How Will Air Source Heat Pumps Affect Electricity Load Profiles in Buildings in Ireland? A Data Logger Used to Model Electrical Energy Profiles

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Abstract—**There are many global factors that are challenging the colossal transition to *Zero Carbon Economy*, ranging from regional conflicts, possible new cold wars, inflation to rising interest rates. The climate challenge is, de facto, an energy transition challenge, which historically takes generations. Governments all over the world are working to implement policy that encourages society to foster clean energy and low-carbon technologies. It is a fine balance between supply and demand of energy networks, whilst maintaining energy security. This was evident in Ireland during the winter of 2022 which witnessed several *Systems Alerts*, from the *Transmission System Operator* (TSO), EirGrid, mainly due to sub-zero temperatures, low wind, and system capacity. In line with the European Union, member states are moving towards the decarbonisation of energy systems. This will require a holistic behavioural change in the way society provide, transport and consume energy. The large scale expansion of low-carbon technologies, namely *Air Source Heat Pumps* (ASHPs) and the electrification of buildings, using a low-carbon intensity electricity grid is generally accepted and predominantly uncontroversial. This paper aims to analyse datasets produced from a *Power and Energy Data Logger* which consisted of time series data recorded at ten minute intervals from two different load sources. The first dataset monitored an ASHP's electrical energy and the second dataset monitored a residential building's electrical energy over a period in winter 2022. This data allowed the author undertake comparative analysis between different scenarios, such as the ASHP's electrical consumption load profile and the *Outside Air Temperature* (OAT). Furthermore, comparisons were made between the TSO's demand profile and the building's new electrical consumption load profile incorporating an ASHP. This paper's main findings are that ASHP's electrical energy profile fluctuates considerably throughout the day, due to continuously changing OAT. Finally, the comparative analysis between the actual heat pump data collected and the previously predicted profile shows clear variations between the two models.**

Keywords—air source heat pump, low-carbon, electrical energy profile

I. INTRODUCTION

This current research paper focuses on datasets from two domestic residential properties in Ireland, both approximately (200m²) but with two very different *Building Energy Ratings* (BER), one built in 2020 with a BER A1 ($house_A$) and the other built in 2007 with a BER C3 ($house_B$). A Chauvin Arnoux PEL 103 Power and Energy Data Logger was installed and commissioned to monitor the electrical energy consumption for an *Air Source Heat Pump* (ASHP) in $house_A$, whereas, the total electrical energy consumption was collected for $house_B$. The research paper [1] analysed evidence from a heat pump field trial in the United Kingdom (UK) using Renewable Heat Premium Payment datasets, which recorded the electricity consumption of nearly 700 domestic heat pump installations every 2 minutes. This allowed the authors to create an aggregated load profile. Similar datasets should be available in Ireland from the Smart Meter Programme, which is due for completion in 2024. These datasets would also allow one to model the *Time-of-Use* (ToU) tariffs that consumers are currently being offered as part of *smart plans*.

With unprecedented energy bills, the cost of supporting the society through this current energy crisis will be second only, in modern history, to that of pandemic support. In Ireland, the Government introduced the *Electricity Costs Emergency Benefit Scheme*, which credited each electricity account holder with three €200 payments (€600 total) [2]. Long before the confrontational issues between Russia and Ukraine, the challenge to decarbonise the built environment, including domestic buildings, was daunting. In fact, given the high energy prices, the electrification of buildings and moving away from fossil fuels (gas / oil), there is a possible scenario being created where heat pumps could be more expensive than gas systems. In Ireland, current residential prices are 13 – 17 c€ / kWh for gas and 39 - 49 c€ / kWh for electricity. Regarding electricity, Ireland is currently the highest per unit cost in Europe, with the average being ca. 28 c€ / kWh [3]. In fact, Ireland has witnessed a steady increase in electricity costs over the last 15 years, with historical data showing that in 2007 the cost was ca. 18 c€ / kWh [4].

However, using more efficient and low-carbon technology will vastly help reduce the consumption of energy used in the built environment. The solution, nonetheless, is not that simple, and concerns of shifting the thermal heating load from the gas grid to the electricity grid is widely debated [5]. There is the obvious clean option of using low-carbon technology on a low-carbon intelligent electricity grid, but the concerns about ramp rates and localised overloads challenges the *Transmission System Operator* (TSO), EirGrid. In fact, the winter of 2022 brought several *System Alerts* (previously Amber Alerts) for the electricity grid, which is when the TSO warn of the potential for temporary electricity supply issues in the near future. Furthermore, due to the supply and demand issues, there has been procurement for 700 MW of temporary emergency generation and the creation of the *Emergency Electricity Generation Act 2022*.

ASHPs, which extract heat from the outside air, provide both space and water heating to buildings are the go-to technology at present for new builds in Ireland. According to the Sustainable Energy Authority of Ireland (SEAI), 1.3 million heat pumps are to be operational in Ireland by 2030 in both new and existing buildings [6]. Although the market share of heat pumps continues to grow, as of 2020 there were only 50,000 ASHPs installed throughout Ireland [7]. This highlights the large uptake of heat pumps that is required in order to achieve the 2030 and 2050 climate targets. However, this rapid market growth will be challenging to continue as electricity prices rise dramatically alongside the general increase to the cost of living crisis. Some [8] have suggested a slower transition for the existing stock, which would include gas and heat pump hybrids. This would allow a replacement of more efficient technology, without the immediate need to upgrade building fabrics which come as a significant cost to the building owner. A slower transition would present the owner with time to complete required upgrades to improve the overall energy rating of the building, a fabric-first approach. Then the building becomes appropriate for a heat pump, which encompasses a holistic end-to-end approach. Unfortunately in Ireland the majority of the domestic building stock involves replacing an existing heating system with a new heat pump, where the buildings were not purpose-built to be heated by heat pumps. SEAI provide grants for building energy rating upgrades such as; insulation (attic and cavity), heating controls and renewable systems. Furthermore, the SEAI offer three schemes to improve the energy efficiency of homes; Better Energy Home Scheme, Better Energy Warmer Home Scheme and National Home Energy Upgrade Scheme.

Governments throughout Europe are implementing support schemes in the form of grants and subsidies to reduce the higher capital costs associated with ASHPs. There were almost 17 million heat pumps installed in Europe by the end of 2021. Furthermore, REPowerEU forecast that a rapid increase in deployment to ASHPs will see an additional 10 million installed in the next five years, and 30 million by 2030 [9]. Looking specifically at Ireland, the Irish government, through the SEAI, offer home owners a grant of €4,500 (apartment) - €6,500 (house) for the upgrading to a heat pump [10]. Heat is the largest energy end-use, followed closely by transport, and accounted for ca. 42% Ireland's final energy consumption in 2021. Furthermore, it is predominately driven by fossil fuels, namely oil and gas [12]. Space and water heating account for ca. 80% of the energy consumed in a typical Irish household [12]. Therefore, to reduce greenhouse gas emissions from carbon-intensive heating systems and an over reliance on imported fossil fuels, a green transition to low-carbon heating systems is required. The current option of ASHPs, as discussed previously, will shift the built environment to the electrification of buildings and mainly heating systems, which needs to be done in parallel with the decarbonisation of the electricity network. The falling carbon intensity (gCO_2 / kWh) of Ireland's electricity compared to that of gas is one of the main drivers of ASHPs. Ireland's electricity grid has transformed over the last number of years, driven mainly by the green sources of generation such as wind and solar, in line with European and national policy. In fact, the electricity grid has witnessed a falling carbon intensity since the turn of the millennium. In 2000, the carbon intensity of the electricity grid was ca. 674 gCO_2 / kWh, whereas in 2021 it had dropped to 389 gCO_2 / kWh, which is a decline of ca. 44% [11]. For further context, at the time of writing this paper, EirGrid's (TSO) smart grid live data showed a lower value of 181 gCO_2 / kWh, which will fluctuate in relation to the level of renewables available to the electricity grid. In relation to CO_2 emissions per capita and as a comparison, Ireland has a value of ca. 12.4 tonnes CO_2 / eq / person [14], whereas Norway at ca. 6.7 tonnes CO_2 / eq / person [15] has ca. 60% of buildings fitted with heat pumps [16].

During winter periods heating energy demand can reach around five times the magnitude of electricity demand in domestic dwellings [17]. Therefore, EirGrid forecast that the largest growth in demand will come from data centres and new large energy users. Furthermore, electric vehicles (EVs) and the predicted significant increased uptake in heat pump technology, particularly in the latter part of this decade, will have a significant effect on electric power demand and thus, the requirements of the local and national electricity grid at certain times of day and year [18]. In Ireland, the electricity grid peak demand times are relatively repetitive each day and the energy suppliers' smart plans are reflective of this. The morning period sees a small increase in demand between 08:00 – 12:00, and later in the day sees a larger increase in demand between 16:00 – 20:00. It is this period which is commonly known as the peak period. Thus, national peak demand reflects the greatest demands on both the capacity of the transmission network and the generation infrastructure [19].

II. METHODOLOGY

A. *Aims and Objectives*

Given the datasets collected from the two sources, this paper aims to explore three research questions - How will the ASHP's electrical energy consumption profile vary when compared to the *Outside Air Temperature* (OAT), what will the residential building's ($house_B$) electrical load profile look like if an ASHP was to be installed and finally, does the actual heat pump profile match that of the previously predicted profile?

B. *Selecting and Cleaning of Dataset*

The datasets produced from the data logger consisted of time series data recorded at ten minute intervals for the given loads. The first dataset monitored the ASHP's electrical energy (HP_{logger}) consumption over a period of 27 days, from 28.10.2022 to 23.11.2022. The second dataset monitored the residential building's electrical energy (RB_{logger}) consumption over a period of 9 days, from 17.10.2022 to 25.10.2022.

It should be noted that the in relation to the ASHP, the electrical energy consumption from the circulation / ancillary pump(s) were not collected.

The data collected included:

- Electricity consumption of the heat pump (HP_{logger}) over ten minute intervals
- Electricity consumption of the residential building (RB_{logger}) over ten minute intervals
- Voltage, current and frequency
- Power (kW / kVA / kVAr)
- Energy (kWh / kVAh / kVArh)
- Harmonic distortion

The ASHP monitored for this research paper was a Samsung AE090JXYDEH/EU air to water, with a thermal load (kW_t) of (cooling / heating) 7.5 kW_t / 9 kW_t and an electrical load (kW_e) of (cooling / heating) 1.95 kW_e / 2.14 kW_e. The residential properties ($house_{A\ \&\ B}$) are connected to the electricity grid as a *Distribution Use of System* (DSoU) Group 1 (DG1) urban domestic customer, with a *Maximum Import Capacity* (MIC) of 12 kVA.

III. Analysis and Results

A. Appraisal of Power and Energy Data Logger

Fig. 1 shows the ASHP's electrical energy consumption profile for the given period, peaking at 90 kW on 22.11.2022. Furthermore, fig. 2 shows that this peak in consumption has a direct correlation with the *Outside Air Temperature* (OAT), which on that day had a maximum temperature of 6°C and a minimum of -1°C, the only day in November 2022 to go below 0°C.

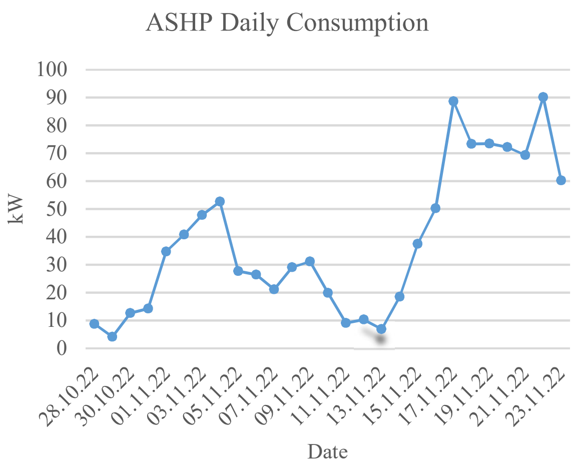

Fig. 1. ASHP Electricity Energy Consumption

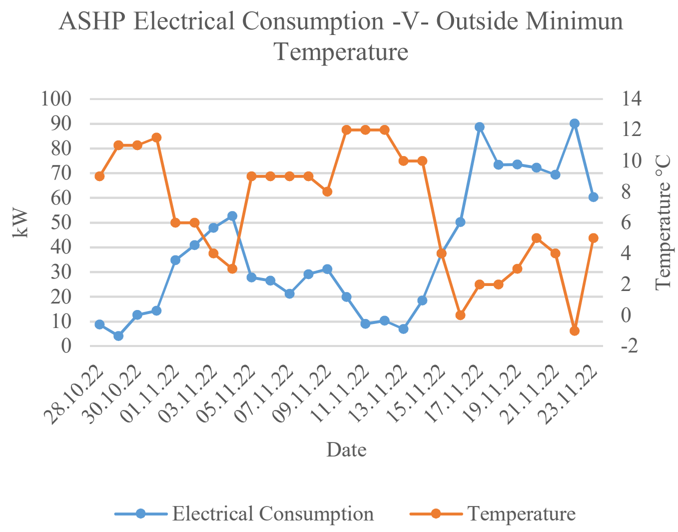

Fig. 2. ASHP Electrical Consumption - V - OAT

The electricity grid in Ireland has a typically similar diurnal load profile throughout the year, with slight variations at weekends. The following patterns have been observed:

- Baseload overnight - this is when the lowest activity occurs from midnight – 05:00; this can be taken as loads which require 24 hour supply (appliances / industry / manufacturing) and off-peak loads (heating / EV charging)
- Increased demand from 05:00 – 09:00 as domestic and commercial activity begins
- Flattening out of demand until midday – 16:00
- Increased demand from 16:00 – 21:00, moving into the peak demand time for the electricity grid
- The cycle then continues as demand drops off again, moving back into baseload (off-peak)

The hourly real-time electrical power demand for Ireland's electricity grid over the same typical period as the ASHP dataset was interpreted from EirGrid [19]. In Fig. 3 the EirGrid demand data is presented over the same time period as the peak demand was experienced from the ASHP (maximum demand day from the data collected). Interestingly, the peak time on the electricity grid, which was discussed previously, which is generally between 16:00 – 20:00 was actually one of the lowest demand periods from the heat pump. This did, however, vary from day-to-day.

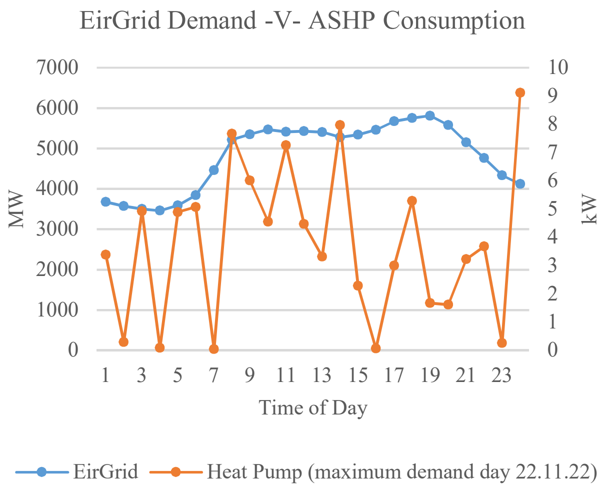

Fig. 3. EirGrid Demand –V- ASHP Consumption

However, Fig. 4 illustrates the average daily electrical load profile which would occur if the residential building (*house*$_B$) was to install an ASHP, representing the electrical load profile for the ASHP and the house combined (an average demand day from the data collected). Interestingly, this dataset shows a bimodal profile with two distinct peaks similar to that of national demand. Moreover, another concern highlighted by this dataset is the potential for a localised overload, as previously discussed, to occur in the residential building (*house*$_B$) due to the high maximum demand peaks. This scenario could have further implications for the local electrical grid, in a wider context, if more ASHPs and electric vehicle chargers were to be installed. However, it should be noted that the load assessment conducted on this residential building (*house*$_B$) revealed no large unique loads, such as an electric shower (10 kW) or electric vehicle charger (7 kW), which would further increase the maximum demand.

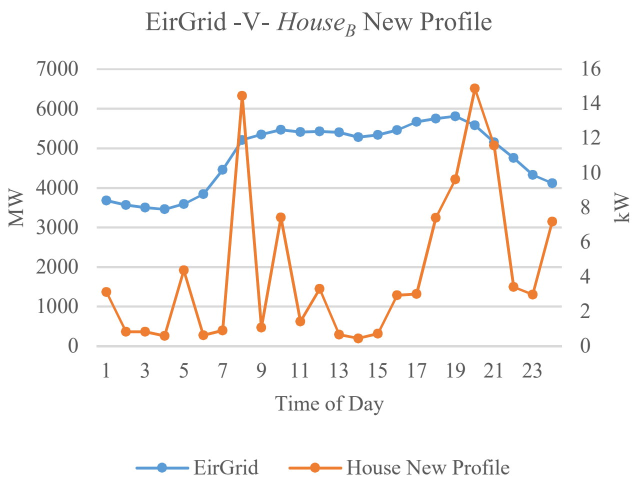

Fig. 4. EirGrid –V- *House*$_B$ New Profile

Furthermore, following on from the author's previous research, the electricity bills continued to be collated for *house*$_B$ from 12.02.2022 - 15.02.2023 (giving a total of 36-months of electricity bills). The data extracted from the bills show a total annual consumption of 4.6 MWh at a cost of €1,693 (this includes PSO, Standing Charge and VAT) and as previously alluded to, the unit costs have increased several times in the 36-month period, starting at 17 c€ / kWh and ending at 40 c€ / kWh (Q4 2022). This annual electricity usage data is marginally above both the Central Statistics Office (CSO) median residential metered electricity consumption of 3.6 MWh [20] and the Commission for Regulation of Utilities (CRU) typical annual consumption of electricity of 4.2 MWh [21]. This is somewhat concerning, as *house*$_B$ does not contain any unique larger loads which would inevitably increase the electricity consumption profile.

Fig. 5 shows data from previous research [23], where the heat pump predicted load was modelled using energy billings and converting the gas consumption to that of an electrical load. With this previous modelled dataset, a comparative analysis is used to illustrate the actual heat pump data against the predicted profile. The findings in fig. 5, which illustrates the maximum daily consumption monitored and a typical average daily consumption, indicates a variation in the actual and predicted consumption profile. Furthermore, some studies suggest [22, 23] that the heat pump profile is somewhat smooth given the continuous operation, compared to that of a gas boiler, which tends to react to the reduction of *Indoor Air Temperature* (IAT). However, it is evident from fig. 5 that this is not the case with clear peaks and troughs throughout the day.

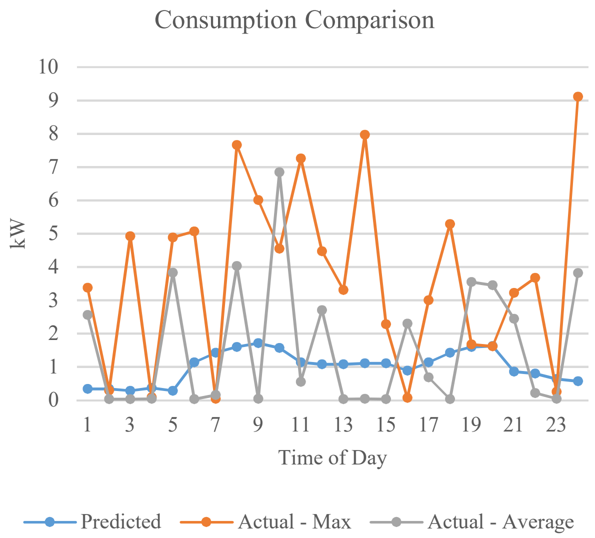

Fig. 5. Consumption Comparison

B. Cost Considerations

TABLE I

Typical Time of Use Tariff Details

Time Band Name	Time of Day	Prices Category	Prices
Night	Midnight – 8 am	€	23.39c / kWh
Day	8 am – 5 pm	€€	44.51c / kWh
Peak	5 pm – 7 pm	€€€	47.46c / kWh
Day	7 pm – 11 pm	€€	44.51c / kWh
Night	11 pm - Midnight	€	23.39c / kWh
Flat Rate	24 hours	€€	40.89c / kWh

Source: [26]

Customers could have concerns about moving from a flat rate tariff to a smart plan, which would allow a *Time-of-Use* (ToU) tariff, or what is also known as a dynamic tariff. These concerns range from electricity consumption data being collected and stored by suppliers, to moving to the wrong smart plan, which have been highlighted and addressed by both the CRU and ESBN under the *National Smart Meter Programme* (NSMP) [24, 25]. The primary reason why energy suppliers are providing these new tariffs, overseen by the CRU, is to change demand-side behaviour and essentially flatten the peak demand times. There is another train of thought, beyond the scope of this research, that suggests aligning the dynamic tariffs with the real-time carbon intensity of the electricity grid, and this may be possible in the future with smart services and smart grid technology advances. Therefore, when there is a high volume of renewable energy available on the electricity grid, consumers should be encouraged to increase demand during this *green peak period*.

The tariff pricing information above was collated from Electric Ireland [26], an energy supplier in Ireland, and using the dataset from the heat pump, the highest daily consumption 24-hour period (22.11.2022) was used as a comparison of the flat rate and the ToU tariff. The findings show that during the 24-hour period, the flat rate tariff would cost €36.85, whereas the ToU tariff would cost €32.92, offering a saving of €3.93 over a 24-hour period. That said, and as can be seen throughout this dataset and other research, the load profiles of heat pumps vary greatly from hour-to-hour and day-to-day.

IV. Conclusion

This follow-on research paper further examines the immediate move to the electrification of the built environment, namely the decarbonisation of heating systems. The ethos of this research is to examine the challenges and opportunities in reducing energy demand and maximising the contribution from low-carbon and renewable technologies to assist the reduction of CO_2 emissions, while ensuring the occupants are comfortable and able to heat homes in an affordable manner. The results of this research show that there is no easy answer or solution to the decarbonisation of both heating systems and the electricity grid. In fact, the best solution will be a myriad of different strategies and technologies being implemented over the coming decades. The most recent report from the International Panel on Climate Change (IPCC) highlights that climate-resilient development is essential to preventing runaway global warming [27]. In fact, there are concerns that the structures in place in relation to action and plans are inadequate to tackle the defining crisis of this and future generations. The IPCC also contends that there is a substantial gap between government commitments to cut CO_2 and the actual levels that are required to limit warming to that of 1.5°C above pre-industrial levels.

As was alluded to in previous research by the author, another major issue within “services for buildings” in this transition to *Zero Carbon Economy* is a skills shortage, alongside a material shortage. In the UK, the government ordered an independent review of the approach taken to delivering net zero, Mission Zero – Independent Review of Net Zero [28]. This report, similar to Irish Government reports, highlights the real threat of falling behind in the race to net zero, due to the lack of a skilled workforce that can deliver low-carbon technologies. That said, academia and industry are working together and developing new courses and programmes in the area of low-carbon. In fact, the Knowledge Centre for Carbon, Climate and Community Action (IKC3) have developed stackable micro-courses, summer schools, collaborative levering, micro-credentials and digitalisation, and TU Dublin’s ClimateLaunchpad for green business ideas. This will be a significant challenge given the looming deadline, set recently by the European Parliament, which outlines that from 2028 all new buildings must be zero-emissions and integrate solar technologies where possible, and buildings operated or owned by public authorities by 2026.

The retrofitting of exiting housing stock for lower emissions and improved energy efficiency will be a major challenge for government and industry for the next decade and beyond. A common approach being used is the whole-house energy system approach, but this relies heavily on data-driven decision-making. This will require a cross sectorial approach, using data from the initial building assessor’s findings, building occupant’s real-time usage to TSO real-time generation mix and carbon intensity being presented through some digital access platform. Today, buildings that are designed for energy efficiency are usually highly controllable and intelligent, enabling them to respond to real-time changing internal and external conditions. More energy efficient buildings can better meet the needs of occupants, but also can work in collaboration with the TSO, as the electrification of services (and battery storage / electric vehicle charging) gives the diverse building load profile a unique ability to respond quickly and easily to the needs of the electricity grid. Furthermore, if the building in question is being retrofitted over a given time period, the incremental impact of each upgrade can be monitored. In relation to $house_B$ which has an annual electrical consumption of 4.6 MWh, it is estimated that if a photovoltaic and battery storage system was to be installed it would meet ca. 2.8 MWh of the household demand, with excess being sold back to the grid during summer months. However, this warrants further investigation and detailed modelling.

Finally, this paradigm shift in the built environment, where on-site electricity generation and energy storage is becoming commonplace, the traditional passive unidirectional relationship between buildings and energy networks are changing to that of an active bidirectional one.

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