Imbalance Factor
Rural0	1.28
Rural1	1.66
Rural2	1.63
Rural3	1.95
NewBuild	1.76
Urban0	1.13
Urban1	1.09
Urban2	1.15
Urban3	1.09
Urban4	1.20

- The scaled voltage drop matrix was then extrapolated to each client on the network, as each node can contain multiple buildings, which in turn can contain multiple clients.
- Now multiplying the voltage drop matrix by a vector of loads at each **client** gives a vector of voltage drops for each **client** instead.
- This matrix could then be utilised by Passiv's coordination algorithms to find the best way to shift demand across homes to keep the network within voltage drop constraints.



Example 'client' voltage drop matrix for Rural0 network.

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Heat demand modelling



- Similarly to the discovery phase, heat demand was simulated for homes on each of the sub-networks in order to estimate the additional electricity demand from the transition from gas to heat pumps providing space heating and hot water.
- These heat pump electricity profiles were added onto baseload electricity profiles. This gives an accurate and realistic forecasts of total electricity demands arising from electrifying heat with heat pumps and allows us to simulate different levels of heat pump penetration and the impact on the network (in the Scenario Modelling section).



- Unlike in discovery, we modelled multiple types of networks, each with different housing stock. It was important to capture these differences to keep the network modelling representative, so we used a different set of archetypes for rural, new build and urban networks.
- For each type of network, we chose a set of 20 house archetypes (which will be mapped onto the real homes on the network).
- These 20 archetypes represent the full range of houses expected on that type of network in terms of physical size and the occupants living in them, and also encompass diversity of space heating and hot water demand patterns.
- For each archetype, a simulation run was carried out at half hourly resolution across a whole year to create heat pump electricity profiles
 - Very cold conditions were included to ensure peak demand is represented
 - Both Passiv optimised controls and standard manufacturer controls were simulated as the implications for peak demand are different.



House archetypes (Rural)

House build type	Insulation level	Occupant type	Work schedule	House size
1 bed flat	Random	Single	Full time	1x small, 2x medium, 1x large
3 bed terraced	Random	Couple	Full time	1x small, 2x medium, 1x large
3 bed semi	Random	Old	Retired	1x small, 2x medium, 1x large
4 bed detached	Random	Family	Full time	1x small, 2x medium, 1x large
5 bed detached	Random	Family	Part time	1x small, 2x medium, 1x large

- 20 archetypes: five different build types and four different sizes of each, in line with typical distribution of properties on a rural network.
- Each uses unique digital twin, with randomised thermal dynamics and a heat transfer coefficient consistent with the house type/size.
- Each build type is assigned an occupancy type, which affects the choice of heating schedule, heating setpoint, and hot water consumption profile (which have an impact on heat pump usage patterns).

House archetypes (New Build)

House build type	Insulation level	Occupant type	Work schedule	Number simulated
2 bed flat	Well insulated	Single	Full time	4
2 bed semi	Well insulated	Old	Retired	4
3 bed semi	Well insulated	Couple	Full time	4
3 bed detached	Well insulated	Family	Part time	4
4 bed detached	Well insulated	Family	Full time	4

- For new builds, we randomly sampled 20 archetypes with parameters in line with our experience of new build houses. These have much better insulation levels, and hence have lower heat demands than the rural houses.
 - As before each house simulated is unique, and has unique occupancy characteristics (schedules and setpoints).
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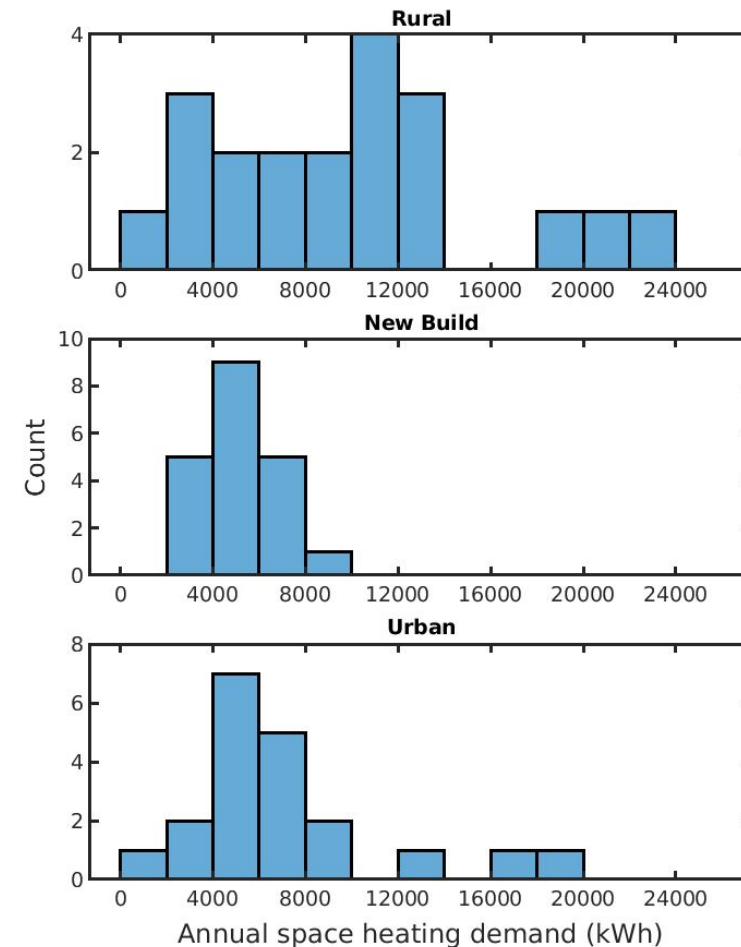
House archetypes (Urban)

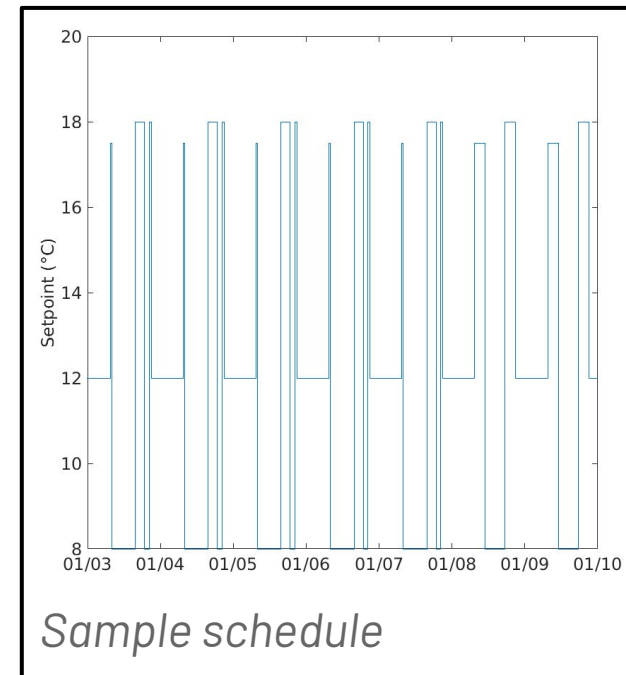
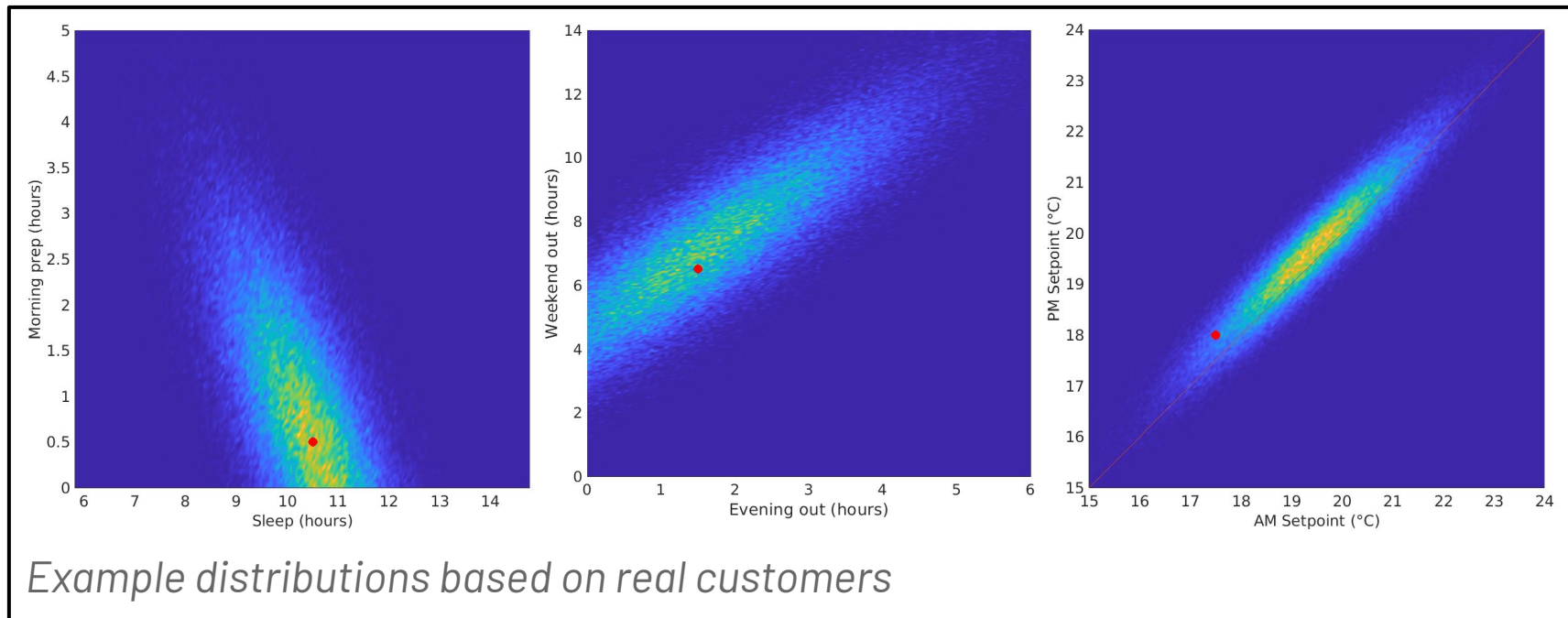
House build type	Insulation level	Occupant type	Work schedule	House size
1 bed flat	Random	Single	Full time	2x small, 2x medium
2 bed flat	Random	Couple	Full time	2x small, 2x medium
3 bed flat	Random	Old	Retired	2x small, 2x medium
2 bed terraced	Random	Family	Full time	2x small, 2x medium
3 bed terraced	Random	Family	Part time	2x small, 2x medium

- For the urban networks, we modelled a much higher proportion of small flats and semi-detached properties. We randomly sampled 20 representative archetypes for the region selected, where almost all homes were small to medium sized semi-detached properties or flats.
 - Again, each house simulated is unique, and has unique occupancy characteristics (schedules and setpoints).
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House archetypes: fabric heat demand

- The 20 houses have diverse heat demands for each of the network types.
- These will be mapped onto smaller or larger homes on the network to match ADMD data points (see Scenario Modelling).
- Rural houses generally demand more heat, whilst both the new builds (better insulated) and urban houses (smaller) require less heat.
- This impacts the energy demand across the network.

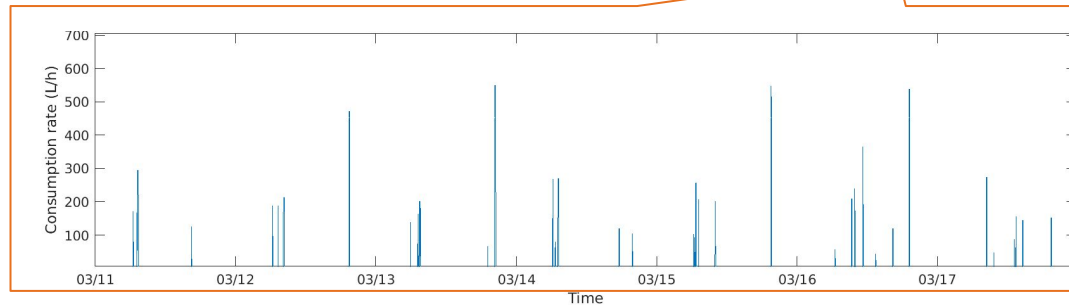
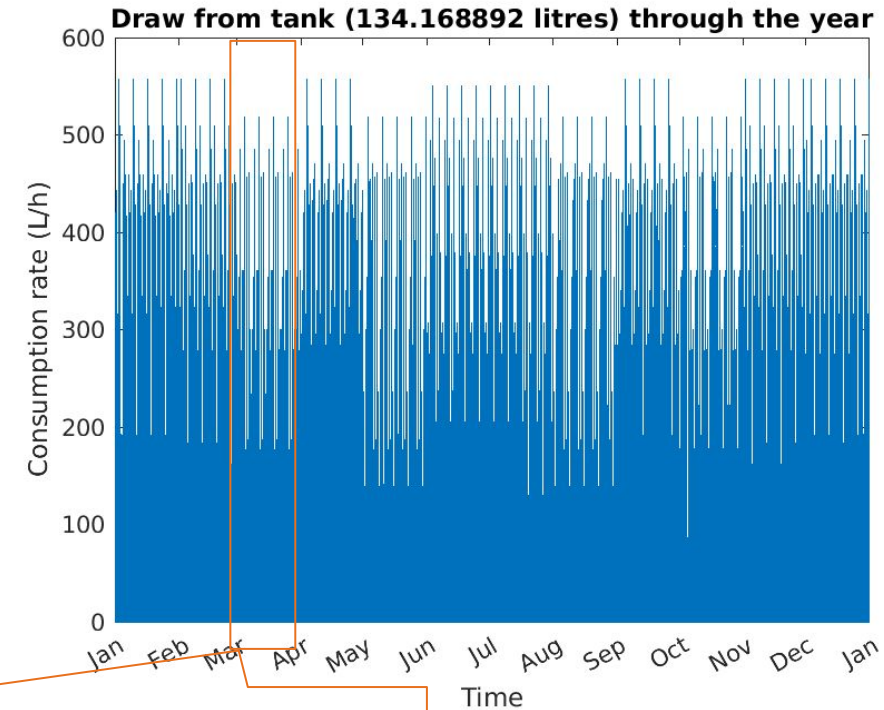




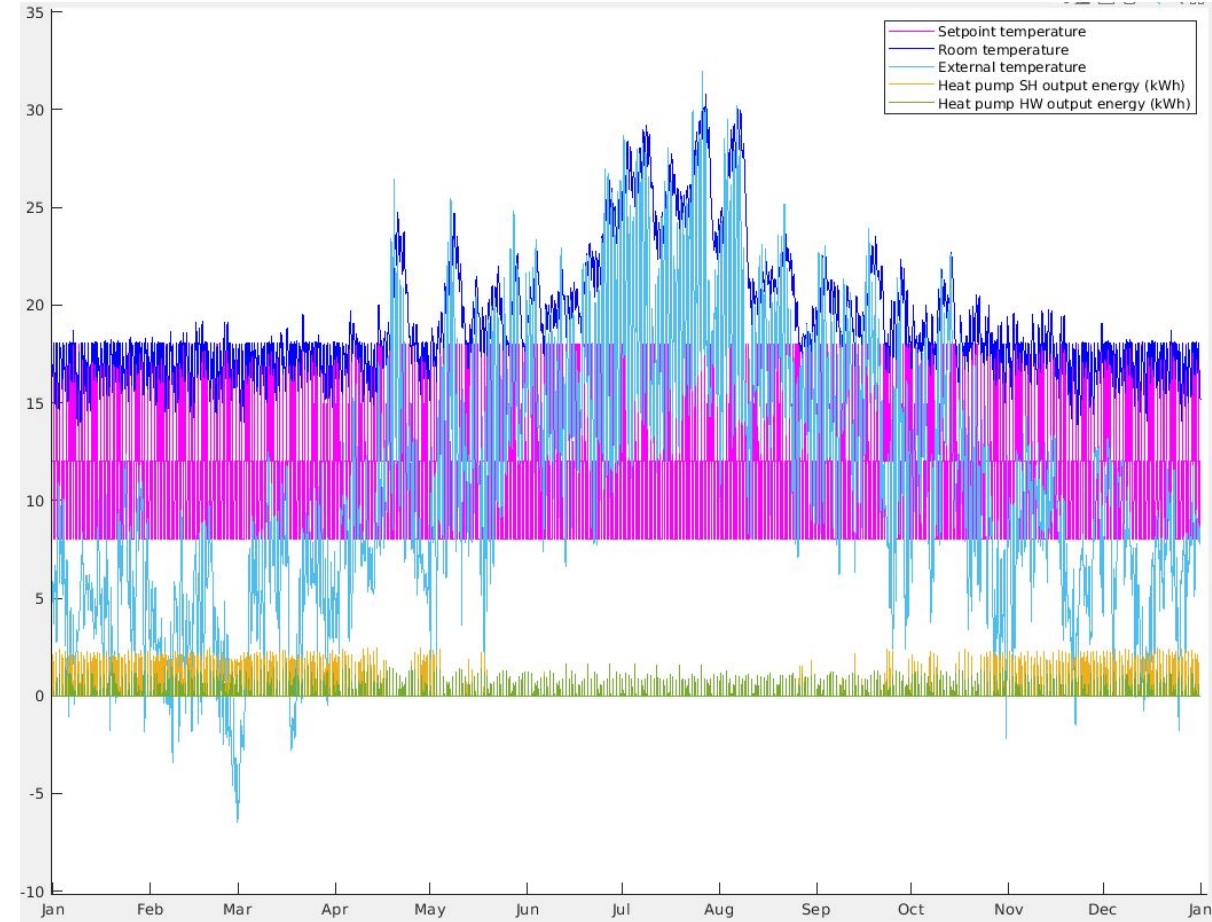
Each archetype has a randomly generated schedule and setpoint, dependent on the occupants and their working schedule.

- For example, this represents retired occupants being likely to be at home more during the day, with the house heated warmer

- Hot water usage estimated per month for each archetype based on number of occupants (SAP assumptions)
- Use real consumption patterns (from previously monitored homes), chosen to match by similar monthly consumption
- Create yearly consumption profile to be used within simulations (more accurate than a simple demand profile)



- The Passiv annual forecasting tool was used to simulate the electrical demand from the heat pump for each archetype.
- This tool allows us to forecast detailed energy demand at half hourly intervals throughout a whole year.
- Weather data was used from the closest weather stations to the networks modelled. In the cases with rural networks, we used representative rural data from Kent, as the networks were spread between Kent and East Sussex.
- 2018 weather data was used, as this year had a prolonged cold spell ("Beast from the East") so we are able to assess the impact of the 'worst case' weather scenario on the network.

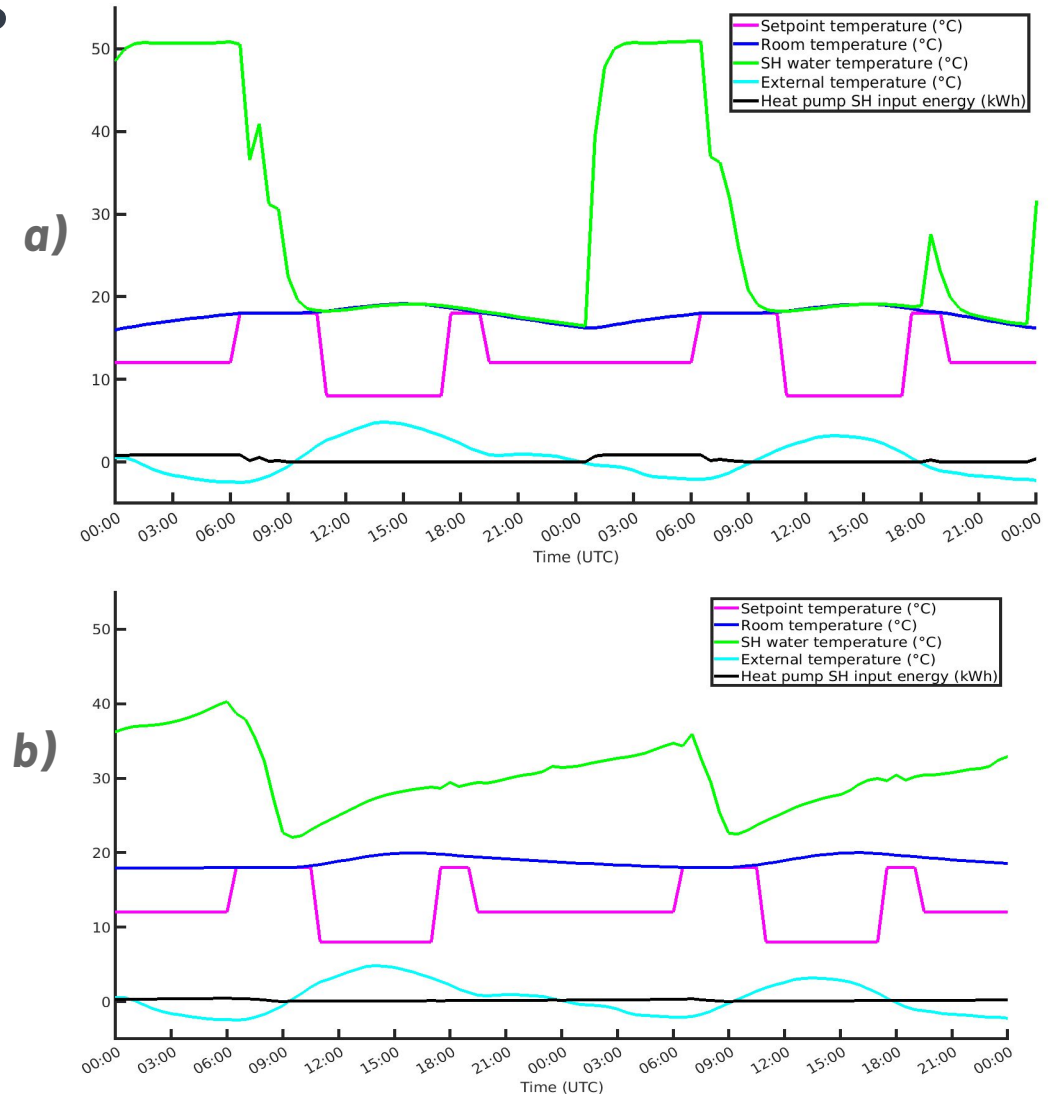


An example plot of a subset of annual forecast outputs

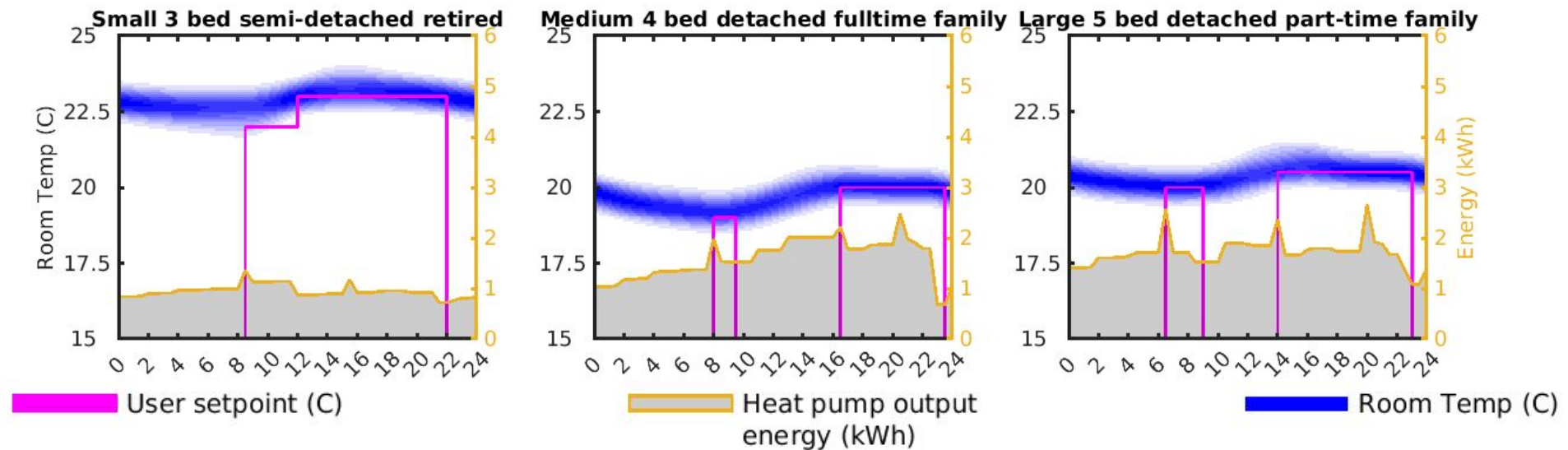
For each archetype, we simulated two control strategies (see graph on right):

- **(a) Standard manufacturer controls:**
time-clock with optimum start (weather compensated flow temperature)
- **(b) Passiv optimised controls:**
theoretically optimised controls
(dynamical flow temperature to minimise running cost)

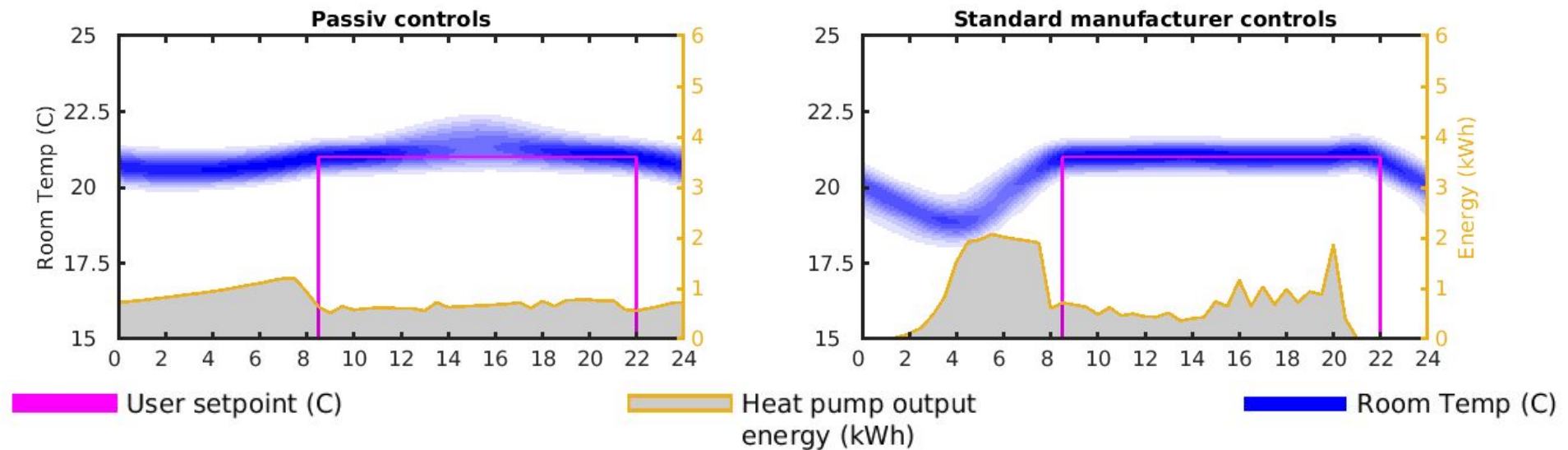
Optimised controls run the heat pump continuously and gently with lower flow temperatures, leading to flatter demand profiles which put less strain on the network.



- Example outputs from the annual forecast simulations, showing profiles for the month of January for three different archetypes.
 - Graphs show scheduled setpoints, achieved room temperatures, and heat demand (in kWh per half hour)
 - Heat pump demand varies significantly archetype-to-archetype



- Example outputs from the annual forecast simulations, showing profiles for the month of January for each control strategy
 - Graphs show scheduled setpoints, achieved room temperatures, and heat demand (in kWh per half hour)
 - Peak demand is significantly flattened by the Passiv optimising controls



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Scenario modelling + network comparison



- Estimate what level of heat pump penetration (% of homes) is likely to be possible on a variety of subnetworks if heat pumps are installed randomly with manufacturer controls.
 - Estimate the percentage of peak demand and voltage drop reduction possible from Passiv inter-home coordination on various network types.
 - Verify whether different types of networks (rural, new build estates, urban) have different characteristics and hence face different challenges.
 - Do rural networks have more of a voltage drop issue than a capacity issue, as homes are typically further from the substation?
 - Is voltage drop less of an issue on urban networks (due to their density) and new build networks (as they're more recently connected and hence cables are more ready for electrification of heat)?
 - Find the maximum possible reduction in peak demand at the substation from using Passiv coordination on a new build network with 100% heat pump penetration.
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- Produce a full year electricity baseload profile for each home using UKPN data (seasonal demand for each profile class with an ADMD for each individual home)
 - Map each home on the sub-network to one of the 20 archetypes used for the heat demand simulations, ensuring that larger houses are mapped to higher ADMDs
 - Compare each network in the scenarios where there are no heat pumps installed, and 100% heat pumps installed.
 - Determine a random installation order, to simulate the real world installation of heat pumps.
 - For each network, calculate the percentage heat pump penetration at which either the maximum demand exceeds the substation limit or the maximum voltage drop (on any home) exceeds the statutory range.
 - For a subset of interesting networks (one of each type), find the reduction in voltage or drop possible (and subsequent improvement in number of installs) using Passiv's coordination algorithm.
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Scenario modelling: list of scenarios

- 1) Baseline: electrical baseload only, no heat pumps – i.e. today's network
- 2) Add heat pumps (with standard manufacturer controls) to 100% of homes
- 3) Install heat pumps one-by-one in a random installation order for each network.
- 4) Maintain the same random installation order and install them one-by-one, but instead the heat pumps have Passiv optimised controls.
- 5) Again, keep the same random installation order, but instead the heat pumps have Passiv optimised controls, and Passiv network coordination algorithms applied. Complete this for 3 sample networks (one of each type).
- 6) For the new build network, find the maximum peak demand reduction possible from using Passiv optimisation and coordination

Determine maximum penetration in each case

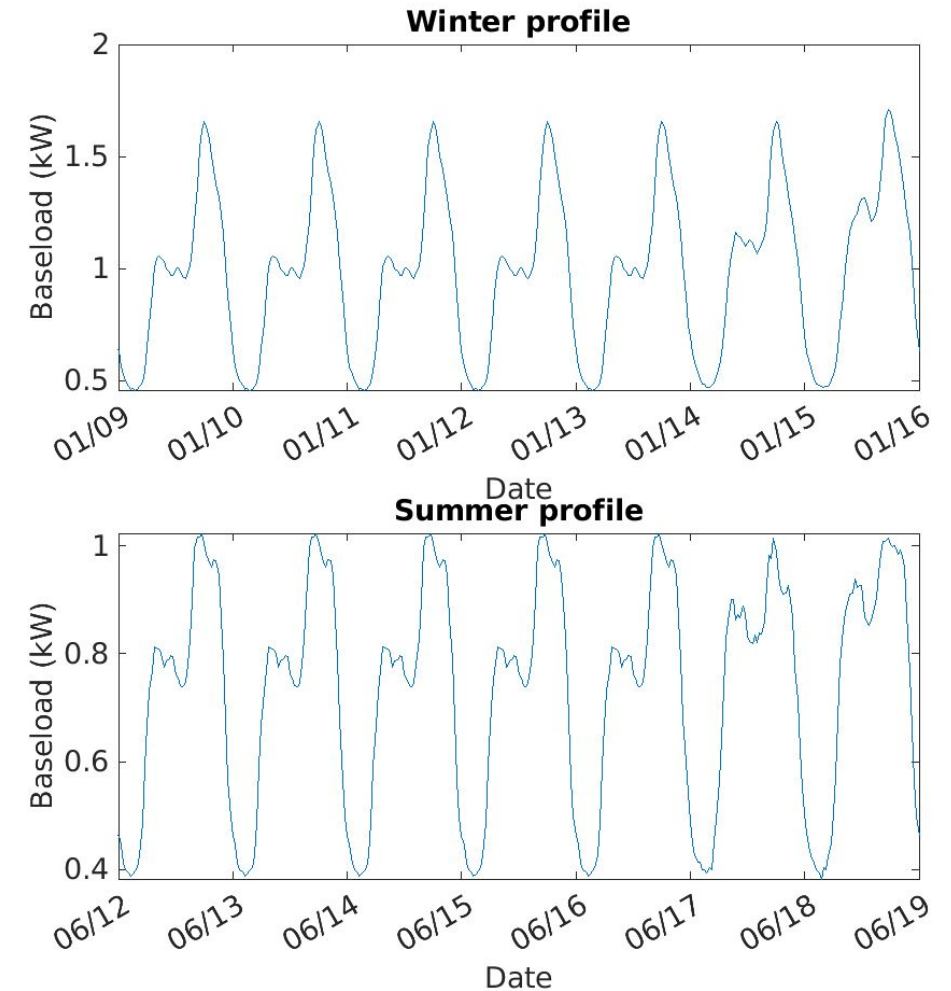
Focus mainly on peak winter conditions (using 'Beast from the East' cold spell at the end of Feb 2018)

A whole year baseload profile was calculated for each property by scaling profiles provided by UKPN, such that the maximum power matched ADMD figures from the DPlan export.

- The profiles provided by UKPN covered each ELEXON profile class, by season and day of the week.
- The DPlan export included ADMD values for each client on each network.

These profiles are used for all scenarios as the total non-heat-pump electrical load.

This demand is any non-heat pump electrical demand and is considered to be uncontrollable and hence unshiftable.

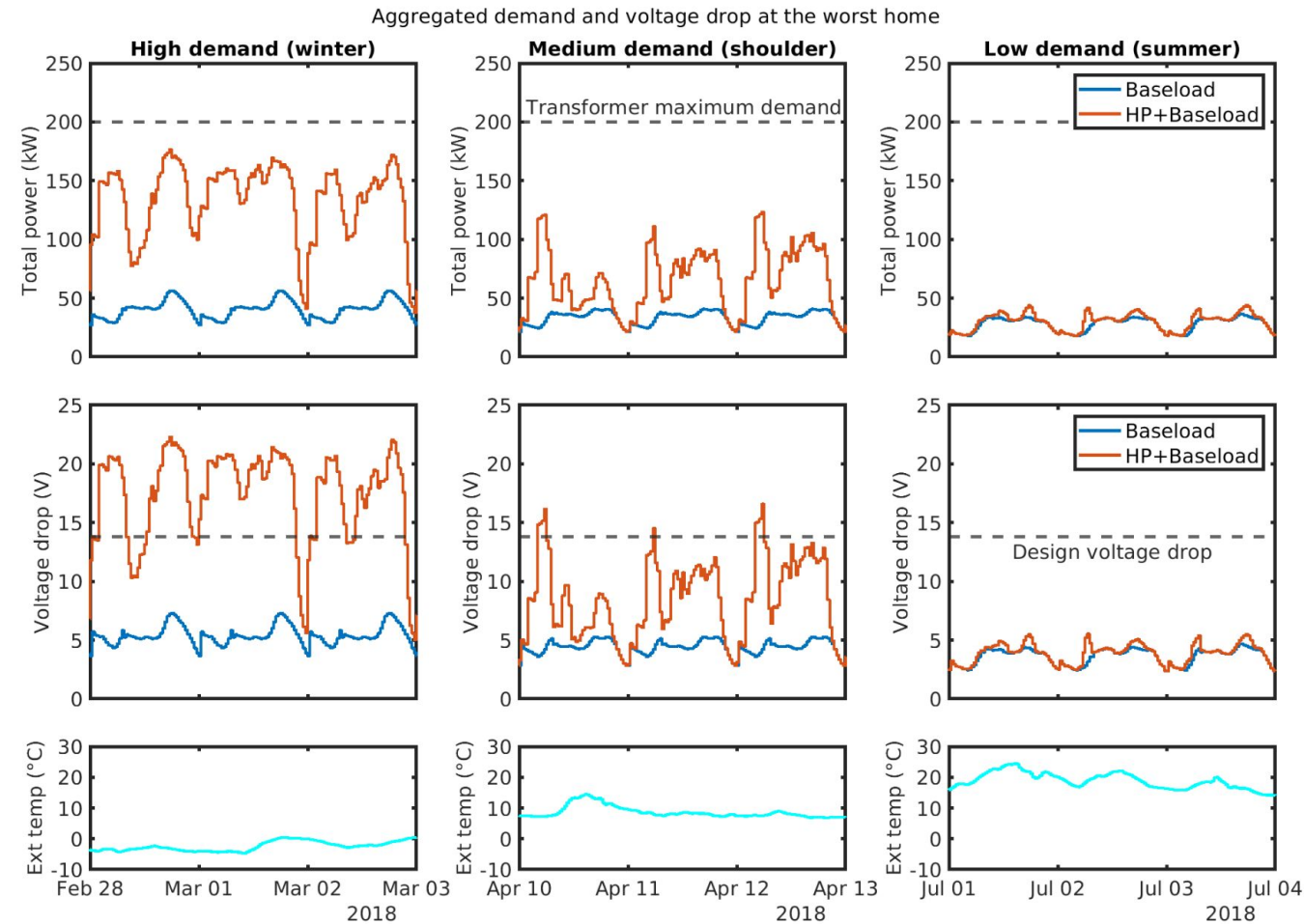


Mapping archetypes to homes on the network to simulate HP electrical demand

- For each sub-network, we model each client (property) on the network.
 - All non-domestic clients are excluded from decarbonisation (but their baseload electrical demand is included).
- Each of the remaining domestic clients is assigned to one of the 20 archetypes simulated for the corresponding network type (rural/urban/new build).
- Archetype assignment is done by ADMD as a proxy for house size, to ensure that larger homes get larger heat load
 - We assumed there to be equal numbers of each archetype.
 - Homes with the smallest ADMDs are assumed to be small heat demand homes (e.g. 1 bed flats), and homes with the largest ADMDs are assumed to be the largest heat demand homes.

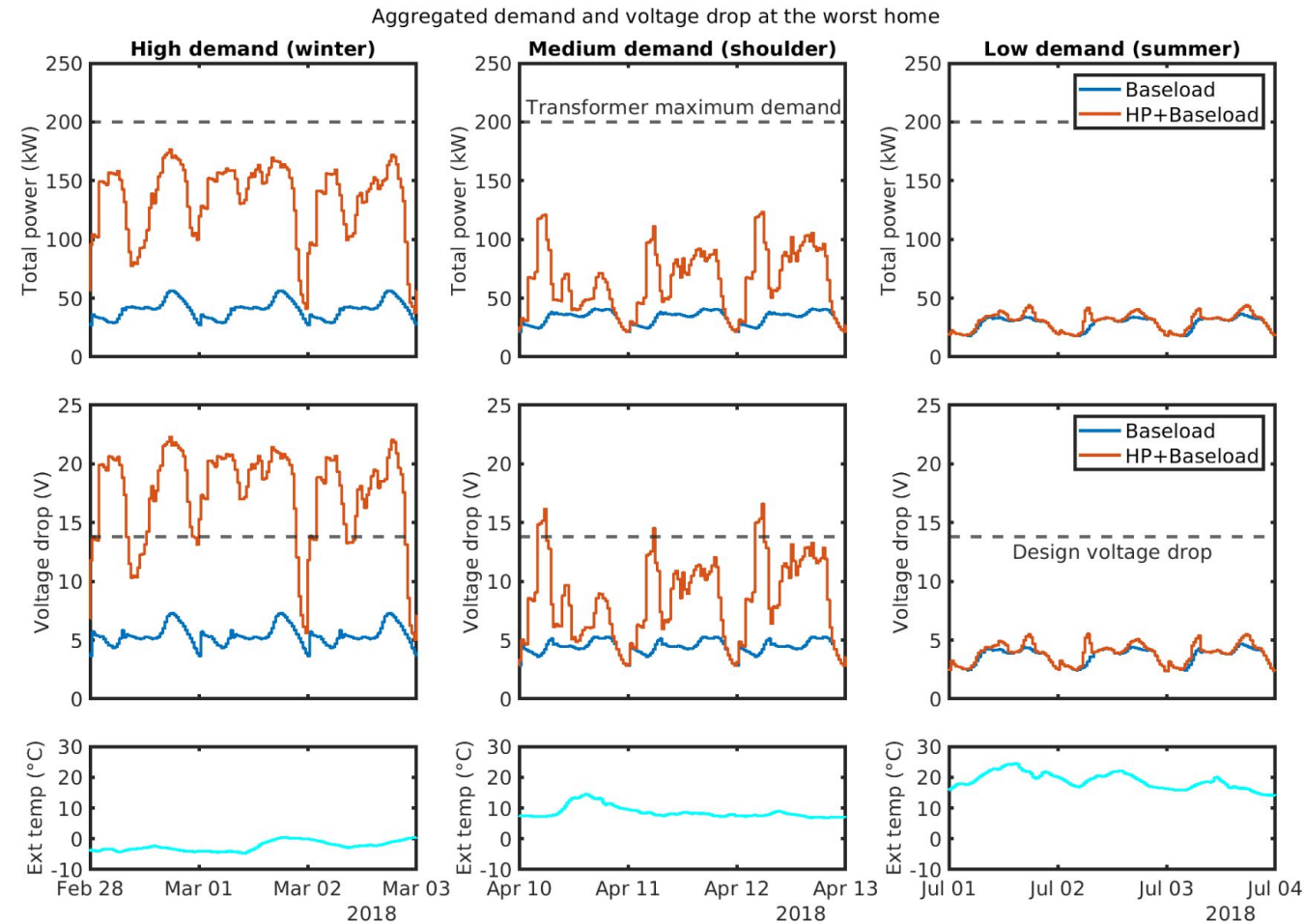


- The following slides run through a comparison of 2 scenarios for each network.
- We compare electrical baseload only (without any heat pump installs, i.e. the current network) against a scenario where all homes have heat pumps with standard manufacturer controls.
- The figures show how aggregate demand at the substation and voltage drop (shown at the worst home) vary in the different seasons and weather conditions.
- The blue line shows the electrical baseload only scenario, and the red/orange line shows the case with 100% heat pump installs.



Scenario comparison: Rural0

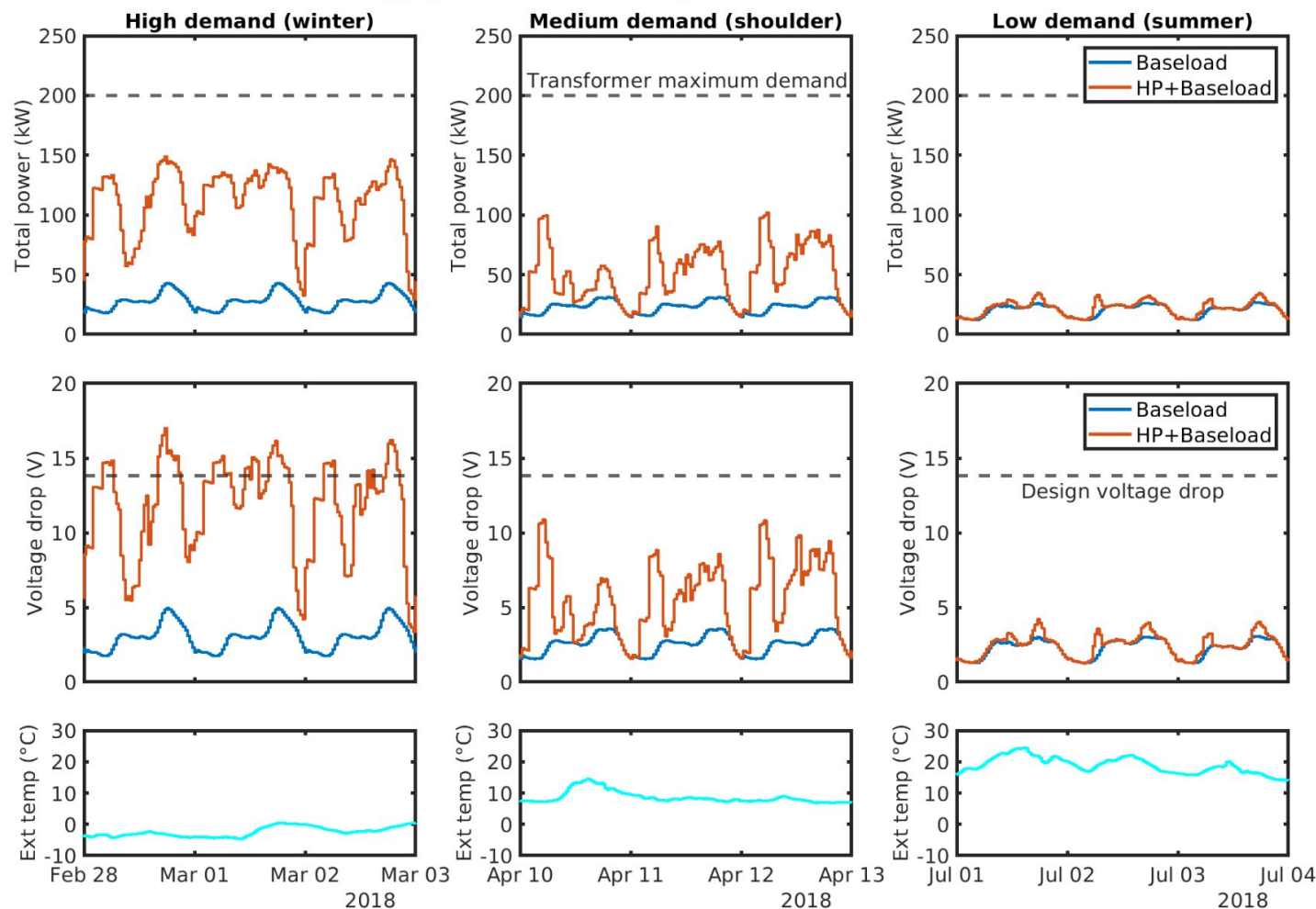
- For the Rural0 network, we observe that without any heat pump installs the total demand and maximum voltage drop across the network is well within the network constraints.
- With all homes installing heat pumps, the aggregate demand across the network is still within the constraints of the transformer, even on the coldest day of the year (with peak space heating demands).
- Voltage drop has become an issue at the worst homes in peak winter (and is a small issue in shoulder season). Here, homes are above the maximum statutory limit on voltage drop of 13.8V (6% of 230V).
- In summer, the only demand is from hot water, so there is little difference from the baseline scenario.



Scenario comparison: Rural1

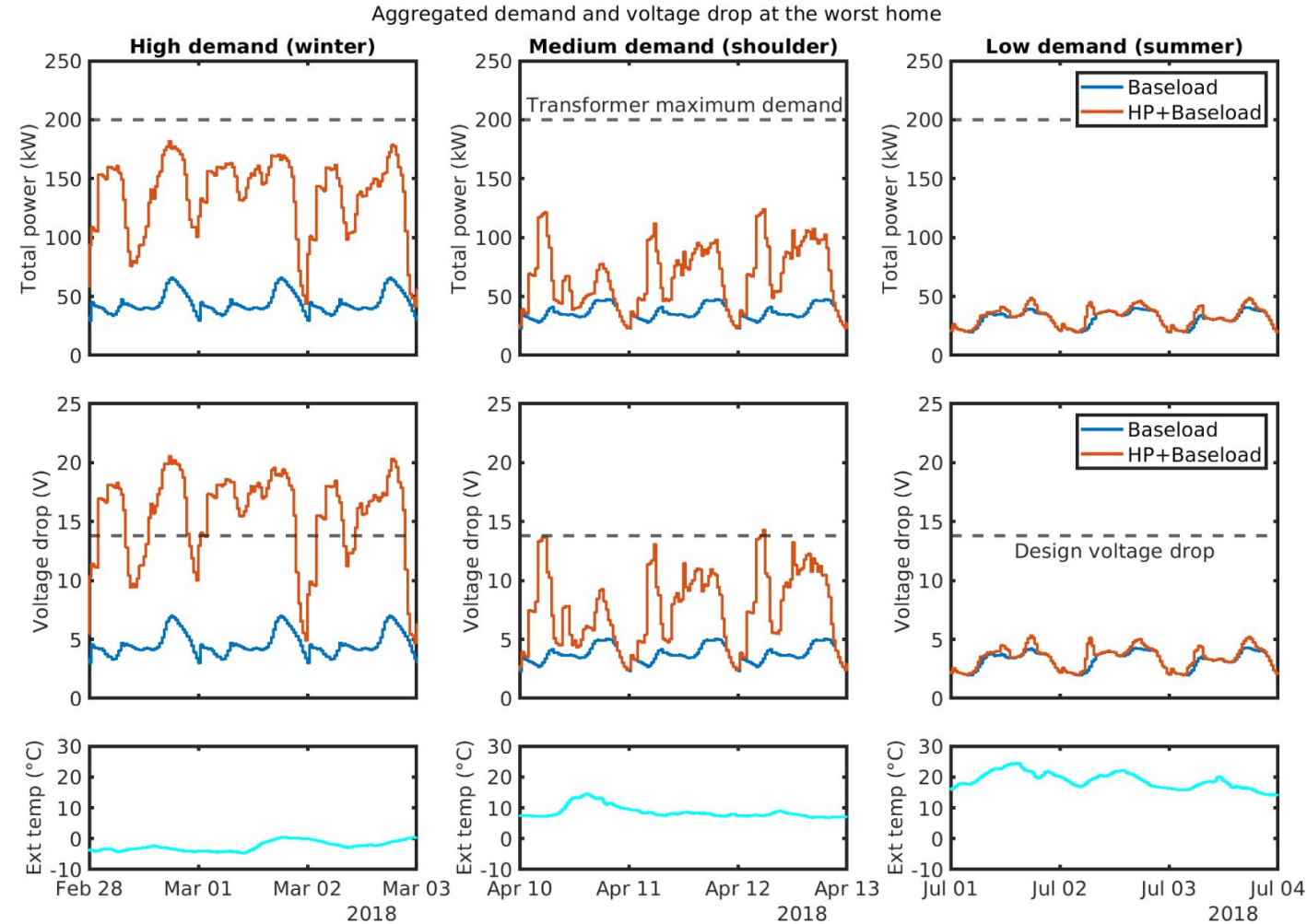
- The Rural1 network has slightly less demand than Rural0 but has the same capacity transformer. We would expect this to be the case, as the Rural1 network has 54 clients, compared to the 63 clients for Rural0.
- As a result of this, with all homes installing heat pumps, the aggregate demand across the network is more comfortably within the constraints of the transformer, even in peak winter.
- Voltage drop is less of an issue than for Rural0, but still exceeds the maximum statutory limit in peak winter.

Aggregated demand and voltage drop at the worst home

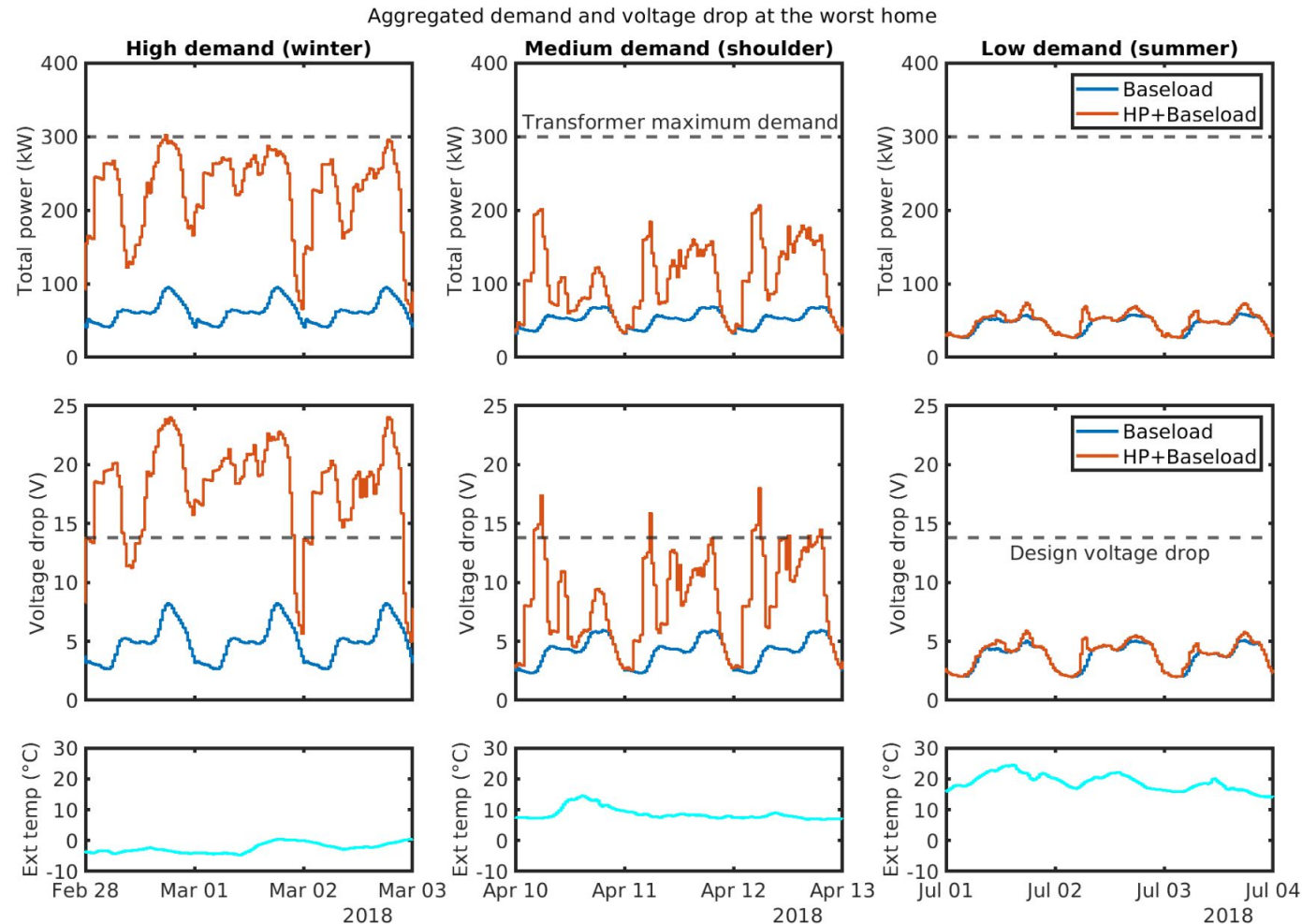


Scenario comparison: Rural2

- The Rural2 network is very similar to Rural0.
- Again, with all homes installing heat pumps, the aggregate demand across the network is always within the constraints of the transformer, but voltage drop is an issue in peak winter.

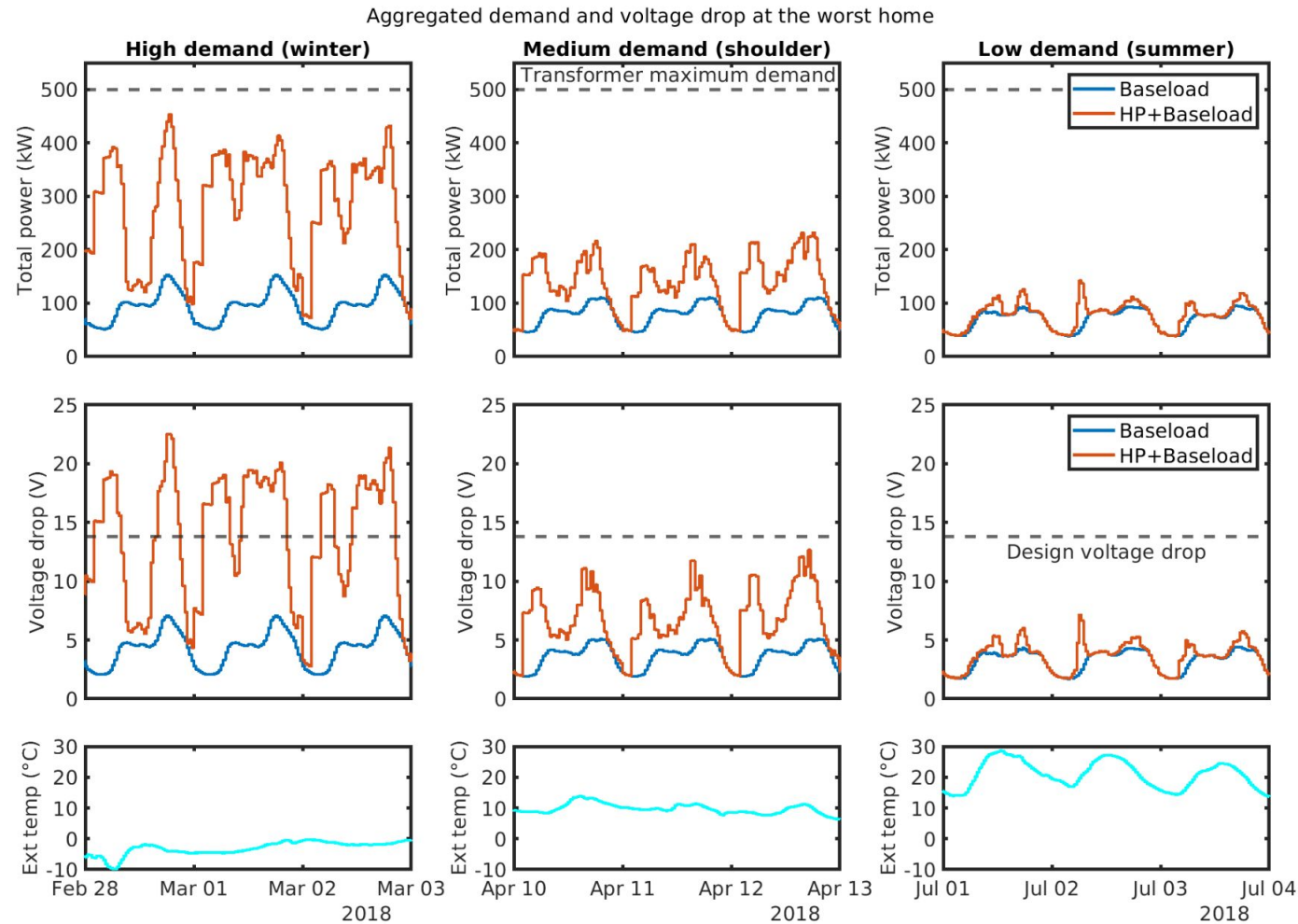


- For Rural3, when heat pumps are added to all homes on the network, voltage drop is an even larger issue in peak winter than on the other rural networks.
- Demand is also close to capacity in peak winter, despite the increased capacity of 300kVA for this network. This is expected, as there are more clients on this network than the other rural networks (112 compared to 54-70 for the other networks).



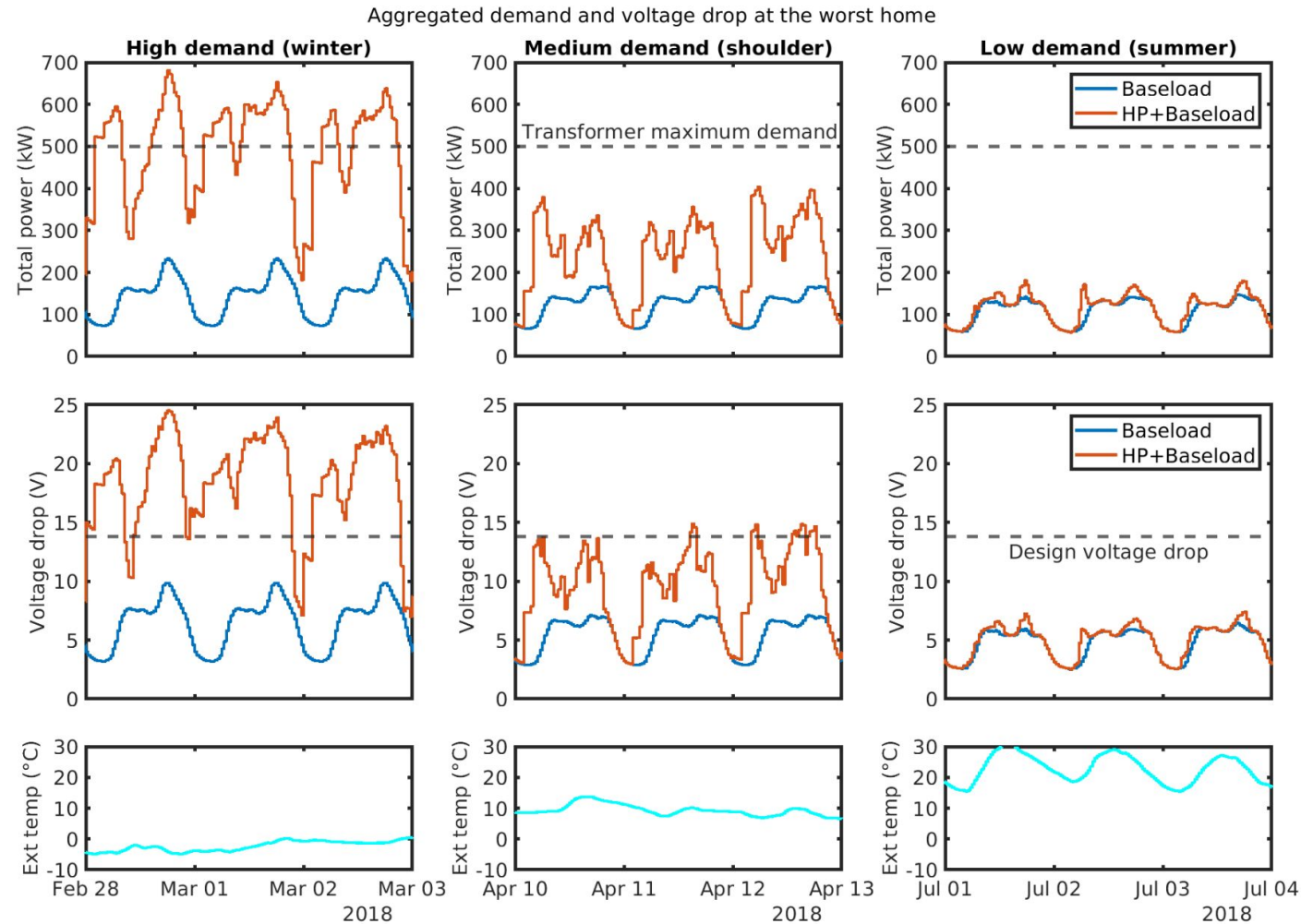
Scenario comparison: NewBuild

- For the new build network, again voltage drop appeared to be the primary issue in peak winter conditions.
- There were over 200 homes on this network, so it's possible that the older and longer cables in the ground for the rural networks are offset by the smaller number of clients.

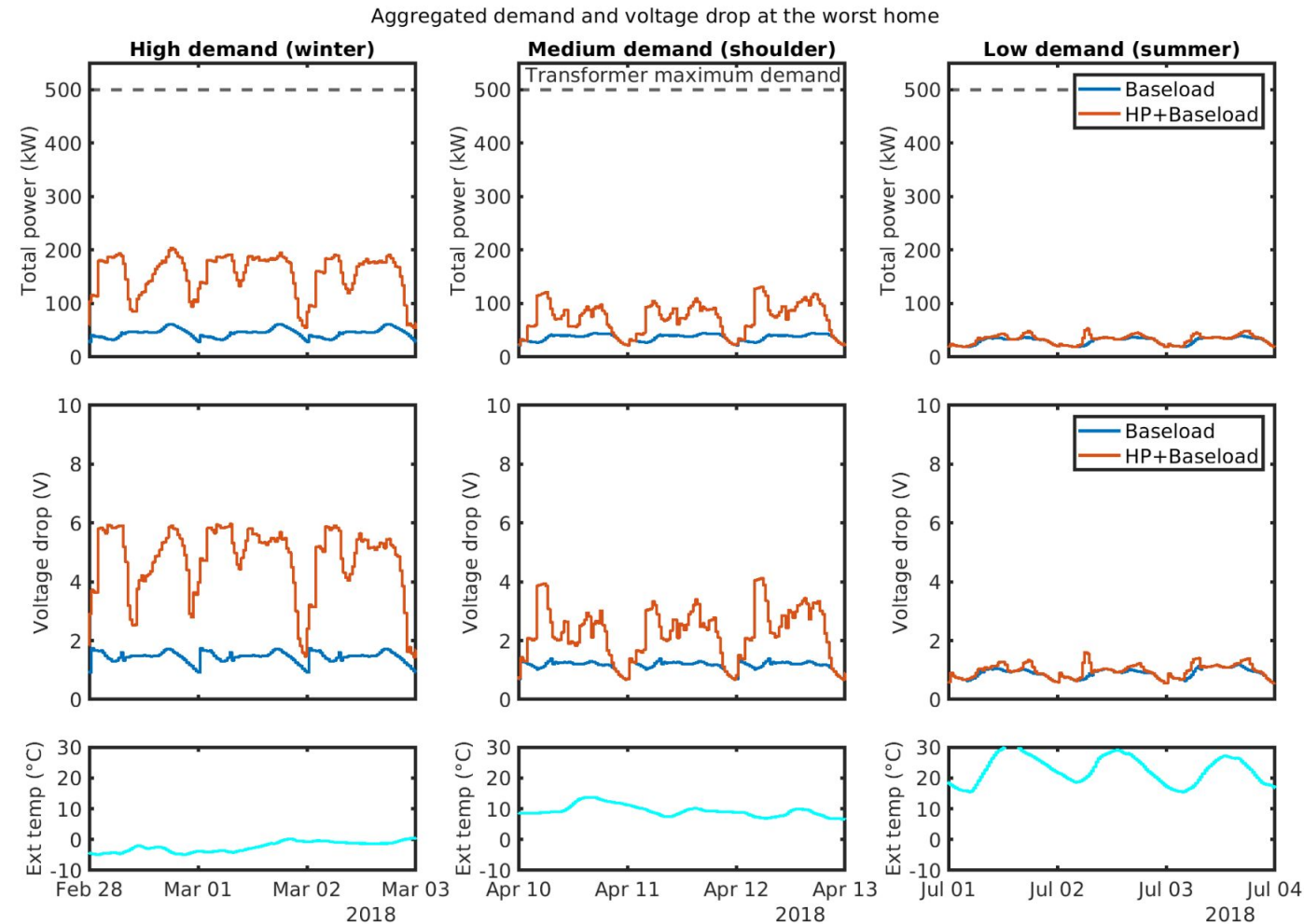


Scenario comparison: Urban0

- For the Urban0 network, both voltage drop and aggregate demand are issues in peak winter.
- In shoulder season, voltage drop remains a slight issue, but demand is no longer an issue.

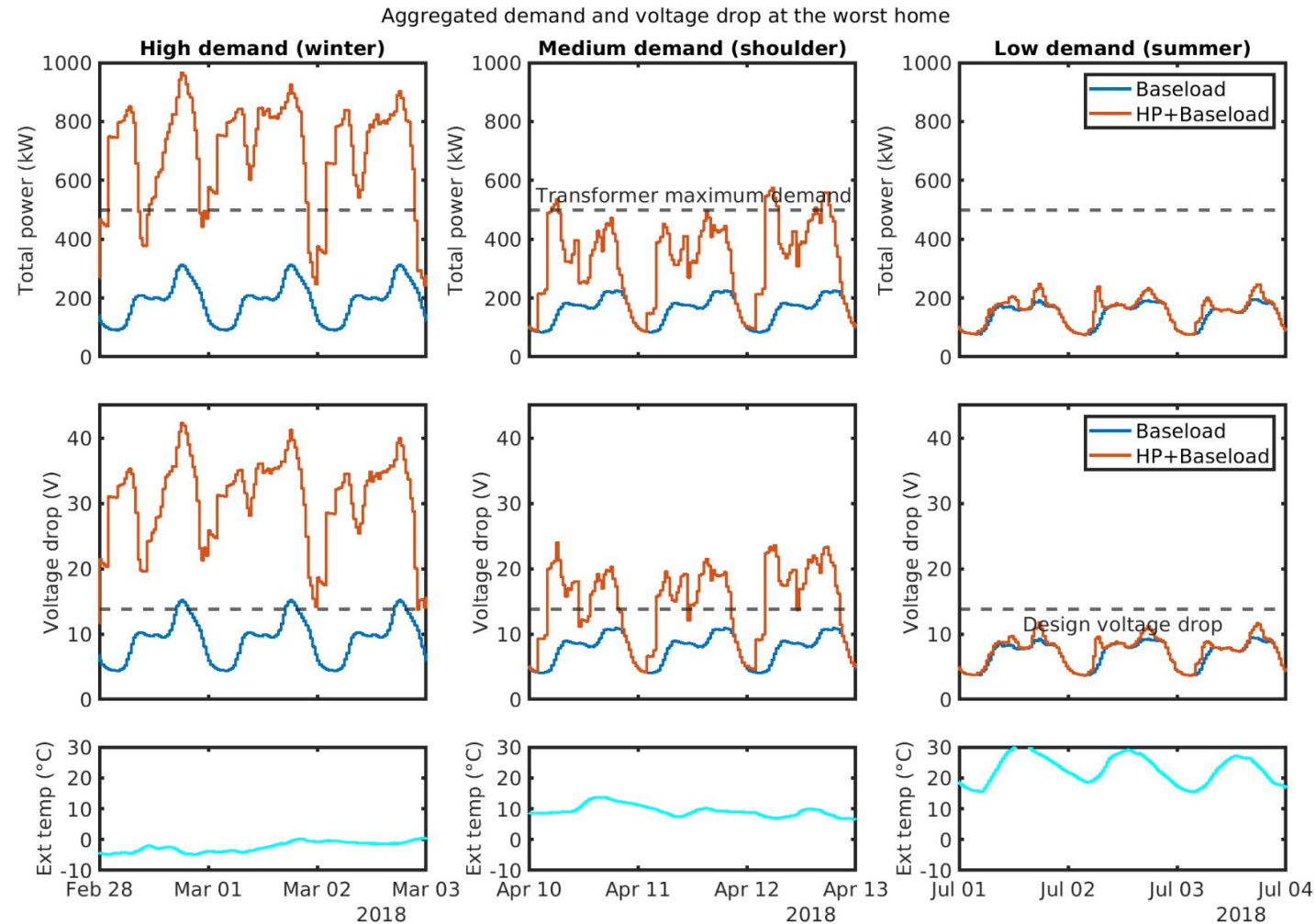


- For the Urban1 network, there is very low demand in comparison to the network capacity.
- Even in the peak winter case with 100% heat pump installs the network is comfortably within the network constraints.
- This is expected, as it's a 500kVA network, but only has 86 clients.
- This network would not be interesting to conduct further analysis on, as it never experiences any capacity or voltage drop issues in the worst case scenario.



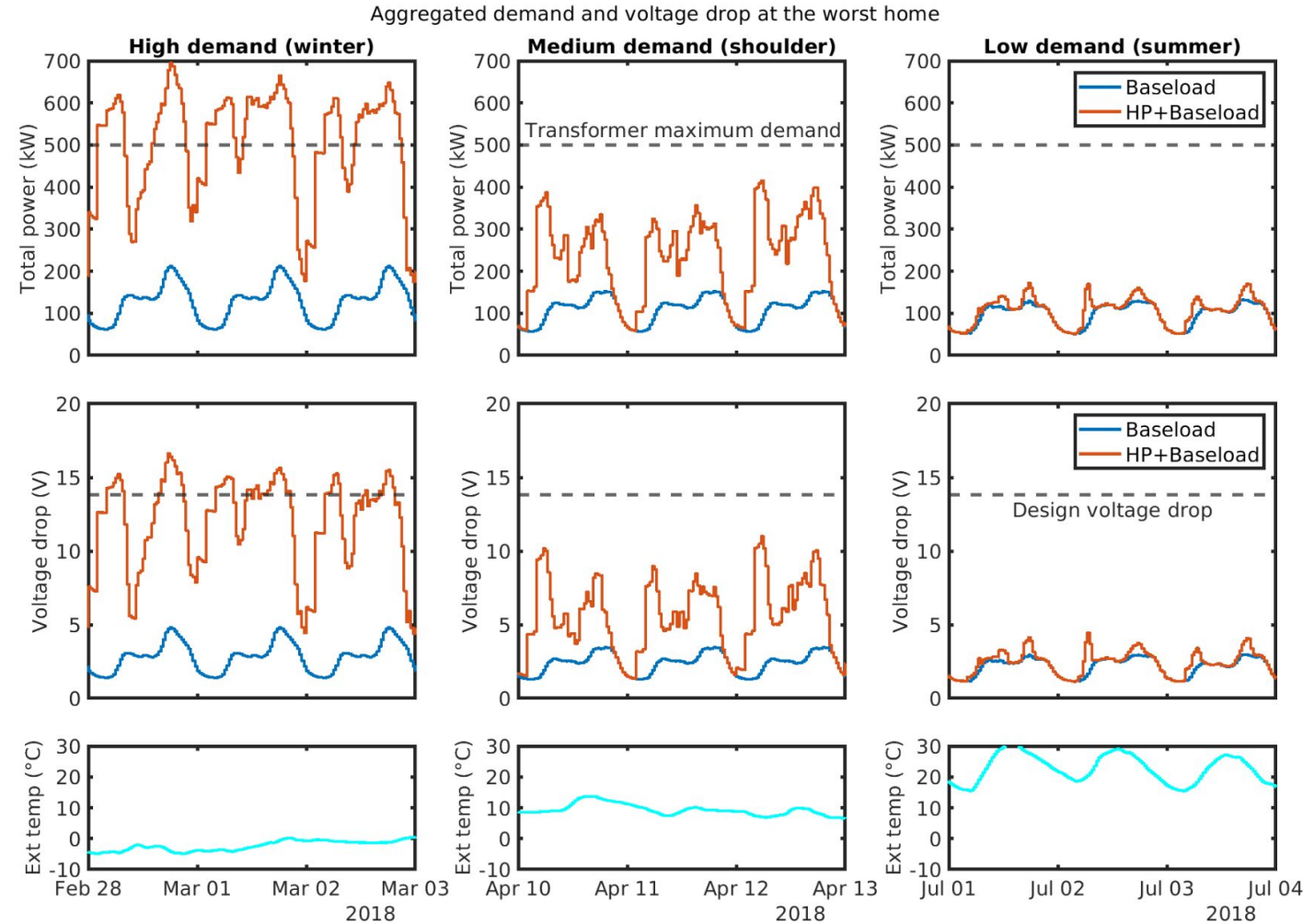
Scenario comparison: Urban2

- For the Urban2 network, both voltage drop and aggregate demand greatly exceed the network constraints in the case with 100% heat pump installs in peak winter.
- Even in shoulder season, voltage drop and aggregate demand are still issues.
- Voltage drop is modelled to be a minor issue in the current network (with no heat pump installs).
- This means the Urban2 network is not an interesting case for further analysis, as we model baseload to be any uncontrollable load, so we will never be able to install any heat pumps on this network and meet the network constraints in peak winter.



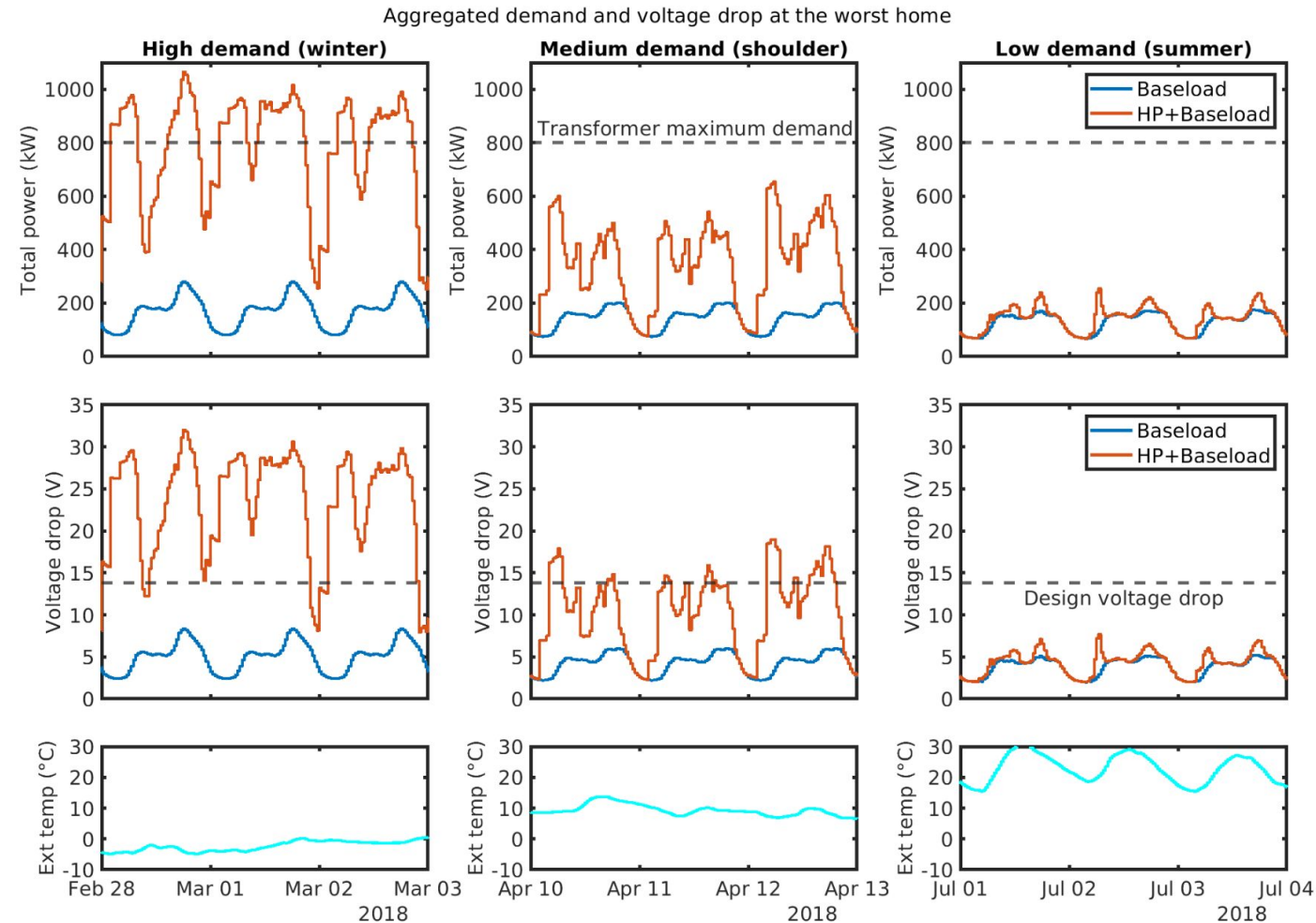
Scenario comparison: Urban3

- For the Urban3 network, there are minor voltage drop issues in the peak winter case with 100% heat pump installs.
- Aggregate demand seems to be the main issue on this network, with peak winter demand reaching 700kW, with a network constraint of 500kVA.



Scenario comparison: Urban4

- The Urban4 network has a larger substation capacity of 800kVA. Despite this, the aggregate demand still exceeds this in peak winter, due to the network supplying 444 clients.
- Voltage drop is a larger issue on this network, particularly in peak winter, but is also a minor issue in shoulder season.



passiv Network comparison: example voltage drop matrices

- It is interesting to note that on the rural networks, each client has a greater impact on each other client in terms of voltage drop per kW of power used. This is likely due to the longer distance cables required to reach each client.
- However, when the impact on voltage drop is summed across the larger number of clients on new build and urban networks, we tend to observe similar voltage drop issues.
- The highest impact on a client's voltage drop is their own usage and usage at the same node (diagonal and near diagonal entries in the matrix). This means, in the urban networks, due to tens or hundreds of blocks of flats being at the same node, these demands can add up to cause large voltage drops (as seen in the centre of the matrix for Urban3 (b) below).

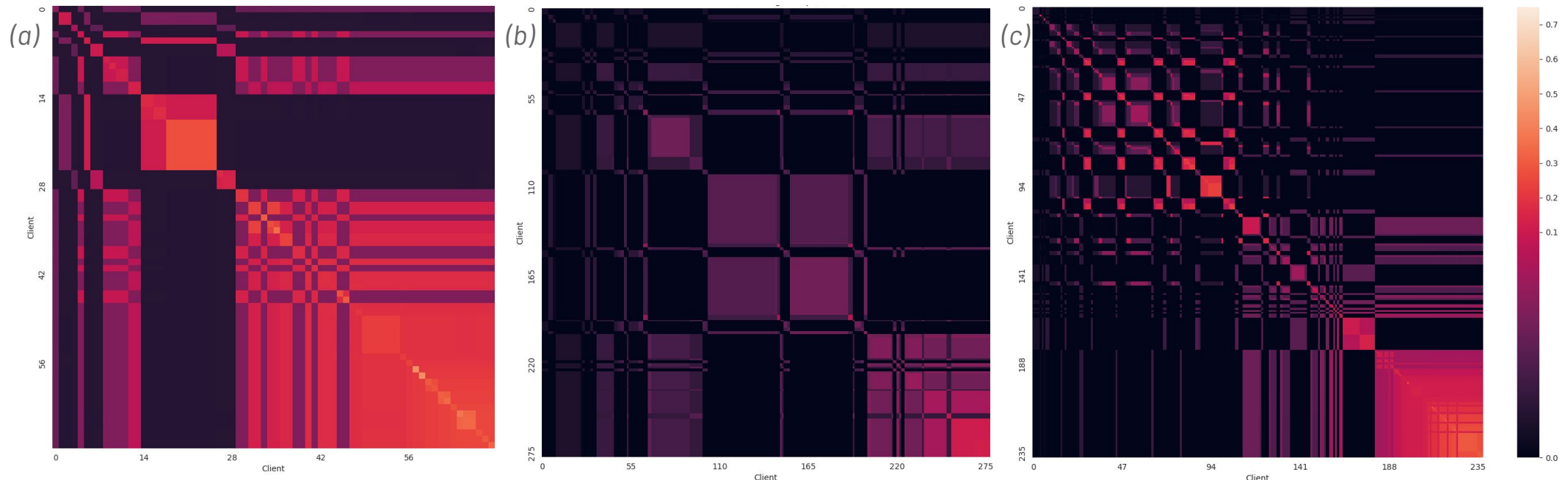
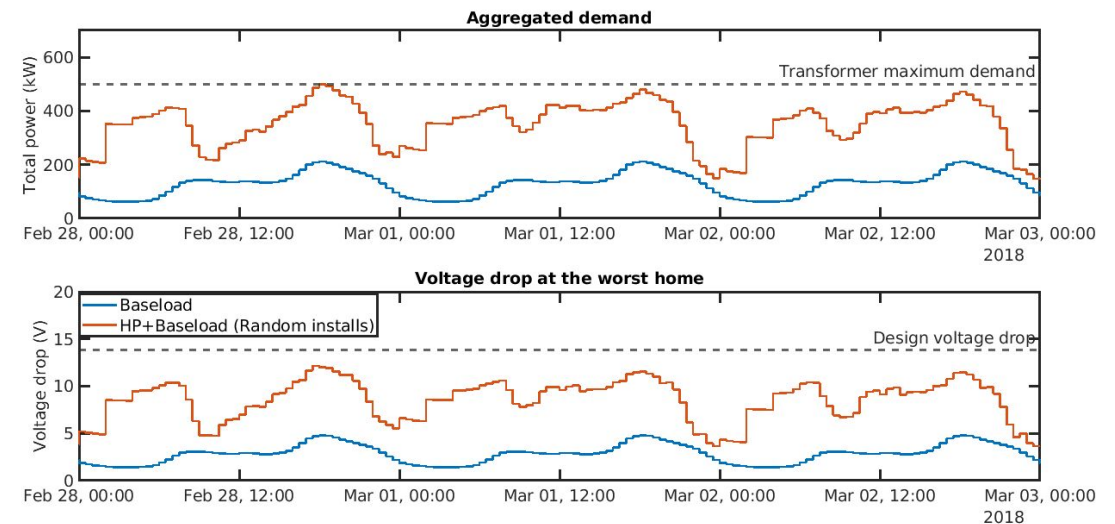
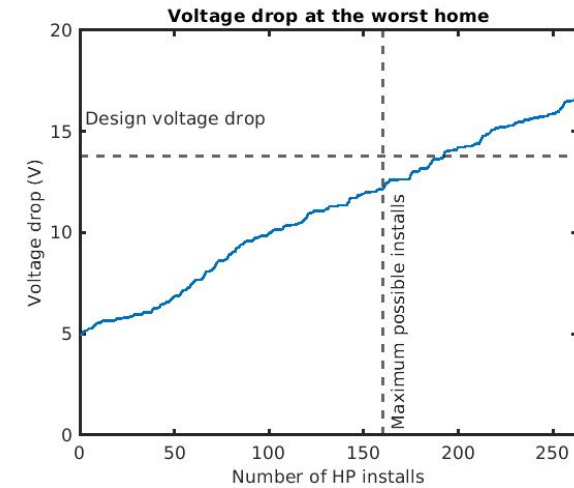
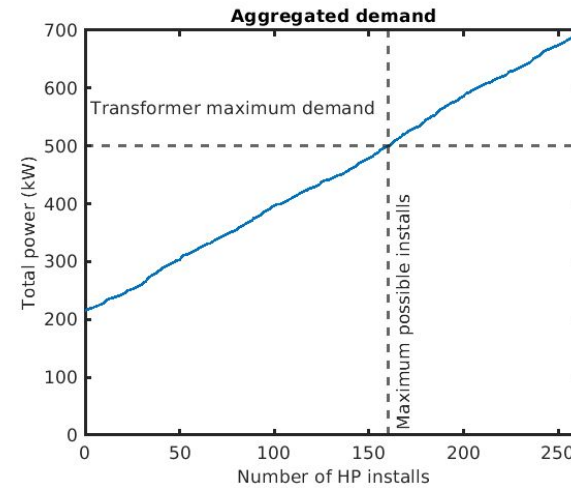


Figure shows voltage drop matrices (V/kW) for (a) Rural2 (b) Urban3 and (c) NewBuild.

For each network we determined a random installation order for heat pumps across the network and determined how many can be installed before network constraints are violated.

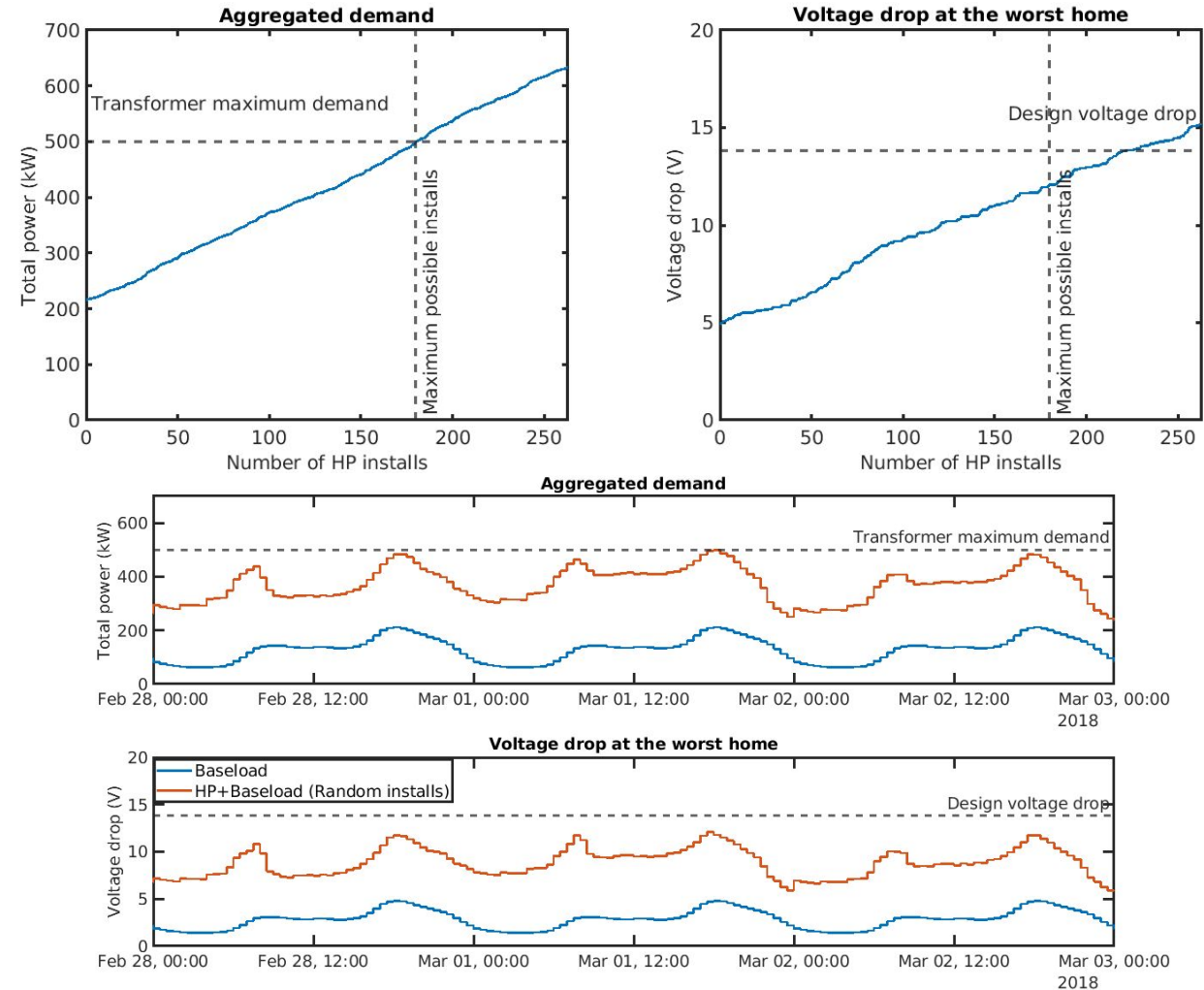
- Assume **standard manufacturer controls**, and consider peak winter conditions.
- Here, aggregate demand is the constraining factor stopping more heat pump installs.
- 160/263 homes could have heat pumps installed.
- This number decreases if other demand also increases (e.g. more EV charging).
- This is representative of what could happen if no action is taken and homes are free to connect and notify the DNO.



Figures show how aggregate demand and VD at the worst home vary with the number of HP installs. The demand and VD for the maximum number of installs case is plotted over the coldest 2 days observed.

We used the same random installation order and considered what would happen if these homes had **Passiv optimised controls**.

- The controls naturally flatten demand in order to improve heat pump performance.
- The possible number of heat pump installs increases to 180 from 160 (of 263 homes).
- Both the consumer and the network benefits, as the heat pumps are running more efficiently.
- Improvement is limited as many of the heat pumps are flat out anyway.



Figures show how aggregate demand and VD at the worst home vary with the number of HP installs. The demand and VD for the maximum number of installs case is plotted over the coldest 2 days observed.

Random installation order (standard controls vs. Passiv optimised controls)

Where heat pump installs are randomly selected, networks with a voltage drop issue are not guaranteed to see a notable improvement in the number of installations when moving from standard manufacturer controls to Passiv optimised controls, due to benefits being very dependent on the installation order.

It's possible that the first infeasible install causes a large increase in voltage drop over the statutory limit, e.g. from 13.4V to 17V. This is because some homes have a major impact on other homes local to them on the network. Although optimisation can bring this closer to the limit (e.g. back to 14V), it may not be possible to increase the number of installs further. Rural0 is an example of a network with this problem (as shown in the figure).

However, if the model gets past the first previously infeasible install, it's possible that further installed homes have very little effect on the homes experiencing the worse voltage drop (e.g. they're on a different feeder), then optimised controls are likely to be able to massively increase the number of installs on the network. The NewBuild network is an example of a network like this.

Hence, it can be better to consider the percentage reduction of demand and voltage drop, instead of just the number of installs.

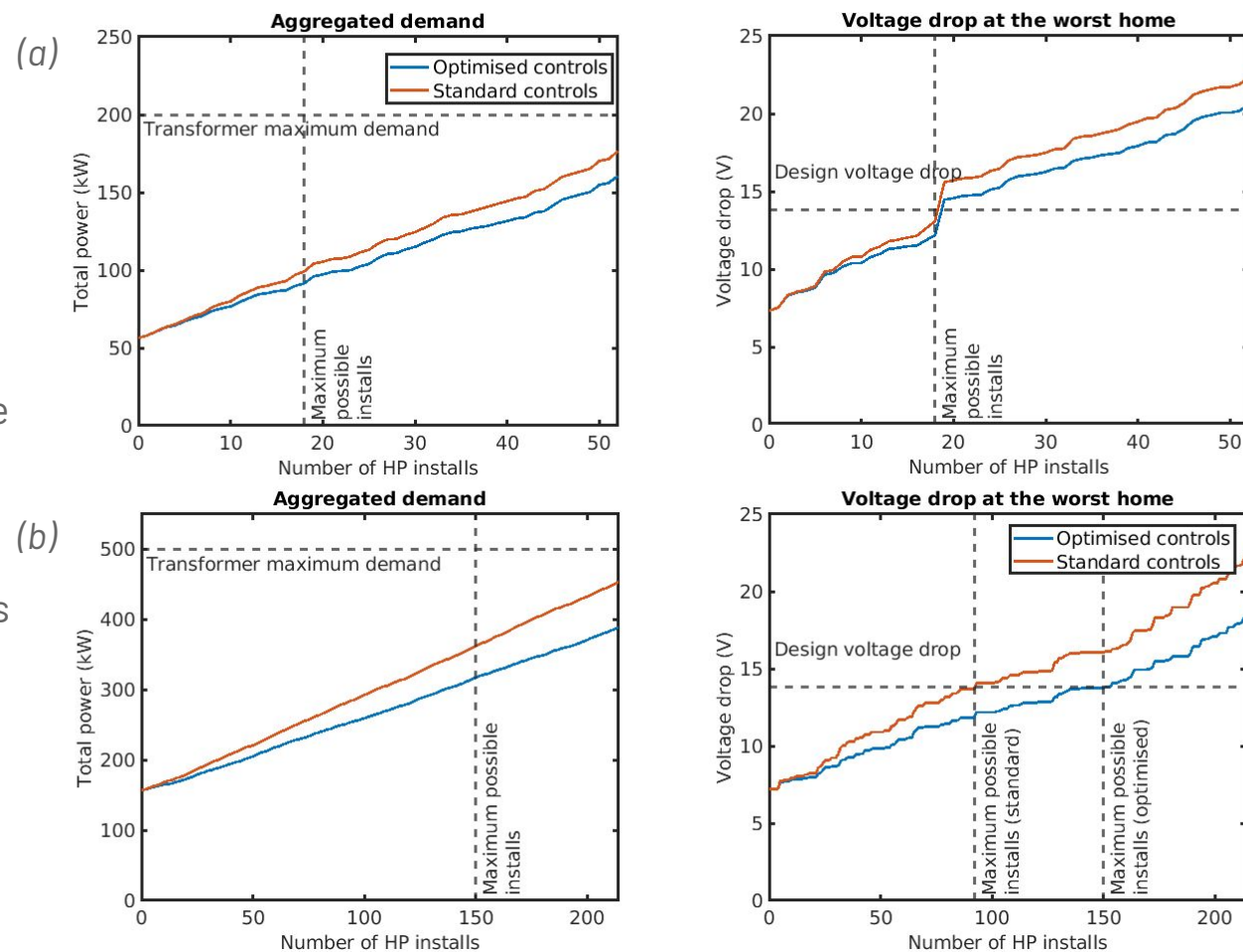


Figure shows reduction in demand and voltage drop made using Passiv optimised controls on networks (a) Rural0 and (b) NewBuild

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Network comparison: summary

Network	Clients (Domestic)	Worst VD impact between 2 clients (V/kW)	100% HP installs		Max random installs		Optimised reduction* (%) Installs = Max Passiv controls		Primary issue
			Worst VD (V)	Peak agg demand (capacity) (kW/kVA)	Standard control	Passiv control	Peak agg demand	Worst VD	
Rural0	63 (52)	0.504	22.3	176 (200)	18	18	8	7	Voltage drop
Rural1	54 (46)	0.746	17.0	149 (200)	36	39	8	9	Voltage drop
Rural2	70 (51)	0.449	20.5	182 (200)	26	26	5	5	Voltage drop
Rural3	112 (91)	0.614	24.0	302 (300)	42	42	5	5	Voltage drop
NewBuild	234 (214)	0.327	22.5	453 (500)	92	150	12	14	Voltage drop
Urban0	262 (244)	0.125	24.5	680 (500)	53	57	4	3	Voltage drop
Urban1	86 (77)	0.072	6.0	204 (500)	77	77	8	2	N/A
Urban2	385 (356)	0.216	42.3	965 (500)	0	0	0	0	Voltage drop
Urban3	278 (263)	0.125	16.6	694 (500)	160	180	8	8	Capacity
Urban4	444 (428)	0.090	32.0	1065 (800)	94	110	6	6	Voltage drop

The data suggests that the majority of networks have bigger voltage drop issues than capacity issues.

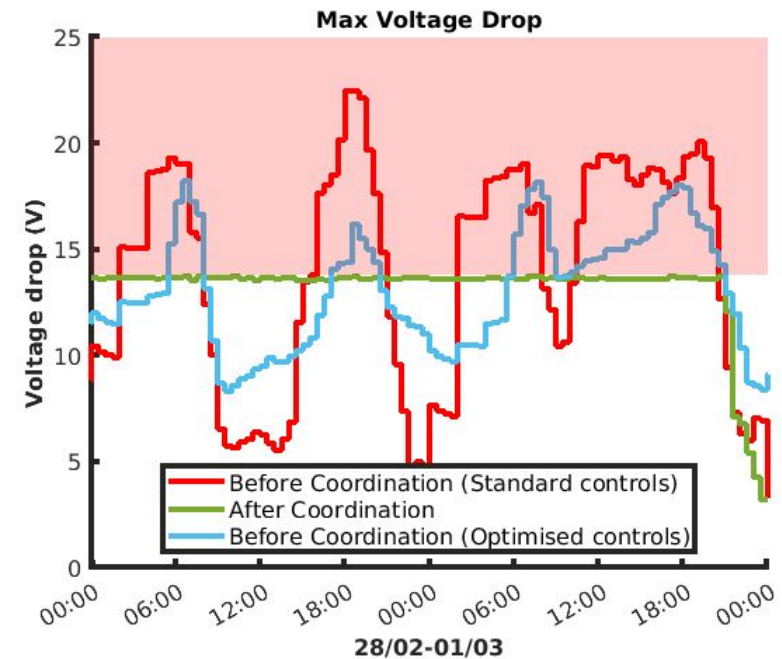
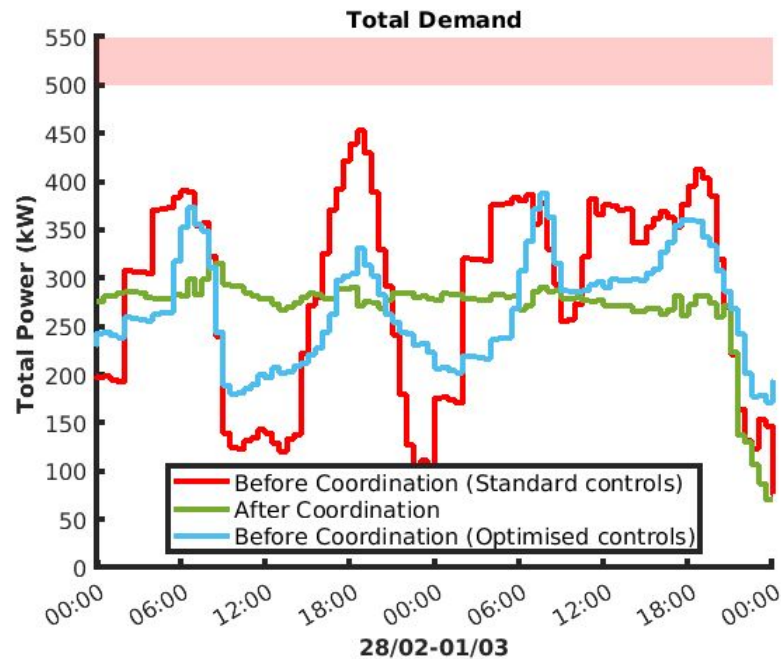
Note that optimised reduction percentages are low, as for a lot of the networks not many heat pumps are installed, so a large proportion of the load is unshiftable baseload. Also, heat pumps are almost running flat out during peak winter, so optimisation can't reduce much of the load.

*Optimised reduction is the reduction compared to the case with no Passiv controls, with the heat pumps installed in the random ordering, with the number of heat pumps being the maximum possible in the Passiv controls case (e.g. 110 for Urban4).

- Pick the coldest two days of the year, as this is significant for network capacity.
 - Use Passiv aggregate coordination algorithms to manage demand to try to stay within limits for (a) total overall demand and (b) maximum voltage drop at any home
 - Utilises the **voltage drop matrix** calculated previously
 - Determines the best strategy for shifting demand on each home so as to make the best use of overall network capacity
 - Works by heating up homes in advance of the overall network peak, where possible
 - Householder thermal comfort is not compromised (maximum of 0.5°C under setpoint)
 - Repeat this with different levels of heat pump penetration and find the maximum number of heat pumps where coordination can keep demand within network limits.
 - We repeat this for one network of each type (Rural0, NewBuild and Urban3). This gives us a range of networks facing different issues, as Urban3 has a capacity issue, whilst the other 2 face voltage drop issues.
 - This process emulates a scenario where every heat pump on the network has Passiv smart controls and these systems are interacting with Passiv cloud services to manage overall demand.
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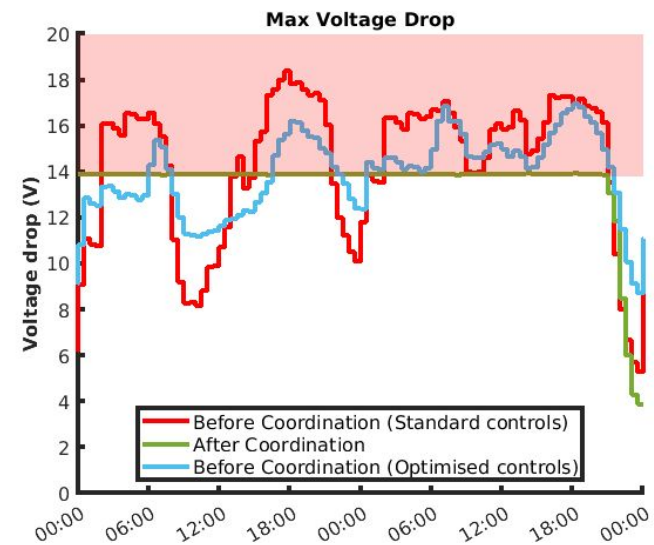
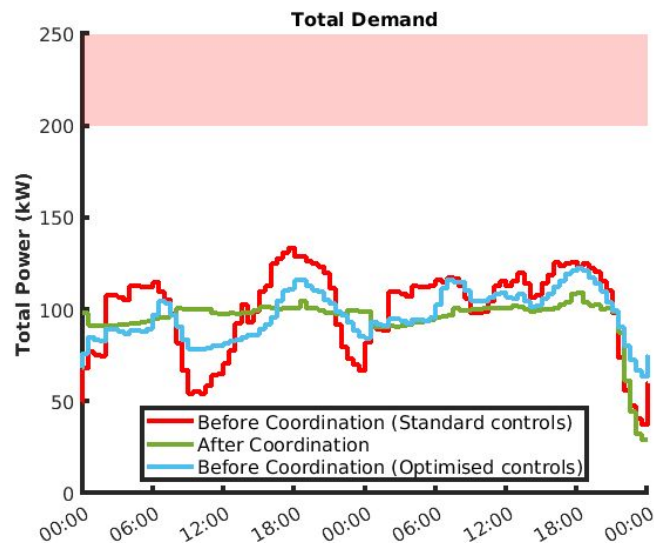
Network coordination- example impact: NewBuild network

- The graphs show the impact of the coordination at a network level in the scenario with 100% of the network having heat pumps installed.
- Shifting demand to different times in exactly the right pattern means that voltage drop can be kept below the maximum (13.8V) at all times.



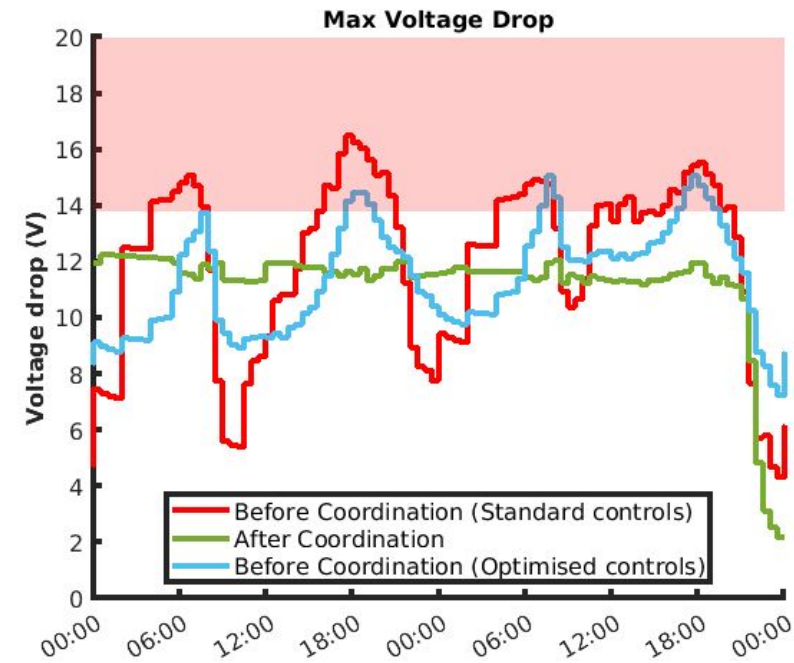
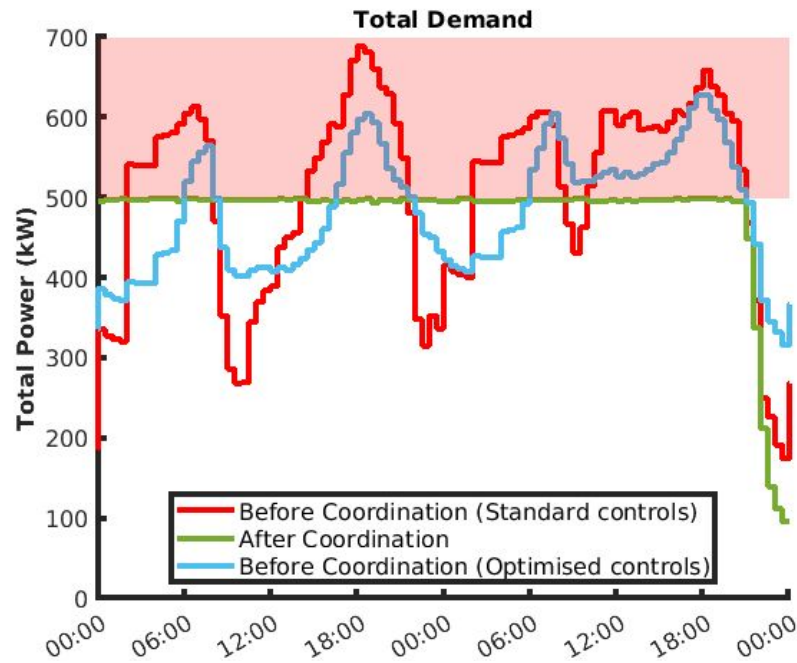
Network coordination- example impact: Rural0 network

- The graphs show the impact of the coordination in the scenario with 33 randomly assigned homes having heat pumps.
- Again, shifting demand allows voltage drop to remain below the maximum (13.8V) at all times.
- If any more heat pumps were added, it would not be possible to keep within the constraints.
- Strategically ordered installs could alleviate these issues, but this is not a realistic scenario.



Network coordination- example impact: Urban3 network

- The graphs show coordination at a network level in the scenario with 259 randomly chosen homes on the network having heat pumps.
- In this network, demand is the issue, and is shifted to ensure we stay within the 500kVA limit of the substation.



Network coordination: Summary

Network	Clients (Domestic)	Max random installs (standard controls)	Max random installs (Passiv controls)	Max random installs (Passiv coordination)
Rural0	63 (52)	18	18	33
NewBuild	234 (214)	92	150	214
Urban3	278 (263)	160	180	259

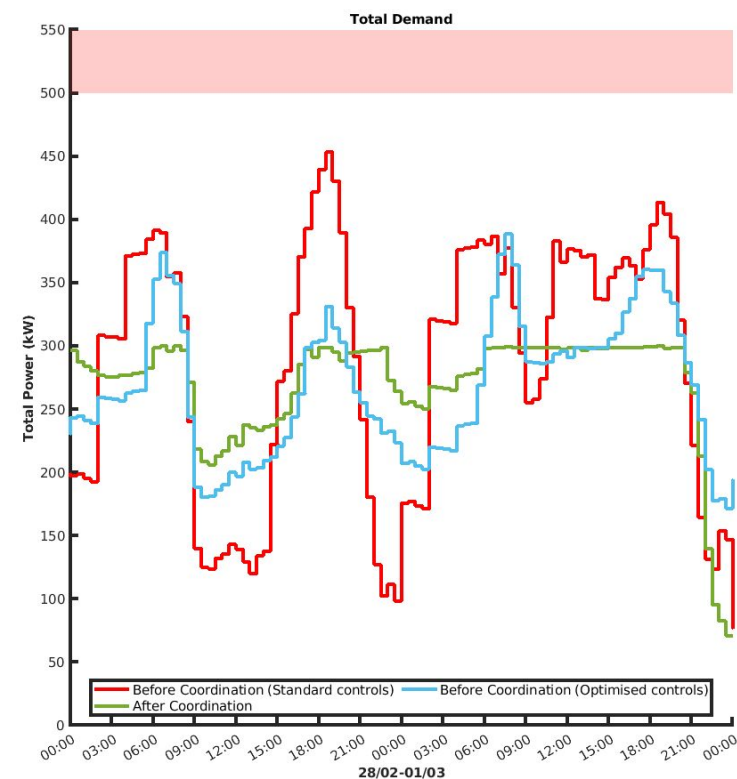
- The maximum number of heat pump installs where the network constraints can be honoured can be increased for all networks.
- In the NewBuild case, we can install heat pumps on every home on the network with coordination.
- Coordination and optimisation combined achieves a 18-30% reduction in peak demand and a 25-39% reduction in peak voltage drop.
- Coordination achieves 11-20% improvement in peak demand reduction over optimisation alone, and a 18-26% reduction in peak voltage drop.

Network	Standard controls (Num homes = coordination maximum)		Passiv controls (Num homes = coordination maximum)		Passiv coordination (Num homes = coordination maximum)	
	Peak demand (kW)	Peak VD at worst home (V)	Peak demand (kW)	Peak VD at worst home (V)	Peak demand (kW)	Peak VD at worst home (V)
Rural0	134	18.4	123 (-8%)	17 (-8%)	110 (-18/11%)	13.8 (-25/19%)
NewBuild	453	22.5	389 (-14%)	18.6 (-17%)	316 (-30/19%)	13.8 (-39/26%)
Urban3	689	16.5	628 (-9%)	15 (-9%)	500 (-27/20%)	12.3 (-25/18%)

We also investigated a scenario where we solely tried to minimise the aggregate demand at the substation, in the case with a new build site with 100% heat pumps. The graph shows the results of coordination and the table shows the resulting aggregate demands:

Network	Standard controls (kW)	Passiv controls (kW)	Passiv coordination (voltage drop minimisation) (kW)	Passiv coordination (aggregate demand minimisation) (kW)
NewBuild	453	389 (-14%)	316 (-30/19%)	300 (-34/23/5%)

- The algorithm was able to decrease aggregate demand by a further 5% than when it was trying to minimise voltage drop, up to a total of 34% when comparing to standard controls.
- Hence, it could be possible for a new build site to use a transformer with a 34% lower capacity with Passiv coordination and optimisation in place.



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Summary



- We have modelled 10 networks of 3 different types and investigated the challenges and constraints that these networks face with rising heat pump uptake.
 - We have found that voltage drop is a larger issue than we first anticipated in urban and new build networks, with 8/10 of our modelled networks reaching voltage drop constraints before capacity constraints when installing heat pumps.
 - We have evaluated how optimisation and coordination could be used to alleviate the problems faced by the network, with coordination and optimisation combined achieving up to a 34% reduction in peak aggregate demand and up to a 39% reduction in peak voltage drop.
 - This could allow the network to face less issues as heat pump uptake increases or, if this was rolled out across a new build site, reduce the need for larger capacity transformers.
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Next steps

- Align HeatNet coordination scenario outputs with UK Power Networks own baseline modeling to ensure consistency and integration.
- Evaluate how combined outputs can be incorporated into ongoing network planning and maintenance through a Beta phase toolkit.
- Examine practical approaches for network coordination, focusing on enabling consumer participation, financial incentives, and technical mechanisms to achieve the necessary demand shifting.

