REACH Alpha

Community Heat Load Modelling

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Introduction

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Project aims

The REACH Alpha project is working with rural community energy groups to identify local decarbonisation priorities and explore ways to accelerate their transition to net zero using a modular energy centre.

This modular solution within a constrained electricity network offers a shared resource that supports the expanded use of low-carbon heating, rapid electric vehicle (EV) charging, and renewable energy generation.

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Modelling aims

- The economic efficiency of the modular energy centre as a solution supporting local decarbonisation depends heavily on the uptake of EVs and low-carbon heating systems.
- To evaluate this, it's important to simulate the energy demand of each home in the community in various future energy scenarios.
- Simulated typical community heat pump loads and worst-case (coldest winter) scenarios can inform the optimal sizing of the modular energy centre.
- We show how optimised smart controls and coordinated control strategies can mitigate the peak worst-case scenario aggregate electricity demands across the community.

Work packages

This slide deck contains the complete content for the following work packages:

- WP2 - Baseline community low-carbon heat loads
  - Simulating the demand of heat pumps in two communities in various future energy scenarios.
- WP3 - Coordinated community control of low-carbon heat loads
  - Modelling and evaluating two contrasting methods for coordinating residential low-carbon heat loads across two communities.

Heat demand modelling

Heat demand modelling: objective

- Simulate the heat demand of homes in the Bigbury Net Zero (BNZ) and Awel Aman Tawe (AAT) communities, to estimate the additional electricity demand from the transition from gas boilers to hybrids and heat pumps.
- These heat pump electricity profiles can be added to baseload and EV electricity profiles. This gives realistic forecasts of total electricity demands arising from electrifying heat with low-carbon heating systems.
- This will allow us to simulate different future energy scenarios with varying levels of heat pump and EV penetration and model the impact on aggregate load at the community level.

Heat demand modelling: approach

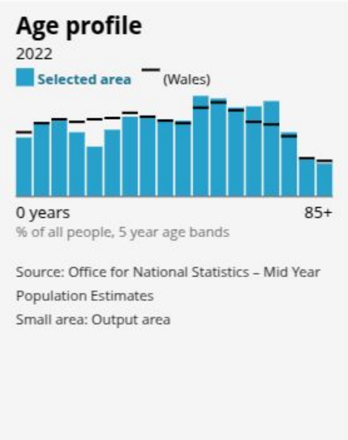
- Choose a set of 20 house archetypes for each community (which will be duplicated and mapped onto the real houses in each community)
- These 20 archetypes represent the full range of houses in terms of physical size and the occupants living in them, and also encompass diversity of space heating and hot water demand patterns.
- For each archetype, 2 simulation runs are carried out at a half hourly resolution across a whole year to create heat pump electricity profiles in 2 weather scenarios:
  - Typical year- to provide examples of typical heat pump operation.
  - Coldest year- to ensure peak demand is represented.
- The heat pump operates under standard manufacturer controls (with a time-clock with optimum start and weather compensated flow temperature), as an example of how heat pumps could operate without any smart controls.

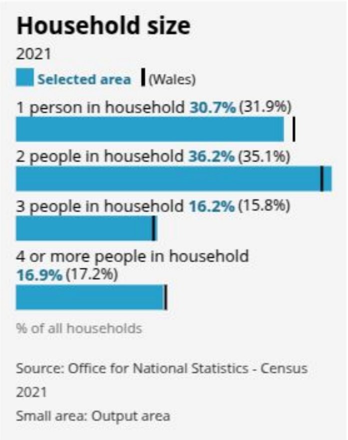
Determining house archetypes

- Each community is simulated using 20 archetypes, using a unique digital twin.
- These digital twins have randomised thermal dynamics and a heat transfer coefficient consistent with the house size.
- Each archetype is assigned an occupancy type and work type, which affects the choice of heating schedule, heating setpoint, and hot water consumption profile (which have an impact on heat pump usage patterns).
- Low-carbon heating systems were allocated to archetypes, such that the proportion of archetypes with each heating system type were aligned with the energy scenarios we modelled for the communities. This ensures that each archetype is duplicated a similar number of times, to more accurately extrapolate the heat load to the community level.

Heat demand modelling: Occupancy and Work

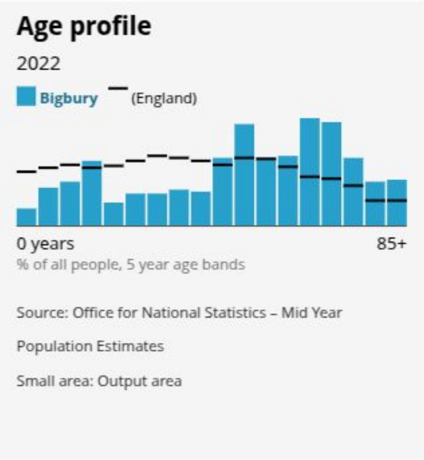
- For AAT, ONS data from Gwaun-Cae-Gurwen and Cwmllynfell in South Wales was used to inform the type and number of occupants, and the work patterns used.
- The age profile was used to inform the proportion of older occupants (more likely to have higher setpoints) and the work types, as older occupants are likely to be retired. This impacts the heating schedule set.
- Household size was used to inform the number of occupants- the proportion of families, couples and single occupants.
- Hours per week worked was used to inform the proportion of part time workers, which influences the heating schedules set.

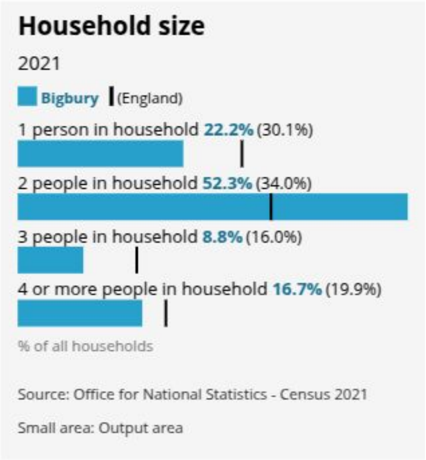




Heat demand modelling: Occupancy and Work

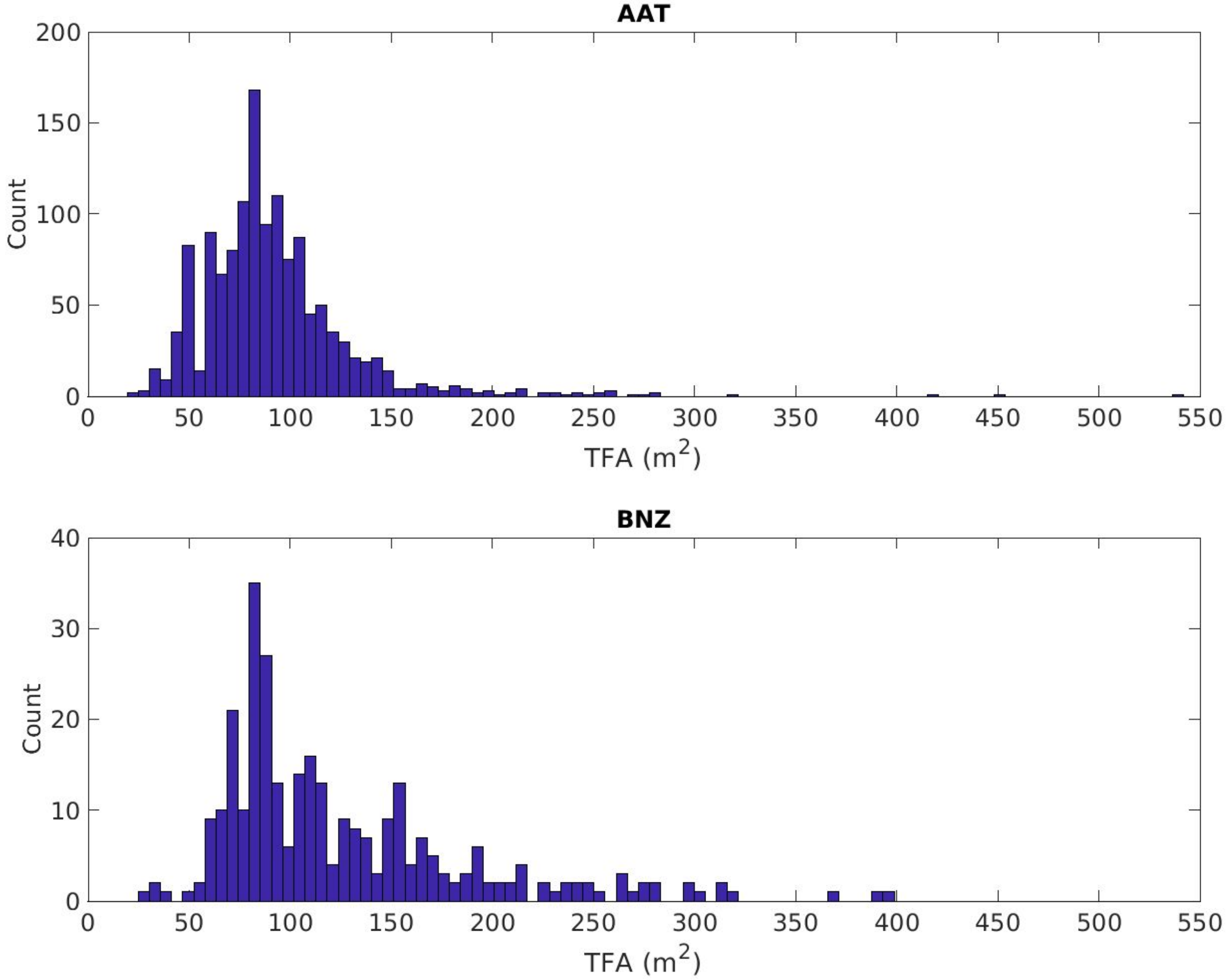
- For BNZ, ONS data from Bigbury in South West England was used for the same purpose.
- It was noticeable that Bigbury had a much higher proportion of older occupants and retirees than the national average. This was reflected in our archetype selection.
- The majority of households had 2 occupants. Hence, the number of families and single occupant archetypes is lower for Bigbury.





Heat demand modelling: House size

- EPC data was used to determine the total floor areas (TFA) of the houses.
- The BNZ area has a higher proportion of larger properties than the AAT area.
- For each community, quantiles at 20 evenly-spaced points were sampled from the sample distributions.
- These floor areas, were fed into the models, in order to estimate heat demands.



Heat demand modelling: Heating systems

- 2024 DFES (Electric Engagement pathway) scenarios for 2035 and 2050 were used to proportionally allocate heating systems to archetypes.
- For the AAT community, due to the higher uptake of thermal storage, a higher proportion of archetypes were given thermal stores.
- Ground source heat pumps and heating systems with thermal stores were more likely to be assigned to larger houses.
- Only low-carbon electrified heating systems were modelled, as these contribute to the aggregate electricity load.

Community	Technology	Baseline	2035	2050
AAT	Hybrid	0	31	27
AAT	Non-hybrid ASHP	34	152	225
AAT	Non-hybrid ASHP + thermal storage	0	172	460
AAT	Non-hybrid GSHP	1	24	216
AAT	Non-hybrid GSHP + thermal storage	0	23	224
BNZ	Hybrid	0	17	15
BNZ	Non-hybrid ASHP	43	79	104
BNZ	Non-hybrid ASHP + thermal storage	0	15	37
BNZ	Non-hybrid GSHP	6	13	21
BNZ	Non-hybrid GSHP + thermal storage	0	7	15

House archetypes

- The 20 archetypes for AAT are summarised here.
- The proportions of types of homeowners and work types were determined by the data on the previous slides.
- These inputs directly feed into the schedule and setpoint choices in the simulations, and the thermal dynamics of the archetypes.

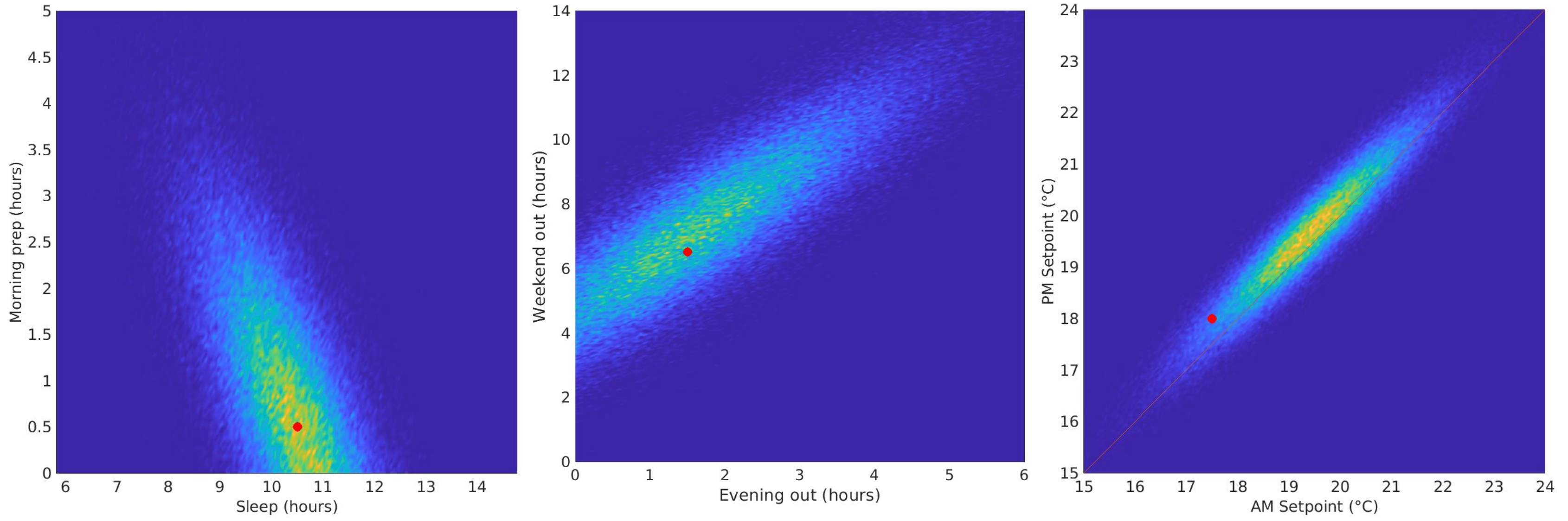
TFA	HeatingSystemType	HomeownerType	WorkType	ThermalStore
46.67142	Heat Pump	Single	Fulltime	No
48.01547	Heat Pump	Couple	Fulltime	No
59.78	Heat Pump	Single	Fulltime	No
64	Heat Pump	Couple	Parttime	No
69	Heat Pump	Old	Retired	No
73	Heat Pump	Family	Fulltime	Yes
76	Heat Pump	Single	Fulltime	No
80	Ground Source He	Couple	Fulltime	No
81.95928	Heat Pump	Single	Parttime	Yes
83.92	Ground Source He	Family	Fulltime	Yes
86.34095	Heat Pump	Old	Retired	Yes
90.05142	Heat Pump	Family	Parttime	Yes
94	Ground Source He	Couple	Fulltime	No
97.23333	Heat Pump	Old	Retired	Yes
102	Ground Source He	Family	Fulltime	No
106	Hybrid Heat Pump	Old	Retired	No
113	Heat Pump	Family	Fulltime	Yes
121	Ground Source He	Old	Retired	Yes
132.1515	Heat Pump	Family	Parttime	Yes
154	Ground Source He	Family	Fulltime	Yes

House archetypes

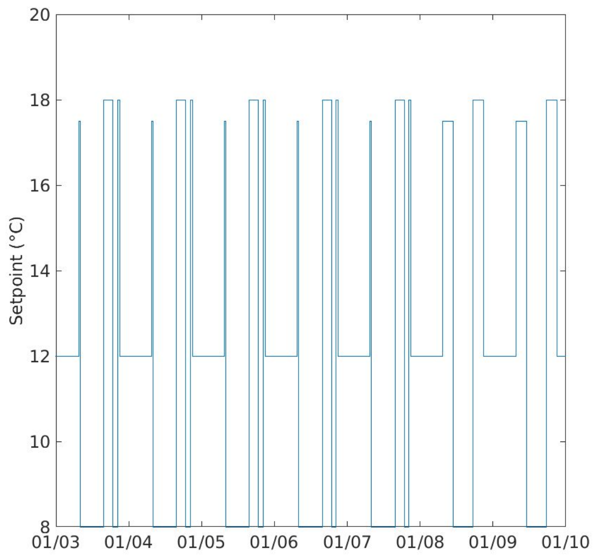
- The 20 archetypes for BNZ are summarised here.
- The floor areas areas were much larger, and hence the corresponding simulated heat demands were higher in the BNZ community, compared to AAT.
- The higher proportion of older and retired occupants is reflected in the work and homeowner types.

TFA	HeatingSystemType	HomeownerType	WorkType	ThermalStore
62.83333	Heat Pump	Single	Fulltime	No
71	Heat Pump	Couple	Fulltime	No
74	Heat Pump	Old	Retired	No
79.635	Heat Pump	Couple	Fulltime	No
82.145	Heat Pump	Old	Retired	No
83.96	Heat Pump	Family	Fulltime	No
87	Heat Pump	Couple	Parttime	No
89.16666	Heat Pump	Family	Fulltime	No
95	Heat Pump	Single	Fulltime	No
104	Heat Pump	Old	Retired	No
110	Heat Pump	Couple	Fulltime	Yes
115	Hybrid Heat Pump	Old	Retired	No
125.8333	Heat Pump	Couple	Fulltime	No
133.1666	Heat Pump	Old	Retired	Yes
148.885	Ground Source He	Couple	Parttime	No
153	Heat Pump	Family	Parttime	Yes
166.2916	Ground Source He	Old	Retired	No
189.5	Hybrid Heat Pump	Old	Retired	No
215	Heat Pump	Family	Fulltime	No
263.6666	Ground Source He	Family	Parttime	Yes

Modelling of heating setpoints & schedules



Example distributions based on real customers



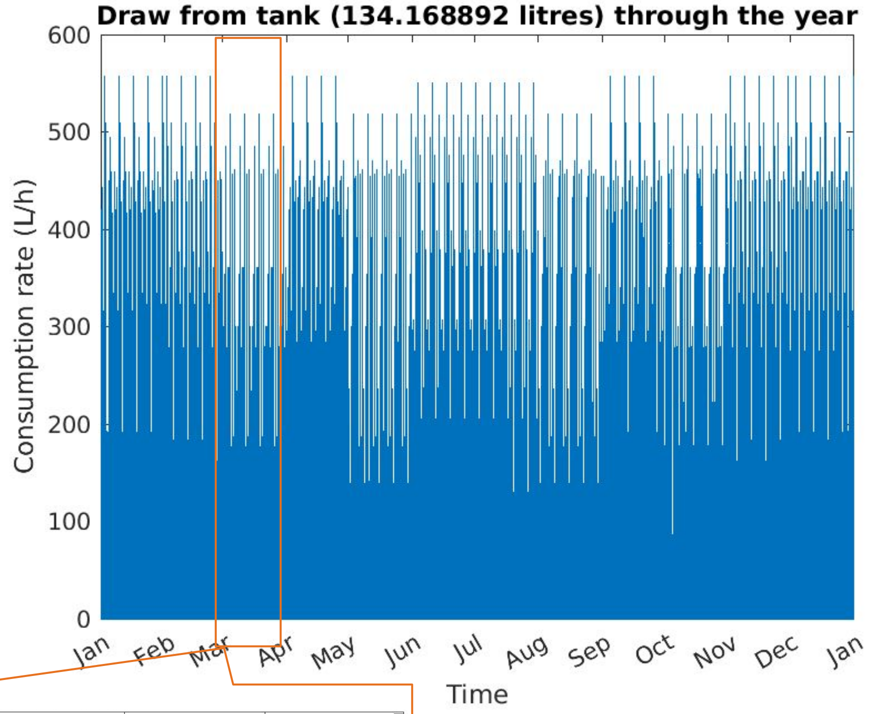
Sample schedule

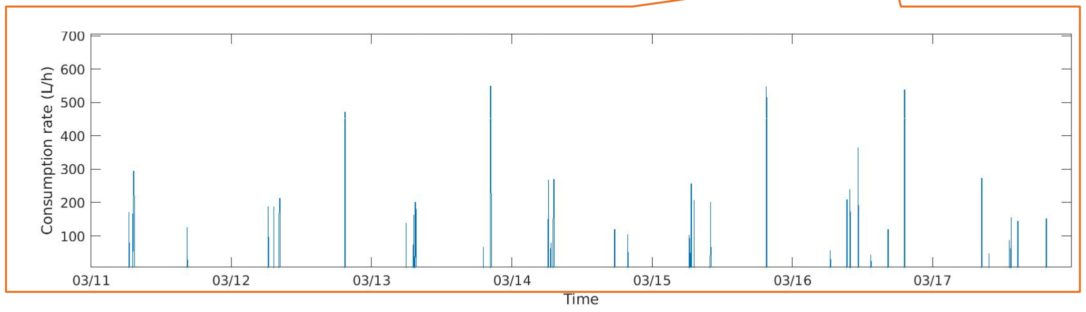
Each archetype has a randomly generated schedule and setpoint, dependent on the occupants and their working schedule.

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

Domestic hot water modelling

- 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)





Annual forecasts

- 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.
- Load profiles and running costs can be predicted for different heating system options and low carbon technology configurations.

An example plot of a subset of annual forecast outputs

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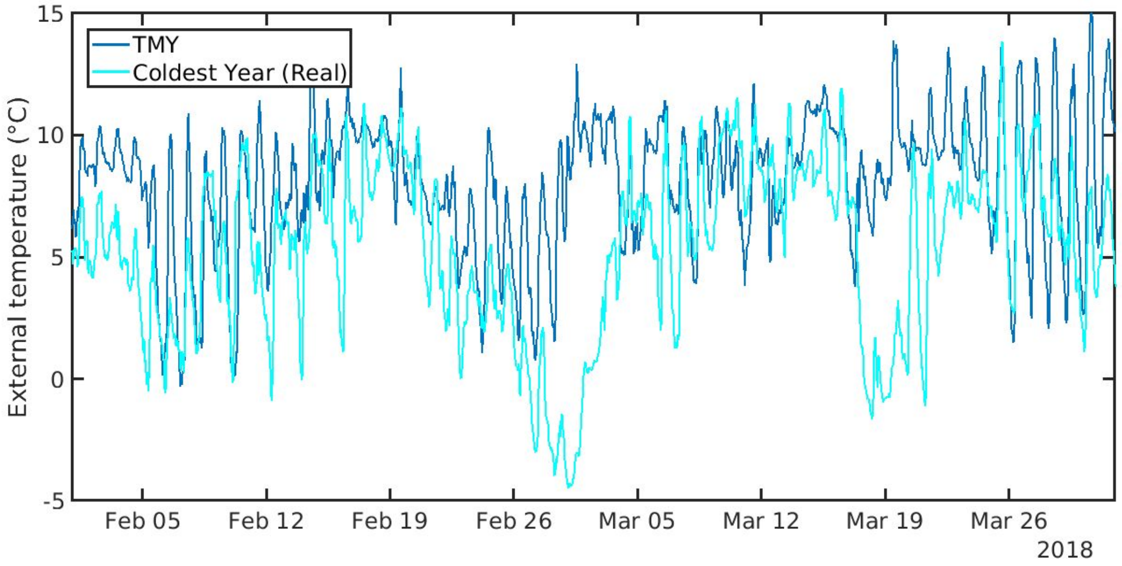
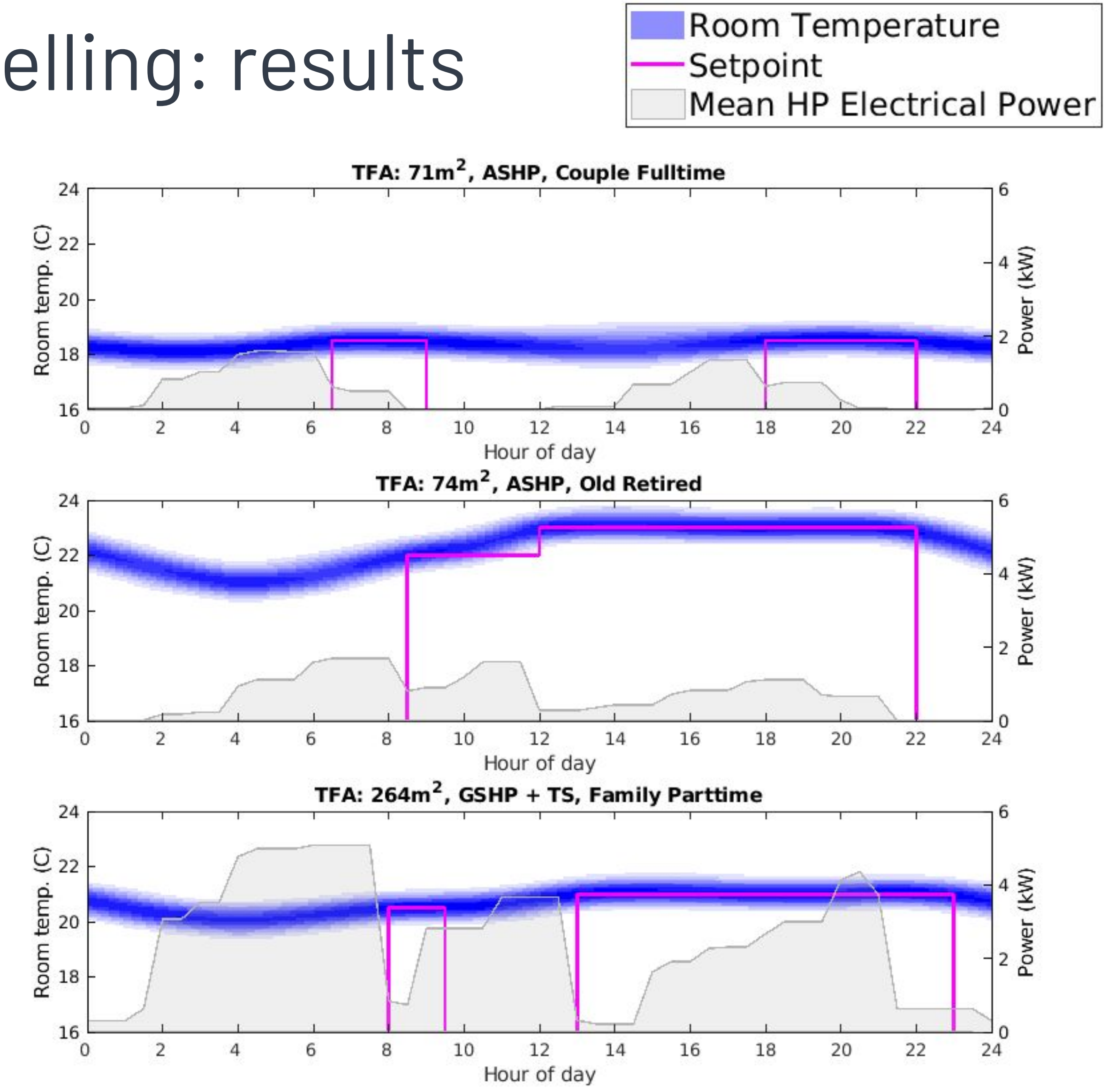
Weather data

- Weather data was used from Mumbles Head and Plymouth, as they were the nearest weather stations to the AAT and BNZ communities respectively.
- For the coldest weather scenario, 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 aggregate community demand.
- For more typical profiles, Typical Meteorological Year (TMY) weather data was used. The TMY data is selected by analysing historical data and finding real months of data which best match the long term averages of daily min/max temperature and daily irradiation. A comparison of this weather data for BNZ for February and March is shown below.



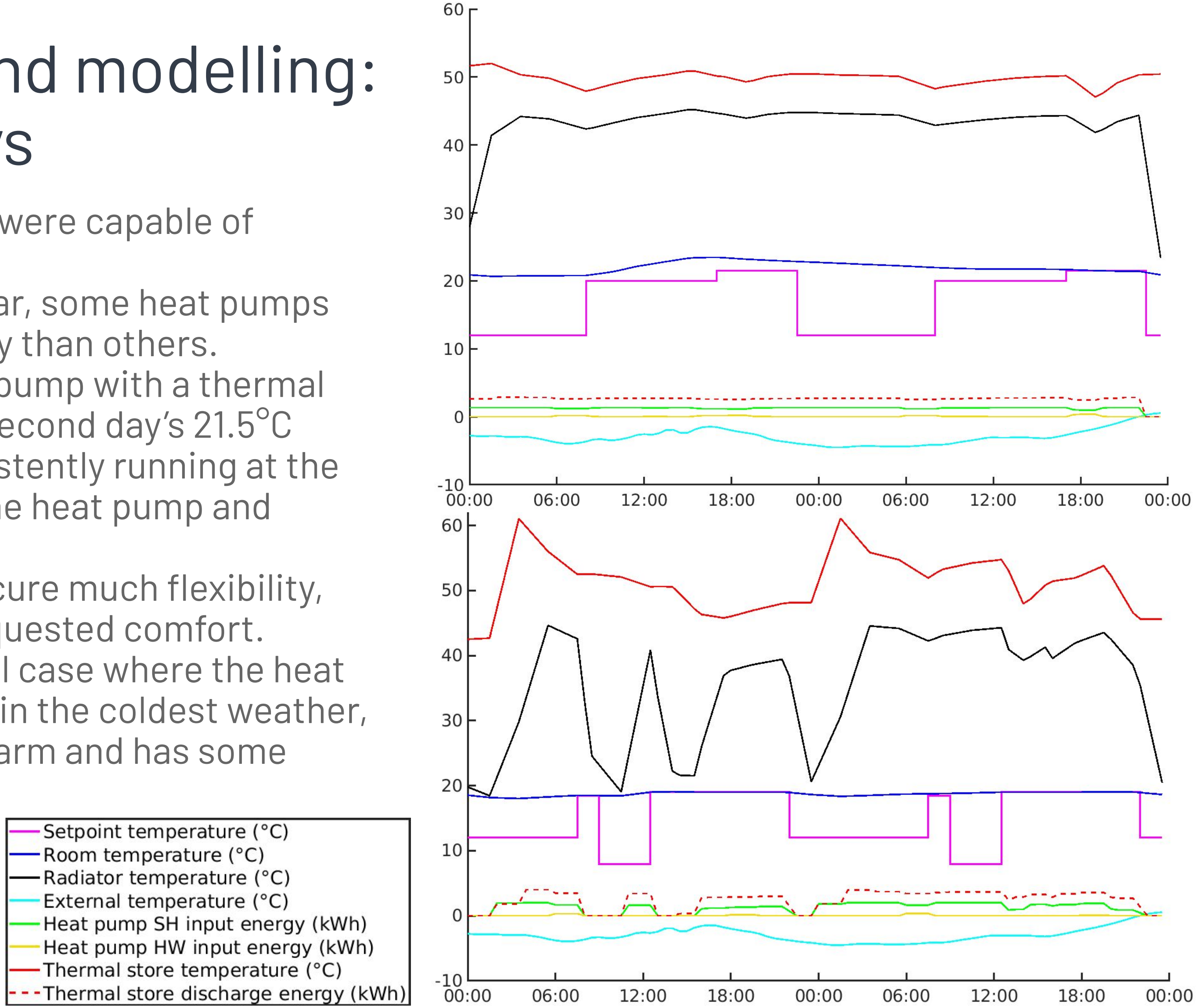
Heat demand modelling: results

- Example outputs from the annual forecast simulations, showing average heat pump electricity demand profiles for the month of January in typical weather conditions.
- Three different archetypes from the BNZ community are shown.
- Graphs show scheduled setpoints, achieved room temperatures, and heat demand (in kWh per half hour).
- Heat pump demand varies significantly archetype-to-archetype. Here, the largest archetype is compared to 2 of the smallest.
- Different occupancies cause changes in heating patterns.



Heat demand modelling: coldest days

- Heat pumps were sized such that they were capable of meeting heating demands at all times.
- However, on the coldest days of the year, some heat pumps are capable of providing more flexibility than others.
- The top graph shows a simulated heat pump with a thermal store that has to preheat to meet the second day's 21.5°C evening setpoint. This is despite consistently running at the maximum electrical power output of the heat pump and discharging the thermal store.
- For homes like this, we are cannot procure much flexibility, without violating the householder's requested comfort.
- The bottom graph shows a more typical case where the heat pump is running hard most of the time in the coldest weather, but still keeps the house sufficiently warm and has some room for flexibility.



Scenario modelling

Scenario modelling: approach

- Use 2024 DFES (Electric Engagement pathway) scenarios for 2035 and 2050 to find the numbers of each low-carbon asset in the community.
- Produce a total non-heat electricity load profile (EV usage plus other 'baseload') for each community in these scenarios.
- Map each low-carbon heating system in the community to one of the 20 archetypes used for the heat demand simulations.
- Calculate the aggregate demand (non-heat load plus heat load) resulting from the simulations in the case with standard manufacturer controls and the coldest weather conditions.
- Investigate whether aggregate demand can be decreased using a simple switch-off command at times of peak load.
- Run Passiv optimisation and inter-home coordination on all heating systems to minimise aggregate load, whilst maintaining user comfort.

Predicted community asset uptake

- 2024 DFES (Electric Engagement pathway) scenarios for 2035 and 2050 were used to find the numbers of each low-carbon asset in the community.
- Each archetype is replicated, such that the total number of each heating system aligns with the predicted DFES scenarios.
- The number of EVs was also determined using these scenarios.
- There are 1488 MPANs in Awel Aman Tawe (AAT) and 383 in Bigbury Net Zero (BNZ). This was used to determine the number of baseload profiles used.

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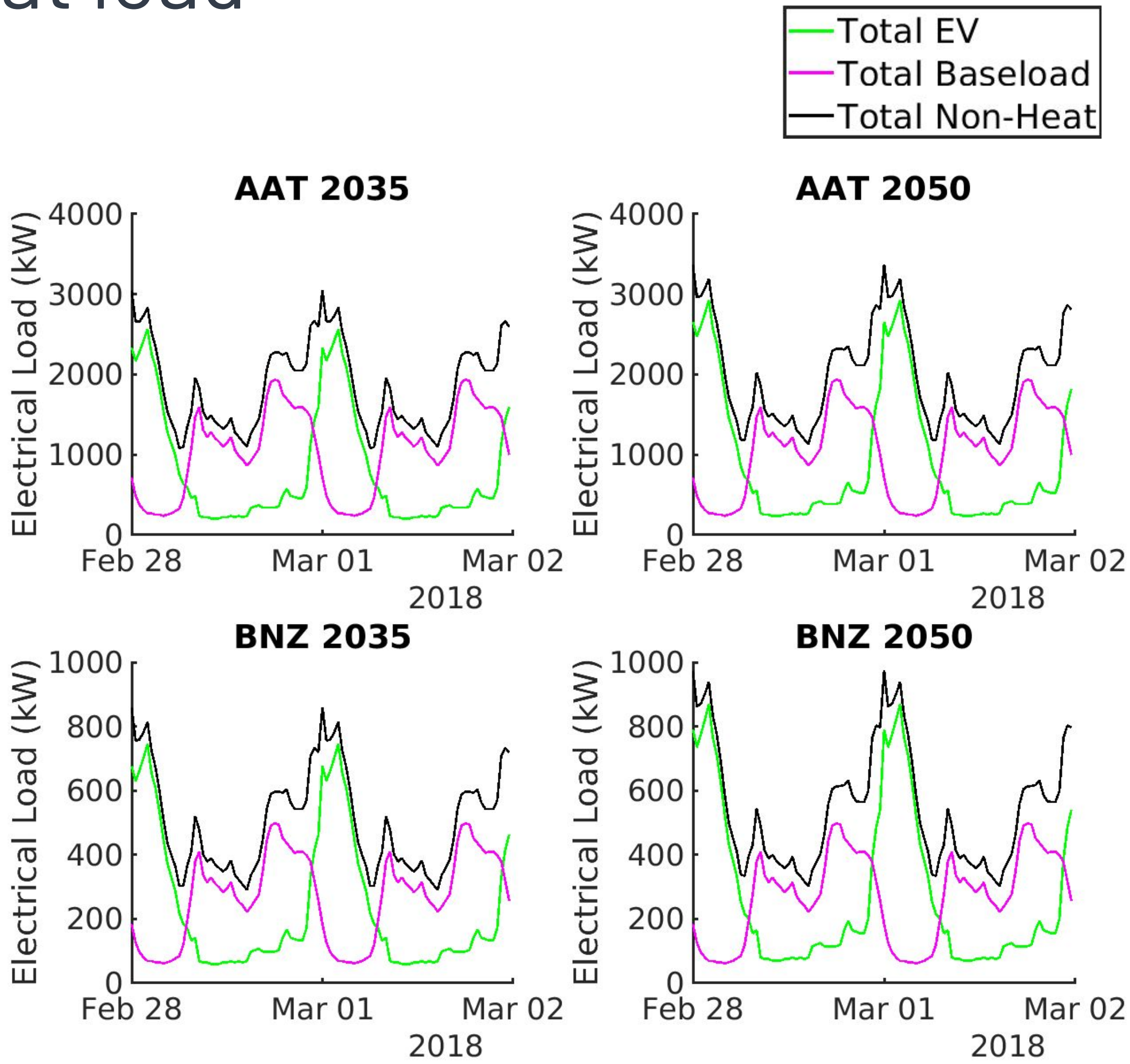
AAT	Non-hybrid GSHP + thermal storage	0	23	224
AAT	EV	31	1476	1681
BNZ	Hybrid	0	17	15
BNZ	Non-hybrid ASHP	43	79	104
BNZ	Non-hybrid ASHP + thermal storage	0	15	37
BNZ	Non-hybrid GSHP	6	13	21
BNZ	Non-hybrid GSHP + thermal storage	0	7	15
BNZ	EV	19	428	500

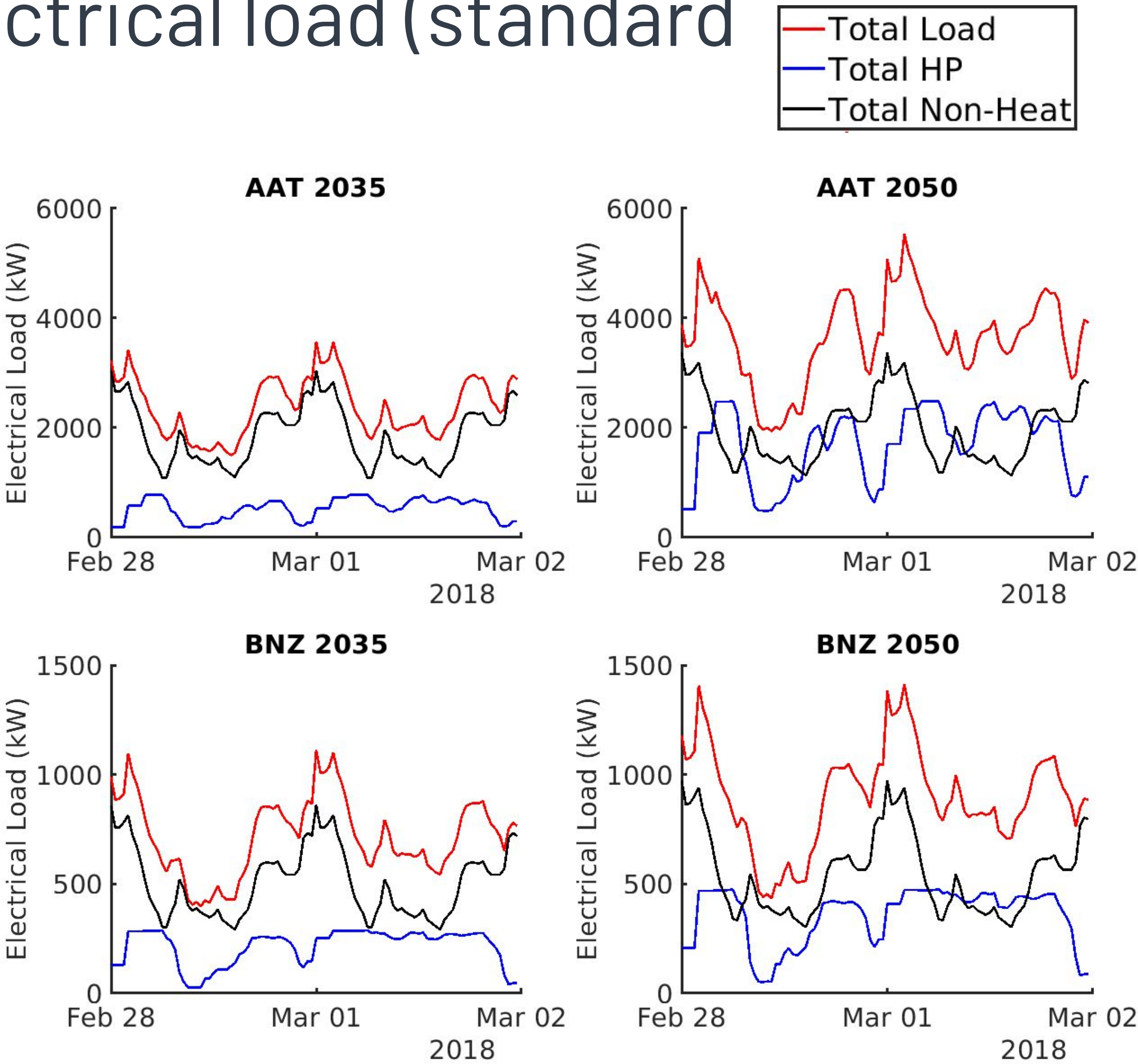
Modelling non-heat load

- Diversified EV and baseload profiles provided by National Grid were used to simulate non-heat loads.
- EV profiles are characterised by high overnight usage, whilst other baseload usage follows a pattern of high usage during the morning and evening hours.
- Non-heat, non-EV baseload is assumed to be constant. Increased EV uptake between 2035 and 2050 causes a small increase in non-heat load.
- If EV chargers are not controlled intelligently, the largest peaks occur overnight.



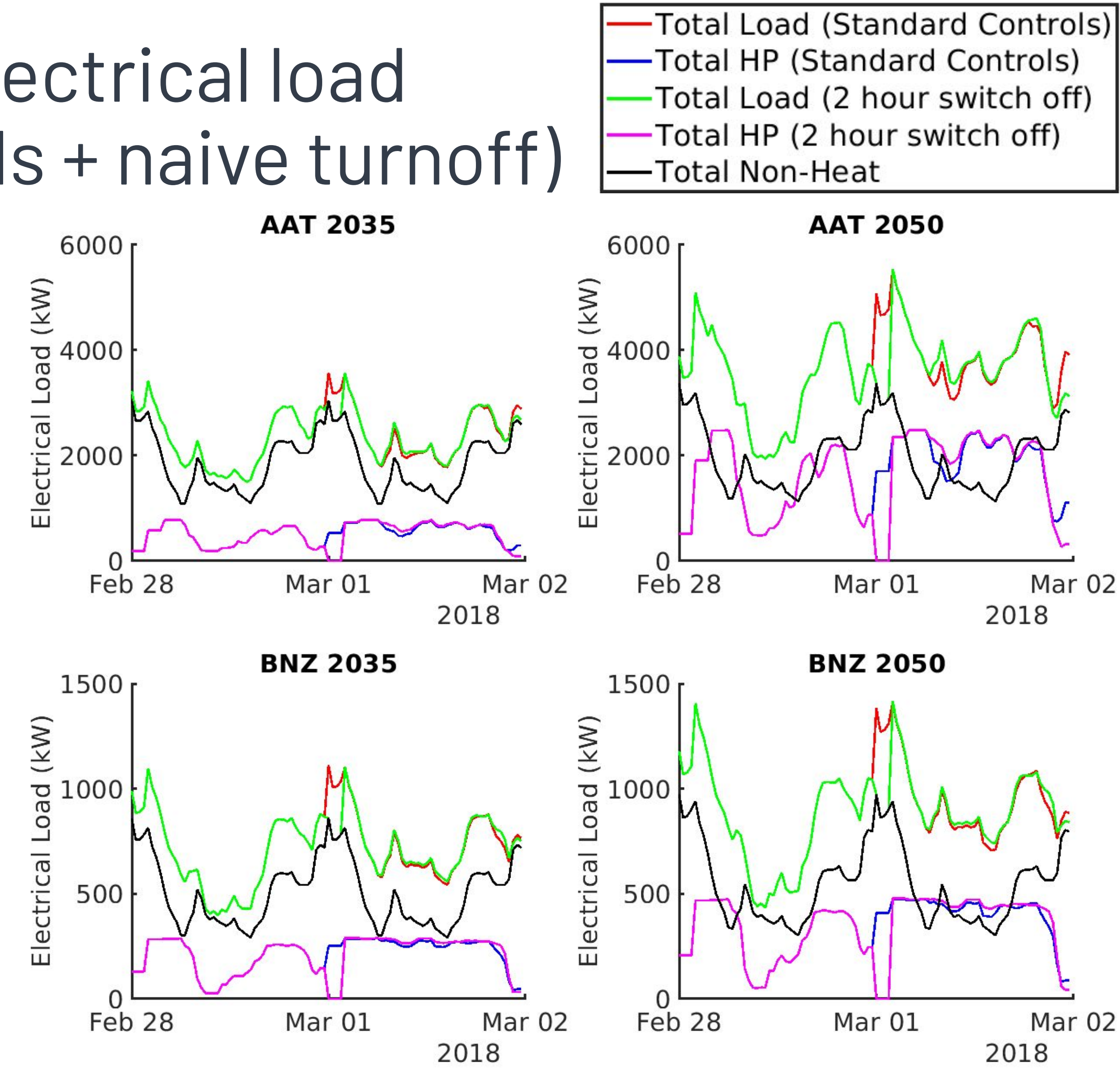
Modelling total electrical load (standard controls)

- In the coldest conditions, heat pumps are running near their capacity most of the time.
- Even with a optimum start, time-clock control strategy, the heat pumps will have to run throughout the night to hit any morning setpoints.
- This results in even higher demand during the EV peak.
- This becomes more of a problem in 2050, as heat pumps become a larger proportion of the total load.
- AAT has a slower uptake of heat pumps than BNZ, hence heat pumps cause less of an issue in 2035.



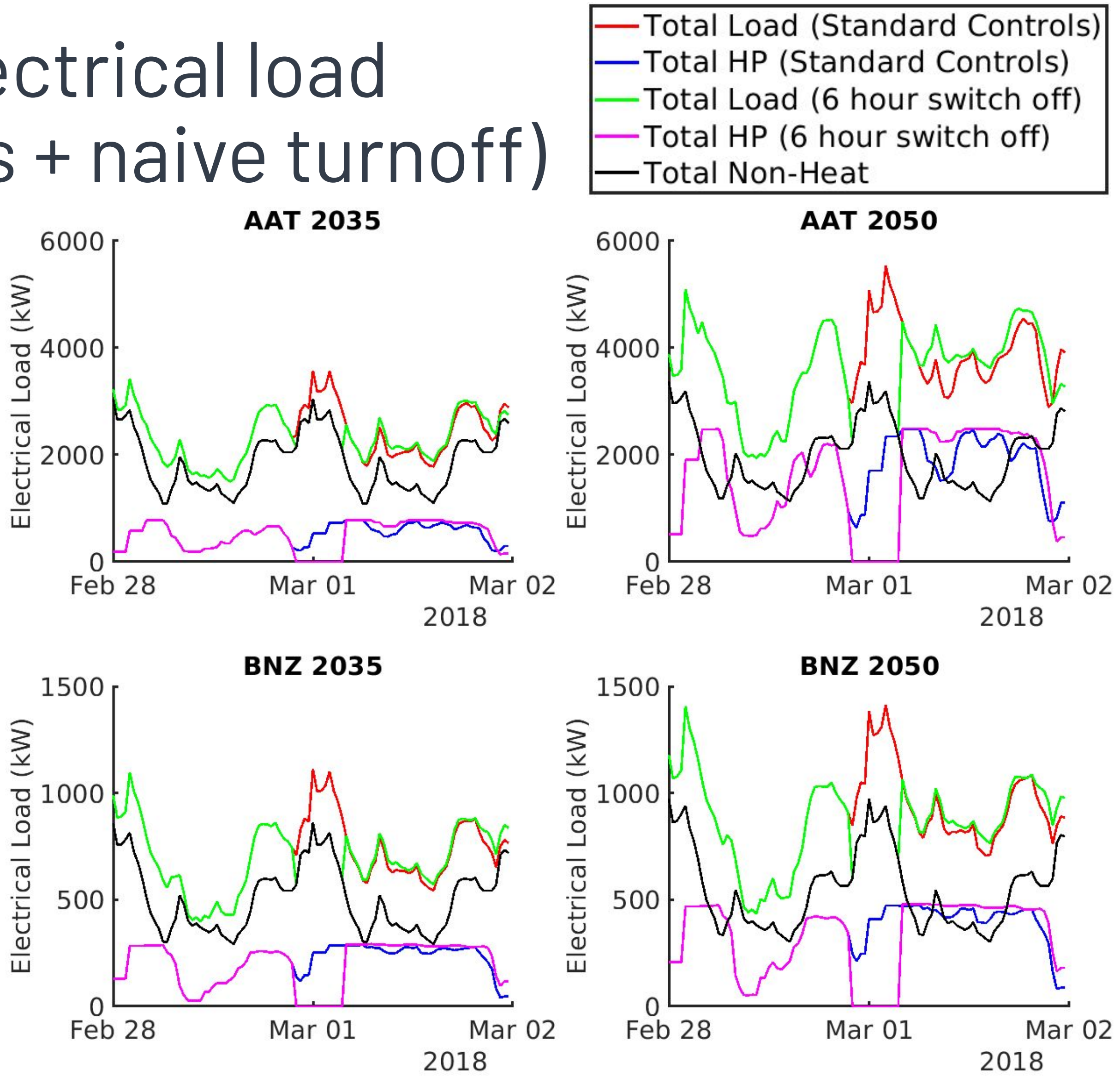
Modelling total electrical load (standard controls + naive turnoff)

- We simulate a scenario where the modular energy centre sends an automated command to adjust heat pump settings to turn off for two hours in individual homes.
- This was scheduled overnight on Feb 28/March 1st between 00:00-02:00 (when the existing EV peak occurred).
- This duration is insufficient to avoid the peak, as the EV peak lasts longer than this.
- Immediately after, most heat pumps turn back on at near maximum power, causing an issue at 02:00.



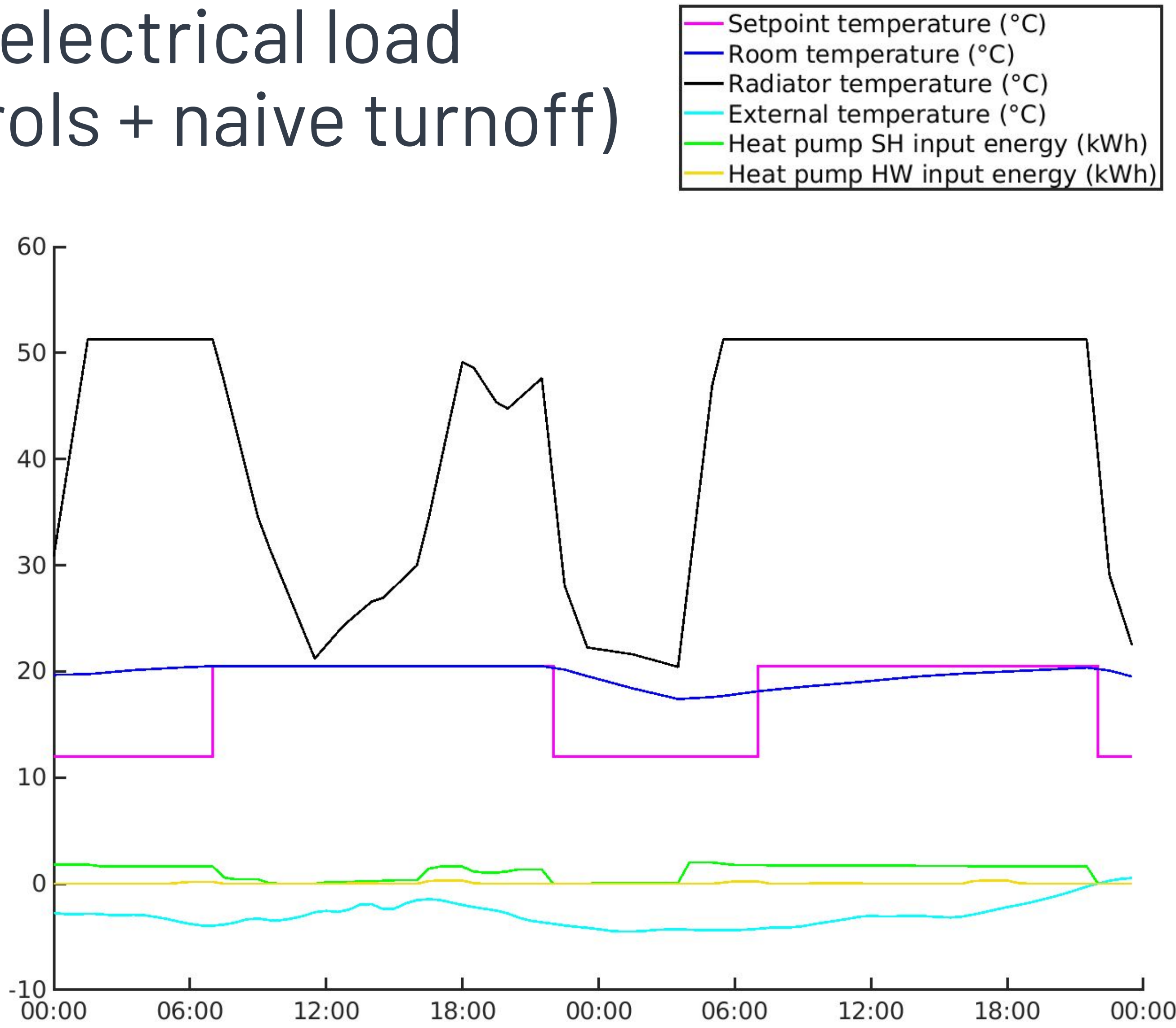
Modelling total electrical load (standard controls + naive turnoff)

- We also simulate a scenario where the modular energy centre sends an automated command to adjust heat pump settings to turn off for six hours in individual homes.
- This was scheduled overnight on Feb 28/March 1st between 22:00-04:00 (when the existing EV peak occurred).
- This does reduce the overnight peak in all cases, however this greatly impacts householder comfort.



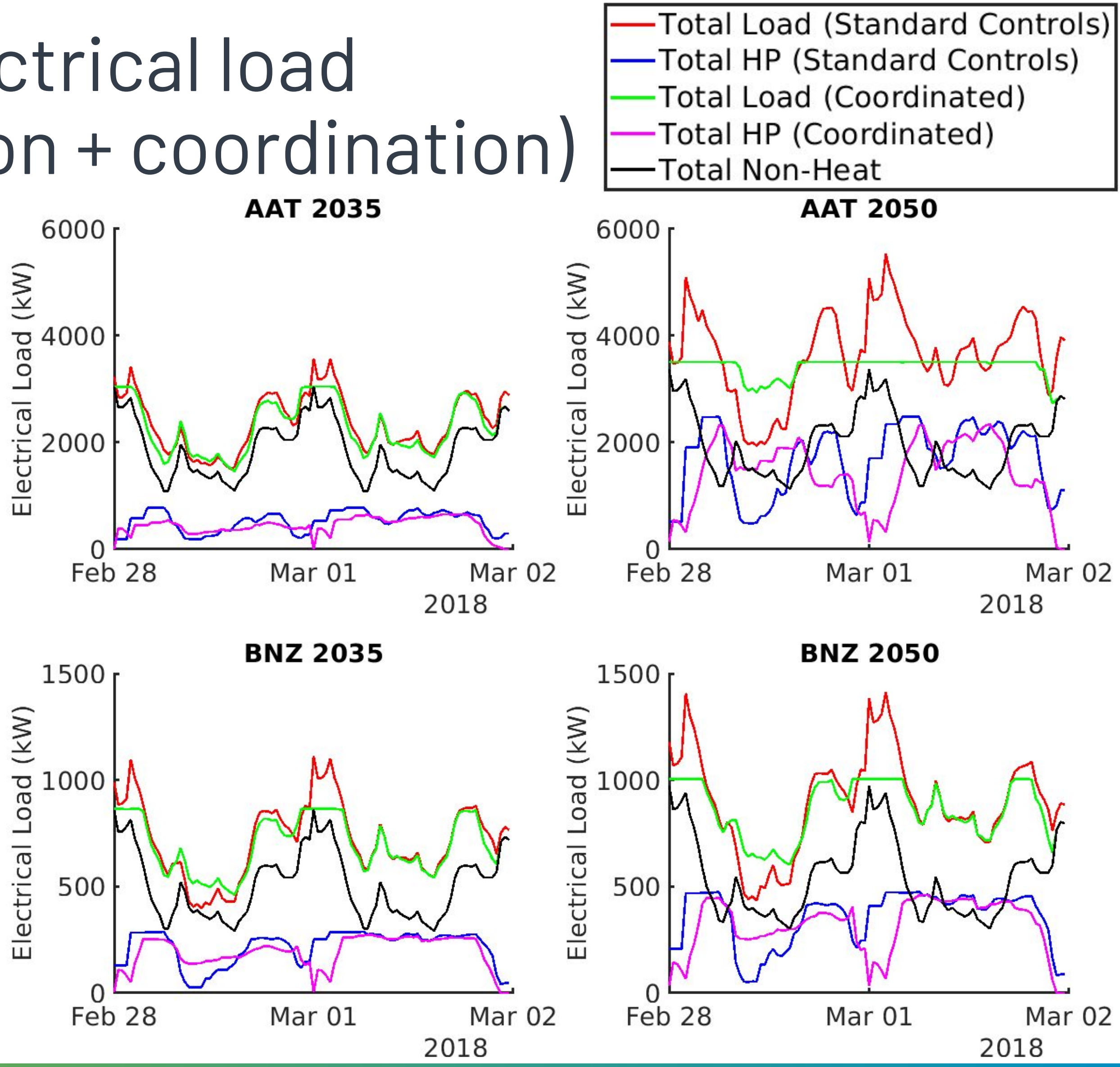
Modelling total electrical load (standard controls + naive turnoff)

- Although the peak overnight demand is reduced in all cases, turning off the heat pump for 6 hours is not an acceptable solution as the householders will be cold for the next day.
- For the archetype shown here, the turn off period causes a major drop in temperature.
- The heat pump has to run at its maximum power and maximum flow temperature for the next day, yet it never recovers to hit the requested setpoint.



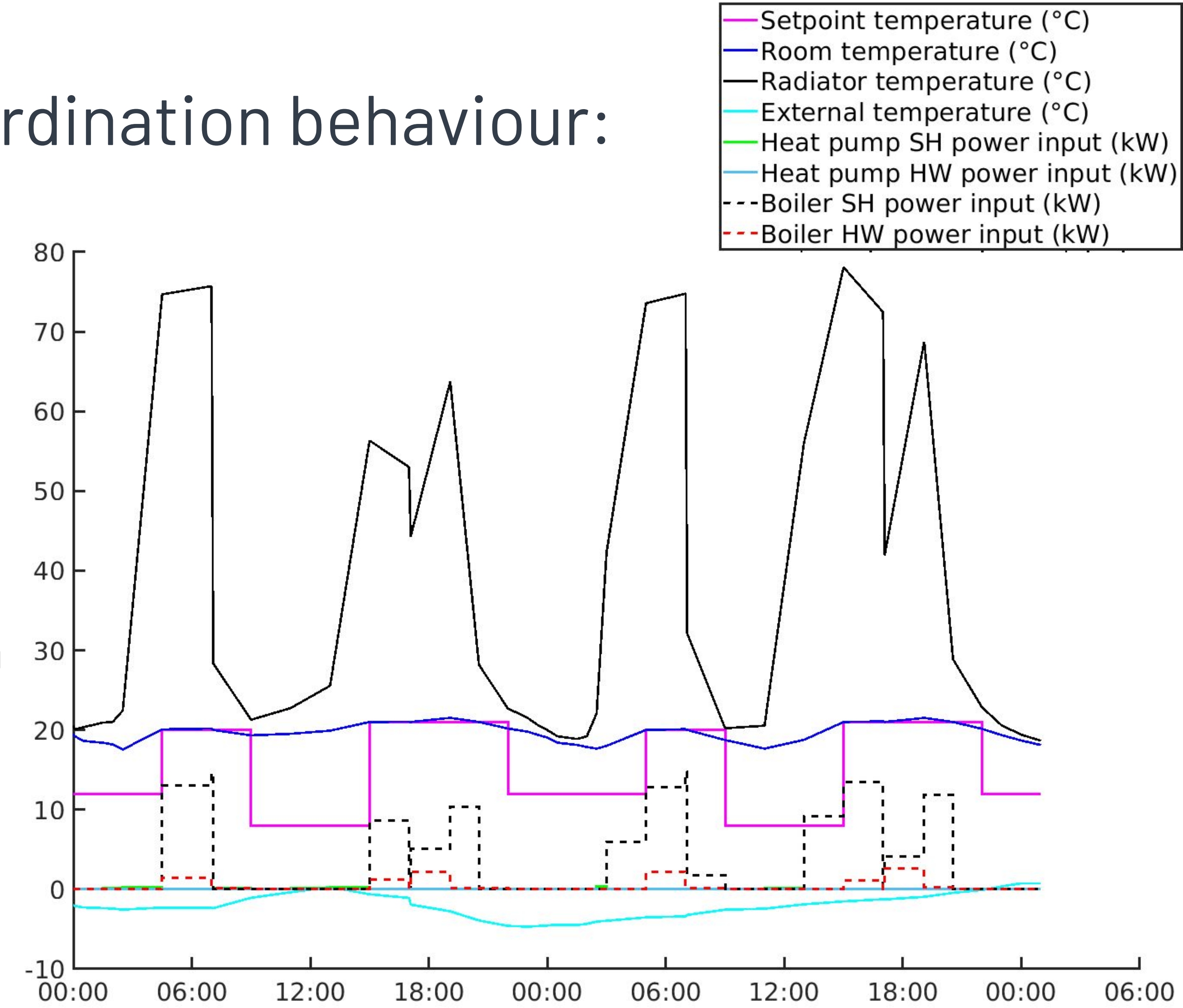
Modelling total electrical load (Passiv optimisation + coordination)

- Passiv coordination attempts to restrict aggregate power to set levels within certain time periods.
- Here, we setup the maximum power limits to flatten the load as much as possible.
- This results in a much flatter demand profile, and is able to work around the overnight EV spike without compromising on comfort (allowing each home to be a maximum of ~0.5°C under setpoint).



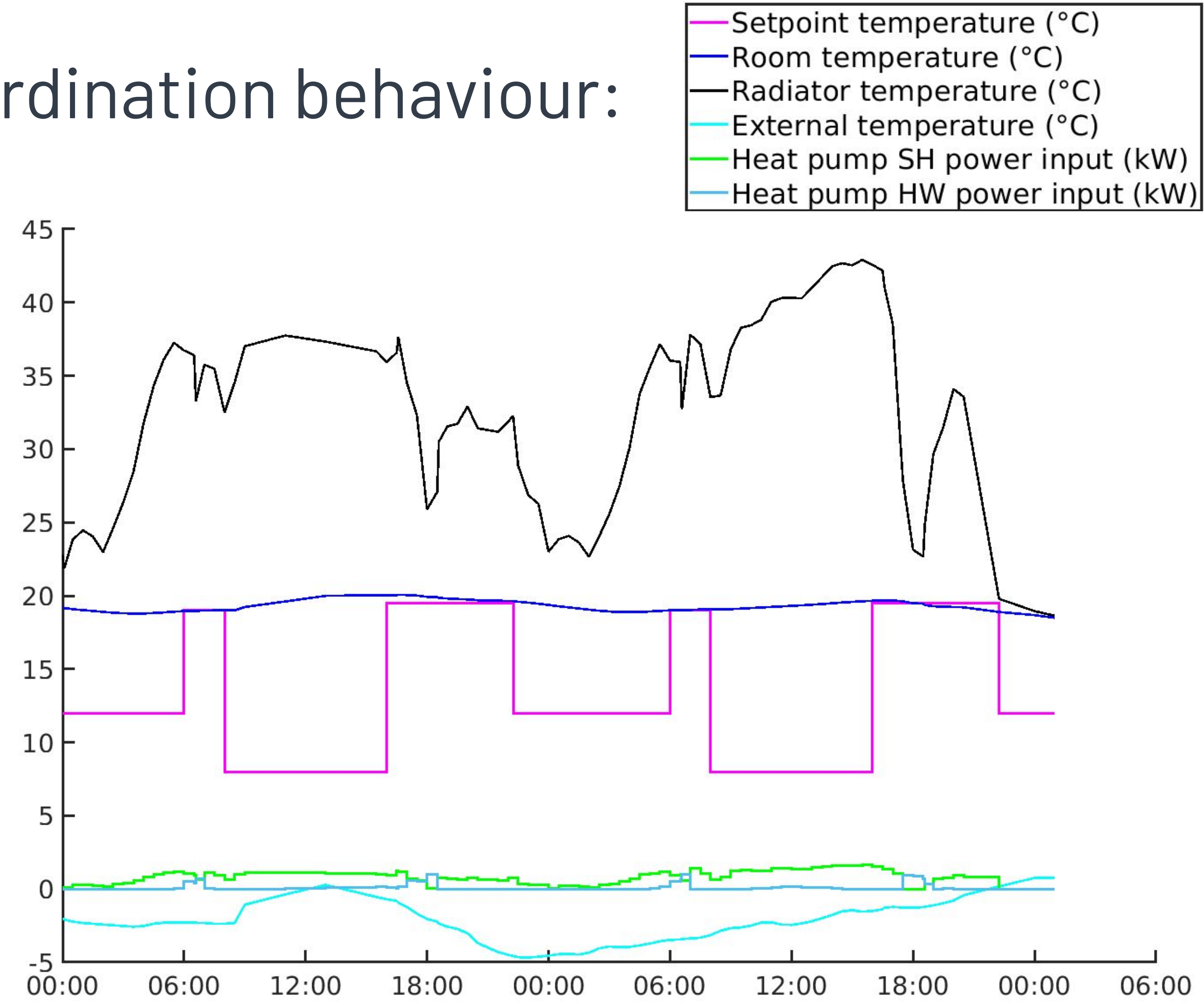
Sample coordination behaviour: Hybrid

- This shows an example of how a hybrid operates would operate during this period under coordination in the AAT community.
- The hybrid is likely to run the boiler in cold conditions regardless, as it is more cost effective to do this.
- Hence, it can meet the householder's comfort and honour a 0kW maximum electrical power at any time.
- Hybrids are the best type of heating system for procuring flexibility with no downsides for the occupants.



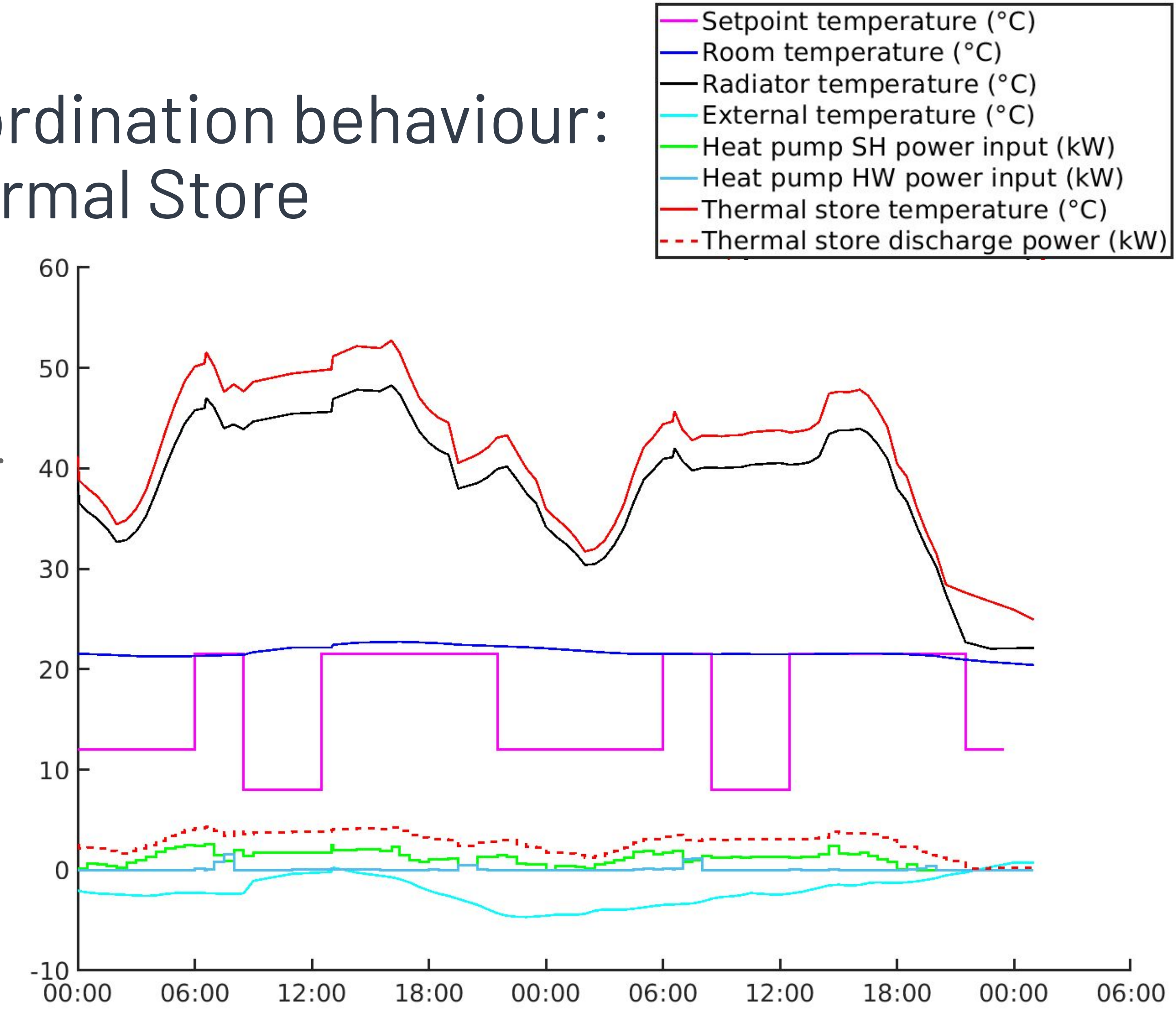
Sample coordination behaviour: GSHP

- This shows an example of how a ground source heat pump would operate optimally during this period under coordination in the AAT community.
- The heat pump reduces overnight usage, particularly in the worst half-hour of EV load and at higher flow temperatures during the day.



Sample coordination behaviour: ASHP + Thermal Store

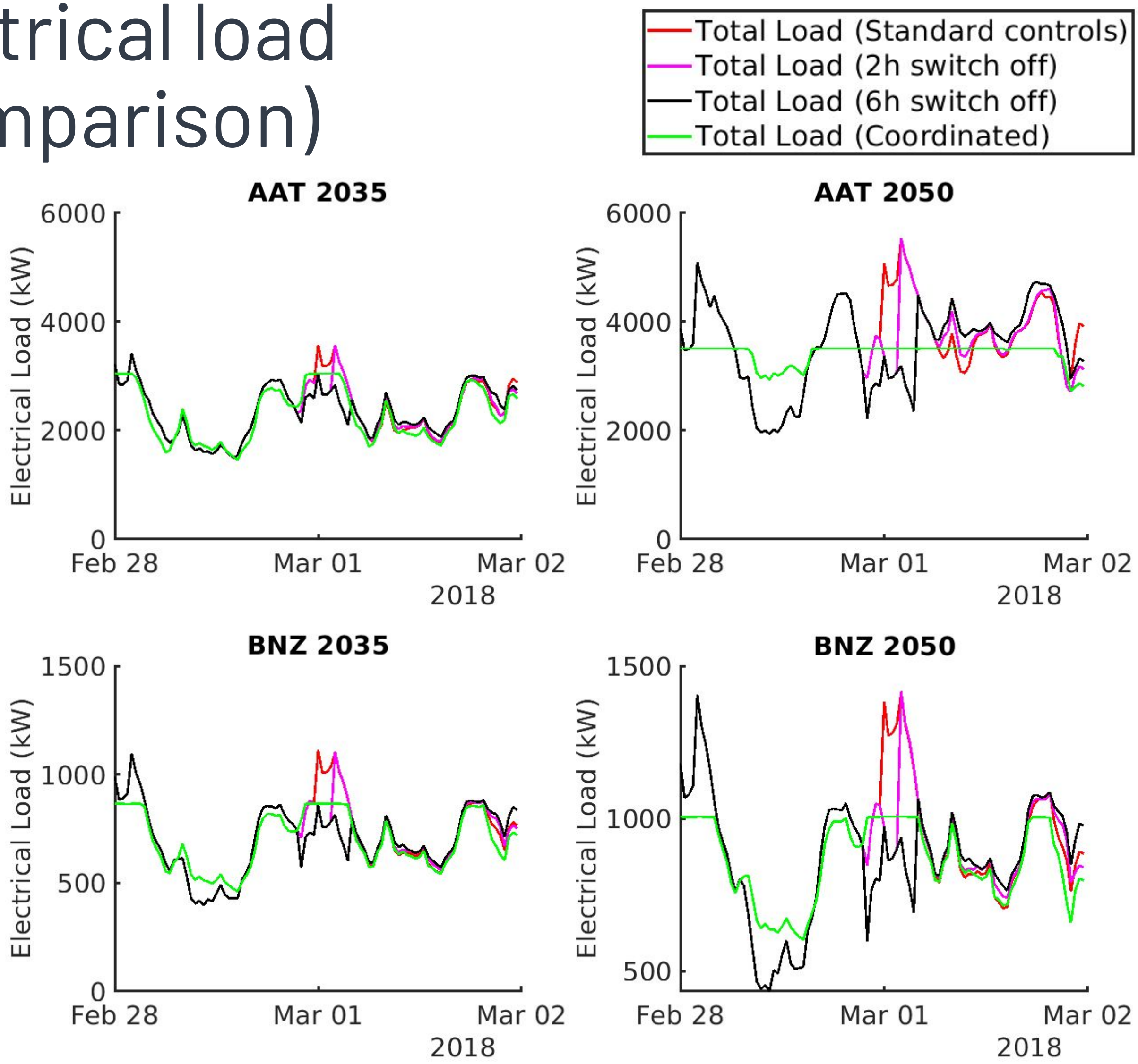
- This shows an example of how an air source heat pump with a thermal store would operate optimally during this period under coordination in the AAT community.
- The thermal store provides some additional flexibility, by allowing the thermal store to discharge during the overnight signal to reduce power.
- Hence, the heating system can still hit the desired setpoint in the morning.



Modelling total electrical load (Aggregate load comparison)

- Passiv controls reduce the peak load by coordinating across all homes, to create a flatter demand profile.
- In all scenarios, Passiv coordination provides a similar or better reduction in peak load than a simple switch off method. This could reduce the required capacity of the energy centre.
- Note that control strategies have different impacts on householder comfort. In particular the 6 hour switch off scenario has a big impact on householder comfort whereas the Passiv coordination scenario ensures comfort is maintained.

Scenario	Standard controls	Standard controls + 2h switch off	Standard controls + 6h switch off	Passiv coordination
AAT 2035	3574	3572	3046	3047
AAT 2050	5534	5539	4527	3509
BNZ 2035	1112	1104	860	865
BNZ 2050	1411	1416	1065	1006



The table shows the peak load (kW) in the communities on the evening/morning of Feb 28th/March 1st, with various control strategies.

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Modelled comfort comparison

- This table shows the maximum room temperature below the requested setpoint at the worst home, with various control strategies.
- Passiv coordination provides comparable comfort to standard non-smart controls at the worst homes, allowing only a maximum of ~0.5°C under setpoint.
- This is more equitable, as homes switch off according to their ability to provide flexibility, whilst ensuring that no individual home is particularly cold.
- As shown previously, switching heat pumps off without coordination means some householders will be cold for the following day.

Scenario	Standard controls	Standard controls + 2h switch off	Standard controls + 6h switch off	Passiv coordination
AAT 2035	0.5	1.12	2.86	0.38
AAT 2050	0.5	1.12	2.86	0.51
BNZ 2035	0.19	0.98	2.57	0.50
BNZ 2050	0.19	0.98	2.57	0.52

Modelled comfort comparison

- This table shows a 'discomfort' metric defined by the total "degree-hours" below desired room temperature setpoint, averaged across homes.
- Here we see that the AAT 2050 coordinated scenario causes more 'discomfort' over more homes, as coordination leverages the allowed 0.5°C under setpoint, when attempting to minimise maximum power.
- In reality, 0.5°C below setpoint is likely to be insufficient to be perceived as 'discomfort' for householders.

Scenario	Standard controls	Standard controls + 2h switch off	Standard controls + 6h switch off	Passiv coordination
AAT 2035	0.05	0.85	5.41	0.1
AAT 2050	0.04	0.85	5.52	2.03
BNZ 2035	0.03	2.03	8.57	0.41
BNZ 2050	0.04	2.09	9.04	0.88

Summary

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Conclusions

- We have calculated the additional electrical demand from installing low carbon heating systems in 2 communities, in 2035 and 2050 uptake scenarios. These used 20 archetypes for each community and simulated every half hour of the year (in a typical year and a cold year).
- We have analysed the impact of a cold spell on total load in the community and evaluated various peak load mitigation strategies:
    - Where a 'switch off' command is issued, it needs to be for a sustained duration to completely avoid the EV peak.
    - However, this will cause discomfort to homeowners in the following day.
    - Passiv optimisation and coordination can flatten or adjust demand as required by the energy centre, whilst simultaneously ensuring no individual house is overly cold.

Next steps

- Enhance the modelling scenarios for each of the communities, including more detailed housing archetypes, user set points and technology uptake rates.
- Carry out additional scenario runs to identify interactions between energy demands, such as heating and EV charging and control signals, and dynamic tariffs and requests for flexibility.
- Include assumptions from community groups on preferences for future service models, including options for delivering optimal community-based flexibility arrangements.