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How will Heat Pumps affect Electricity Load Profiles for Buildings in Ireland? Empirical data used to model possible financial impacts facing consumers

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***Abstract*—The current geopolitical situation is certainly challenging the colossal transition to *Zero carbon Economy*. In fact, in the coming years, the electricity sector will have to find new innovative ways to meet the ever increasing need for energy without the over reliance on fossil fuels and their country of origin. Over the next decade, oil and gas boilers will not be permitted in new buildings in Ireland, in line with the Irish Building Regulations, *Technical Guidance Document L – Conservation of Fuel and Energy 2021*. This is a major shift in traditional building services methodology and heat technology. In line with the *European Union Green Deal*, member states are developing and updating policies in an effort to foster this energy transition. The main areas of focus are the three pillars of energy and the associated carbon emissions; electricity, transport and heat. This paper aims to examine energy bills, electricity and gas, for a domestic family premises over a 24 month period. This data will allow the author to build a demand load profile model for the energy consumption and thus, forecast the transition to the electrification of building services. Today, the readily available solution on offer for industry are heat pumps (HP) which will allow the fuel source to move away from a carbon heavy source to a cleaner electricity source. This paradigm shift in thermal demand technology, to a decarbonised electricity source may place a large burden on the national electricity grid during peak demand times. Given the acute energy crisis being currently witnessed throughout Europe, this paper highlights the potential increased electricity bills that consumers might face while shifting to heat pumps. This paper's main findings are that without Demand Side Management (DSM) tools and smart services, such as *smart meters* and *Time-of-Use* (ToU) tariffs, consumers could face increased winter energy bills in the region of 184%.**

Keywords—zero carbon, building services, electrical demand load profile

I. Introduction

In Ireland, there is currently a major shift from traditional space heating and hot water technologies, which requires many different decarbonisation scenarios to be modelled. This new direction of heating technology and design practices is primarily driven by the *European Green Deal* and European Directives, namely the *Energy Performance of Building Directive, Energy Efficiency Directive* and the *Renewable Energy – Recast to 2030 (RED II)*. In fact, institutions operating within Horizon Europe and InvestEU programmes are driving most of the Research and Development (R&D) investment in that area. The latter cross sector directive focuses in on three pillars of energy and the associated carbon emissions; electricity, transport and heat. Furthermore, domestic space heating and hot water represent a significant energy demand and are a large source of carbon emissions throughout Ireland. Fossil fuel technology, gas and oil, represented 74% of domestic heating requirements throughout Ireland in 2021 [1]. Thus, further incentives must be put in place to improve the energy efficiency of the existing housing stock and continue with the installation of low or zero carbon technologies.

Furthermore, Ireland is heavily dependent on fossil fuel imports for the aforementioned pillars of energy. This flow of energy is not sustainable in a net zero model and has come to the fore in recent times due to geopolitical circumstances. In fact, Europe's energy prices have reached unprecedented high levels, thus, exposing the fragile system [12]. Moreover, forecasts predict that the shift to lower energy consuming buildings and switching to lower carbon heating technologies could see Europe cut its spending on gas imports by €15 billion in 2030 and €43 billion in 2050 [12].

The European Commission envisions that by 2030, all new buildings must be zero-emissions. This is being enforced within member states by national government and building regulations, which have been developed in conjunction with European Directives. Looking specifically at Ireland, the Building Regulations, *Technical Guidance Document L – Conservation of Fuel and Energy 2021*, highlights the shift to *nearly Zero-Energy Buildings* (nZEBs). Moreover, this new direction of design will require buildings to consume little energy, be powered by renewable energy sources, where possible, emit no on-site carbon emissions from fossil fuels and must indicate any global warming potential based on whole-life cycle emissions on their *Energy Performance Certificate* (EPC) [13]. Moreover, the electrification of building services, which is being guided by CIBSE TM67:2021, coupled with energy efficiency and low carbon electricity grid will be a key solution to meeting such directives [14].

Ireland's Climate Action Plan calls for 400,000 heat pumps to be installed in existing dwellings up to 2030, with a further ca. 850,000 to be installed in newly built homes [2]. This high electrification scenario will see heat pumps supply 12-20% of heating demand in 2030 and 33-38% in 2050. These technologies are available now and are the most cost effective decarbonisation option for many heat users [4]. In fact, the Irish Government, in conjunction with the Sustainable Energy Authority of Ireland (SEAI), are actively promoting heat pump technologies through incentive schemes such as the *Support Scheme for Renewable Heat* (SSRH). This alternative heating technology, which will be fuelled by cleaner zero carbon electricity is possible, but presented complex issues for EirGrid, the Transmission System Operator (TSO), in relation to grid supply and demand. This coming at a time when demand is already at an all-time high, which has been primarily driven by the massive increase in data centre development and transport [3,6]. This will present issues for the national electricity grid as the electrical energy demand increases and thus, so will the peak electricity demand. However, the decarbonisation and the achievement of a modern flexible and dynamic electrical infrastructure is a crucial foundation for the progress within the heat sector.

This increased demand on the electricity grid, due to market adaption of heat pumps, will put pressure on, both on the distribution and transmission infrastructure. Looking to 2030, the electricity demand is set to increase as consumers, both large and small, find new ways to use the resource. Therefore, EirGrid have included a forecast for electric vehicle and heat pump growth in Ireland over the next ten years. In line with the government's Climate Action Plan, EirGrid will track the uptake in these aforementioned technologies over the next ten years and will adjust targets and forecasts accordingly [6]. That said, the modelled scenario for 2030 shows that electric vehicles and heat pumps will be dwarfed by large energy users, such as data centres and heavy manufacturing. Currently, Ireland's electricity grid has an all-time high demand of 6.9 GW (21.12.2010) [7], if the modelled increase demand scenarios to 2030 are extrapolated using the low (9%) and high (48%) models, this could see 7.5 GW and 10.2 GW, respectfully [6]. However, EirGrid contend that the forecasts maybe reduced somewhat by allowing for energy efficiency savings, particularly the effect of smart meters [6]. It is assumed that the role out of smart meters could cause the peak electricity demand to decease by up to 8% for domestic users [6, 8]. This reduction in peak demand will be facilitated with the introduction of smart services, such as remote reading, *Time-of-Use* (ToU) tariffs and smart bills [9]. Currently, there are 620,000 smart meters installed throughout Ireland. In 2024, the National Smart Meter Programme will be completed, and this will see the installation of 2.4 million electrical smart meters at a cost to the end user of €1.2 billion.

II. METHODOLOGY

A. *Aims and Objectives*

This paper aims to meet two main objectives. Firstly, analysis of the energy bills, electricity and gas, for a domestic family premises (200m²) (Building Energy Rating) (BER C1) over a 24 month period. The energy bills will be used to build a demand load profile for consumption of electricity and gas for the given period. Secondly, the paper explores how determining possible future scenarios pertaining to heat pump uptake / roll out, in terms of forecasting peak demands on the given premises and thus, the potential wider effect on the national electricity grid. The gas load profile was converted to an electrical load using a *Coefficient of Performance* (CoP) of 3.5, which will give a forecasted overall electrical demand load profile [15]. However, even by using a high CoP, which is somewhat more challenging to maintain in peak winter, this still represents a very significant shift in order to meet future thermal demands through the electrification scenario [14].

B. *Selecting and Cleaning of Dataset*

The data collected consisted of collated bi-monthly energy bills over a 24 month period from February 2020 to February 2022. The dataset acquired consisted of the actual energy consumption, kilowatt-hours (kWh), for the bi-monthly periods. The energy bills highlighted the total kWh of usage for the given time period, thus, a typical load profile model for this type of premises was developed to display monthly, weekly and daily energy consumption patterns [16]. Furthermore, the heating demand load profile was extrapolated to construct a future heat pump scenario and subsequent increase in electricity demand.

In relation to the energy bills, it is estimated that heating loads will reduce by half by 2050 if building upgrades and heat pumps become widespread. The alternative option of sticking with the status quo could see consumers paying considerably more for hydrocarbon based systems [12]. Whereas, European average retail electricity prices are projected to remain around 15 c€ / kWh as the grid decarbonises through the uptake of renewables. Consumers may see an initial increase in energy bills, but as the *Time-of-Use* (ToU) tariffs becomes widely available, there should be a reduction due to behaviour patterns and a real-time awareness of usage costs [8].

III. ANALYSIS AND RESULTS

A. *Appraisal of Energy Bills*

Fig. 1 & 2 illustrates the electricity and gas demand profile for the premises, which has been modelled on the energy bills from the period February 2020 to February 2022. The demand profile shows typical peaks and troughs between the summer and winter months. This papers will examine the increase demand on the installation as the heating system upgrades to a heat pump. As one can see, the peak electricity demand will see a dramatic increase when the heating energy requirements convert from gas to electricity. A closer examination will be presented for a daily demand profile.

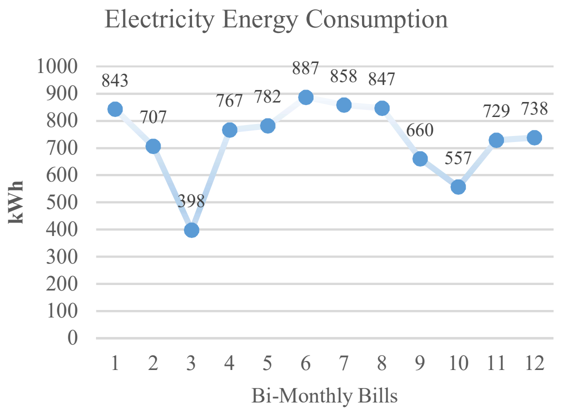

Fig. 1. Electricity Energy Consumption (kWh) for 24 Month Period

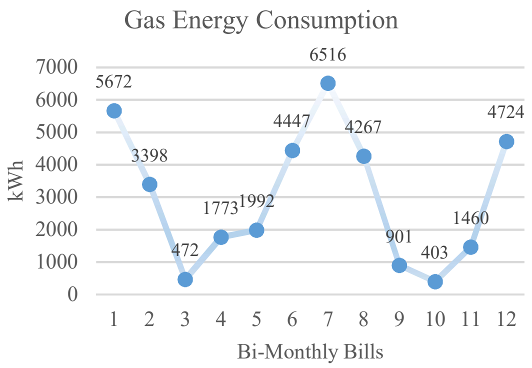

Fig. 2. Gas Energy Consumption (kWh) for 24 Month Period

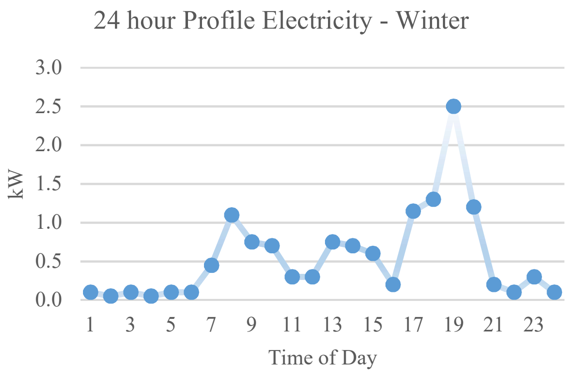

Fig. 3. Typical Daily Electricity Load Profile - Winter (kW)

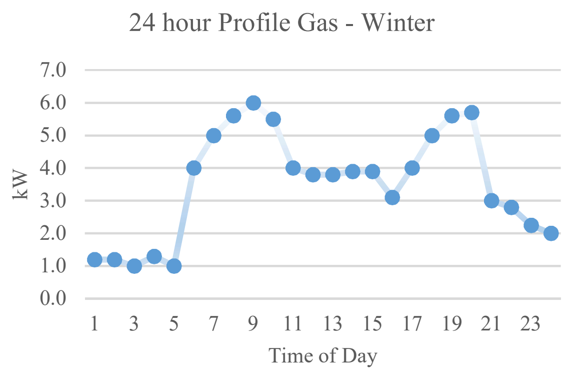

Fig. 4. Typical Daily Gas Load Profile - Winter (kW)

A daily load profile for both electricity and gas were extrapolated from the aforementioned datasets. Fig. 3 & 4 illustrates the typical peak demand times for electricity and gas. However, reference [5] contend that heat pumps don't experience the typical peaks of a traditional gas boiler. Moreover, heat pumps should rather have a smoother demand profile, thus, eliminating the increase on peak electricity demand. However, the heat pumps are likely to be operated for longer in order to achieve and maintain desired indoor temperatures [5]. That said, having a peak or a smoother profile won't directly affect the consumers' billing amount as the unit cost per kilowatt-hour (kWh) will remain the same, as illustrated in Table II. Notwithstanding, with the imminent introduction of *Time-of-Use* (ToU) tariffs, this will offer consumers the opportunity to avail of Demand Side Management (DSM) tools, and thus, the incentive to alter the load profile pattern, this is discussed further in the conclusion.

The daily electricity profile was taken from period 10.12.21 – 11.02.22 which saw an average consumption of 13.2 kWh each day. Whereas, the daily gas profile was taken from period 07.12.21 – 11.02.22 and saw average consumption of 84.7 kWh each day, this was calculated using a conversion factor of 11.46 (as per the energy provider data). A winter profile was used to illustrate thermal peak demand on the system and the fact that the heat pumps would be required to work harder during the colder months, thus, more electrical loading.

The following considerations highlight the building's conversion of thermal heating requirements from a gas to an electricity energy source, this is to reflect the major shift that will be witnessed throughout the sector in the move to building electrification [14]. As was previously mentioned, a CoP of 3.5 was used to directly convert the gas demand to that of an electrical demand. The daily thermal demand of 84.7 kWh_t was converted to an electrical demand of 24.2 kWh_e.

The final considerations examine the full adoption of building electrification and moreover, presents the daily forecasted electricity load profile. Looking at the system's new electricity demand, Fig. 5 illustrates daily peaks and troughs that could potentially be witnessed in the sample model and in a wider context and thus, pressures and the national and local grid. As was alluded to previously, the existing electrical demand of 13 kWh and the newly converted heat pumps demand of 24.2 kWh gives a new daily total electrical demand of 37.4 kWh. Furthermore, in the context of peak demands, the existing electricity demand, in conjunction with the new heat pump demand, models a new peak demand of 4.1 kW, this is a peak demand increase of 64%.

TABLE I
New Electricity Energy Consumption (kWh) Incorporating Heat Pump

Existing Electrical Demand	New HP Electrical Demand	New Total Electrical Demand
13 kWh	*24.2 kWh*	*37.4 kWh*

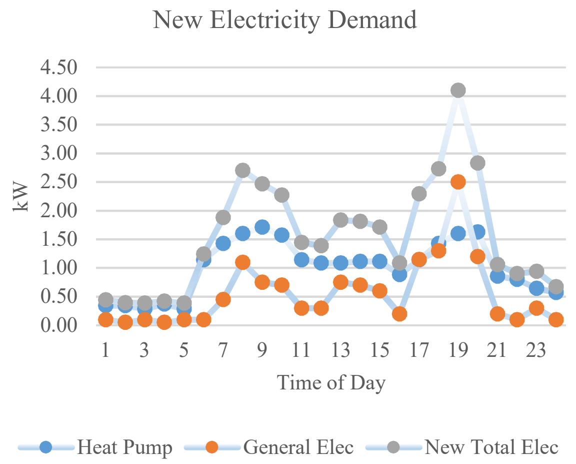

Fig. 5. Potential New Daily Electricity Load Profile - Winter (kW)

B. *Cost Considerations*

The following considerations highlight the building's electricity bill from two scenarios, firstly the existing costs and secondly the cost incorporating the new heat pump and associated energy consumption. The unit cost of electricity used was 21 c€ / kWh, this was the most recent unit cost on the electricity bills which were collected for this paper. That said, it should be noted that during the 24 month billing period examined, there were three unit price increases witnessed, starting at 17 c€ / kWh and finishing at 21 c€ / kWh. Furthermore, there were also increases to the *Public Services Obligation* (PSO) and the *Standing Charge* (SC), this is at a time when the Irish Government will be increasing the *Carbon Tax* in the latter part of Q2 2022.

Firstly looking at the existing costs, the billing period being modelled is 64 days and during that period the electrical energy consumption was 843 kWh. Therefore, a daily electrical energy consumption of 13.2 kWh was assumed. This gave a unit costing of €177 for the billing period, this value doesn't include PSO, SC or VAT. Secondly the costs incorporating the new heat pump, a daily electrical energy consumption of 24.2 kWh was assumed, thus, providing a new daily total electrical energy demand of 37.4 kWh. Therefore, resulting in a new electrical energy demand for the 64 day billing period and a new total of 2,393 kWh. This gave a unit costing of €502 for the billing period, this value doesn't include PSO, SC or VAT either. This dramatic increase in costing, could potentially present the consumer with a 184% energy bill increase during the winter period, without the aforementioned Demand Side Management (DSM) incentives.

TABLE II
New Billing Considerations

Existing Electrical Energy Consumption & Costs	***Units used: 843 kWh*** ***Billing period: 64 days*** ***Unit Cost: 21 c€ / kWh*** ***Cost: €177***
New Electrical Energy Consumption & Costs (HP)	***Units used: 2,393 kWh*** ***Billing period: 64 days*** ***Unit Cost: 21 c€ / kWh*** ***Cost: €502***

It should be noted that this paper used a worst case scenario for the peak energy consumption pattern, and thus, a winter profile was used. The seasonal performance of the heat pump will vary over the full heating season and effect the CoP. The ratio of heat out and electrical energy in will suffer as the ambient temperate begins to drop in colder months, putting further pressure on the electrical demand. Furthermore, if this premises underwent building upgrades the BER would improve and thus, the energy bills would see a reduction.

IV. Conclusion

This paper examines a sample of energy bills, electricity and gas, for a domestic family premises over a 24 month period, with particular focus on the winter load profile. Given the acute energy crisis now being faced right cross Europe, this paper highlights the potential dramatic increased electricity bills that consumers might face while shifting to heat pumps, if further Demand Side Management (DSM) steps are not taken on this path to decarbonisation. These further steps should include; buildings to reduced energy consumption and improve energy efficiency, be powered by renewable energy sources, smart meters and *Time-of-Use* (ToU) tariffs. This shift to emit little or no on-site carbon emissions can be driven through the electrification of building services. In fact, smart meters should play a significant role in ensuring affordable energy pricing and offer some reduction in peak electricity grid demand. As highlighted in Ireland's Climate Action plan, the smart meter programme should be completed by 2024 offering consumers more choice, information and enabling a more proactive use of electricity. Moreover, this digitalisation of energy management, at the macro level, will be essential for Ireland to achieve a modern flexible and *dynamic electrical infrastructure* which will enable the growth of renewable energy and thus, further expand its ability to embed intermittent power generation. In relation to increasing consumer prices, energy poverty must be at the forefront of the change. As the *just transition* gains momentum, government policy must ensure that this new model continues to foster areas of society on low incomes, which are the most vulnerable to energy property [10].

The paper highlights future scenarios for a heat pump roll out and discusses the opportunities and challenges faced in regard to forecasting peak demands in individual premises and on the national electricity grid. EirGrid have noted that the overall demand increase from heat pumps will only be a small fraction of the total system demand, however, it is significant enough to include in the future forecasting models. That said, there has been a notable focus on the "tech sector" over the last number of years, from a jobs perspective and as a growth sector. However, what this energy crisis and future planning scenarios are showing, is that without a secure and *sustainable energy infrastructure*, no area of society can prosper.

Another potential issue within *"services for buildings"* in this transition to *Zero carbon Economy* is a skills shortage. The Irish Government's paper, Skills for Zero Carbon – *The Demand for Renewable Energy, Residential Retrofit and Electric Vehicle Development Skill to 2030* [11], highlights that the realisation of European Union targets, in terms of renewable energy technology, low carbon technology will require an expansion of occupations and skills in those niche or emerging sectors. In fact, in the short term, there may be a shortage of workers in these sectors including, engineers, electricians, plumbers and the newly developed occupation, heat pump installers. Furthermore, industry and academia must ensure alignment in relation to providing training, upskilling and research in the area of the *Zero carbon Economy*.

In relation to future works, the author would like to explore other possible scenarios, such as the addition of Electric Vehicles (EVs) to the electrical demand load profile. Furthermore, include a micro-generation source, such as Photovoltaics (PV), roof mounted or Building Integrated Photovoltaics (BIPV). Building regulations and the advancement in technology have driven on-site generation for both new buildings and retrofits. Such a modern electrical system has become viable and more commonplace with the alternative option of Electrical Energy Storage Systems (EESS). Therefore, the combination of the research outlined in this paper, alongside future works, may offer building users the opportunity to import energy, store energy during times of over-generation and sell energy back to the electricity grid when the dynamic prices are high.

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